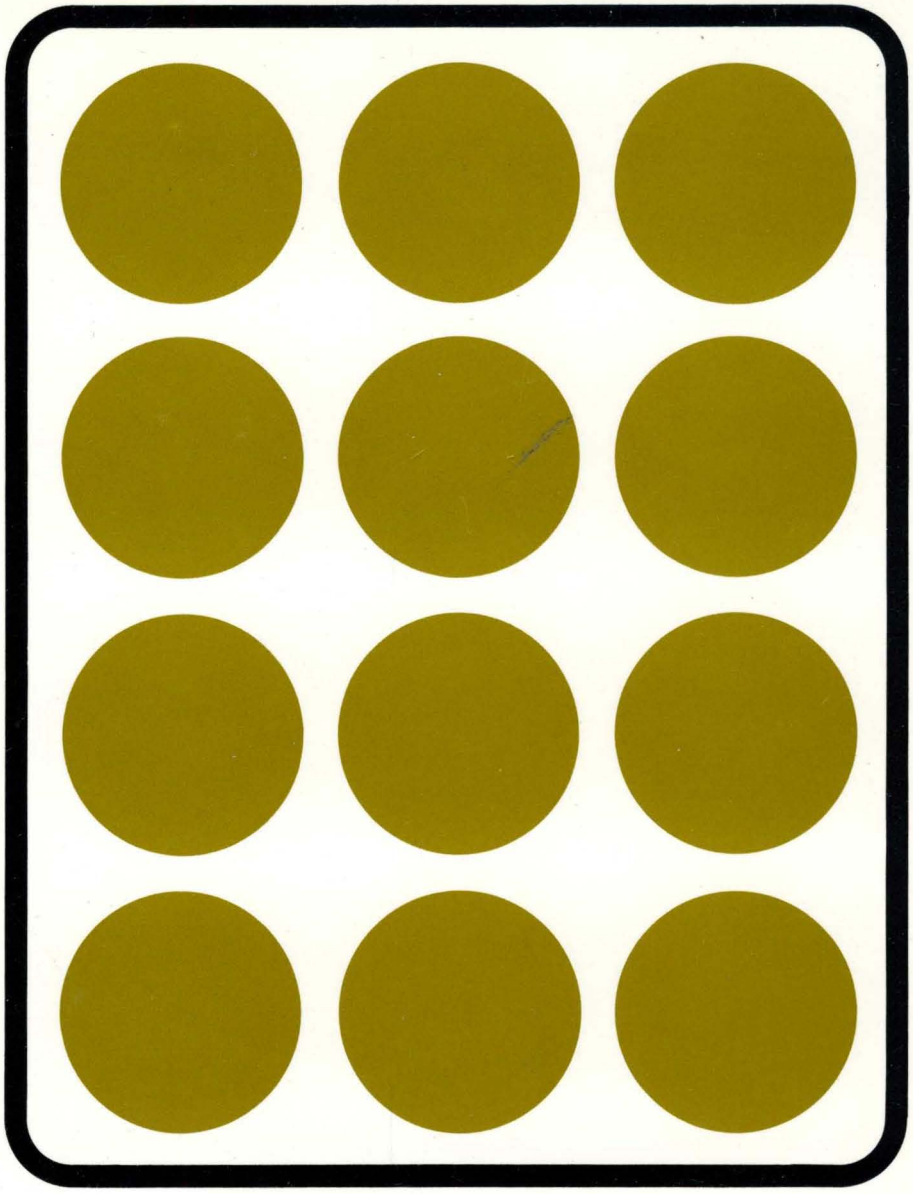
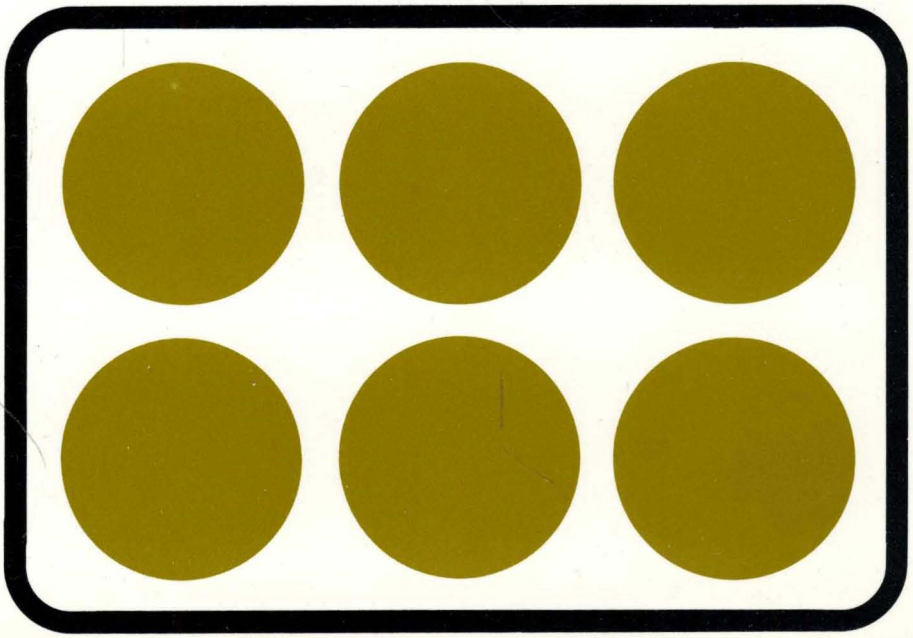


1989 DISK/TREND® REPORT



OPTICAL DISK DRIVES

1989 DISK/TREND® REPORT

OPTICAL DISK DRIVES

July, 1989

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FOREWORD

It has been a very good year, compared to previous periods. The optical drive industry is finally starting to show signs of living up to its promise. 1988 shipments were up significantly in all categories and show signs of continued strong growth in 1989.

Overconfidence is unwarranted, however. The lack of standards for read/write media remains a nagging problem. Adequate rewritable media supplies are lacking and interchange has yet to be demonstrated under field conditions. Distribution channels need more promotional and technical support from disk drive manufacturers. More software is required. Efficient, high volume production facilities must be completed if the market growth projected in this report is to be realized. And optical disk drive performance and cost both need improvement. It's still not an industry for the fainthearted or underfinanced.

DISK/TREND ON DISK, statistical and specification tables on floppy disks, is again offered, but only subscribers to the DISK/TREND Report can obtain DISK/TREND ON DISK. Instructions for using the disks are included at the end of this report.

We are always willing to help you at any time by providing additional information on the industry which we may have available. And, as always, we welcome and appreciate your suggestions for improvements in the DISK/TREND report.

James N. Porter

Robert H. Katzive

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

SUMMARY: OPTICAL DISK DRIVES

Industry size

In 1988, the optical disk drive industry substantially improved upon its 1987 performance. CD-ROM shipments, spurred by usage in consumer equipment, led unit shipment growth, but all categories improved significantly. Altogether, 286,000 drives were shipped in 1988, generating revenues of $295.2 million. Only 2.7% of unit shipments were made by U.S. manufacturers, but U.S. firms captured 7.9% of industry revenues due to differences in product mix between U.S. and non-U.S. suppliers.

In 1992, worldwide unit shipments are expected to increase to about 1,989,700 units, while revenues will rise to $2 billion. U.S. manufacturers' share of unit shipments will rise to 22.1% of units and 38.3% of revenues. 54.1% of the 1992 unit shipments, but only 13.3% of revenues, will be from CD-ROM read-only drives. About 11.2% of the 1991 revenues, but only 1.4% of 1992 shipments, will be derived from high end read/write drives, because of higher average unit prices.

In last year's report, a specific forecast was made for IBM shipments. Uncertainty concerning IBM's intentions and timing has increased to the point where DISK/TREND finds it impossible to forecast IBM shipments with any degree of confidence, so we have not done so this year.

Non-U.S. manufacturers of optical drive systems have an advantageous position because of previous design and manufacturing experience with optical drives, and delays by U.S. firms in introducing rewritable drives have increased that advantage. Revenues for U.S. optical drive manufacturers actually declined about 17% in 1988. However, U.S. firms will gradually catch up as they begin to ship rewritable drives.

INTRODUCTION

The DISK/TREND report on optical disk drives is now in its fourth year of publication, and continues with the format previously established. For those readers unfamiliar with DISK/TREND reports, a few useful points will help in interpreting the information presented.

* As with other DISK/TREND reports, this report concentrates upon disk drives used with computers, rather than upon media, controllers, or other related topics. Optical video disk drives for entertainment, optical tape drives, and optical card drives are not covered.

* All unit totals are given in spindles. At present, all optical disk drives have one spindle, but may have more in future products.

* The values of any leased disk drives are given on an 'if-sold' basis in all DISK/TREND estimates.

* Market share tables are usually included in DISK/TREND reports, but have been omitted for some sections of this year's report on optical disk drives because the 1988 market was still too small for market share figures to be meaningful.

* This year's report divides optical disk drives into three groups:

    * Read-only optical disk drives

    * Read/write optical disk drives less than 1 gigabyte

    * Read/write optical disk drives more than 1 gigabyte

  The two read/write groups include all drives with the capability to both read and write data on an optical disk, regardless of whether individual drives are intended to operate primarily in a write-once mode, an erasable (rewritable) mode, or to have multifunction capabilities. However, where rewritable drives are becoming a significant forecast segment, they are specifically forecast.

* Reseller sales have been included in the PCM/Reseller category rather than OEM/Integrator for greater visibility. See the definitions section for details.

* For the second year, the data contained in the tables of DISK/TREND reports is being offered on floppy disks as an option to report subscribers. Instructions for use of the disks have been included as a section of the report.

TABLE 1

CONSOLIDATED WORLDWIDE REVENUES

OPTICAL DISK DRIVES

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1988 Revenues		Forecast 1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	1.6	2.4	.3	.6	--	--	--	--	--	--
Other U.S. Captive	--	--	4.7	4.7	4.7	4.7	8.6	8.6	12.0	12.0
TOTAL U.S. CAPTIVE	1.6	2.4	5.0	5.3	4.7	4.7	8.6	8.6	12.0	12.0
PCM/Reseller	3.9	3.9	9.7	9.7	56.8	92.4	141.0	212.1	178.2	273.2
OEM/Integrator	13.0	17.3	38.7	45.2	102.3	131.9	242.1	320.2	303.9	485.6
TOTAL U.S. NON-CAPTIVE	16.9	21.2	48.4	54.9	159.1	224.3	383.1	532.3	482.1	758.8
TOTAL U.S. REVENUES	18.5	23.6	53.4	60.2	163.8	229.0	391.7	540.9	494.1	770.8
Non-U.S. Manufacturers										
Captive	6.7	98.6	17.2	148.2	32.6	192.4	42.0	229.7	48.2	265.8
PCM/Reseller	33.2	50.8	54.4	81.2	82.4	119.7	115.6	171.6	174.7	274.6
OEM/Integrator	70.4	122.2	175.7	286.0	251.4	420.3	330.9	539.8	426.5	696.8
TOTAL NON-U.S. REVENUES	110.3	271.6	247.3	515.4	366.4	732.4	488.5	941.1	649.4	1,237.2
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	128.8	295.2	300.7	575.6	530.2	961.4	880.2	1,482.0	1,143.5	2,008.0

Marketing channels

The marketing channels used by optical drive manufacturers include captive, PCM/reseller, and OEM/integrator. The PCM/reseller channel has been redefined to include dealers and distributors as well as direct sales by manufacturers to end users. The OEM channel includes system integrators and "value added resellers", as well as system manufacturers.

OEM shipments of $139.5 million accounted for 47.3% of 1988 revenues. The OEM share is expected to increase to 58.9% during the forecast period, exceeding a billion dollars, as re-writable optical drives are incorporated into new generations of equipment.

PCM/reseller shipments were $54.7 million, 18.5% of shipments in 1988, and are expected to rise to $547.8 million in 1992, about 27.3% of shipments. Add-ons to existing systems should help sales in this channel.

Captive shipments in 1988 were $101.0 million, an increase of 64%, reflecting improved sales of small drives in the Japanese domestic market, as lower priced systems and automated libraries have reached the market. Captive shipments will rise as system development programs using optical disk storage by numerous manufacturers result in system introductions in this and coming years and should reach $265 million in 1992, exclusive of possible IBM sales.

Revenues are given in this report based on the price of each drive the first time it is sold to a non-affiliated buyer, at captive end user, PCM or OEM levels. Prices are based on disk drives alone, without controllers or other accessories, and leased drives are valued at the price they would command if actually sold. The OEM price of the drive is typically 1/4 to 1/5 of its captive price.

TABLE 2

CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES
MARKET CLASS REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES BY MANUFACTURER TYPE	1988 Revenues $M	1988 Revenues %	Forecast 1989 $M	Forecast 1989 %	Forecast 1990 $M	Forecast 1990 %	Forecast 1991 $M	Forecast 1991 %	Forecast 1992 $M	Forecast 1992 %
U.S. Manufacturers										
IBM Captive	2.4	.8%	.6	.1%	--	--	--	--	--	--
	--		-75.0%		-100.0%		--		--	
Other U.S. Captive	--	--	4.7	.8%	4.7	.4%	8.6	.5%	12.0	.5%
	--		--		--		+83.0%		+39.5%	
PCM/Reseller	3.9	1.3%	9.7	1.6%	92.4	9.6%	212.1	14.3%	273.2	13.6%
	--		+148.7%		+852.6%		+129.5%		+28.8%	
OEM/Integrator	17.3	5.8%	45.2	7.8%	131.9	13.7%	320.2	21.6%	485.6	24.1%
	--		+161.3%		+191.8%		+142.8%		+51.7%	
Total U.S. Manufacturers	23.6	7.9%	60.2	10.3%	229.0	23.7%	540.9	36.4%	770.8	38.2%
	-17.2%		+155.1%		+280.4%		+136.2%		+42.5%	
Non-U.S. Manufacturers										
Captive	98.6	33.4%	148.2	25.7%	192.4	20.0%	229.7	15.4%	265.8	13.2%
	--		+50.3%		+29.8%		+19.4%		+15.7%	
PCM/Reseller	50.8	17.2%	81.2	14.1%	119.7	12.4%	171.6	11.5%	274.6	13.6%
	--		+59.8%		+47.4%		+43.4%		+60.0%	
OEM/Integrator	122.2	41.5%	286.0	49.9%	420.3	43.9%	539.8	36.7%	696.8	35.0%
	--		+134.0%		+47.0%		+28.4%		+29.1%	
Total Non-U.S. Manufacturers	271.6	92.1%	515.4	89.7%	732.4	76.3%	941.1	63.6%	1,237.2	61.8%
	+90.7%		+89.8%		+42.1%		+28.5%		+31.5%	
Worldwide Recap										
Captive	101.0	34.2%	153.5	26.7%	197.1	20.5%	238.3	16.1%	277.8	13.8%
	--		+52.0%		+28.4%		+20.9%		+16.6%	
PCM/Reseller	54.7	18.5%	90.9	15.8%	212.1	22.1%	383.7	25.9%	547.8	27.3%
	--		+66.2%		+133.3%		+80.9%		+42.8%	
OEM/Integrator	139.5	47.3%	331.2	57.5%	552.2	57.4%	860.0	58.0%	1,182.4	58.9%
	--		+137.4%		+66.7%		+55.7%		+37.5%	
Total All Manufacturers	295.2	100.0%	575.6	100.0%	961.4	100.0%	1,482.0	100.0%	2,008.0	100.0%
	+72.7%		+95.0%		+67.0%		+54.2%		+35.5%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

Product mix

In 1988, read-only drives accounted for 81.5% of unit shipments, up from about 74% in 1987. Small capacity read/write drives accounted for 14.9% and large capacity drives held a 3.6% share. Read-only drives will retain their lead in unit shipments, but strong shipment growth of rewritable drives during the forecast period will result in a nearly balanced split between read-only and rewritable drive unit shipments in 1992, with high capacity drives capturing only a 1.4% shipment share.

Read/write drives under one gigabyte have captured the lead in revenues, accounting for $120.2 million in 1988, a 40.7% share. By 1992, revenues will rise to $1.51 billion, a 75.5% share, as a result of very strong shipments of rewritable drives.

The biggest absolute growth in unit shipments will come from read-only drives, which are expected to increase from 232,800 units in 1988 to 1,076,000 units in 1992. Games and other consumer applications account for a third of the 1992 total. Revenue growth is lower than the growth rate for unit shipments due to declining average prices: Although new product introductions will help to support prices in the next year or two, prices will decline relentlessly under the spur of competition.

As of mid-1989, there were fourteen manufacturers with 4.72" read-only drives in the market (up five from last year) and eighteen manufacturers of write-once 5.25" drives (up from seventeen last year). Six manufacturers have announced 5.25" rewritable drives. Eleven manufacturers are offering 12" drives. Nine are write-once, one is read-only, and one is rewritable. One manufacturer has an announced 3.5" erasable drive but its specifications are not yet final. Additional manufacturers have made technology announcements of 5.25" and 3.5" rewritable drives and several others are

developing, but have not yet announced, such products. One 14" drive has been announced. Three firms make 8" drives, but this configuration is not yet a major factor in the optical drive market.

As shown in Table 8, all but one of the 4.72" drive manufacturers and over two thirds of the 12" drive manufacturers are Asian firms. Most of the 5.25" drives are now of non-U.S. origin. In 1989, the first 4.72" optical disk drive using write-once media became available, albeit on a captive basis, and erasable drives in that size are expected to appear in 1991. Most optical disk drives shipped will use smaller disks -- 3.5", 4.72", and 5.25". The initial volume shipments of read/write drives have been write-once configurations, but in 1989 and after, rewritable drives are expected to capture the largest share of read/write drive unit shipments. For 8", 12" and 14" diameters, erasability will arrive at a later date, because design difficulties with larger diameter erasable media are yet to be overcome. The 3.5" optical disk drives are expected to be almost all rewritable types, beginning with the first production shipments in 1990 of magneto-optical drives.

5.25" and 4.72" drives will be produced in the full size and half high form factors established originally by 5.25" floppy drives. In 1986, full size drives dominated, but by 1988, the trend to half high models was nearly complete for read-only optical drives. The read/write drives are more complex than the typical read-only drive and require substantial re-engineering to fit in the half high profile, but a few are available as of mid-1989. 3.5" optical drives, when available, will use the 41 millimeter package height normally found in most of today's small diameter Winchester drives.

Figure 1
CHANGING PRODUCT MIX
CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES

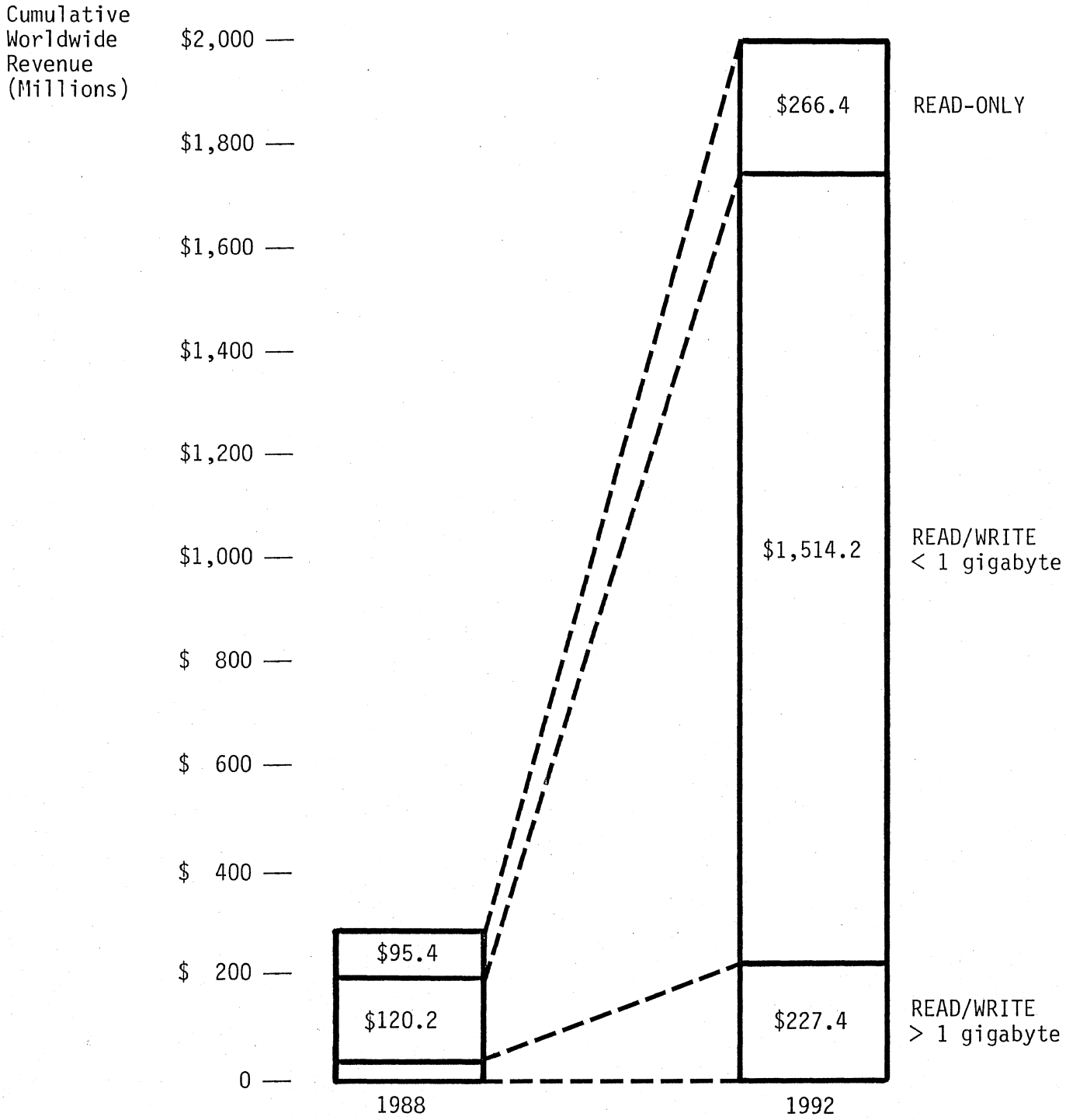

TABLE 3

CONSOLIDATED WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES	1988		Forecast							
ALL MANUFACTURERS	Revenues		1989		1990		1991		1992	
	$M	%	$M	%	$M	%	$M	%	$M	%
READ-ONLY	95.4	32.3%	165.6	28.8%	217.4	22.6%	249.8	16.9%	266.4	13.3%
ALL CAPACITIES	+136.7%		+73.6%		+31.3%		+14.9%		+6.6%	
READ/WRITE	120.2	40.7%	301.6	52.4%	598.7	62.3%	1,043.1	70.4%	1,514.2	75.5%
LESS THAN 1 GIGABYTE	+157.4%		+150.9%		+98.5%		+74.2%		+45.2%	
READ/WRITE	79.6	27.0%	108.4	18.8%	145.3	15.1%	189.1	12.7%	227.4	11.2%
MORE THAN 1 GIGABYTE	-5.1%		+36.2%		+34.0%		+30.1%		+20.3%	
Total Worldwide Revenue	295.2	100.0%	575.6	100.0%	961.4	100.0%	1,482.0	100.0%	2,008.0	100.0%
	+72.7%		+95.0%		+67.0%		+54.2%		+35.5%	
% U.S. Mfg.	7.9%		10.4%		23.8%		36.4%		38.3%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

Figure 2
CHANGING PRODUCT MIX
CONSOLIDATED WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES

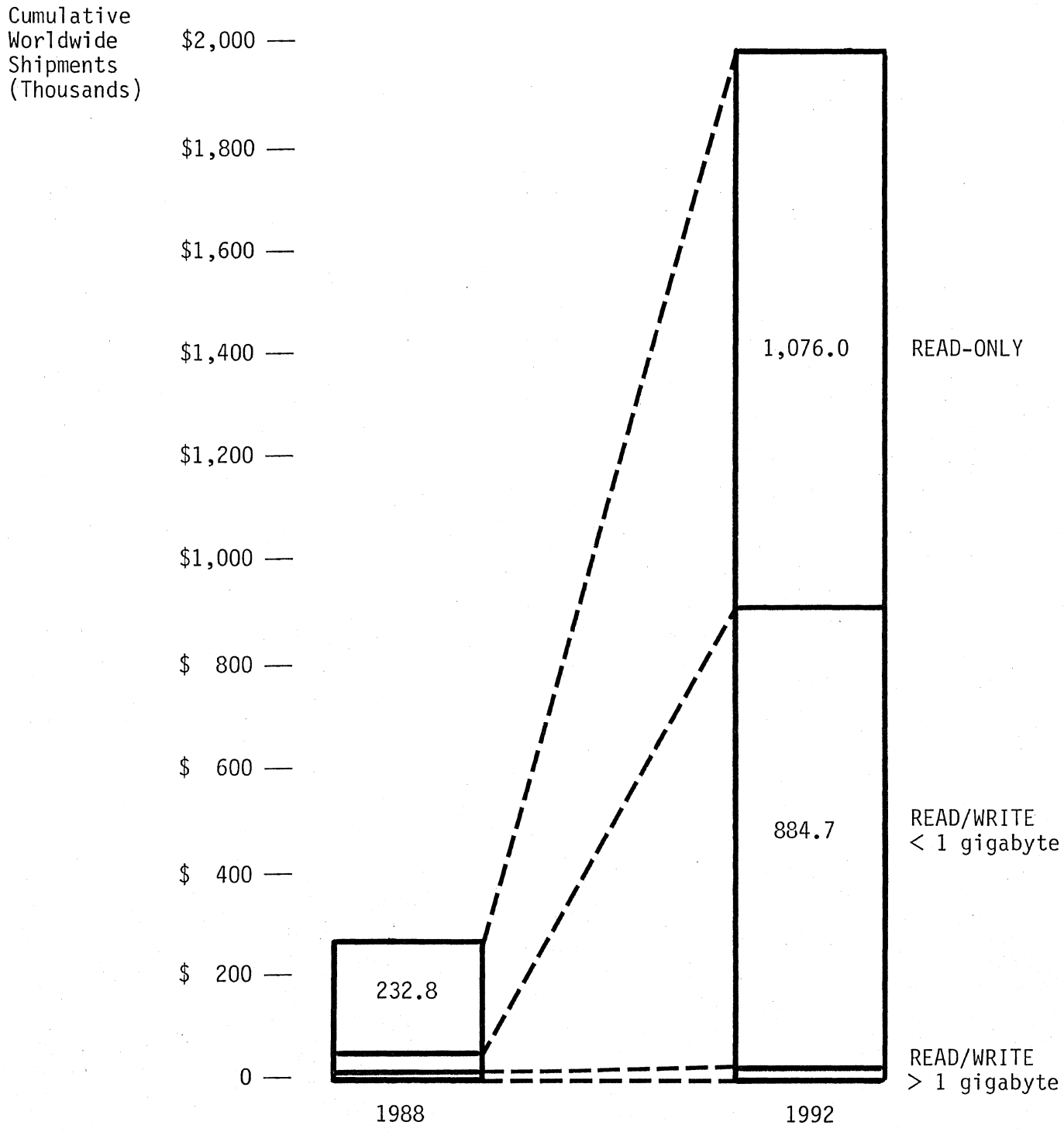

TABLE 4

CONSOLIDATED WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

UNIT SHIPMENT SUMMARY

UNIT SHIPMENTS IN THOUSANDS	1988 Shipments Units	1988 Shipments %	1989 Forecast Units	1989 Forecast %	1990 Forecast Units	1990 Forecast %	1991 Forecast Units	1991 Forecast %	1992 Forecast Units	1992 Forecast %
READ-ONLY	232.8	81.5%	455.4	77.7%	674.0	71.4%	888.0	62.4%	1,076.0	54.1%
ALL CAPACITIES	+214.2%		+95.6%		+48.0%		+31.8%		+21.2%	
READ/WRITE	42.6	14.9%	118.3	20.2%	253.8	26.8%	511.0	35.9%	884.7	44.5%
LESS THAN 1 GIGABYTE	+144.8%		+177.7%		+114.5%		+101.3%		+73.1%	
READ/WRITE	10.6	3.6%	12.9	2.1%	17.7	1.8%	23.6	1.7%	29.0	1.4%
MORE THAN 1 GIGABYTE	+34.2%		+21.7%		+37.2%		+33.3%		+22.9%	
Total Worldwide Shipments	286.0	100.0%	586.6	100.0%	945.5	100.0%	1,422.6	100.0%	1,989.7	100.0%
	+187.7%		+105.1%		+61.2%		+50.5%		+39.9%	
% U.S. Mfg.	2.7%		1.9%		8.4%		17.3%		22.1%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

OEM market

Non-U.S. firms continued their domination of the OEM segment of the optical drive market. The U.S. share of OEM worldwide unit shipments in 1988 was only 5.3%, and this will decline further until volume shipments of rewritable drives from U.S. firms actually begin. U.S. firms captured 12.4% of OEM revenues in 1988, reflecting the higher average price of U.S. optical disk drives, which include no CD-ROMs. Due to shipments of small rewritable drives in 1992, the U.S. unit share should increase to 26%, while the U.S. share of OEM revenues is expected to climb steadily each year after 1989 to 41%, due to the heavy non-U.S. production of lower priced CD-ROM drives.

The read-only optical drive market, which is almost entirely based on the CD-ROM, will be retained by non-U.S. manufacturers; these firms have unassailable strengths in volume manufacturing and engineering experience with read-only optical drives.

In the read/write drive market, especially for rewritable drives, the contest will be more equal. The fast moving and adaptable U.S. firms should be able to compete by meeting market needs more quickly than their foreign counterparts. However, the U.S. firms are limited by the need to source critical components, such as lasers, from non-U.S. companies.

There will be a significant niche market for write-once drives, but no significant competition for magnetic disk drives until fast rewritable optical drives go into production. Even then, displacement of magnetic disk drives will be nominal until optical disk drive performance and price catches up with magnetic disk drives. System OEMs have interest in using rewritable optical disk drives to replace tape drives, but prices competitive with small tape drives are required to exploit this opportunity.

TABLE 5

OEM WORLDWIDE REVENUES
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

REVENUE SUMMARY

WORLDWIDE REVENUES	1988		Forecast							
ALL MANUFACTURERS	Revenues		1989		1990		1991		1992	
	$M	%	$M	%	$M	%	$M	%	$M	%
READ-ONLY	28.8	20.6%	66.0	19.9%	89.1	16.1%	101.4	11.8%	105.8	8.9%
ALL CAPACITIES	--		+129.2%		+35.0%		+13.8%		+4.3%	
READ/WRITE	71.5	51.4%	202.8	61.4%	370.1	67.2%	633.1	73.7%	923.1	78.2%
LESS THAN 1 GIGABYTE	--		+183.6%		+82.5%		+71.1%		+45.8%	
READ/WRITE	39.2	28.0%	62.4	18.7%	93.0	16.7%	125.5	14.5%	153.5	12.9%
MORE THAN 1 GIGABYTE	--		+59.2%		+49.0%		+34.9%		+22.3%	
Total Worldwide Revenues	139.5	100.0%	331.2	100.0%	552.2	100.0%	860.0	100.0%	1,182.4	100.0%
	+27.6%		+137.4%		+66.7%		+55.7%		+37.5%	
% U.S. Mfg.	12.4%		13.6%		23.8%		37.2%		41.0%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

TABLE 6

OEM WORLDWIDE SHIPMENTS
OPTICAL DISK DRIVES
PRODUCT CATEGORY REVIEW

UNIT SHIPMENT SUMMARY

UNIT SHIPMENTS	1988		Forecast							
IN THOUSANDS	Shipments		1989		1990		1991		1992	
	Units	%	Units	%	Units	%	Units	%	Units	%
READ-ONLY	65.9	62.5%	175.2	62.0%	270.0	58.0%	375.4	51.3%	460.0	43.3%
ALL CAPACITIES	--		+165.9%		+54.1%		+39.0%		+22.5%	
READ/WRITE	32.8	31.1%	99.0	35.0%	183.7	39.3%	339.6	46.3%	581.9	54.7%
LESS THAN 1 GIGABYTE	--		+201.8%		+85.6%		+84.9%		+71.3%	
READ/WRITE	6.9	6.4%	8.9	3.0%	13.0	2.7%	18.0	2.4%	22.5	2.0%
MORE THAN 1 GIGABYTE	--		+29.0%		+46.1%		+38.5%		+25.0%	
Total Worldwide Shipments	105.6	100.0%	283.1	100.0%	466.7	100.0%	733.0	100.0%	1,064.4	100.0%
	+16.0%		+168.1%		+64.9%		+57.1%		+45.2%	
% U.S. Mfg.	5.3%		3.1%		9.2%		19.2%		26.0%	

Note: Percentage figures with plus/minus signs refer to year-to-year growth rates.

TABLE 7

1988 ESTIMATED MARKET SHARES

WORLDWIDE REVENUES OF ALL OPTICAL DISK DRIVES
(Value of non-U.S. currencies estimated at average 1988 rates)

	CAPTIVE		PCM		OEM		TOTAL INDUSTRY	
	$M	%	$M	%	$M	%	$M	%
U.S. MANUFACTURERS								
Optimem	--	--	--	--	6.7	4.8	6.7	2.3
Other U.S.	2.4	2.4	3.9	7.1	10.6	7.6	16.9	5.7
U.S. Total	2.4	2.4	3.9	7.1	17.3	12.4	23.6	8.0
NON-U.S. MANUFACTURERS								
ATG Gigadisc	--	--	--	--	8.1	5.8	8.1	2.7
Hitachi	15.3	15.1	30.2	55.2	14.0	10.0	59.5	20.2
Laser Magnetic Storage	--	--	4.6	8.4	19.8	14.2	24.4	8.3
Matsushita Electric	4.3	4.3	--	--	5.9	4.2	10.2	3.5
Matsushita Graphic Comm. Systems	12.2	12.1	--	--	1.6	1.1	13.8	4.7
NEC	17.9	17.7	.6	1.1	1.5	1.1	20.0	6.8
Ricoh	8.0	7.9	--	--	24.2	17.4	32.2	10.9
Sony	3.0	3.0	15.3	28.0	23.9	17.1	42.2	14.3
Toshiba	31.5	31.2	--	--	12.2	8.8	43.7	14.8
Other Non-U.S.	6.4	6.3	.1	.2	11.0	7.9	17.5	5.9
Non-U.S. Total	98.6	97.6	50.8	92.9	122.2	87.6	271.6	92.0
WORLDWIDE TOTAL	101.0	100.0	54.7	100.0	139.5	100.0	295.2	100.0

TABLE 8

CURRENT PRODUCT LINES
MANUFACTURERS OF OPTICAL DISK DRIVES

Codes: C = Captive
O = OEM/Integrator
P = PCM/Reseller
E = Erasable

DISK/TREND PRODUCT GROUP:		10 Read-Only Optical Drives	11 Read/Write Optical Drives <1 GB	12 Read/Write Optical Drives >1 GB
U.S. Manufacturers (11)	Type			
Bernoulli Optical Systems	O			5.25
Cherokee Data Systems	O		5.25	
Eastman Kodak	C,O			14
IBM	C		5.25	
Information Storage, Inc.	O,P		5.25	
Laserdrive	O		3.5 E, 5.25	
Maximum Storage	O		5.25	
Maxoptix	O		5.25 E	
Optimem	O			12
Reference Technology	O	12		
Shugart	O		5.25	
Asian Manufacturers (22)				
Canon	C,O		5.25 E	
Chinon	O	4.72		
Fujitsu, Ltd.	C,O		5.25	12
Goldstar Telecommunication	O	4.72		
Hitachi, Ltd.	C,O,P	4.72	5.25	12
JVC	O	4.72		
Kawatetsu Advantech	O		5.25	
Matsushita Electric Ind.	O	4.72	5.25, 5.25 E, 3.5 E	
Matsushita Electronic Comp.	C,O	4.72		
Matsushita Graphics Commun.	C,O		8	
Mitsubishi Electric	O		5.25	
Mitsumi Electric	O	4.72		
NEC	C,O	4.72		12
Nikon	O			12 E
Nippon Columbia	O	4.72		
Pentax Teknologies	O		5.25	
Pioneer Electronic	O	4.72	5.25, 8	
Ricoh	C,O		5.25, 5.25 E	
Sanyo	C,O	4.72	5.25	12
Sharp	O		5.25 E	
Sony	C,O	4.72	5.25 E, 8	12
Toshiba	C,O	4.72	5.25	12
Yamaha	C		4.72	
European Manufacturers (2)				
ATG Gigadisc	O			12
Laser Magnetic Storage	O	4.72	5.25	12

Numbers in table are diameters in inches.

TECHNICAL REVIEW

Optical data storage offers new capabilities that can be applied to a variety of storage problems. There are three classes of technology competing for assignments in various applications:

* Read-only optical disk drives.
* Write-once (non-rewritable) optical disk drives.
* Erasable (rewritable) optical disk drives.

Important technical issues still remain to be completely resolved for these technologies, including:

* The need for lower cost, higher power, higher frequency lasers.
* High media fabrication costs and inadequate yields.
* Conflicting physical and recording standards, preventing media interchange between drives.
* Requirements for low mass head design for improved performance and cost.
* Slow or inefficient error detection and correction.

All of these problem areas are currently being addressed, and the capabilities of optical disk drives are improving. The most rapidly improving area is drive performance. Recent improvements in rewritable phase-change media offer some hope for eventual availability of a "universal" drive capable of using write-once or rewritable media.

Finally, it is necessary to realize that optical storage is only one of several technologies to be considered as a potential solution in a given application. One of the reasons for the initial slow growth of the optical storage industry has been the prior availability of proven solutions offering less risk and, often, lower cost.

Optical disk technology and applications

The three existing optical storage technologies are discussed in the following sections.

* Read-only optical disks: The read-only optical disk category is dominated by the CD-ROM. Storage capacities of 550 to 600 megabytes are typical of these products. CD-ROM technology borrows heavily from the designs of 4.72" CD audio players now in volume production. CD-ROM acceptance benefits from industry agreement on the CD standards developed jointly by Sony and Philips and upon the recording format standard for computer data proposed by the High Sierra group. In addition to the 4.72" CD-ROM, which is limited in performance, high performance 12" read-only drives are also available from Reference Technology. Other formats for optical read-only memory (OROM) have also been proposed, notably a 5.25" format, but have aroused little interest.

  Mass production of read-only optical disks must be done by a mastering process, rather than by recording directly on the disk. While this means that the cost per disk can be low, mastering costs and turn-around time make production of single disks or short runs economically unattractive.

  While it is possible to use properly designed read-only media with write-once drives, and 3M and other companies have proposed such media in a 5.25" format, the low costs of the CD-ROM relative to read/write drives make it unlikely that competition from read/write drives will significantly inhibit the growth of the CD-ROM market. Conversely, read-only devices other than CD-ROM are unlikely to be of great interest except for a limited number of applications dependent upon drive performance.

  Most read-only optical drives will be used with small systems to provide personal access to large amounts of information. The success of read-only optical disks, in general, depends upon the existence and timely development of a data base publishing industry willing to make use of the CD-ROM format to support its clients. As of mid-1989, there were about 700 titles in a fully commercial status available on CD-ROM, (up from about 250 in mid-1988) and of these, only Microsoft's "Bookshelf" and games for home systems appear to have any prospects for broad acceptance. Apple Computer's announcement of a CD-ROM drive for its Macintosh line has stimulated much new publishing activity aimed at Apple users, but the applications to date are narrow in scope.

* Non-reversible optical disks: The first optical disk recording systems to enter the market were "non-reversible" or "write-once" systems. A few systems with optical drives were sold in Japan in 1984, but it wasn't until 1986, after many years of

costly development programs undertaken by several European and Japanese manufacturers, that such devices began to move into a firm production status.

Because they have track densities typically in the range of 16,000 tracks per inch, write-once drives are capable of higher areal densities than magnetic recording techniques now in use. Some drives can provide several gigabytes on a single removable disk. Writing techniques involve changing the reflectivity of an area of the disk, either by making a small hole or causing a reflectance change. Recording systems are available which alter the writing layer from an amorphous to a crystalline state, and others deform the surface of the media to cause a reflectance change.

Writing power required at the surface of the disk is in the range of 10 milliwatts for writing at useful rotation rates of the media. Losses in the optical subsystem of the head require a laser with emitted power in the 20 to 30 milliwatt range. Read power is typically in the 2 milliwatt range, but must be carefully controlled to avoid an inadvertent write due to the cumulative effects of successive read operations. To achieve media interchange, drives must be able to sense what type of media formulation is in use and adjust power levels accordingly.

Write-once drives require more complex logic to operate with computer operating systems which expect a disk drive to be rewritable.

Although not yet demonstrated in field use, extensive accelerated testing indicates that write-once disks should provide archival lives which equal or exceed those of magnetic media, with 10 years being a commonly encountered specification for archival life of the media. Some firms specify a 30 year lifetime. Lifetime is limited by the gradual appearance of defects on the recording layer, typically an alloy of tellurium, due to the corrosive effects of water and oxygen on the metal films used in the recording layers of the media. The termination point of media lifetime occurs when the error correction capability of the drive is no longer capable of coping with the gradually increasing media defect density. Some recently introduced media based on dye or dye-polymer designs have no metallic films and are expected to be more corrosion resistant than the original generation of metallic films. Other optical media using platinum or tin alloys as the recording layer offer corrosion resistance, but may trade off write sensitivity for the improved longevity obtained.

The largest application for write-once recording technology is the archival storage of documents. The document is usually stored as a document image, rather than as character data. Image storage systems were early entrants to the market in Japan, offered by Toshiba, Matsushita Electric, and others. The

early emphasis on optical document storage systems in the Japanese market is explained by the extremely complicated Japanese language. Since most business communication and records are in handwritten characters, the Japanese emphasis first on copying machines, then facsimile transmission, and now optical document storage systems is understandable. At this time, it does not appear that optical document storage systems will be able to compete on a price per image basis with microfilm. However, the fast and convenient access to stored images provided by optical disk systems is creating a major place for them in the emerging office automation market. As an example, at the 1989 AIIM conference, over 40 firms displayed small and large optical disk based systems designed to supplement or replace microfilm systems used for record management.

The write-once systems now available or entering the market use comparable, but differing technologies, with capacities per disk in the range of one hundred megabytes to over six gigabytes. The smaller capacity products are being marketed initially as OEM drives for use in small systems; larger capacity drives are being used in captive systems and by a few OEM purchasers.

Obviously, the market for this generation of optical disk systems will be limited to the niches which can tolerate nonreversibility. These niches do exist and the low cost per byte of optical storage has opened selected markets to optical disk systems. In some applications, the ability of write-once storage systems to maintain an audit trail or indicate whether or not stored data has been modified is a significant benefit.

Large automated libraries that provide random access to tens or hundreds of disks make the use of large scale optical storage potentially very attractive for banks, insurance companies, governments and other organizations with massive records that must be easily accessed. But the markets are specialized, the required software is complex, and system manufacturers have been slow to act. Little displacement of magnetic disk drives will result in the foreseeable future. Some displacement of tape in archival applications is probable.

* Rewritable optical disks: The possibility for eventual inroads into the market for magnetic disk drives exists with rewritable optical disk systems. Magneto-optical recording has seen development activity for more than twenty years, and "phase change" optical recording has attracted considerable attention during the past few years. Rewritable optical recording based upon dye-polymer technology developed by Optical Data, Inc., and planned drives from Tandy have also received attention.

Low-end rewritable optical drives offer the long term promise of higher capacities and access times equivalent to those offered by many of today's small magnetic rigid drives. Such drives

should be more reliable than magnetic disk drives due to the decreased chance of head crashes obtained through more head/disk separation, but are not yet able to offer the same cost/performance as magnetic drives. High-end rewritable drives await the availability of larger diameter rewritable media, which is difficult to fabricate within the current state of the art.

Especially impacted will be magnetic tape. The ability to add an optical disk for backup using the same controller used for other system disks offers the system OEM an attractive opportunity to reduce system complexity and cost while simultaneously improving performance.

Most current magneto-optical development programs involve using a low power laser to change the magnetic state of the active layer on a disk. The laser raises the temperature of the active layer into the range of the Curie point while a magnetic field is present, causing individual magnetic domains on the disk to align with the direction of the external field. Changes in magnetic orientation are detected during reading, as the affected spot on the disk causes a small rotation in the polarized light reflected from the surface or transmitted through the disk. However, magneto-optical disks have not yet shown the ability to overwrite in place: A complete sector must be erased before the sector can be rewritten. While several approaches offer technical solutions to this problem, all seem to add undesirable complexity and cost to the drive or media. Magneto-optic media require less laser power for writing than do write-once media because there is no need to physically deform the writing layer or cause it to melt.

Phase change optical recording involves a different type of amorphous coating, in which individual spots on the disk are changed by laser irradiation from a crystalline state, during which light is reflected, to a noncrystalline state, during which light is absorbed. Fujitsu has revealed a comparable process in which different crystalline states are used to vary reflectivity. Media stability with time, phase reversal time, and the limited number of possible write/erase cycles still represent problem areas for rewritable phase change technology. However, if the price is competitive with tape technology, phase change media having a write/erase cycle limit of at least 1000 cycles could compete in the backup market. Matsushita Electric has reported fabricating media with over 100,000 cycles capability, so this segment of the market seems within the grasp of the technology.

A third recording technology, potentially the least expensive to manufacture, is rewritable dye or dye/polymer. As of yet, only limited success has been obtained with this technique because developers have not been able to demonstrate a large number of write/erase cycles. As a result of the Tandy announcement, much industry attention is being given to the possibility of market-

ing low cost drives with limited erasability media for use as a replacement for cartridge tape drives and some write-once optical drives.

Individual firms are also working on other proposed reversible optical recording technologies, but none of these is known to have overcome all of the problems, which have included: Slow completion of the reversal cycle, limitations on the number of reversals before degradation, poor shelf life, and low recording density.

Two other interesting, but low probability technologies have commercial possibilities. One is a rewritable recording process based upon the micro-deformation of a thin metal film as the result of laser irradiation. When irradiated at a higher power level, the deformed spot assumes its original shape. The films involved are typically Ni-Ti or Cu-Zn-Al alloys. The other approach, which is being developed by Optex Corporation, involves "electron trapping," by shifting the energy level of electrons in a material which holds them in a stable state for long periods in either the high or low energy state. A visible wavelength laser pulse moves an illuminated area to a high energy state. An infrared laser pulse causes the electrons to revert to the low energy state, emitting light as they do so. The presence or absence of light in response to a read (infrared) pulse yields a bit of information. The process is infinitely reversible, but is subject to interference from unwanted ambient light. Neither approach is close to being in a manufacturable status.

Magneto-optical storage is manufacturable. The technical problems have been overcome by the U.S., Japanese and European companies working in the area, and a few of these firms have committed to the heavy investment required to establish volume production capability. Technology and product announcements of drives and media in 3.5" and 5.25" formats have been made by Canon, Maxoptix, 3M, Sony, Sharp, Ricoh and several other firms. Sony and Canon began to manufacture magneto-optical drives and media in volume in 1988 and additional firms will start in 1989. While media and drive producers have concentrated upon magneto-optical recording, phase change technology could follow shortly if acceptable stability, write/erase cycling and producibility are feasible.

Technical issues: Most of the technical issues apply to all three of the optical storage technologies described above. A few, such as the overwrite issue, apply to a specific technology. Key enhancements to optical drive performance are likely in the following areas.

* Recording heads: The optical recording head is a relatively complex device incorporating the laser, detector, optics, and, frequently, a fine positioning mechanism. The result is a relatively massive head assembly, which, in turn, slows access time and increases the power required to position the head. For the first generation of write-once optical drives, which were used with document storage systems, the long average access time, typically in excess of 125 milliseconds, was not a critical factor. However, the desire of many firms to use optical drives in data processing systems is creating pressure for faster average access time. Considerable work is underway at many firms aimed at reducing the mass of optical head assemblies, and is beginning to bear fruit in such products as the Maxoptix 5.25" rewritable drive, which has an average seek time in the 30 millisecond range. This performance has been achieved by using a split optic system in which only the objective lens, focus and fine tracking mechanisms are mounted on the moving carriage, substantially reducing the total mass of the head assembly.

  Some optical drives are being fabricated using a single stage positioner, which assists in reducing head complexity and associated mass. An example is a drive designed by Bernoulli Optical Systems, which uses a single stage rotary actuator. This drive is also the first commercial optical drive to incorporate two heads, one on each side of the disk, permitting both sides to be read independently and simultaneously.

  The use of holographic optical elements to replace many of the heavier glass lenses and supporting structures is being explored by several firms. While providing simplicity, the transmission efficiency of holographic systems currently available is less than that of conventional optics, restricting the use of holographic optics to applications which require less write power at the surface of the media. Pencom International is now in limited production of holographic optical elements suitable for use in magneto-optic rewritable drives and read-only drives.

  Molded glass aspheric lenses will be used in smaller drives. These lenses, some of which are molded using plastic rather than glass, substantially reduce cost, weight and complexity of the optical path in the head. Some advanced techniques currently being explored at Osaka University and other institutions have the potential to result in a monolithic assembly in which laser and lens are fabricated as a single unit.

Work is also being done with heads using composite laser assemblies that are capable of emitting separate read, write and erase beams through a common optical channel. These assemblies are intended to permit direct read-after-write operations in which the read beam can interrogate the disk immediately after a bit is written to insure that a write error was not made. Composite assemblies of this type are very difficult to fabricate and align. As error correction techniques improve, they may not be necessary to achieve adequate performance.

* Lasers: The amount of power available from the laser in the optical drive is a limit on how fast a spot on the disk can be written, and thus, a limit on the rotation speed and data transfer rate that can be obtained. Semiconductor lasers now in development appear able to double or triple the available power of lasers in use in current products. As these new laser products are found to be economically and technically suitable, a significant increase in data transfer rates and a significant decrease in latency will be obtained. As a result, optical disk drives are expected to be able to match the 10 megabit/second data transfer rates of small rigid disk drives by 1991. More powerful lasers permit the use of beam splitting techniques useful in improving tracking and direct read during write operations and will make it easier to use holographic lens systems at higher data transfer rates or with less sensitive media.

  A second limitation related to the laser is spot size, which is a function of laser wavelength, among other factors. Work on shorter wavelength lasers may result in smaller spot sizes and an increase in bit density. Doubling the frequency halves the spot size, which results in a theoretical quadrupling of the storage density. However, large improvements are not anticipated in the near future due to the difficulty of producing a semiconductor laser that will operate at near blue wavelengths with adequate power and stability and at reasonable cost. A promising indirect approach is the use of a frequency doubler as reported by Matsushita Electric. This technique has yet to be shown suitable for volume production. About the best improvement expected in the near future is an AlGaInP laser with a wavelength of about 650 nanometers, compared to the commonly used AlGaAs 780 nanometer devices of today. Production volumes of the improved lasers are expected in late 1990 or 1991, and this should result in an areal density improvement by a factor of about 1.4.

* Recording disks: Although write-once optical media was originally in short supply, the manufacturing capacity problem has largely been resolved as new facilities have gone into production. The rewritable media now available is the magneto-optic type, and will eventually be available in adequate quantities although there have been some media shortages due to yield problems. Media suppliers were not prepared for the rapid ramp-up in rewritable drive production that began in late 1988.

Magneto-optic media will have to make a transition through one more generation to arrive at designs that will permit direct overwriting in the place of previously recorded data, rather than requiring a separate erase pass. It is likely that more than one solution will be offered, probably incompatible, further aggrevating the media interchange problem.

Most read/write optical disks made to date use complex multilayer designs and sputtering techniques to deposit the various layers. But manufacturing techniques have evolved to the point that several manufacturers can make disk media that can withstand the range of temperatures and humidities likely to be experienced without undue media degradation. At present, there is over-capacity among media suppliers, in the aggregate. However, because write-once optical disks from different manufacturers are not widely interchangeable among drives, media availability is still a concern where specific pre-formatting is required and is available only from a single drive or media manufacturer. Manufacturers of rewritable drives claim that there will be a significant degree of media interchange capability between drives of differing manufacturers. While this is plausible, it has yet to be demonstrated in field conditions.

Media manufacturers have yet to fully characterize the distribution of media defects so that designers of error correction electronics can design optimum chips. However, there is considerable improvement in the raw error rate. Hitachi, for instance, has reported that with suitable process precautions a raw error rate of one bit in ten million is obtainable. This is a thousand times better than the raw error rates obtained with early optical media.

Media life is still a concern. Accelerated life tests indicate that media can be expected to have a useful life of 10 years or more, but there is no field experience of actual lifetimes of this duration. Protection of the active layer of rewritable media to achieve longer lifetimes still requires further improvement. Basic problems were resolved by late 1987, but the complexity of manufacturing operations for magneto-optic media still causes significant yield problems.

Some innovative products, such as the dye based disks offered for use with the Pioneer and Ricoh write-once optical drive, offer potentially lower costs and improved environmental stability because the active layer has no metal components subject to corrosion. Rewritable dye based media is being investigated as well, but the number of write/erase cycles demonstrated has so far not exceeded 10,000 cycles. The mid-1988 announcement by Tandy of rewritable drives and media using dye based technology, while very premature, pointed out the utility of even limited erasability media for consumer and some computer based applications.

Rewritable phase-change media, in development at Matsushita and other firms, is at the 100,000 cycle mark and has demonstrated millions of cycles in the laboratory. Limited availability of rewritable phase-change media from at least one firm is anticipated by the end of 1989.

Most of the substrates used so far have been plastic. However, the ability of glass to provide smoothness, freedom from distortion at high rotation rates, minimal optical dispersion and superior environmental protection is causing this material to be seriously evaluated as a substrate material. While glass substrates are expected to be much more expensive than plastic, a factor discouraging use, their potential for use in new generations of rigid disk drives suggests that economies of scale could develop sufficiently to make them attractive for use in optical media. There is evidence that glass substrates, being smoother, result in substantially improved error defect rates, which in turn can reduce drive latency due to error correction time.

The limitations of plastic for larger diameter and high stability disks may encourage the use of glass. Media produced for the LMS 12" drives, for instance, uses glass substrates. In mid-1987, Sharp announced rewritable optical disk drives using glass as a substrate. The 5.25" rewritable drive sold by Matsushita uses a glass substrate, and it is likely that other rewritable drives will also make use of glass.

* Head positioning methods: The track density achieved on an optical drive is much higher than that obtainable on a magnetic disk drive because most optical drive designs use the pregrooved substrate as a device to provide tracking information to the head positioning servo. Some designs, such as those favored by ATG Gigadisc and Laser Magnetic Storage, use an embedded servo technique for fine tracking. There is considerable controversy as to which approach should be considered the standard approach. The two formats are not interchangeable in present drive designs. Still another method, called the discrete block format, has been proposed for 3.5" rewritable drives and is being seriously considered by standards committees.

  Drive manufacturers have not been able to reach a consensus as to a standard approach, and the result has been extended argument in standards committees, confusion and irritation on the part of prospective OEMs, and a significant contribution to delays in the growth of the market for write-once optical drives. The dispute has now been extended to rewritable drives. However, the leading suppliers have so far elected to go with the continuous tracking format. While there may be an extended delay in formulating an official standard, there is a fair chance that the continuous tracking format will become a de facto standard for all sizes of drives.

Major increases in track density in the next few years are not expected, and most drives will remain in the range of 15,000 to 20,000 TPI. However, as manufacturers go to higher rotation rates to improve latency and transfer rates, it will be necessary to redesign tracking and focusing servo systems to operate at higher bandwidths.

* Packaging: Most small optical drives are being packaged to fit into a standard 5.25" form factor so that they can be mounted in a personal computer easily. The next generation, offering half-height profiles, is starting to appear. The first such products were CD-ROM drives, such as the ones introduced by Matsushita Electric and Toshiba, but half-high write-once and rewritable 5.25" optical drives are beginning to appear. Ricoh has already announced a half-high write-once model. The 3.5" rewritable drives now being designed will fit into a standard 41.3 millimeter high space. Unfortunately, optical disk drives are forced to conform to magnetic disk drive form factor standards, which continue to evolve. Within a few years, 3.5" drives with capacities under 100 megabytes will typically use heights of 25.4 millimeters, with some at 18 millimeters.

  There is less packaging pressure on larger diameter drives, but it is important for these drives to be designed in a way that enhances their use in automated library subsystems, or at least does not detract from it.

  Many larger diameter drives are table-top or rack mounted. 12" products are typically rack mounted as are the 8" units now beginning to appear on the market. 8" drives may displace 12" drives in some document storage systems, but interest in the 8" form factor seems to be concentrated among producers of stand-alone document storage systems or industrial systems, rather than with small system manufacturers. Suppliers of larger data systems and subsystems will prefer to remain with the 12" size because of its larger capacity per media unit. This leaves a relatively narrow niche for the 8" form factor at present, but as 5.25" designs top out in terms of available capacity per disk, 8" designs may look more appealing.

  Several firms are working on write-once and rewritable drives using the 4.72" CD-ROM format. The existence of such a product is looked upon with disfavor by many potential CD-ROM publishers, who are concerned that piracy will become a problem if copying is made too easy. The experience of the software industry suggests that these fears are valid, and the availability of a writable CD format product may discourage publishers and slow early industry growth. Nevertheless, drive manufacturers will continue to investigate the CD format and one manufacturer, TDK, has stated that it is interested in providing write-once media for the CD format. Yamaha introduced a CD format write-once system in 1989 using media supplied by Fuji Photo Film.

* Interface: The most common interface encountered on optical drives is SCSI, covering the range from low-end CD-ROM players to larger drives intended for use with multi-user or document storage systems, and there has been some work done on a modification of the ESDI interface to support optical drives. Interfaces compatible with IBM personal computers are also common on CD-ROM hardware and 5.25" drives. Drives used in proprietary systems -- largely of Japanese manufacture -- have frequently used proprietary interfaces, but as these and other drives make their way into OEM markets, the standardized interfaces will be the most common.

* Software: Rewritable optical disk drives are logically similar to magnetic disk drives, so the preparation of system software that supports a rewritable optical disk is a routine task. However, software support for a write-once drive is a task of formidable magnitude. Lack of appropriate software is one of the factors that has slowed the acceptance of write-once optical drives. While drive manufacturers are expected to supply such basic software items as routines that link the drive to major operating systems, manufacturers of complete systems or storage subsystems will find that they must do the bulk of the software themselves or contract the work to a third party.

  Some firms have incorporated sophisticated firmware in their drives to avoid degradation of throughput caused by error correction, write verification, bad sector rewrites and other delay factors. While this does not affect the raw data transfer rate to or from the drive, the observed throughput can increase by as much as a factor of 10 over a drive without such features.

  Software for CD-ROM preparation and retrieval is becoming less difficult to locate. In many cases, software is supplied on the CD-ROM, with the published material. As most CD-ROM published works are of a textual or data base nature, publishers must obtain efficient text search or database search software. A few software specialty houses, such as TMS, Inc., and Bluefish, acquired by Lotus Development, make such programs available. Hewlett-Packard, in mid-1988, announced that it would supply a retrieval package to help its customers develop CD-ROM applications. Microsoft offers a CD-ROM device driver that is supplied with most of the CD-ROM drives shipped today.

* Standards: Physical standards for CD and CD-ROM were initially jointly set by Sony and Philips. The initial joint design was for an audio consumer product and this effort by two major firms was sufficient to establish a de facto standard. The subsequent definition of the CD-ROM specification drew heavily upon the earlier design, and also became a de facto standard. In early 1986, Sony and Philips released an additional specification called CD-I (CD-Interactive) which defines a free-standing appliance rather than a computer peripheral. Limited hardware availability is expected in 1989.

Another supplementary standard, CD-ROM XA was announced in 1988. XA is a supplement to the CD-ROM specification that applies to digital audio data interleaving with other types of data. Such interleaving permits rapid access to audio data associated with other recorded information without requiring head repositioning. Some minor drive redesign will be needed to accommodate the XA format.

The announcement of the CD-I specification confused the market, especially the publishing segment, and delayed the release of published materials in the CD-ROM format. CD-I is more likely to appeal to the consumer marketplace than achieve success in the computer peripheral market, and major firms, such as Lotus, IBM, Intel and Microsoft have tended to ignore CD-I in favor of a competing format, DVI (Digital Video Interactive), now sponsored by Intel.

Initial recording format standards for CD-ROM were prepared by the High Sierra Group, an ad hoc organization consisting of several firms concerned with CD-ROM. This proposed standard was submitted in mid-1986 to ANSI to begin the formal process of standards development. The work of the High Sierra group moved through the formal standards making process relatively quickly, and after only minor changes became ISO standard 9660 in 1988. The format defined is applicable to both CD-ROM and CD-I, and the commonality provided should encourage publishers to resume their CD-ROM publishing efforts which may have been delayed by the uncertainties caused by the CD-I announcement. Standards interest in CD-ROM has now shifted to the interactive formats, user interface standards for retrieval software, and standards to support a universal cataloging method for CD-ROM.

Physical standards for other types of optical drives are not as advanced, and lack of standardization has delayed acceptance of optical drives by OEMs. The ANSI X3B11 technical subcommittee has submitted an unrecorded media standard for 5.25" write-once disks for ISO approval. It originally was intended to encompass only the continuous tracking servo approach, but the price for getting this through the committee was an agreement to also submit the sampled servo approach for inclusion in a "dual standard" at a later time. ISO has embraced both approaches, and 1989 should see a final ISO release.

It was hoped by many that IBM's announcement of the 3363 would provide a stimulus for the committee to move more rapidly to a standard, lest the committee be preempted by user acceptance of the 3363 as an industry de facto standard. But the lackluster performance and limited capabilities of the IBM drive didn't impress committee participants or the market, so there was no impact on the content of the ANSI group proposal. IBM's current focus in standards committee activities is directed toward 3.5" rewritable drives. IBM personnel have been very active in supporting this standards effort.

The standards efforts of the various national standards groups have resulted in ISO draft standards, number 9171-1 and 9171-2, covering the 5.25" write-once cartridge and both of the proposed servo formats. Unfortunately, the dual format remains a confusion factor to OEMs considering inclusion of optical drives in their systems, and is one of the factors that has delayed final approval of the draft specification.

Standardization efforts for rewritable drives and media have proceeded more quickly, as they were able to build on much of the work done for the 5.25" write-once effort. Standards for 5.25" and 3.5" families of drives and media should become available in the 1989-1990 period. The 5.25" standard effort is bedeviled by the same servo format arguments that hampered the write-once standards effort, while the 3.5" standards are mired in disputes about what the disk diameter and cartridge thickness should be, as well as the format issues.

At present, there is no standardization in any other size. There are already so many 12" drive designs in the field that standardization of this size is unlikely in the near future. Although there have been some efforts, notably the convergence of the Optimem and ATG Gigadisc designs for commonly usable media, the diversity of existing designs makes it difficult for most manufacturers to agree to changes because of the major costs of product redesign. New generations of 12" drives may be standardized to a greater degree, as working groups have been set up within the American X3B11 subcommittee and the Japanese SC23 standards subcommittees to consider standards for newer products.

While Eastman Kodak is the only commercial supplier of 14" drives at present, there is also a standards effort underway to define a standard for 14" write-once media.

* Libraries: Random-access libraries, commonly called "juke-boxes", are devices that automatically pick, load, unload and refile media units for an optical disk drive. While not part of the drive, they are frequently associated with the drive in high-end archival systems where very large amounts of data must be accessed and maintained on-line. A library unit may store from 10 to over 200 disk units: Typical retrieval and load time are in the order of a few seconds. Some of these devices have multiple picking assemblies so that access/load operations can be overlapped.

The original libraries were too expensive to be attractive for use with lower capacity optical drives. However, small optical drives are beginning to receive library support and to be offered for use in departmental systems. Numerous 5.25" libraries have been introduced by firms such as NKK, Cygnet, Hewlett-Packard, and Hitachi, and were displayed at several trade shows in 1989. It is also quite likely that the random access disk lib-

1989. It is also quite likely that the random access disk libraries available for CD players will migrate to the computer world as an accessory for the CD-ROM. One early model of a CD-ROM library unit was displayed at the Microsoft CD-ROM conference in March, 1988, and Pioneer has announced the availability of a multi-disk library that incorporates a CD-ROM drive.

Drives designed for use in libraries must be able to withstand many thousands of cartridge insertions by robot pickers and must accommodate electrical control of cartridge loading and unloading. They should also minimize spin-up time, load time and unload time. However, in a library environment, average access time tends to be hidden by the much longer load/unload cycle time.

Integration of a library device into a computer system requires a substantial software design effort for even small systems. Integration into a mainframe environment is a major task that can involve several man-years of effort.

* Error correction: Error detection and correction (EDAC) will continue to be required to deal with the relatively high defect density of optical media. The techniques and designs developed to deal with this problem in optical storage may also migrate to the magnetic storage arena as storage densities increase and the impact of small physical defects on magnetic media become proportionately greater. Error correction can be implemented in chip form. This is the case for CD-ROM already, and ECC chips for other optical drives have been prepared by several firms.

  Most errors that occur are single-bit errors and can be readily corrected in minimal time. ECC techniques can also handle multiple bit errors up to the design limit of the system, but the correction process can add noticeably to the latency of the data retrieval process.

  A number of algorithms are being used for the ECC function. At the present time, standards efforts in the U.S. lean towards endorsing the use of long-distance Reed-Solomon codes for the purpose of error detection and correction in read/write drives. Some Japanese firms have favored product codes, a method of performing error correction on a multi-dimensional data array, and the issue is still unresolved.

  At least two firms in the U.S., Cyclotomics (an Eastman Kodak subsidiary) and Data Systems Technology, have developed algorithms and chips that will perform the bulk of the error detection and correction process, so the implementation of these functions should not be onerously expensive. Both of these firms are using Reed-Solomon codes.

  Error correction is a complex process and requires an amount of time that introduces significant delays in data transmission

from the drive to the host computer. Overall performance can be greatly improved by efficient on-the-fly error correction implementations. Laserdrive has already developed such a product, and other firms are expected to offer this feature in order to gain competitive advantage. The use of media with an inherently low raw bit error rate where the errors are mostly single bit errors also helps to minimize pipeline time for error correction.

Competing technologies

In making technology comparisons, it is important to remember that all technologies evolve and must be considered as "moving targets." Almost all forms of data storage have shown consistently improving bit storage density, track density, lower power requirements, faster access times, more intelligence and smaller size. Much of the experience gained in developing magnetic disk drives is applicable to the design of optical disk drives, and it appears that some techniques used by optical drive designers may be applicable to the design of magnetic disk drives. This type of cross-fertilization hastens the development of both technologies.

Because development is a slow process and acceptance of a new product does not occur overnight, displacement of existing products by the new optical products will be far from instantaneous, even where the optical product is highly suitable for a given task. The following sections review the various contenders and discuss expected progress in the years ahead.

Magnetic disk drives

* Rigid disk drives: Rigid magnetic disk drives are the mainstay of today's auxiliary storage devices. Except on the lower end of the capacity and performance range, they appear relatively immune from serious displacement by optical drives over the next few years. The relatively high mass of the optical drive head makes it quite difficult for optical drives to match the access time performance of today's voice coil magnetic drives. Another factor to consider is that the typical optical drive has only

one data surface under the head at any one time, while a typical magnetic drive has several surfaces available, reducing the time required to access data.

Magnetic disk drive technology has continued to improve. By the time optical drives improved performance to the point where they could offer 40-50 millisecond average seek time on a 300 megabyte drive, magnetic drives typically offered sub-20 millisecond times on drives of the same capacity or larger. Sub-12 millisecond times are offered by the most advanced rigid magnetic drives. It is unlikely, therefore, that the magnetic drive will be seriously threatened for the next few years in its role as a high performance system disk.

For applications where removability is important, the advantages of using an optical disk drive to perform the combined functions of a tape drive and a rigid system disk drive, or to build large on-line data libraries, may outweigh performance considerations. Such applications can include data distribution, save/restore of data, or use as a system disk in a security oriented environment. Here, the rewritable optical disk will make inroads on the uses of rigid magnetic disks. But the cost of even a low-end optical drive will substantially exceed that of a low-end magnetic drive for some years to come, so mass displacement of magnetic disk drives by optical disk drives is improbable.

* High capacity flexible disk drives: It is within the capabilities of today's technology to fabricate a floppy disk drive offering over 40 megabytes of storage capacity, and 20 megabyte devices are expected to be in production in 1989. These high capacity floppy drives could compete with the very low-end of potential optical disk drive products. The market for personal computers has grown at a rapid rate, and shipments of small disk drives are keeping pace, creating a market for backup devices large enough to attract new product types.

  Although the 10 and 20 megabyte 5.25" flexible disk drives available in recent years have had nominal impact in the industry, two new firms, Insite Peripherals and Brier Technology, plan to ship 3.5" floppy drives with capacities of 20 megabytes in 1989. Brier has announced a 43 megabyte drive using a 26,000 BPI and 1,021 TPI format. But capacities in this range are only the beginning of the potential expansion of floppy drive capabilities.

  Another significant rival technology is waiting in the wings to boost floppy disk drive capacity. Perpendicular recording for flexible disks has received considerable attention in recent years. Toshiba has announced a development project for a 16 megabyte, 3.5" drive based on barium ferrite as the recording material. In addition to Toshiba, Sony and Matsushita Electric have revealed programs to develop 3.5" drives and media using perpendicular recording.

By using a sputtered thin film on a Mylar substrate, disks for perpendicular recording could achieve linear densities of at least 50,000 BPI, but problems with head wear and stiction seem to be retarding efforts in this direction.

It is likely that the largest limitation to the development of markets for the very high capacity floppy will be media availability. Success would require that media be produced by the millions of units, which would be difficult with today's batch sputtering processes, and durability remains a problem for thin film media used with head in-contact floppy disk drives.

Another major problem is that of incompatibility. So far, none of the proposed drives being considered are interchangeable with each other. It would be very unusual for a business area based upon removable media to be successful without widespread interchangeability.

An interesting development is the introduction of flexible media drives that combine optical and magnetic technologies. Bernoulli Optical Systems (BOSCO), Insite Peripherals and several other firms have active development programs for such products. Such drives might offer significant competition in various applications due to favorable drive and media costs.

BOSCO is a joint venture between Iomega and ICI, and has been developing an optical disk drive using flexible media. The 5.25" write-once drive uses the Bernoulli principle, as do other Iomega products, to position and stabilize the disk relative to the head. The drive is unusual in another way: It has two independent single stage rotary actuators and heads on both sides of the media. Insite's 3.5" drive uses standard magnetic media with a visible servo pattern on the disk surface, combined with optical tracking methods.

* Stretched surface recording: SSR, as this technique is commonly known, was devised by the 3M Corporation. It employs a disk composed of magnetically coated plastic film stretched across concentric cylindrical rings. The chief characteristic of this technology is that it allows a head to fly on an air cushion backed by a deformable surface that bulges slightly in the region under the head. This provides close head-media separation needed for high capacity but also makes the product head crash proof. Disk drives using this design technique could be produced in either fixed or removable format and might offer the same capacity as a small Winchester or optical drive. The media, however, will have a cost only 1/3 to 1/4 of the rigid disk media in current or projected use. The cost compared to optical media is even lower. 3M has had various arrangements with other firms interested in developing drives for SSR disks for several years, most of which are no longer active, but no commitment for SSR drive or media manufacturing has been announced.

Alternative optical devices: Cards and tape

* Optical cards: Two companies have announced optical cards: Drexler Technology Corporation and Optical Recording Corporation. The optical card announced in 1981 by Drexler Technology Corporation offers up to 4 megabytes of read-only or write-once storage contained on a credit card sized plastic substrate. In 1986 Optical Recording Corporation, a Canadian firm, announced optical card technology capable of storing up to 200 megabytes in a credit card size format. The active recording layer is a metal/dye combination. Production of drives and controllers suitable for use with the card media is yet to be done on a commercial scale.

  The Drexler cards will most frequently be used by insurance or medical organizations for client/patient record keeping. The card format allows ready transportation and read back of large volumes of information. The card is capable of withstanding considerable handling and is suitable for usage by individual patients. Other applications include software distribution, inventory control, security/access control, and programming of numerical control machines and other industrial automatic equipment. Because of its relatively limited capacity and/or performance, the optical card is not a competitor to the optical disk drive.

  An early program using an optical card with 2 megabyte capacity was established at Health Management Services, a subsidiary of Maryland Blue Cross/Blue Shield, but concerns about media multiple sourcing caused delays. Drives for this program will be made by Canon. Canon, Matsushita Electric and Toshiba have all indicated that they would offer an optical card reader as a peripheral device for small computers. These three firms and seventeen others are all licensees of Drexler Technology.

  The write-once format and limited capacity of the Drexler card will limit it to specialized applications. The cost of the drive is unlikely to decrease below the cost of a floppy disk drive, so the optical card is unlikely to displace the large number of floppy disk drives widely used for software distribution. The optical card will make its mark in the development of new applications rather than in the penetration of existing uses of storage devices.

* Optical tape: Optical tape drives, just leaving the developmental stage, represent another potential solution for those needing a way to store large amounts of archival data. So far, only write-once technology has been shown to be feasible for these devices. While optical tape devices are inherently less capable of fast access to data than are disks, they do provide substantially greater capacity than magnetic tape in a single

media unit, eliminating the need to handle as many media units per volume of data accessed. So far, only a few firms have been active in the optical tape field. The best known are Docdata N.V., which has been developing a 6.2 gigabyte tape drive for use with IBM compatible tape controllers, and Laserstore, which has been working on a 2.5 gigabyte product. The Laserstore product will have a SCSI interface and be packaged in an 8" form factor.

CREO Products, a Canadian firm, has been working with ICI on a write-once optical tape drive. The optical media, slit instead of punched, is similar to the media being supplied by ICI to BOSCO for its optical flexible disk drive development program.

Magnetic tape drives

* High performance tape drives

Magnetic tape drives are shifting away from the reel-to-reel format in favor of cartridge formats. The IBM 3480 is setting a new standard for high end tape drives and imitators have appeared. 3480 class products are competitive with the lower end of the optical disk product lines in terms of capacity, but are inferior in terms of average access time. However, as rewritable optical disk drives become available, they have the potential to displace a significant fraction of the tape drives used for save/restore applications.

Storage Technology Corporation has introduced an automated tape cartridge library that uses standard IBM 3480 type tape cartridges and can hold up to 6,000 tapes in each modular unit. It will not be seriously challenged by optical drive based systems until IBM introduces an anticipated rewritable disk based library storage system, possibly in the early 1990s.

Helical scan tape drives offer some prospect of competition for archival and save/restore applications. A variety of recording formats, all incompatible, are being offered, including modified VHS videotape recorders, 8 millimeter cassette, and DAT (digital audio tape). Several companies are currently offering helical scan recorders. All of these products offer large capacities and a low cost per bit stored, but suffer from relatively long access times, as do all tape storage systems. For most of them, data transfer rates are unimpressive, lying in the 150 to 300 kilobyte per second range. Because all of these technologies are based upon consumer equipment designs, media is widely available. The availability of existing consumer products can reduce the cost of developing and manufacturing derivative products as computer peripherals. Nevertheless, significant redesign is required to transform consumer grade helical scan tape products into reliable computer peripherals.

The most notable success in the helical scan computer peripheral market is Exabyte, which has achieved a modest commercial success for its 8 millimeter format drives. However, lack of standardization and second sources inhibit sales of all of the helical scan competitors. Much as CD-ROM has benefited from the sales and technology of CD audio players, the data version of DAT should also benefit as consumer product sales grow. However, it remains to be seen if data DAT can meet the prices established by cartridge tape, high capacity floppy disks and low-end optical drives.

* Low performance tape drives

Cartridge tape products have been increasing in capacity and performance since their introduction in the 1970s. Three tape widths are in use: .15", .25", and .5". Capacities range from 4 to 100 megabytes in the .25" and smaller formats, and new products are available in higher capacities in 5.25" form factors. The .5" tape cartridge drives will offer 240 megabytes in a 5.25" form factor. Some manufacturers are adopting the physical format of the 3480 cartridge in their drives but not the recording format; such products will be less expensive than the 3480 but will not offer media interchangeability with IBM systems.

These products are threatened to some degree by write-once technology, and will definitely be impacted by small rewritable optical disks offering similar or greater capacity at equivalent prices. The disk products also have the advantage of being able to share a controller with the disk drive being backed up, resulting in overall cost savings for system OEMs. Given the early state of optical technology, displacement effects won't be felt for several years.

The primary use of low-end cartridge tape drives is to back up rigid disk drives. They are also occasionally used for software distribution, especially for multi-user microcomputer based systems. Because the price of optical media is expected to be several times that of cartridge tape media, the use of optical media for software distribution will be retarded until media costs are approximately equivalent. Since software distribution tasks rarely require the entire capacity of the media unit, the extra capacity of optical disks is not necessarily an advantage. Most programs load from the distribution media sequentially, and random access is not as important a consideration as it would be in general purpose storage/retrieval operations.

Low performance reel-to-reel tape drives are currently used for data logging, for program and data interchange, and for hard disk backup on minicomputers and some multi-user microcomputers. These products are relatively expensive and bulky, and are vulnerable to gradual displacement as optical storage devices and high capacity tape cartridge devices come into wide use.

Bubble memories

Bubble memories today are not serious competition to optical memories. 4 megabit chips are available today, with 16 megabit chips expected by 1991. 64 megabit chips are expected to be the next step, but a period of several years will be required to work out all of the manufacturing technology. They are unlikely to be available until after 1995. Chips of this capacity conceivably could be used in arrays that might eventually be capacity competitive with low-end optical and magnetic disk memories, although it is highly unlikely that bubbles can compete on a cost per bit basis.

Bubble technology bit density theoretically can be extended beyond that achievable with optical or magnetic technology if VBL (vertical Bloch line) storage proves to be feasible as a manufacturable technology. Much of the fundamental exploratory work on VBL is being performed at Carnegie Mellon University and Kyushu University, but some industrial exploration is happening at NEC, Hitachi, Magnesys and Sony. It will be at least 5 years -- and probably 10 -- before this technology is used in very large capacity arrays. If feasible, however, the inherently parallel organization of bubble memories promises to bring the equivalent of head per track performance to very large capacity storage devices. Such devices would be formidable competition to low-end optical and magnetic disk storage.

At the present time, bubble memory is used almost entirely in military, aerospace, and harsh environment industrial applications. While the most typical modular capacities are in the 720 kilobyte to 1.2 megabyte range, customized packages of up to 40 megabytes can be purchased at a cost of $5,000 per megabyte.

DEFINITIONS

Many basic terms have varying meanings within the computer industry, depending upon the role of the person speaking. In this report, such terms are used in the way most disk drive manufacturers use them.

MARKET CLASSIFICATION

Market class is used here, arbitrarily, to differentiate captive, PCM and OEM disk drive marketing activities.

Captive: Disk drives manufactured internally or by a subsidiary of a computer manufacturer or system OEM, and sold or leased primarily for use with systems offered by the manufacturer. Note that the term is used to describe the products, not the manufacturer; drives sold to PCM or OEM market classes are classified accordingly. Most DISK/TREND statistics separate data between IBM captive and "other captive", but the term still pertains to the disk drives involved, not the manufacturer.

Examples:

* Drives sold by Toshiba with its office systems are considered captive, if internally manufactured.

* In the case of a joint venture disk drive manufacturer such as Laser Magnetic Storage, a joint venture of N. V. Philips and Control Data, LMS drives sold by Philips are considered captive, and LMS drives sold by Control Data are considered captive, PCM or OEM as appropriate.

Non-captive: Any public sale or lease by any disk drive manufacturer, except sales or leases of internally manufactured drives by computer manufacturers or system OEMs primarily for use with their own systems. Both OEM and PCM shipments are included in the non-captive category.

Example:

* Shipments by Hitachi are non-captive, except for drives sold with systems made by the parent company or other subsidiaries.

PCM/Reseller: Plug compatible subsystems sold or leased by "plug compatible manufacturers" or their distributing organizations directly to end users, for use with systems sold by another manufacturer. Also includes drives sold in the "aftermarket" -- shipments by drive manufacturers to subsystem producers, distributors, retail chains, mail order firms, and individual dealers. It includes any drives which are equipped to be connected without additional hardware to systems of all types, including minicomputers and small business systems, or drives sold as add-on devices by dealers and distributors.

OEM/Integrator: Drives sold by the original producer to system manufacturers which resell them as part of complete computer systems. Also includes sales to system integrators, or "value added resellers", which combine finished system components and software to provide complete systems for specific applications. Sales by a disk drive manufacturer to a second drive manufacturer for resale are included only in shipment totals for the originating drive manufacturer, except when drives are produced on a contract manufacturing basis with a design supplied by the disk drive manufacturer which finally sells the drive to a third party.

GEOGRAPHIC CLASSIFICATION

Geographic analysis is based upon two regions: The U.S. and non-U.S. Together, these two regions comprise the worldwide market.

U.S. vs. Worldwide SHIPMENTS: Shipments are classified U.S. or worldwide depending on the shipment destination of a drive's first public sale.

Examples:

* An OEM shipment by a U.S. drive manufacturer to a European system manufacturer is included in worldwide totals.

* An OEM shipment by a Japanese drive manufacturer to a U.S. system manufacturer is included in U.S. totals.

U.S. vs. Non-U.S. MANUFACTURERS: Manufacturers are classified U.S. or non-U.S., depending on the location of the firm's headquarters, regardless of the location of individual manufacturing plants.

Examples:

* Maxoptix is considered a U.S. manufacturer, even though the firm plans to manufacture some of its disk drives in non-U.S locations.

* LMS is considered a non-U.S. manufacturer, since the majority ownership is non-U.S.

UNITS OF MEASUREMENT

Spindles: The basic unit in counting disk drives. One spindle or spindle disk assembly consists of the disk drive mechanism required to utilize a single disk or disk stack. All DISK/TREND unit totals are counted in spindles. Optical drives currently produced all have one spindle, but future drive configurations may include more than one spindle.

Revenue: Based on sales of disk drives alone, as normally sold by individual manufacturers. Controllers and library units sold as separate units are not included, nor are spare parts or service. When individual disk drive models include integral control functions, such as may be required for the first drive on a string of drives, the actual value of the complete unit is used. Sale prices are estimated public

sale transaction prices, whether at captive end user, PCM or OEM levels. Prices used for leased drives are on an "if sold" basis, at captive or PCM levels, as appropriate. All prices are in 1989 constant dollars.

Forecasts: Expected shipments and revenues for current or announced products in new production. Evolutionary improvements within existing formats are included, but completely new configurations or technologies are not included. Examples:

* Enhancements such as double surface versions of existing single surface configurations and revised encoding schemes are anticipated in DISK/TREND forecasts.

* Innovations such as non-standard size disks or new physical configurations may require establishment of new DISK/TREND product groups.

APPLICATION CLASSIFICATION

Shipments of disk drives are classified by the following computer applications:

Mainframe/superminicomputer: Disk drives attached to the processor or connected terminal of a mainframe or supercomputer.

Minicomputers/multiple user microcomputers: Includes business and professional uses, including network file servers, that typically serve multiple users. Examples: IBM System AS/400, HP 3000

Personal computers: Business and professional computers normally used by a single user. Examples: IBM PS/2 model 70, Apple Macintosh.

Office systems/workstations: Specialized equipment for dedicated use in specific office applications such as word processing or document storage. Examples: Wang OIS series, Toshiba TOSFILE.

Non-office systems/workstations: Specialized equipment for dedicated non-office applications such as design, order processing/shipping, industrial control, military, medical, law enforcement applications.

Consumer and hobby computers: Systems sold primarily to consumers for non-business applications. Examples: Commodore 64, MSX systems, most Atari models (Apple II is considered to be a professional/business microcomputer).

Other applications: Any application not included above.

READ-ONLY OPTICAL DISK DRIVES

1989 DISK/TREND REPORT

READ-ONLY OPTICAL DISK DRIVES

Coverage

Examples of disk drives in this group include:

4.72" disk diameter (CD-ROM)

Chinon	CDS-430, CDS 430i
Goldstar Telecommunication	GCDR-200
Hitachi	CDR-1503S, CDR-3500, CDR-3600
JVC	XR-R1001, XR-R100
Laser Magnetic Storage	CM121, CM131, CM210, CM212
Matsushita Electric	EMI-103, SQ-D1, SQ-D101
Mitsumi Electric	CRMC-SR001N
NEC	PC-CD101, CDR-30, CDR 80, N5267-31
Nippon Columbia (Denon)	DRD-250, DRD-251, DRD-550, DRD-551
Pioneer	CDM-6
Sanyo	ROM-3000, ROM-3001, ROM-4005
Sony	CDU-510, CDU-541, CDU-6100, CDU-7101
Toshiba	XM-2200A, XM-3201B, XM-5100A

12" disk diameter

Reference Technology	2000

A read-only optical drive is equipped only to read an optical disk. It does not have a laser capable of developing write power, a method to switch the laser into a writing mode, nor electronics required for writing data. The optical read-only drive is sometimes referred to generically as OROM (Optical Read-Only Memory), but almost all drives in this category are of the CD-ROM type and are capable of reading 4.72" or smaller media. The CD-ROM is the dominant product type in this group because manufacturers leveraged the design, manufacturing and standards infrastructure developed for CD audio players, but CD-ROM performance is slow because of its strong design similarity to audio CD players. For purposes of this report, CD audio players that have been equipped with electronics to read CD-ROM formatted disks are considered as CD-ROM drives.

Market status

1988 was a strong growth year for read-only drives. Games became an important application area, and sufficient CD-ROM titles were available to spark major shipment increases for business use. 232,800 CD-ROM drives were shipped in 1988, all manufactured by non-U.S. companies. Hitachi, Sony, Laser Magnetic Storage and Toshiba were the major producers. Reference Technology, a U.S. firm, is shipping very small quantities of a 12" read-only memory that offers more capacity and faster access times than CD-ROMs. This firm also remarkets the Hitachi CD-ROM.

Digital Equipment Corporation was the first major system manufacturer to offer a CD-ROM as a system peripheral, but Apple and Hewlett-Packard have since done the same. Others, such as IBM, have demonstrated CD-ROMs on their systems, but have made no product announcement. IBM has made public statements in support of certain recording formats and standards, including XA and DVI, suggesting that IBM may become a CD-ROM publisher, if not a drive manufacturer.

The market for read-only disk drives continues to be driven by publishers. Success for hardware manufacturers depends upon the availability and market acceptance of a wide variety of materials published in the CD-ROM format. As of mid-1989, about 1,000 titles have been announced, but of these, only about two thirds have been delivered. So far, only Microsoft's 'Bookshelf' seems to have the potential to attract a significant business-oriented following. In Japan, several game titles have achieved significant sales. NEC Home Electronics will be offering a variant of its "PC Engine" home system incorporating CD-ROM in the U.S. in 1989. As a group, manuals and product documentation seem to be the most widely used

types of CD-ROM published materials to date, but consumer applications, including games, are likely to succeed them as the largest CD-ROM application in 1989.

The preparation of materials for CD-ROM publication can be time-consuming and expensive, but systems and software to help prepare and format CD-ROM publications have become available, reducing both expense and risk to the publisher. Facilities for mastering and replicating disks are available and adequate, although most publishers would prefer to have shorter lead times available to them. In 1989, Yamaha introduced a system that can prepare a CD-ROM format disk using 4.72" write-once media.

The cost of preparing the master copy from which CD-ROM replica copies are made has decreased to under $3,000, an affordable level for even smaller firms. However, the cost of preparing (authoring) the material can be substantial. Some specialized equipment (authoring systems) are available to improve the mechanics of the process, but a well designed CD-ROM publication can cost hundreds of thousands of dollars and much time to compose. Replicated disk prices at the OEM level are $3 or less per disk. Authoring costs and complexity still discourage some potential publishers.

Marketing trends

Forecasted 1989 worldwide unit shipments of 455,400 units will rise rapidly to 1,076,000 units in 1992. This greatly exceeds the forecast in last year's DISK/TREND report; the arrival of a viable consumer oriented market is responsible for much of the gain.

With twelve firms competing for a limited market, CD-ROM drive prices will decline rapidly. Early average OEM prices were in the $600 to $700

range, declining to the $500 range in 1987. The average OEM price is expected to drop to the $230 range in 1992, and low performance machines for consumer-oriented applications are at or below that point already.

Hitachi, Sony, Laser Magnetic Storage and Toshiba are the largest suppliers of non-captive CD-ROM drives, and are listed in order of rank. NEC Home Electronics is the largest supplier on a captive basis.

Personal computers, home systems, point of sale equipment, and single user workstations will provide the dominant attachment opportunities for CD-ROMs in the next few years. Higher performance CD-ROM drives will also be used with file servers in network installations. Early sales of CD-ROM drives have been generated by system manufacturers (such as DEC, H-P, Apple) and publishers or aftermarket subsystem manufacturers offering packages consisting of drive, software, published material and interface. Amdek, for instance, distributes a package consisting of the Hitachi drive, Microsoft system software and the Microsoft 'Bookshelf' applications package. CD-ROM drive distribution has expanded to software stores, mail order firms, subsystem integrators and other indirect distribution channels. In Japan, CD-ROM drives are sold in department stores for the NEC PC Engine and have been embedded in certain desktop systems such as the home-oriented Fujitsu FM Towns 386-based computer and several Sony personal workstations.

Because many drives are offered with an IBM PC or SCSI interface, retail dealers will easily be able to add CD-ROM drives to PC systems as sufficient data base and supporting software products become available. Because the majority of the PC market is in the U.S., and the U.S. is already a large market for specialized data bases, CD-ROM sales will also be greatest in the U.S. in the near future.

The business oriented CD-ROM market will be little affected by CD-I, CD-V and other variant CD formats aimed at mass consumer markets. Video capabilities of the type provided by Intel's DVI video compression chips may expand the CD-ROM's role in computer assisted training and education. The chips are expected to be in volume production in 1990, and boards with DVI capability are currently available for use by software developers.

Applications

The read-only optical disk drive is best understood as a device that makes possible disk-based electronic publishing. The published content can be of broad general interest, such as a dictionary or atlas, or specific to a company, such as a manual or parts list. Data bases currently distributed include Department of Commerce statistics, drug side effects, legal research materials, computer system and software documentation, construction materials catalogs, and selected professional publications. Text oriented data bases are especially suitable for implementation on read-only memory. These include legal cases, encyclopedias and other educational materials, news files, technical papers and all types of reference works.

Electronic publishers must face the same site licensing and copy protection issues that are currently debated by software providers. Some publishers may defer product availability until they can define their multi-user access policies. Others may attempt (probably unsuccessfully) to prevent unauthorized access through copy protection schemes. The best protection will be the nature of the data: If it must be updated frequently to be useful, copiers may not find it worth the time and bother.

The dissemination of large amounts of static or slowly changing data in machine readable format is a logical role for optical drives, especially for the CD-ROM format. The low cost of mass replicated media and the ability of the drive to fit into the user and operating environments of personal computers and other small computer systems make this an attractive option.

CD-ROM also has the inherent capability to store and recover digitized images and audio, a characteristic which suggests many applications in the field of technical training, language instruction, and other educational uses. When it becomes available, the DVI data compression chip set developed by RCA Laboratories and now being commercialized by Intel may remove some of the technical barriers. IBM, Microsoft, Lotus and others have indicated their support for DVI, but have not yet released specific products that use it.

Still needed is an inexpensive, easy to use mechanism for transferring images or audio material to a CD-ROM document. Currently available equipment is too expensive to encourage small publishing projects, but inexpensive scanning/editing systems are expected within a year or two.

Currently, read-only drives appear primarily on micro-based systems, including individual personal computers and workstations, which accounted for 51.3% of drive unit shipments in 1988. Consumer applications, notably the NEC PC Engine, accounted for 27.9%. In 1992, consumer applications, led by games, are expected to be the largest application area with 34.9% of the units sold, followed closely by single user computers with 33.1%. In the future, CD-ROM drives will increasingly be attached to department level network file servers and to large processors through microcomputer based file servers to provide access to CD-ROM data bases for mainframe

and minicomputer use. In 1992, larger systems will together absorb 6.3% of the units sold.

CD-ROM may eventually find a market in on-board mapping systems for vehicle navigation and dispatching. Several firms are investigating such applications, which could be useful for sales staffs, public service personnel, taxi drivers, urban planners, and public utilities. Interest also exists in the U.S. defense community.

Materials likely to appear in CD-ROM format will be concentrated in one of three application groups:

Electronic publishing

* Large publicly available data bases, such as those compiled by economists for use with econometric models.
* Educational materials for languages, technical training, driver education and other curricula.
* Indexed textual data bases, such as information on drug toxicology, legal case citations, or bibliographies.
* Maps, including those used for on-board vehicle navigation. Such systems could be used eventually in personal vehicles as well as commercial aircraft, ships and military vehicles.
* Complete back issues of publications, indexed for easy subject analysis.
* Financial industry statistics, such as stock price history, for use by brokers and analysts.

Intracompany data distribution

* Directories, etc., for large organizations.
* Catalogs, parts lists and product data.
* Training materials, product documentation and service manuals. Some of these materials will be sold to customers using the products.

Consumer

* Games and amusements.

* Point of sale applications, including product and service demonstrations.

* Educational materials

Technical trends

The technology in this product group is relatively stable, as it derives from the consumer CD player. The areas receiving the most attention are:

* Integration of audio and video content into CD published materials. The XA format will be the common base for both CD-I and DVI development.

* Standards for file formats, so that disks can be used on any small computing system.

* Average access times, which decreased below the .5 second range in 1986 and have dipped well under 400 milliseconds in 1989.

* Improved error correction.

* Programmable library units for CD-ROM drives. These may be based upon units being developed for automotive CD player systems.

* Packaging of the CD-ROM disk in a carrier, or cartridge, that provides protection from scratches and prevents excessive vertical disk motion while the drive is in operation. Unfortunately, there are several cartridge styles proposed or in use, which is slowing the standardization effort.

* Development of software to support use with major operating systems and application programs. Software for efficient searching of large data bases and text files is necessary to generate large sales of CD-ROM and is becoming available.

* Cost reduction programs. Plastic molded lenses, for instance, are replacing polished glass lenses.

* Packaging of drives in half height format.

* Development of SCSI and IBM personal computer interfaces.

* Development of document preparation and other support software and systems for publishers preparing CD-ROM materials.

A yet unresolved standards issue pertains to the design of the cartridge (caddy) used to contain the disk. The cartridge holds the disk in place within the drive, preventing loss of focus due to vibration, shock, or mounting in other than a horizontal position, and permits the drive to be used in vehicles or to be mounted in a vertical position within a system enclosure. As of mid-1989 most of the Japanese suppliers now use a common approach, but LMS remains a major holdout for its own design.

As for other standards issues, the early establishment of the Sony/Philips de facto standard for CD-ROM established a basis for CD-ROM physical disk interchangeability and provided a mechanism for identification of a disk and files upon the disk. The High Sierra Group, an ad hoc task force consisting of a group of companies interested in CD-ROM, subsequently prepared a proposed recording standard and submitted it in 1986 to ANSI and ECMA for initiation of the formal standards-making process. This has now become ISO standard 9660, the existence of which is encouraging the normally conservative publishing community to move forward with plans to publish in the CD-ROM format. The XA format proposed by Philips, Sony and Microsoft in 1988 appears likely to extend an orderly standards process into the interactive format area.

Other standards issues do not involve the drive directly. A standard user interface is highly desirable so that end users do not have to learn a host of different data retrieval formats. More standardized interfaces between data retrieval software, data, and user interfaces are also needed.

The packaging of CD-ROM drives has changed rapidly. In 1986, most of the drives shipped were not compatible with the full height and half high form factors that have been adopted for 5.25" magnetic disk drive pro-

ducts. Early CD-ROM drives were free-standing or top loading types. CD-ROM packaging has moved rapidly to half height configurations, but the new wave of 3.5" disk drives used in personal computers will extend the life of the stand-alone package. Today, most CD-ROM drive models in production are half high models: Matsushita Electric exhibited a half high CD-ROM at the 1986 NCC conference and other major suppliers subsequently did the same.

The introduction of the IBM PS/2 family of personal computers confirmed an emerging de facto standard for 3.5" storage peripherals. There is some possibility of 3.5" CD-ROMs appearing in a few years, but the nominal shipment levels compared to floppy or rigid disk drives will probably force both system manufacturers and end users to be satisfied with external packaging for 4.72" CD-ROMs used with personal computers. It seems unlikely that retooling to obtain a 3.5" format will be economically attractive in the near term unless a consumer audio version appears that can absord some start-up costs.

Most CD-ROMs will be offered with SCSI interfaces and host adapters for IBM personal computers. DEC is already offering the Philips CD-ROM as a peripheral for the Micro-VAX processor line, Apple is offering CD-ROM as a Macintosh peripheral, and other system manufacturers are expected to offer interfaces to CD-ROMs on various systems.

System integrators are beginning to consider CD-ROM capabilities on file servers. As a result, there is interest in jukeboxes for CD format drives, but the slow access time of the CD-ROM has led most server designers to design around multiple drive configurations. Prototype equipment was shown at the 1988 Microsoft conference, and a few firms have announced autochangers for CD-ROM. However, except for Yamaha's mastering system,

writable CD-format media and systems are still not available, and the early enthusiasm of Philips and other potential producers seems to have cooled as a result of concerns about piracy and uncertainty as to whether development should be aimed at write-once or erasable media. The prospects for writable CD-format drives are reviewed in the discussion of read/write drives with under 1 gigabyte capacity.

Forecasting assumptions

1. CD-ROM players will be in production status in at least eleven companies in 1989. The form factor will fit within the 5.25" half high standard, but there are no immediate expectations for a 3.5" drive.

2. The formatted disk interchange standard for CD-ROM will be accepted almost universally by drive manufacturers and publishers, and the Japanese cartridge format will become the dominant form, even in the absence of a formal standard.

3. Non-U.S. suppliers will dominate the CD-ROM hardware market. There will be no significant production by U.S. firms.

4. Increasing production volume and competition will reduce the quoted CD-ROM average OEM price to $330 in 1990. Most drives will have on-board controllers, and their $25 to $50 price increment is included in the above amount.

5. There will be a significant demand for CD-ROMs by system and subsystem integrators who will add them to specialized workstations, file servers, and memory subsystems.

6. CD-ROMs will appear on approximately 3% of the installed business oriented PC base and on about 1% of the installed base of home and educational systems by the end of 1992.

7. CD-ROM growth will not be impacted in 1990 write-once drives in the CD-ROM form factor. No other form of read-only optical memory will seriously challenge CD-ROM before 1992.

8. The CD-I format will impact primarily the home and education markets. Hardware will not appear until the latter part of 1989 and there will be additional shipment delays while programs and published materials are prepared. CD-I will have relatively minor impact on the CD-ROM in the business market. DVI will have no significant impact until 1991.

8. Media mastering and replicating capacity will be adequate and will not be a restriction on growth for read-only optical memory markets.

9. Automated libraries for CD-ROMs will be required to make CD-ROMs practical peripheral devices for mainframe and minicomputer systems. Such libraries will be available by late 1990.

1989 DISK/TREND REPORT

TABLE 9

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1988		Forecast							
	Revenues		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM/Reseller	--	--	--	--	--	--	--	--	--	--
OEM/Integrator	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. NON-CAPTIVE	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. REVENUES	--	--	--	--	--	--	--	--	--	--
Non-U.S. Manufacturers										
Captive	--	18.8	4.8	35.0	16.1	50.2	22.7	61.5	28.3	72.8
PCM/Reseller	31.2	47.8	44.6	64.6	57.0	78.1	64.8	86.9	65.1	87.8
OEM/Integrator	18.0	28.8	33.9	66.0	39.6	89.1	49.7	101.4	55.2	105.8
TOTAL NON-U.S. REVENUES	49.2	95.4	83.3	165.6	112.7	217.4	137.2	249.8	148.6	266.4
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	49.2	95.4	83.3	165.6	112.7	217.4	137.2	249.8	148.6	266.4
OEM Average Price ($000)	.440	.440	.420	.380	.330	.330	.270	.270	.230	.230

TABLE 10

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1988		Forecast							
	Shipments		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	--	--	--	--	--	--	--	--	--	--
PCM/Reseller	--	--	--	--	--	--	--	--	--	--
OEM/Integrator	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. NON-CAPTIVE	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. SHIPMENTS	--	--	--	--	--	--	--	--	--	--
Non-U.S. Manufacturers										
Captive	--	65.5	20.0	128.0	62.0	193.0	89.0	241.0	113.0	291.0
PCM/Reseller	66.7	101.4	107.2	152.2	154.0	211.0	202.6	271.6	241.0	325.0
OEM/Integrator	40.8	65.9	80.1	175.2	120.0	270.0	184.1	375.4	240.0	460.0
TOTAL NON-U.S. SHIPMENTS	107.5	232.8	207.3	455.4	336.0	674.0	475.7	888.0	594.0	1,076.0
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	107.5	232.8	207.3	455.4	336.0	674.0	475.7	888.0	594.0	1,076.0
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	179.0	333.9	386.3	789.3	722.3	1,463.3	1,198.0	2,351.3	1,792.0	3,427.3
WORLDWIDE TOTAL	179.0	333.9	386.3	789.3	722.3	1,463.3	1,198.0	2,351.3	1,792.0	3,427.3

TABLE 11

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1988 Revenues		Forecast							
			1989		1990		1991		1992	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
OEM	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. REVENUES	--	--	--	--	--	--	--	--	--	--
NON-U.S. MANUFACTURERS										
Captive	--	18.8	--	35.0	--	50.2	--	61.5	--	72.8
PCM	--	47.8	--	64.6	--	78.1	--	86.9	--	87.8
OEM	--	28.8	--	66.0	--	89.1	--	101.4	--	105.8
TOTAL NON-U.S. REVENUES	--	95.4	--	165.6	--	217.4	--	249.8	--	266.4
WORLDWIDE RECAP										
Captive	--	18.8	--	35.0	--	50.2	--	61.5	--	72.8
	--	+596.3%	--	+86.2%	--	+43.4%	--	+22.5%	--	+18.4%
PCM	--	47.8	--	64.6	--	78.1	--	86.9	--	87.8
	--	--	--	+35.1%	--	+20.9%	--	+11.3%	--	+1.0%
OEM	--	28.8	--	66.0	--	89.1	--	101.4	--	105.8
	--	-23.4%	--	+129.2%	--	+35.0%	--	+13.8%	--	+4.3%
Total Revenues	--	95.4	--	165.6	--	217.4	--	249.8	--	266.4
	--	+136.7%	--	+73.6%	--	+31.3%	--	+14.9%	--	+6.6%
ANNUAL SHARE, BY DIAMETER	--	100.0%	--	100.0%	--	100.0%	--	100.0%	--	100.0%

TABLE 12

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1988 Shipments		Forecast							
			1989		1990		1991		1992	
	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"	12"	4.72"
U.S. MANUFACTURERS										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
OEM	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. SHIPMENTS	--	--	--	--	--	--	--	--	--	--
NON-U.S. MANUFACTURERS										
Captive	--	65.5	--	128.0	--	193.0	--	241.0	--	291.0
PCM	--	101.4	--	152.2	--	211.0	--	271.6	--	325.0
OEM	--	65.9	--	175.2	--	270.0	--	375.4	--	460.0
TOTAL NON-U.S. SHIPMENTS	--	232.8	--	455.4	--	674.0	--	888.0	--	1,076.0
WORLDWIDE RECAP										
Captive	--	65.5	--	128.0	--	193.0	--	241.0	--	291.0
	--	+3,019.0%	--	+95.4%	--	+50.8%	--	+24.9%	--	+20.7%
PCM	--	101.4	--	152.2	--	211.0	--	271.6	--	325.0
	--	--	--	+50.1%	--	+38.6%	--	+28.7%	--	+19.7%
OEM	--	65.9	--	175.2	--	270.0	--	375.4	--	460.0
	--	-8.5%	--	+165.9%	--	+54.1%	--	+39.0%	--	+22.5%
Total Shipments	--	232.8	--	455.4	--	674.0	--	888.0	--	1,076.0
	--	+214.2%	--	+95.6%	--	+48.0%	--	+31.8%	--	+21.2%
ANNUAL SHARE, BY DIAMETER	--	100.0%	--	100.0%	--	100.0%	--	100.0%	--	100.0%

TABLE 13

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

	1988 Estimate		1992 Projection	
APPLICATION	Units (000)	%	Units (000)	%
MAINFRAME/SUPERMINI General purpose	.6	.2	20.4	1.9
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	1.9	.8	47.3	4.4
PERSONAL COMPUTERS Business and professional, single user	119.4	51.3	356.2	33.1
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	28.7	12.3	74.2	6.9
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	14.6	6.3	201.2	18.7
CONSUMER AND HOBBY COMPUTERS	64.8	27.9	375.6	34.9
OTHER APPLICATIONS	2.8	1.2	1.1	.1
Total	232.8	100.0	1,076.0	100.0

TABLE 14

READ-ONLY OPTICAL DISK DRIVES, ALL CAPACITIES

MARKET SHARE SUMMARY
Worldwide Shipments of Non-Captive Disk Drives

	1988 Net Shipments					
	To United States Destinations			Worldwide		
	Units (000)		%	Units (000)		%
Drive Manufacturers	4.72"	Total		4.72"	Total	
HITACHI	40.0	40.0	37.2	73.0	73.0	43.6
SONY	40.0	40.0	37.2	48.0	48.0	28.7
LMS	11.5	11.5	10.7	23.0	23.0	13.8
TOSHIBA	13.6	13.6	12.7	14.7	14.7	8.8
Other U.S.	--	--	--	--	--	--
Other Non-U.S.	--	2.4	8.0	8.6	8.6	5.1
TOTAL	107.5	107.5	100.0	167.3	167.3	100.0

READ/WRITE OPTICAL DRIVES LESS THAN 1 GIGABYTE

1989 DISK/TREND REPORT

READ/WRITE OPTICAL DISK DRIVES LESS THAN 1 GIGABYTE

Coverage

Examples of disk drives in this group include:

3.5" disk diameter

Laserdrive	(Preliminary -- erasable)

4.72" disk diameter

Yamaha	YPR-1

5.25" disk diameter

Cherokee Data Systems	Tracker, M600
Fujitsu	M2505B
Hitachi	M-301S,OD 101-1, OD-112-2 (Erasable)
IBM	3363
Information Storage Inc.	525 WC, 525 GB
Kawatetsu Advantech	KL200S, KL1200S
Laser Magnetic Storage	510
Laserdrive	M810, M820, M840, M850
Matsushita Electric Industrial	LF-5010, JU-9400, JU9500 (Erasable)
Maximum Storage	APX-3200, APX-4000
Maxtor	Tahiti (Erasable)
Mitsubishi Electric	MW-5D1-11, ME-5E1 (Erasable)
Pentax Teknologies	LW-S501
Pioneer	DD-8002, DDU-5001
Ricoh	RO-5041WL, RO-5030E (Erasable)
Sanyo	SOF-M90
Sharp	JY-700 (Erasable)
Shugart Corporation	5984
Sony	SMO-D510 (Erasable)
Toshiba	WM-D050, WM-D070

8" disk diameter

Matsushita Graphic Commun.	PF-10
Pioneer	DD-8001
Sony	WDD-2000

Two types of drives fit into this group: Write Once Read Many, (WORM) and Erasable (Rewritable). Provided that a drive is capable of writing and reading, it is classified in this group even if it can also be used with read-only media. CD-Write-Once (CD-WO), available in 1989,

also fits into this category. The read/write drives discussed in this section are typically used with small computer systems of the mini and micro class and with intelligent workstations. Small automated libraries (jukeboxes, in industry parlance) used in departmental level mass storage subsystems are typically equipped with 5.25" read/write drives.

Market status

"In turmoil" best describes the state of the market for low capacity read/write drives. New suppliers have appeared or dropped out, 3.5" optical drives expected in 1988 were significantly delayed, and a 4.72" write-once drive has appeared in the marketplace. Despite the confusion, significant growth occurred, with 5.25" drives the dominant form factor.

1988 unit shipments, bolstered by the first deliveries in volume of rewritable drives, reached 42,600 units, up 144.8% from 1987. Ricoh, Sony, Matsushita Electric, ISI and Canon were the leading shippers. Worldwide revenues grew 157.4% to $120.2 million. 1988 shipments from IBM were minor.

83% of 1988 unit shipments were write-once drives, almost all 5.25", but in 1989, rewritable drive shipments are expected to outstrip write-once drive shipments by a 55 to 45 ratio. The early adoption of the rewritable optical drive by NeXT is playing a major role in driving the rapid early growth of rewritable drive shipments.

8" drives have had some use in Japan, largely for stand-alone document storage systems. While they offer more capacity than the 5.25" drives, their larger form factor and higher price limit usefulness in many applications. However, as 5.25" drives reach the practical limit of cap-

acity with currently available technology (probably about 800 megabytes per side), 8" drives may be seen as an acceptable compromise between size and capacity needs in a limited number of cases. Most OEM's will prefer to use multiple 5.25" drives. At present, 8" jukeboxes are not available.

System manufacturers and integrators are now taking optical drives seriously. Hewlett-Packard is distributing the Sony rewritable drive and also selling it as part of H-P systems in an H-P designed jukebox. IBM has internal design programs for both 5.25" and 3.5" drives. The system design activity that started in 1987 and earlier has created a shipment upsurge in 1989 that is expected to continue for several years.

The most successful penetration of the system integrator market to date has been achieved through the combined efforts of Ricoh and Maxtor, which has exclusive rights to market Ricoh WORM optical drives in the U.S. OEM market. Maxtor's reach into the OEM arena put Ricoh far in the lead for 1987 and 1988 shipments to OEMs. In the process, Maxtor received an education in the vagaries of the optical drive marketplace which will serve it and its Maxoptix subsidiary well as Maxoptix starts volume production of the "Tahiti" 5.25" rewritable drive in 1989.

Rewritable drives have left pre-manufacturing status. Canon and Sony made significant shipments in 1988, and Ricoh, which manufactures drives using an Olympus supplied mechanism, shipped modest quantities in 1988. However, 3.5" rewritable drive development efforts have slipped badly. The Maxtor 3.5" erasable drive to be built by Seiko Epson was withdrawn, and the 3.5" drive being developed by Verbatim has been delayed by the transfer of the Verbatim drive development effort to Laserdrive. Laserdrive intends to produce a 3.5" rewritable drive, but it will be markedly different from the product announced under the Verbatim label.

Write-once media appears to be available in more than adequate quantity. Any of the major optical media producers have the capability to supply several times the current needs of the industry. Given the modest size of the industry to date, some write-once optical media manufacturers may decide to withdraw from the market. Rewritable media is in short supply, but should be available in adequate quantities by the end of 1989 as media suppliers ramp up production and improve yields.

Marketing trends

The explosive growth of rewritable drive shipments is driving the shipment forecast for disk drives in this group. For the total product group, 118,300 units are expected to ship in 1989, and shipments of 884,700 units are expected in 1992. Rewritable drives will account for 86% of shipments in 1992, and of these, 78% will be 5.25" and 22% will be 3.5" units. About 14% of the 1992 total will be write-once units, largely 5.25", but including a small number of 8" and 4.72" drives.

Some major Japanese disk drive firms, while developing and announcing 5.25" optical disk drive products, have made relatively small efforts to develop the U.S. market, preferring to wait until demand is stronger and standards issues are resolved to the point where production equipment can be designed with little risk of a need to retool in the short term. Others, such as Ricoh, Canon, and, to some extent, Sony, are relying upon sales arrangements with strong U.S. storage products and systems producers. Eventually, 12 to 15 competitors are anticipated.

A few Japanese producers have concentrated on 8" drives in the less than one gigabyte range that can be used in office automation systems, but

the thrust of the majority of Japanese firms is toward 5.25" drives with 300-400 megabytes capacity per side. Most OEMs prefer the 5.25" form factor, leaving the 8" drive of interest primarily for specialized industrial and office systems.

Recently, manufacturers in this group have announced new, higher capacity, but unstandardized write-once drives. These actions seem to indicate a belief that the advantage gained from selling an improved product will outweigh the advantages of waiting for a standard in a market of limited size and growth prospects.

The list of competitors in this group has changed in the last year. Pentax announced its 5.25" write-once optical disk drive. Canon began production of an erasable drive. Yamaha introduced a CD format mastering system with a write-once drive. Maxtor, one of the most formidable competitors in the high capacity 5.25" magnetic disk drive market, announced a relatively high performance erasable 5.25" drive in 1988 and created, Maxoptix, a joint venture with Kubota, in 1989 to manufacture the drives. Further entrants are expected. IBM has shown strong interest in 5.25" and 3.5" rewritable drives, but while it is reasonable to anticipate eventual product announcements, the exact nature and timing is not possible to forecast with certainty.

Disk drives using rewritable media will divert growth from write-once disk drives. Both 3.5" and 5.25" configurations will be included, as shown below. Small quantities of 4.72" (CD-WO) write-once drives began shipping in 1989, but the outlook for erasable 4.72" drive shipments is unclear and shipments are unlikely before late 1992.

Projected Growth: Write-Once vs. Erasable Drives, 5.25" and Smaller

Worldwide captive & OEM unit shipments (In thousands)	1990			1991			1992		
	5.25"	4.72"	3.5"	5.25"	4.72"	3.5"	5.25"	4.72"	3.5"
Write-once	77.7	.8	--	104.1	1.1	--	121.5	1.2	--
Erasable	167.1	--	6.3	349.7	--	54.9	595.8	--	165.4
Total	244.8	.8	6.3	453.8	1.1	54.9	717.3	1.2	165.4

The large forecasted growth in 3.5" erasable drive shipments will result from an expected displacement of cartridge tape drives used with small systems for backup and save/restore applications. Growth could be even larger if prices, which are initially expected to exceed the $1,000 level, are set to compete better with small tape drive pricing. In 1991, 5.25" write-once drive growth will start to flatten as a result of competition from both 5.25" and 3.5" erasable drives, but existing manufacturing commitments should result in growth until then.

Before 1991, it is unlikely that IBM will be in internal production of any optical disk drive. However, IBM's announcement of the 3363 placed it in the market as a competitor, even though the drive mechanism was produced for IBM by Matsushita Electric. IBM is expected to eventually introduce small erasable optical disk drives of its own manufacture in the future. These drives will probably be applied in applications using IBM personal computers and advanced technical workstations, and also as the key element in a mass storage system. IBM's interim strategy of adopting a purchased mechanism was a low risk opportunity to gain experience in the optical storage marketplace, although sales have been embarrassingly low.

The CD-WO is a read/write drive in the CD-ROM physical format. The first such product, based on present CD-ROM mechanisms, has modest performance, and is available only as part of a mastering system produced by Yamaha, which does not intend to produce the drive for OEM sale.

While a CD-WO drive offered at a price under $500 could generate large sales, publishers of CD-ROM disks, fearing a recurrence of the piracy that has plagued personal computer software publishers, discourage the development and marketing of a read/write drive in CD-ROM format. Those that would welcome it for its capability to update a previously distributed data base, prefer to obtain the update capability with proposed 3.5" and 5.25" media that combine a read-only area with a writable area.

In some instances, storage systems may use rewritable drives for temporary or working data sets and then write the final form of the data to a write-once drive for archival storage. As a result, increasing sales of rewritable drives could have a moderately beneficial influence on write-once drive sales as well. However, as experience with tape libraries has shown, rewritable media is acceptable, even desirable, in most off line storage applications.

Applications

Write-once and rewritable optical drives under 1 gigabyte are finding applications as save/restore devices in microcomputer and minicomputer systems where interchange isn't required, but are used primarily as a method for storing images in office, medical, and other specialized systems. As interchange capability for rewritable drives is proven, they

will also begin to acquire the role of a data distribution device. The faster erasable drives are expected to find additional uses as system disks in high-security applications requiring vault storage of recorded media when the equipment is unattended. As optical drive performance begins to compete with the performance of small form factor Winchester disk drives, optical drives are expected to displace some rigid disk drives in other situations where removability is an advantage.

A very important application will be as file server storage devices associated with automated libraries. About 3% to 5% of the 1989 production of drives in this class is expected to be used in jukebox subsystems, such as those sold by Hewlett-Packard, Cygnet, Hitachi, NKK and others.

In 1989, personal computers were the leading equipment application, accounting for 39.2% of shipments. Non-office and office workstations were in a virtual tie with 24.5% and 24.4% shares, respectively. The office environment will continue to be the most significant consumer of smaller capacity optical drives and will consume 28% of unit shipments in 1992. Non-office workstation use will decline to 19%. Minicomputers, file servers and other multi-user applications are expected to use 18% of the units throughout the forecast period, but applications with personal computers will decline to 23%.

Tandy Corporation's 1988 technology announcement of a low cost drive using limited erasability dye-polymer media and Matsushita's 1989 technology announcements about 3.5" drives using phase change media have aroused much (perhaps, too much) industry interest in the utility of limited erasability media for save/restore applications where a high number of write/erase cycles is not required. For most backup purposes, media with a 10,000 cycle capability would be more than adequate. With annual small

rigid disk drive shipments surpassing the fifteen million unit mark and cartridge tape drive shipments near two million units, a low cost, functionally superior backup device should have good sales prospects.

Media with a read-only section and a writable section, when available, can serve as a vehicle for software and data base distribution, providing that cost of the media is low. The writability feature permits timely update of a previously installed data base. Furthermore, the ability to write gives the data base publisher certain security and anti-piracy options not readily available on read only media, in that individual disks or sections of disks can be serialized or encrypted for use on a specific system or group of systems at nominal cost.

Most departmental level systems for document storage or image storage will use the lower capacity, higher performance read/write drives. Entry level departmental applications will use small library units with five to thirty-two media units to contain all the required records in a conveniently accessible form. Larger organizations will use libraries containing hundreds of disks. Entry level systems will be found in office automation, medical, law enforcement, CAD/CAM, and smaller financial applications, and their larger cousins will be found in corporate or divisional information centers of large financial institutions, government agencies, defense contractors and aerospace firms.

Erasable optical storage is expected to significantly displace tape storage devices, when drive prices decline below $500 and customer confidence in the new technology increases. However, the high end user price of the media ($100 to $200 compared to $15 to $20 for a tape reel or cartridge) will limit initial acceptance.

Specific applications for read/write optical disk drives under 1 gigabyte include:

Save-restore operations

* Save-restore disk data backup.

* Archival storage of files.

Reference level storage

* Storage of programs, freeing up fixed magnetic disk drives for data.

* Storage of data bases frequently used but infrequently changed.

Document storage

* Storage of images for use in departmental or small organizational CAD/CAM, medical, law enforcement, and financial record systems.

* Office automation systems at the departmental level.

Data distribution

* Production and distribution of updatable data bases in quantities too small to warrant mass replication costs or where replication delays are too long for timeliness.

System disk

* Function as system disk where moderate performance is adequate and high capacity is needed.

Technical trends

Major issues for the small drives include media technology, access times, media lifetime error rates, single-pass rewritability, and software. Other significant issues are track following and servo control and substrate materials. Most of these are issue areas for larger drives as well, so this section also applies to larger drives, unless otherwise noted.

Write-once recording: A variety of optical recording technologies and media fabrication processes are in use, creating interchange problems and OEM confusion. At present, pit forming or bubble forming writing methods are in the majority, but writing using the phase change between amorphous and crystalline states to vary reflectivity at a spot is becoming more common. Sony, Fujitsu and Matsushita are currently using phase change recording. Write-once dye based media is being used by Eastman Kodak, Pioneer and Ricoh. In general, these are not interchangeable, although more sophisticated drives capable of detecting media type could accommodate some degree of interchange.

Flexible write-once drives and media are expected in sample quantities from Bernoulli Optical Systems by late 1989. The basic technology was demonstrated at the 1989 AIIM conference.

Rewritability: There are several technologies contending for acceptance in rewritable optical media, but magneto-optical media is the only currently available method capable of meeting user demands for sensitivity, erasability, and stability. However, magneto-optical techniques may not be the long range solution. Progress has been made in erasable phase change and other types of erasable recording even though these technologies are behind magneto-optical in development. Phase change media offering at least 100,000 write cycles may be on the market by late 1989, and there are prospects for extending the number of write cycles to well over one million. The high cost of manufacturing the required multi-layer structures and complex overwrite latency solutions makes magneto-optical technology subject to competition as the preferred erasable media technology in the long run.

Provided that an adequate number of erase cycles can be demonstrated, it is likely that the second generation of erasable media will make use of phase change techniques. Phase change media may permit the interchange of write-once and erasable media on a single drive, something that is not inherent to magneto-optical recording.

Dye based media may eventually become commercially significant for erasable optical disks. Now in R&D status, this type of media is less subject to degradation problems and uses inexpensive materials. While it requires more development to provide an adequate number of write/erase cycles for general use, 1,000 to 10,000 cycles is probably adequate for tape replacement applications. Dye based media is likely to be solvent coatable and relatively inexpensive to produce, and may operate with existing drives (except those configured for magneto-optical media). Obtaining an adequate number of write/erase cycles is technically difficult, and dye based erasable media will not be commercially available until 1991 or later. Furthermore, multiple lasers may be required in drives using dye-based media, raising drive cost. However, dye based media's relative immunity to environmental influences enhances its desirability as a low cost candidate to address the erasability opportunity.

Media lifetime: While accelerated life tests seem to indicate that media lifetimes of 10 years or more are achievable, this aspect of media performance will remain unproven until actually demonstrated. Some suppliers are claiming 20 or 30 year lifetimes, but archivists remain concerned about media lifetime and whether future generations of drives will be compatible with today's media and recording formats. Because organic recording layers such as dyes seem to have better corrosion resistance than the metal films typically used, dye based media may displace the original metal film types over time.

Substrates: Plastic is the currently preferred material, in order to reduce media cost and improve manufacturability. At present, Polycarbonate appears to be the future material of choice, displacing PMMA. PMMA is permeable to water vapor which, in turn, can cause corrosion of the active layer. Epoxy casting, which offers low optical distortion, is also being evaluated as a substrate fabrication technique.

While casting polycarbonate with low birefringence (a form of optical distortion) is difficult, proper formulation and control of the molding process has been shown by some substrate manufacturers to permit fabrication of substrates adequate for 5.25" media. Making polycarbonate 12" substrates is even more difficult because of the problem of keeping tight tolerances over a larger area.

Glass will be used in some small drives. The material is free of birefringence effects that distort the optical path, is non-permeable to moisture, is flat, and distortion free. Most drive makers are now convinced that glass substrates are safe to use in small diameter drives. Sharp and Matsushita have announced 5.25" erasable drives using glass substrate media. Other manufacturers are likely to do the same. The flat glass surface, coupled with high purity materials, can produce media with inherent defect levels considerably better than average. This has the advantage of reducing overall latency in the drive due to the reduced need to perform error correction during data reads.

Average access times: One of the major limitations of optical drives is average access time (seek time plus latency), which exceeds 50 milliseconds on all products yet announced except for the Maxtor 'Tahiti' 5.25" erasable drive. The first generation of magneto-optical drives have an additional latency for writing operations caused by the need to erase each sector before writing. This lack of overwrite capability requires that an additional complete rotation be performed before the drive is ready to write in the selected sector. Several techniques have been proposed to eliminate the need for an erase pass, and it is likely that future generations of M-O drives will not require a separate erase pass. The overwrite solution will come at the expense of additional complexity in the drive, media or both, so there will be a trade-off of performance for cost.

Optical drives may have additional latency associated with write operations due to write verification delays. In both read and write operations, latency is increased if media defects have forced a file to be written in non-contiguous segments, as is frequently the situation. File fragmentation caused by the need to rewrite sectors due to media degradation also is a factor on write-once drives. Some drives, such as the Laserdrive 810 series, incorporate sophisticated firmware and buffering to keep throughput high and offer a significant throughput advantage over less sophisticated designs.

The long access times of today's optical disk drives make them unattractive as competitors for magnetic disks in most system disk drive applications, but are less important when the optical drive is used in an automated library, because the fetch times and drive spin-up times are long in comparison to the drive access time. Reduction of drive spin-up time is important when the drive is used in a library based system in order to minimize the length of the waiting-for-access queue. Spin-up times of 2 seconds or less are desirable.

Manufacturers of smaller drives are targeting average access times, including latency, of under 50 milliseconds for new products. Evolving optical head designs with lower mass and split optics, plus the relatively short head travel distances used on small diameter drives, offer the possibility of reaching average access times in the 40 to 45 millisecond range in 1990.

Because most optical drives have both fine and coarse head positioning mechanisms, the average access time to data within the range of the fine head positioner may be very competitive with the average access times of small magnetic disk drives for similar amounts of data. For instance, an Optimem drive can access a band of tracks from the fine positioner's nominal center position. About 8.3 megabytes lie within this range, and any point in the range can be reached within 30 milliseconds, including latency. This suggests that suitable software could improve the throughput of optical drives, much as the use of cache improves the performance of magnetic disk drives.

Even when head positioning times improve, the amount of data quickly accessible from an optical disk drive will not match that quickly accessible on magnetic disks. Magnetic disks have multiple surfaces and make a cylinder of data available (with a short delay for head switching) from which data can be accessed. Optical drives, which today typically can access a single surface, must always move the head to reach additional tracks -- a more time consuming operation. As heads shrink in mass and cost, optical drives will appear that offer on-line access to both sides of the disk.

Optical disk drives rotate at lower speeds than do typical magnetic disk drives, so optical drive rotational latency worsens the performance of optical drives in comparison with magnetic drives.

Improvements in media materials, laser power, and tracking and focusing servos should eventually enable optical disk latency to approach magnetic disk latency. Canon's rewritable drive operates at 3000 RPM, which is getting close to the 3600 RPM commonly used in the current generation of small rigid disk drives. Erasable media requires slightly less write power than do write-once media, an advantage which can be translated into higher rotation speeds for erasable drives.

Error rate: Error correcting codes are used to compensate for the high raw error rate of optical media. The codes used, typically long distance Reed-Solomon codes, are able to deal with the higher defect density that occurs at the end of media life. While there is a reduction of data capacity on the disk to accommodate the redundancy needed by ECC methods, the loss may be as little as 8%, depending upon the ECC technique used. Where media have a high defect density, the error correction process can add substantial latency to data retrieval times. Drives will begin to incorporate more sophisticated ECC circuitry capable of doing on-the-fly error correction in such a short time that ECC latency will not be observed.

Packaging: Optical disk drives using read/write 5.25" disks are now packaged to conform with the envelope of a full height 5.25" floppy disk drive, limiting use to external mounting with many personal computers. Half height designs are planned and starting to become available in 1989. Ricoh announced a half high model in 1988.

Military interest is spurring the design of ruggedized optical drives. At least 3 firms are actively engaged in pursuing this product area.

Track following: Most optical disk drive units make use of a pre-grooved substrate surface to establish track location. The desire for minimal media cost and certain performance benefits has resulted in the development of drives capable of using grooveless media and a sector servo approach, even though the drive will be more expensive. Because the approaches are fundamentally incompatible, universal interchangeability will not be achieved. The pregrooved method has been adopted by the majority of producers and is expected to remain the most preferred method, although media production technology will require upgrading as areal density increases.

Standards: There are not yet any final optical media or drive standards, but ANSI X3B11, ECMA TC31, ISO TC91/SC23 are all involved in standardization programs for unrecorded media. Standardization efforts are currently concentrated upon the 130 mm media size and the nominal 90 mm size family. An ISO write-once draft standard might be issued in late 1989.

Drafts of standards for 5.25" and 3.5" erasable media are currently in preparation. The physical cartridge will borrow much from the

work done on the write-once standard, but the same conflicts on the track following servo that bedeviled the write-once standards have caused enough conflict to delay the appearance of erasable 5.25" drive standards.

Work on 3.5" standards is currently deadlocked in a dispute over media diameter and cartridge thickness that will take some time to resolve. As of mid-1989, the contest between the servo formats seemed to be favoring the sampled servo approach for 3.5" erasable drives. 5.25" drive producers largely favor the continuous format. No standard device level interface for optical drives exists, but at the system level, SCSI appears to have the status of a de facto standard. The IBM PC/AT interface, usually achieved by use of a host adaptor, also has de facto standard status for both CD-ROM and read/write small drives.

Software: Read/write optical disk drives require specific supporting software, including drivers, operating system utilities, and application programs.

Basic software must address problems presented by the nature of the optical disk drive:

* More storage capacity is available than unmodified small computer operating systems can handle.

* Write-once disks require nonstandard file management utilities and drivers. File updates may result in degraded performance if files and directories are dispersed across the disk.

* Magneto-optical disks require modified system software to handle the overwrite requirement, or must have this function performed by the disk electronics or controller.

* File management functions in the computer operating system must be modified so that the optical disk appears to the operating system to be identical to a magnetic disk drive.

Driver and operating system utilities specific to optical disk drives will be provided by drive vendors for widely used systems such as the IBM PC. Some drive producers, such as Maximum Storage and Laserdrive, are making major efforts to differentiate their products based on software content. System integrators and OEMs will provide system support on less widely used processors.

Application programs frequently will be supplied in the form of object code that is resident on the optical disk itself. The large capacity of the optical disk may permit the inclusion of program versions for several types of popular machines.

Software suppliers will probably have to face the choice of distributing source code to system integrators and OEMs, or remastering (for CD-ROM), or maintaining a significant ongoing effort to pro-

vide support for a complete range of systems. Many will choose to let other organizations bear support costs.

Forecasting assumptions

1. IBM is working on an internally manufactured rewritable 5.25" drive and a 3.5" rewritable drive. The timing and product form are very uncertain. IBM write-once drive shipments beginning in late 1987 will decline through 1989 and then cease.

2. Rewritable media will be available in adequate production quantities by late 1989.

3. Low-end rewritable drives will have competition from high capacity floppy disk drives targeted at the tape replacement market after 1990.

4. Low cost rewritable drives using limited erasability media will enter the market after 1990.

5. Write-once media interchange specifications will be standardized in late 1989 to the extent that the multiple servo format dispute allows it. 5.25" rewritable media specifications will be largely standardized by late 1989 and rewritable 3.5" will be standardized in 1990.

6. 4.72" write-once drives will remain in only limited production through 1992. Rewritable 4.72" drives and media are not anticipated until 1992.

1989 DISK/TREND REPORT

TABLE 15

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1988		Forecast							
	Revenues		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	1.6	2.4	.3	.6	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	1.6	2.4	.3	.6	--	--	--	--	--	--
PCM/Reseller	3.9	3.9	9.7	9.7	56.8	92.4	141.0	212.1	178.2	273.2
OEM/Integrator	7.7	10.5	25.3	27.5	87.1	107.0	220.8	286.9	280.0	444.7
TOTAL U.S. NON-CAPTIVE	11.6	14.4	35.0	37.2	143.9	199.4	361.8	499.0	458.2	717.9
TOTAL U.S. REVENUES	13.2	16.8	35.3	37.8	143.9	199.4	361.8	499.0	458.2	717.9
Non-U.S. Manufacturers										
Captive	3.4	42.4	9.1	75.8	12.3	102.1	15.1	125.3	14.7	147.6
PCM/Reseller	--	--	6.9	12.7	20.7	34.1	43.4	72.6	99.5	170.3
OEM/Integrator	36.7	61.0	122.0	175.3	176.5	263.1	230.8	346.2	309.3	478.4
TOTAL NON-U.S. REVENUES	40.1	103.4	138.0	263.8	209.5	399.3	289.3	544.1	423.5	796.3
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	53.3	120.2	173.3	301.6	353.4	598.7	651.1	1,043.1	881.7	1,514.2
OEM Average Price ($000)	2.0	2.2	1.9	2.0	2.0	2.0	1.9	1.9	1.6	1.6

TABLE 16

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1988		Forecast							
	Shipments		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	.6	.9	.1	.2	--	--	--	--	--	--
Other U.S. Captive	--	--	--	--	--	--	--	--	--	--
TOTAL U.S. CAPTIVE	.6	.9	.1	.2	--	--	--	--	--	--
PCM/Reseller	1.4	1.4	2.4	2.4	22.5	36.2	71.3	105.9	106.9	163.3
OEM/Integrator	3.7	4.7	6.4	7.3	33.8	41.1	107.2	138.1	173.9	273.2
TOTAL U.S. NON-CAPTIVE	5.1	6.1	8.8	9.7	56.3	77.3	178.5	244.0	280.8	436.5
TOTAL U.S. SHIPMENTS	5.7	7.0	8.9	9.9	56.3	77.3	178.5	244.0	280.8	436.5
Non-U.S. Manufacturers										
Captive	.9	7.5	.8	11.9	.8	17.6	1.2	23.9	1.3	31.2
PCM/Reseller	--	--	2.6	4.8	10.0	16.3	25.5	41.6	62.3	108.3
OEM/Integrator	18.8	28.1	70.1	91.7	96.9	142.6	134.6	201.5	198.9	308.7
TOTAL NON-U.S. SHIPMENTS	19.7	35.6	73.5	108.4	107.7	176.5	161.3	267.0	262.5	448.2
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	25.4	42.6	82.4	118.3	164.0	253.8	339.8	511.0	543.3	884.7
Cumulative Shipments										
IBM	1.9	2.5	2.0	2.7	2.0	2.7	2.0	2.7	2.0	2.7
Non-IBM	37.6	63.2	119.9	181.3	283.9	435.1	623.7	946.1	1,167.0	1,830.8
WORLDWIDE TOTAL	39.5	65.7	121.9	184.0	285.9	437.8	625.7	948.8	1,169.0	1,833.5

TABLE 17

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1988 Revenues		Forecast															
			1989			1990				1991				1992			
	8"	5.25"	8"	5.25"	4.72"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"
U.S. MANUFACTURERS																		
IBM Captive	--	2.4	--	.6	--	--	--	--	--	--	--	--	--	--	--	--	--
PCM	--	3.9	--	9.7	--	--	92.2	--	.2	--	194.0	--	18.1	--	245.5	--	27.7
OEM	--	10.5	--	27.5	--	--	106.9	--	.1	--	280.5	--	6.4	--	413.8	--	30.9
TOTAL U.S. REVENUES	--	16.8	--	37.8	--	--	199.1	--	.3	--	474.5	--	24.5	--	659.3	--	58.6
NON-U.S. MANUFACTURERS																		
Captive	12.2	30.2	18.2	45.9	11.7	19.8	64.7	17.6	--	14.0	88.2	23.1	--	10.4	113.2	24.0	--
PCM	--	--	--	12.7	--	--	30.2	--	3.9	--	51.0	--	21.6	--	111.0	--	59.3
OEM	2.6	58.4	4.2	171.1	--	4.3	254.6	--	4.2	1.6	325.9	--	18.7	--	420.8	--	57.6
TOTAL NON-U.S. REVENUES	14.8	88.6	22.4	229.7	11.7	24.1	349.5	17.6	8.1	15.6	465.1	23.1	40.3	10.4	645.0	24.0	116.9
WORLDWIDE RECAP																		
Captive	12.2	32.6	18.2	46.5	11.7	19.8	64.7	17.6	--	14.0	88.2	23.1	--	10.4	113.2	24.0	--
	+58.4%	+147.0%	+49.2%	+42.6%	--	+8.8%	+39.1%	+50.4%	--	-29.3%	+36.3%	+31.3%	--	-25.7%	+28.3%	+3.9%	--
PCM	--	3.9	--	22.4	--	--	122.4	--	4.1	--	245.0	--	39.7	--	356.5	--	87.0
	--	--	--	+474.4%	--	--	+446.4%	--	--	--	+100.2%	--	+868.3%	--	+45.5%	--	+119.1%
OEM	2.6	68.9	4.2	198.6	--	4.3	361.5	--	4.3	1.6	606.4	--	25.1	--	834.6	--	88.5
	+30.0%	+189.5%	+61.5%	+188.2%	--	+2.4%	+82.0%	--	--	-62.8%	+67.7%	--	+483.7%	-100.0%	+37.6%	--	+252.6%
Total Revenues	14.8	105.4	22.4	267.5	11.7	24.1	548.6	17.6	8.4	15.6	939.6	23.1	64.8	10.4	1,304.3	24.0	175.5
	+52.6%	+184.9%	+51.4%	+153.8%	--	+7.6%	+105.1%	+50.4%	--	-35.3%	+71.3%	+31.3%	+671.4%	-33.3%	+38.8%	+3.9%	+170.8%
ANNUAL SHARE, BY DIAMETER	12.3%	87.7%	7.4%	88.8%	3.8%	4.0%	91.7%	2.9%	1.4%	1.5%	90.2%	2.2%	6.1%	.7%	86.2%	1.6%	11.5%

TABLE 18

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1988 Shipments		1989			Forecast 1990				1991				1992			
	8"	5.25"	8"	5.25"	4.72"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"	8"	5.25"	4.72"	3.5"
U.S. MANUFACTURERS																	
IBM Captive	--	.9	--	.2	--	--	--	--	--	--	--	--	--	--	--	--	--
PCM	--	1.4	--	2.4	--	--	36.0	--	.2	--	89.4	--	16.5	--	134.1	--	29.2
OEM	--	4.7	--	7.3	--	--	41.0	--	.1	--	132.1	--	6.0	--	238.9	--	34.3
TOTAL U.S. SHIPMENTS	--	7.0	--	9.9	--	--	77.0	--	.3	--	221.5	--	22.5	--	373.0	--	63.5
NON-U.S. MANUFACTURERS																	
Captive	.8	6.7	1.2	10.2	.5	1.3	15.5	.8	--	1.0	21.8	1.1	--	.8	29.2	1.2	--
PCM	--	--	--	4.8	--	--	13.3	--	3.0	--	23.6	--	18.0	--	54.4	--	53.9
OEM	.4	27.7	.6	91.1	--	.6	139.0	--	3.0	.2	186.9	--	14.4	--	260.7	--	48.0
TOTAL NON-U.S. SHIPMENTS	1.2	34.4	1.8	106.1	.5	1.9	167.8	.8	6.0	1.2	232.3	1.1	32.4	.8	344.3	1.2	101.9
WORLDWIDE RECAP																	
Captive	.8	7.6	1.2	10.4	.5	1.3	15.5	.8	--	1.0	21.8	1.1	--	.8	29.2	1.2	--
	+14.3%	+137.5%	+50.0%	+36.8%	--	+8.3%	+49.0%	+60.0%	--	-23.1%	+40.6%	+37.5%	--	-20.0%	+33.9%	+9.1%	--
PCM	--	1.4	--	7.2	--	--	49.3	--	3.2	--	113.0	--	34.5	--	188.5	--	83.1
	--	--	--	+414.3%	--	--	+584.7%	--	--	--	+129.2%	--	+978.1%	--	+66.8%	--	+140.9%
OEM	.4	32.4	.6	98.4	--	.6	180.0	--	3.1	.2	319.0	--	20.4	--	499.6	--	82.3
	--	+147.3%	+50.0%	+203.7%	--	--	+82.9%	--	--	-66.7%	+77.2%	--	+558.1%	-100.0%	+56.6%	--	+303.4%
Total Shipments	1.2	41.4	1.8	116.0	.5	1.9	244.8	.8	6.3	1.2	453.8	1.1	54.9	.8	717.3	1.2	165.4
	+9.1%	+154.0%	+50.0%	+180.2%	--	+5.6%	+111.0%	+60.0%	--	-36.8%	+85.4%	+37.5%	+771.4%	-33.3%	+58.1%	+9.1%	+201.3%
ANNUAL SHARE, BY DIAMETER	2.8%	97.2%	1.5%	98.2%	.3%	.7%	96.6%	.3%	2.4%	.2%	88.9%	.2%	10.7%	.1%	81.2%	.1%	18.6%

TABLE 19

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

ERASABLE/WRITE ONCE DRIVE ANALYSIS

	1988 --Shipments--		Forecast 1989		1990		1991		1992	
	Units	%	Units	%	Units	%	Units	%	Units	%
U.S. MANUFACTURERS										
Captive Total	.9		.2		--		--		--	
Write-Once	.9	100.0	.2	100.0	--	--	--	--	--	--
OEM/PCM Total	6.1		9.7		77.3		244.0		436.5	
Write-Once	6.1	100.0	9.1	93.9	26.4	34.2	45.2	18.5	58.9	13.5
Erasable	--	--	.6	6.1	50.9	65.8	198.8	81.5	377.6	86.5
Total U.S.	7.0		9.9		77.3		244.0		436.5	
Write-Once	7.0	100.0	9.3	94.0	26.4	34.2	45.2	18.5	58.9	13.5
Erasable	--	--	.6	6.0	50.9	65.8	198.8	81.5	377.6	86.5
NON-U.S. MANUFACTURERS										
Captive Total	7.5		11.9		17.6		23.9		31.2	
Write-Once	7.3	97.4	9.9	83.3	15.4	87.6	19.7	82.5	24.7	79.3
Erasable	.2	2.6	2.0	16.7	2.2	12.4	4.2	17.5	6.5	20.7
OEM/PCM Total	28.1		96.5		158.9		243.1		417.0	
Write-Once	21.0	74.8	34.6	35.9	38.6	24.3	41.5	17.1	39.9	9.6
Erasable	7.1	25.2	61.9	64.1	120.3	75.7	201.6	82.9	377.1	90.4
Total Non-U.S.	35.6		108.4		176.5		267.0		448.2	
Write-Once	28.3	79.6	44.5	41.1	54.0	30.6	61.2	22.9	64.6	14.4
Erasable	7.3	20.4	63.9	58.9	122.5	69.4	205.8	77.1	383.6	85.6
WORLDWIDE RECAP										
Total Worldwide Shipments	42.6		118.3		253.8		511.0		884.7	
	+144.8%		+177.7%		+114.5%		+101.3%		+73.1%	
Write-Once	35.3	83.0	53.8	45.5	80.4	31.7	106.4	20.8	123.5	14.0
	+102.8%		+52.4%		+49.4%		+32.3%		+16.0%	
Erasable	7.3	17.0	64.5	54.5	173.4	68.3	404.6	79.2	761.2	86.0
	--		+783.5%		+168.8%		+133.3%		+88.1%	

Notes: Percentage figures with plus/minus signs refer to year-to-year growth rates.

TABLE 20

READ/WRITE OPTICAL DISK DRIVES, LESS THAN 1 GIGABYTE

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

APPLICATION	1988 Estimate Units (000)	1988 Estimate %	1992 Projection Units (000)	1992 Projection %
MAINFRAME/SUPERMINI General purpose	--	--	44.2	5.0
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	4.5	10.5	159.2	18.0
PERSONAL COMPUTERS Business and professional, single user	16.7	39.2	203.5	23.0
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	10.4	24.4	247.8	28.0
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	10.4	24.5	168.1	19.0
CONSUMER AND HOBBY COMPUTERS	--	--	17.7	2.0
OTHER APPLICATIONS	.6	1.4	44.2	5.0
Total	42.6	100.0	884.7	100.0

READ/WRITE OPTICAL DRIVES MORE THAN 1 GIGABYTE

1989 DISK/TREND REPORT

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

Coverage

Examples of disk drives in this group include:

14" disk diameter

Eastman Kodak	6800

12" disk diameter

ATG Gigadisc	GD1001, GD1002, GD6000
Fujitsu	F6441B1, M2502A/B
Hitachi	OD 301A-1
Laser Magnetic Storage	1200E, 1250E
NEC	N7911/N6329-21, N6513
Nikon	MO-DD120C (Erasable)
Optimem	1000, 2400, 4000, 4400
Sanyo	SOF-8501
Sony	WDD 3000
Toshiba	DF-0450, DF-0460, WM-S500

5.25" disk diameter

Bernoulli Optical Systems	(Preliminary)

High capacity optical disk drives are read/write drives, either write-once or erasable. At present, only write-once drives are available in this capacity range, although Nikon has announced a 12" erasable drive for late 1989 delivery. The existing write-once drives are used primarily with large minicomputers and mainframes in specialized imaging, document storage, or archiving applications. They are frequently used with library devices to provide random access mass storage subsystems capable of handling hundreds of gigabytes of storage. At present, all but one of the available drives in this group use 12" media, and all access a single side of a single disk. The 5.25" Bernoulli Optical Systems drive uses flexible write-once media produced by ICI, with heads on both sides.

Market status

In 1988, 10,600 drives were shipped worldwide, up 34.2% from 1987, due largely to resumption in growth of captive unit shipments by non-U.S. firms. 1988 OEM drive shipments increased modestly by 25.5%. 1988 revenues were $79.6 million, of which 49.2% were derived from OEM sales, down from 55% in 1987. 1988 revenues were about 5% under 1987 revenues despite the unit shipment increase due to declining drive prices and a larger contribution from more price-aggressive suppliers. Over 91% of units shipped were produced by non-U.S. firms. The shipment leaders in 1988 were Laser Magnetic Storage, Toshiba, and Hitachi, with Toshiba holding the leadership as a captive supplier. LMS is the dominant OEM supplier on a worldwide basis.

Japanese firms have historically led this drive group because of early emphasis for use in systems capable of storing documents produced in Asian character sets. However, non-Japanese producers are narrowing the lead of Japanese producers, and are responsible for half of the unit shipments in the over 1 gigabyte optical drive product group.

Government and financial organizations continue to be major markets for high capacity optical disk drives in this group, and some system integrators, including IBM, are beginning to quote on orders of significant magnitude as prospective customers leave the technology evaluation stage and begin making hard decisions about configurations and suppliers. The endorsement of optical technology by Eastman Kodak and other firms supplying microfilm equipment for records management has also helped to expand the available market, as has the availability of library units from several suppliers. In mid-1988, IBM announced the availability of a 12" optical drive and library for System/36 and AS/400 users. IBM obtains the

drive from LMS and the library from Filenet. IBM has also established a business unit to perform optical drive based system integration for specific customers.

Marketing trends

Because high capacity optical disk drives are used mostly in large systems and in specialized applications, shipment growth rates for drives with more than 1 gigabyte capacity remain smaller than for other optical disk drive groups. Worldwide unit shipments are expected to grow moderately from 10,600 units in 1988 to 29,000 units in 1992. Revenues in this same period are forecasted to expand from $79.6 million (27.0% of the worldwide optical disk drive market) to $227.4 million (but only 11.2% of the worldwide optical disk drive market). Growth within the forecast period will be slowed by competition from smaller optical disks, long lead times on software development for use with optical drives in large systems, and the generally higher price levels of storage subsystems based on the large capacity drives.

Applications for the high capacity optical drive emphasize record management applications such as image processing and archiving, where the higher price and lower performance of current products is acceptable. Demand from these markets is increasing, albeit slowly, with highest shipments anticipated after 1990, for reasons discussed in the following section.

Eastman Kodak has been in limited production of a 14" write-once disk drive since 1987. This unit is available to OEMs and is used by Eastman Kodak in its own line of image processing systems on a captive basis. The

firm is offering a variety of systems to the records management market using its own and other optical drives. Its product presentations at recent AIIM conferences were well received, but the greatest short term interest remains concentrated in the smaller systems.

While IBM has an optical disk drive development program underway, no early introduction of internally produced high capacity drives from IBM is anticipated. It is unlikely that IBM will find the low volume of shipments in the high capacity segment an attractive incentive for developing an internally manufactured drive. The most probable IBM optical drive is a small diameter multi-disk configuration using magneto-optical erasable media, with a library mechanism, having capacity per disk less than 1 gigabyte. But IBM usually has multiple development programs, and an 8" or 12" erasable drive is not out of the question despite the technical difficulties involved.

IBM's current policy is to purchase appropriate drives from LMS and library units from Filenet, offering them as standard peripheral subsystems with existing system product lines using appropriate software provided by IBM. DEC has taken similar action, offering the LMS 12" drives as the DEC model RV20, and Unisys has been purchasing 12" drives from Hitachi to run on its 1100 mainframe.

Third parties, including Data/Ware Development and Comparex, also offer optical drive subsystems for attachment to IBM mainframes, and it is likely that other firms will also provide such attachments.

Applications

The major applications for optical disk drives over 1 gigabyte capacity are records management, medical, geophysical, military or industrial imaging, and to accumulate transaction documents that must be stored for future reference. Almost all of these are archival in nature.

Scientific, industrial and defense oriented users of high capacity drives use them for acquiring high volume digitized data from real time inputs and storing it for subsequent analysis, as well as for administrative uses. A few financial institutions use them for accumulating various types of transaction data in other than image form.

Typical usage will include:

Engineering and manufacturing systems

* Centralized drawing/document storage and distribution.
* Document storage for computer integrated manufacturing.
* Document storage and dissemination for construction projects.

Records management

* Personnel records.
* Tax records and tax rolls.
* X-ray and scanner images.
* Law enforcement records.
* Social Security, patent and other government records.
* Large library index files.

Save/restore operations

* Disk backup.
* Archival storage.

Office automation

* Storage and dissemination of office documents.

* Storage of legal documents incorporating signatures and other personal identification.

Transaction audit trails

* Records of reservations, bank transactions, etc.

* Secure area access records.

* Insurance claim and policy records.

Data acquisition

* Capture of data from scanners, seismic detectors or other imaging devices.

* Capture of data having military or intelligence significance.

The early users of high capacity drives have concentrated on the storage of images, including document filing systems used within government bodies such as taxing agencies, law enforcement, and military/intelligence agencies. Drive library units (jukeboxes) are available for use with high capacity optical disk drives, allowing the creation of on-line mass storage subsystems that are attracting the attention of insurance companies, banks, and other large organizations that must have ready recall of large amounts of account related data. Approximately 20% of the drives in this group are shipped in automated library subsystems, and this percentage is increasing at a rate of 4% to 5% annually, so that in 1992, 32 to 36% of the units in this group will be installed in jukeboxes upon shipment. An automated library system using large capacity drives usually has two or more drives to improve overall response time.

In 1988, the largest application areas for high capacity optical drives were office systems, and non-office workstations. Together, these

categories accounted for 64% of unit shipments. In 1992, this pattern will be much the same: The larger drives will continue to find uses in specialized office document filing systems, with non-office workstations and with multi-user processors in the mini and mainframe applications. Workstations will remain the most frequent application.

The records management market will eventually be a major consumer of high capacity optical disk drives, but this market is likely to experience slow growth due to the conservative nature of the market. Records managers will be reluctant to abandon large investments in existing systems without ample experimentation to convince them that there are no hidden perils in the new technology. In some organizations, infighting between MIS managers and records managers will further delay purchase decisions.

Finally, prospective buyers continue to contend with difficulties in obtaining adequate equipment to convert existing film records into a form suitable for optical disk storage, and delays in development of application software.

There will be competition from smaller capacity drives in many system applications and many companies will experiment with a small scale system before making major commitments.

Mainframes and minicomputers will ultimately be hosts for large optical drives, as they have the capability needed to process or distribute the large amounts of data stored. Tape subsystems currently used in mainframe environments will be supplemented by large capacity optical drives operating with automated libraries.

Large capacity optical disk drives will be employed in dedicated systems that store and manipulate engineering drawings, technical specifi-

cations and reference materials. These smaller systems will need smaller library units to meet departmental needs, but most library producers have concentrated on equipment to handle larger diameter disks. If the smaller libraries, with capacity to store 5-10 disks in the 12" size are not produced, this segment of the market will eventually be captured by smaller diameter drives used with library units of 10-20 disk capacity, many of which are already in the market.

Technical trends

Many of the technical issues discussed in the section on optical disk drives under 1 gigabyte capacity also apply to the larger capacity drives in this section. The issues are reviewed here as they pertain specifically to the higher capacity drives.

* Positioning time: Almost all of the released products in this group currently use complex optical head assemblies, resulting in excessive head positioning times. This is of less consequence when the drive is used in a library subsystem, because of the long time required to locate, mount, and spin up the disk to operating speed. Considerable work is being done by manufacturers to reduce drive complexity and to improve access time. Even so, it will probably be several years before typical head positioning times are below 100 milliseconds for these drives.

* Standards: Standards for very high capacity media will take several years to materialize, because the initial product designs are already established, even though incompatible. The ANSI X3B11 committee, which has the U.S. charter to develop such a standard, has begun deliberations, but does not expect to have a standard for 12" or 14" media for some years to come. IBM could change this situation by making a product announcement of a high capacity internally manufactured optical drive and creating a de facto standard, but as already noted, an early IBM announcement of a large capacity drive is unlikely, nor is it clear that any such product would be a large diameter design.

* System design: Many large capacity optical disk storage systems will incorporate an automated library. Several firms, including Cygnet, Filenet, Laser Magnetic Storage, Hitachi and others have designed libraries, discovering in the process that it is a major

project, requiring substantial time and investment. To be a generally applicable product, the library may have to accommodate several brands of disk drives, an awkward consideration given the lack of product standardization in the industry. The library unit also has to be interfaced to the computer system with which it is to be used, requiring significant development time.

* Software: The software required to integrate a write-once optical disk into the operating system environment of a mainframe computer represents a major project, requiring many man years of effort. The integration of erasable disks should be easier, but even these will present some problems. Those aspects of the drive unique to optical storage may be masked by the controller, so that the optical storage subsystem appears as a standard magnetic disk to the operating system.

* Capacity: Capacity per disk is increasing through the use of zoned recording and other compression techniques. Newer 12" drives offer 2.5 gigabytes per side, up from a typical 1 gigabyte per side in earlier models. Shorter wavelength lasers are expected to bring an additional 30% to 40% improvement by 1992.

* Multiple heads: The larger form factor of the high capacity drive permits the eventual use of multiple, independent heads and actuators when economically feasible. Multiple head/actuator assemblies for both sides and one side of the media are being considered, but have not yet been shown commercially.

* Rewritability: Nikon expects to have limited quantities of a rewritable 12" drive and media available in late 1989, but no other firms have indicated definite intentions to offer a commercial product, perhaps because the archival orientation of the market makes write-once media more desirable for many customers.

* Non-removable multiple disks: A multi-disk Winchester-like configuration has been considered by various system manufacturers, but probably won't be seriously attempted until the characteristics of optical drive components have advanced to the point where a drive could closely approach the costs and performance of high capacity magnetic disk drives. The disk diameters employed will probably be 5.25" or 8", and the media will, naturally, be rewritable.

* Packaging: The larger capacity optical disk drives typically have a rack mount configuration. Because these drives will often be used with library devices, there is a need to define a standardized mechanical interface that will permit any drive to be used with any library load/unload mechanism.

For the next few years, the 12" form factor will remain the most frequently encountered form factor in this product group. As areal density improves, 8" and 5.25" drives may also fall into this class of optical drive.

* Track following: Pregrooving of the media continues to be the primary method of providing tracking information to the tracking servo for this product group. There has been some interest in using sector servo techniques to improve tracking. ATG Gigadisc has done substantial development work with this technique and has incorporated it into the design of the ATG 12" drive. ATG and other supporters of the sector servo approach believe sector servoing improves the ability of the drive to accept write-once, erasable, and read-only media on the same drive and makes the drive less sensitive to variations in groove shape and depth. This approach has been proposed by ATG in the preparation of a standard for 12" optical media. Laser Magnetic Storage also favors a sector servo approach for its future products.

* Interface: SCSI is the most commonly encountered interface on the large capacity optical drives. SCSI is likely to remain the preferred choice because of design commitments or until drives with higher performance are technically possible. It is not clear that there will be a standard or semi-standard device level interface for this product class. For most drives, proprietary interfaces are used at the device level at the present time.

  For a 12" drive operating at 1800 RPM, a practical data transfer rate limit is about 10 megabits/second, limited by the spot size and power of the laser. As lasers improve, and as RPM increases, the interface and controller will have to cope with significantly higher data transfer rates. A future 12" drive equipped with a green semiconductor laser and spinning at 3600 RPM could generate a data transfer rate exceeding 37 megabits/second.

* Lasers: The larger form factors of the high capacity optical drive favor the use of head assemblies with multiple lasers. The use of multiple lasers can improve drive performance by permitting direct read during write, higher bit densities, use of unusual active layer material, and possibly other benefits. If head designs that separate the laser from the head optics are adopted to reduce mass, it may also be possible to use non-semiconductor lasers and still achieve reasonable performance. Because non-semiconductor lasers can operate at higher frequencies and powers, very high performance may be possible by using them in optical storage systems. RCA, for instance, has produced a few specialized systems for the U.S. government using non-semiconductor lasers. However, cost and reliability will have to be traded for performance in such designs.

* Media: Larger diameter media requires substrates that will not deform at high rotation rates and will maintain consistent optical properties over the usable area of the disk. The latter point is especially significant for magneto-optical media in which distortion caused by locked-in or dynamic stresses in the substrate creates signal degradation. These mechanical problems may be a significant obstacle to improving the performance of high capacity optical drives.

The current limit on rotational velocity for larger diameter disks is created by available laser write power and the performance of focus and tracking servos, rather than by material failure. 1800 RPM is considered today's state of the art for high capacity drives, and many commercial products operate at half this RPM or less. There are expectations of achieving 2800 to 3600 RPM in the future through the use of non-mechanical focusing techniques and improved substrate materials.

In general, erasable media for large capacity disks is not available except in sample quantities, and, given the current emphasis on small diameter media by media suppliers and standards groups, the availability date of production volumes is probably later than 1990. There are also significant technical problems to be overcome in the fabrication of large diameter erasable media.

* Substrates: Both plastic and glass are in use for 12" media substrates, and Eastman Kodak is using an aluminum substrate for its 14" drive. Because of the difficulty in molding large diameter plastic substrates with adequately low birefringence, it seems likely that glass will play an increasingly prominent role in attempts to fabricate readily producible erasable media for large diameter drives. Producers of glass substrates have demonstrated that glass hardened by ion bombardment has adequate mechanical strength to withstand routine use under projected conditions for future drive designs. However, there is still uncertainty as to the effects of small imperfections such as nicks, scratches or chips caused during handling of the disk. More work must be done by drive, media, and substrate producers to determine whether such imperfections represent a longer term hazard.

  The aluminum substrates being used by Eastman Kodak may be usable for erasable media if erasable dye based media is successfully developed, but the pace of development has been slow and it is unlikely that any practical erasable dye based media will be available within the forecast period of this report.

Forecasting assumptions

1. No IBM-produced units in this category will be shipped through 1992.

2. There will continue to be an adequate supply of write-once media for products in this group.

3. Generally recognized media interchange standards for this product group will not exist during the forecast period.

4. There will be no shipments of 5.25" or 8" drives in this product group within the forecast period.

5. Rewritable 12" drives and media will arrive in the market in 1990, but will have only marginal impact through 1992.

1989 DISK/TREND REPORT

TABLE 21

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

REVENUE SUMMARY

	DISK DRIVE REVENUES, BY SHIPMENT DESTINATION ($M)									
	1988		Forecast							
	Revenues		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	4.7	4.7	4.7	4.7	8.6	8.6	12.0	12.0
TOTAL U.S. CAPTIVE	--	--	4.7	4.7	4.7	4.7	8.6	8.6	12.0	12.0
PCM/Reseller	--	--	--	--	--	--	--	--	--	--
OEM/Integrator	5.3	6.8	13.4	17.7	15.2	24.9	21.3	33.3	23.9	40.9
TOTAL U.S. NON-CAPTIVE	5.3	6.8	13.4	17.7	15.2	24.9	21.3	33.3	23.9	40.9
TOTAL U.S. REVENUES	5.3	6.8	18.1	22.4	19.9	29.6	29.9	41.9	35.9	52.9
Non-U.S. Manufacturers										
Captive	3.3	37.4	3.3	37.4	4.2	40.1	4.2	42.9	5.2	45.4
PCM/Reseller	2.0	3.0	2.9	3.9	4.7	7.5	7.4	12.1	10.1	16.5
OEM/Integrator	15.7	32.4	19.8	44.7	35.3	68.1	50.4	92.2	62.0	112.6
TOTAL NON-U.S. REVENUES	21.0	72.8	26.0	86.0	44.2	115.7	62.0	147.2	77.3	174.5
Worldwide Recap										
TOTAL WORLDWIDE REVENUES	26.3	79.6	44.1	108.4	64.1	145.3	91.9	189.1	113.2	227.4
OEM Average Price ($000)	5.1	5.7	6.8	7.0	7.3	7.2	7.2	7.0	6.9	6.8

TABLE 22

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

UNIT SHIPMENT SUMMARY

	DISK DRIVE UNIT SHIPMENTS, BY SHIPMENT DESTINATION (000)									
	1988		Forecast							
	Shipments		1989		1990		1991		1992	
	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW	U.S.	WW
U.S. Manufacturers										
IBM Captive	--	--	--	--	--	--	--	--	--	--
Other U.S. Captive	--	--	.1	.1	.1	.1	.2	.2	.3	.3
TOTAL U.S. CAPTIVE	--	--	.1	.1	.1	.1	.2	.2	.3	.3
PCM/Reseller	--	--	--	--	--	--	--	--	--	--
OEM/Integrator	.7	.9	1.0	1.5	1.3	2.2	1.8	3.0	2.2	3.8
TOTAL U.S. NON-CAPTIVE	.7	.9	1.0	1.5	1.3	2.2	1.8	3.0	2.2	3.8
TOTAL U.S. SHIPMENTS	.7	.9	1.1	1.6	1.4	2.3	2.0	3.2	2.5	4.1
Non-U.S. Manufacturers										
Captive	.3	3.4	.3	3.5	.4	3.8	.4	4.1	.5	4.4
PCM/Reseller	.2	.3	.3	.4	.5	.8	.8	1.3	1.1	1.8
OEM/Integrator	3.4	6.0	3.9	7.4	5.6	10.8	8.2	15.0	10.3	18.7
TOTAL NON-U.S. SHIPMENTS	3.9	9.7	4.5	11.3	6.5	15.4	9.4	20.4	11.9	24.9
Worldwide Recap										
TOTAL WORLDWIDE SHIPMENTS	4.6	10.6	5.6	12.9	7.9	17.7	11.4	23.6	14.4	29.0
Cumulative Shipments										
IBM	--	--	--	--	--	--	--	--	--	--
Non-IBM	15.6	34.6	21.2	47.5	29.1	65.2	40.5	88.8	54.9	117.8
WORLDWIDE TOTAL	15.6	34.6	21.2	47.5	29.1	65.2	40.5	88.8	54.9	117.8

TABLE 23

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE REVENUES ($M)

BREAKDOWN BY DISK DIAMETER

	1988 Revenues		Forecast							
			1989		1990		1991		1992	
	14"	12"	14"	12"	14"	12"	14"	12"	14"	12"
U.S. MANUFACTURERS										
Other U.S. Captive	--	--	4.7	--	4.7	--	8.6	--	12.0	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	--	6.8	6.5	11.2	9.2	15.7	12.3	21.0	14.5	26.4
TOTAL U.S. REVENUES	--	6.8	11.2	11.2	13.9	15.7	20.9	21.0	26.5	26.4
NON-U.S. MANUFACTURERS										
Captive	--	37.4	--	37.4	--	40.1	--	42.9	--	45.4
PCM	--	3.0	--	3.9	--	7.5	--	12.1	--	16.5
OEM	--	32.4	--	44.7	--	68.1	--	92.2	--	112.6
TOTAL NON-U.S. REVENUES	--	72.8	--	86.0	--	115.7	--	147.2	--	174.5
WORLDWIDE RECAP										
Captive	--	37.4	4.7	37.4	4.7	40.1	8.6	42.9	12.0	45.4
	--	+6.9%	--	--	--	+7.2%	+83.0%	+7.0%	+39.5%	+5.8%
PCM	--	3.0	--	3.9	--	7.5	--	12.1	--	16.5
	--	--	--	+30.0%	--	+92.3%	--	+61.3%	--	+36.4%
OEM	--	39.2	6.5	55.9	9.2	83.8	12.3	113.2	14.5	139.0
	--	-14.6%	--	+42.6%	+41.5%	+49.9%	+33.7%	+35.1%	+17.9%	+22.8%
Total Revenues	--	79.6	11.2	97.2	13.9	131.4	20.9	168.2	26.5	200.9
	--	-1.6%	--	+22.1%	+24.1%	+35.2%	+50.4%	+28.0%	+26.8%	+19.4%
ANNUAL SHARE, BY DIAMETER	--	100.0%	10.3%	89.7%	9.6%	90.4%	11.1%	88.9%	11.7%	88.3%

TABLE 24

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

WORLDWIDE SHIPMENTS (000)

BREAKDOWN BY DISK DIAMETER

	1988 Shipments		Forecast							
			1989		1990		1991		1992	
	14"	12"	14"	12"	14"	12"	14"	12"	14"	12"
U.S. MANUFACTURERS										
Other U.S. Captive	--	--	.1	--	.1	--	.2	--	.3	--
PCM	--	--	--	--	--	--	--	--	--	--
OEM	--	.9	.2	1.2	.3	1.5	.4	2.0	.5	2.2
TOTAL U.S. SHIPMENTS	--	.9	.3	1.2	.4	1.5	.6	2.0	.8	2.2
NON-U.S. MANUFACTURERS										
Captive	--	3.4	--	3.5	--	3.8	--	4.0	--	4.3
PCM	--	.3	--	.4	--	.7	--	.8	--	1.1
OEM	--	6.0	--	7.4	--	9.8	--	12.3	--	15.6
TOTAL NON-U.S. SHIPMENTS	--	9.7	--	11.3	--	14.3	--	17.1	--	21.0
WORLDWIDE RECAP										
Captive	-- --	3.4 +47.8%	.1 --	3.5 +2.9%	.1 --	3.8 +8.6%	.2 +100.0%	4.0 +5.3%	.3 +50.0%	4.3 +7.5%
PCM	-- --	.3 --	-- --	.4 +33.3%	-- --	.7 +75.0%	-- --	.8 +14.3%	-- --	1.1 +37.5%
OEM	-- --	6.9 +25.5%	.2 --	8.6 +24.6%	.3 +50.0%	11.3 +31.4%	.4 +33.3%	14.3 +26.5%	.5 +25.0%	17.8 +24.5%
Total Shipments	-- --	10.6 +35.9%	.3 --	12.5 +17.9%	.4 +33.3%	15.8 +26.4%	.6 +50.0%	19.1 +20.9%	.8 +33.3%	23.2 +21.5%
ANNUAL SHARE, BY DIAMETER	--	100.0%	2.3%	97.7%	2.5%	97.5%	3.0%	97.0%	3.3%	96.7%

TABLE 25

READ/WRITE OPTICAL DISK DRIVES, MORE THAN 1 GIGABYTE

APPLICATIONS SUMMARY
Percentage of Worldwide Shipments

APPLICATION	1988 Estimate Units (000)	1988 Estimate %	1992 Projection Units (000)	1992 Projection %
MAINFRAME/SUPERMINI General purpose	1.2	11.5	1.6	5.5
MINICOMPUTERS AND MULTI-USER MICROS Business and professional, including networks	1.8	17.3	5.2	18.0
PERSONAL COMPUTERS Business and professional, single user	.6	6.0	.3	1.0
OFFICE SYSTEMS AND WORKSTATIONS Dedicated application	3.9	37.0	13.4	46.2
NON-OFFICE SYSTEMS AND WORKSTATIONS Technical, distribution, medical, other specialized	3.0	27.9	8.4	29.0
CONSUMER AND HOBBY COMPUTERS	--	--	--	--
OTHER APPLICATIONS	.1	.3	.1	.3
Total	10.6	100.0	29.0	100.0

1989 DISK/TREND REPORT

OPTICAL DISK DRIVE SPECIFICATIONS

Coverage: The following pages list optical disk drives intended for computer data storage which are now announced or in new production. In a few cases, products are listed for which only preliminary announcements have been made. They are included because they are judged to be significant indicators of industry direction in the production period shown.

Recording medium: The composition of the active layer of optical media is the one described by the drive manufacturer. Formulations of other manufacturers may not operate properly. Recording formats also differ, and for products announced to date, recorded media is generally not interchangeable between systems. Where manufacturers specify that more than one type of media is usable, media type is indicated as "Various".

Operating mode: Rewritable (erasable) drives are indicated on the line describing the operating mode, with the technology type in parentheses.

Interface: Specific interfaces are listed for most of the drives. The abbreviation "PC" means the IBM PC/XT or PC/AT interface.

Speed control: Two abbreviations are used:

CAV=constant angular velocity.

CLV=constant linear velocity.

Capacities: Capacities are listed as "U" for unformatted and "F" for formatted. Because optical drives currently can read only one side of the media, the capacity given is in terms of one side, even if the drive uses two-sided media. In general, optical drives are preformatted, so the

capacity given will be the formatted capacity. Track capacity in CLV drives is variable, so this parameter is given only for CAV drives. For CD-ROM drives, the capacity given is the mode 1 capacity, as this is the way almost all drives are used.

Positioner type: Many optical drives have multi-stage head positioners. A coarse movement positions the head in the general vicinity of the track to be located. A fine, or vernier, actuator then moves the head to the desired track. Where appropriate, the abbreviation "Crs" is used for "coarse".

OEM prices: The 100 unit price is given for most OEM drives sold in the United States. These prices are often changed by the manufacturers without notice and should be considered as guidelines only.

Accuracy: All of the information in this section has been checked for accuracy. Due to rapid changes in the industry, report users may need to make verbal inquiries of the manufacturers for updates. Where data is not available, the abbreviation "NA" is used. Where a specification is not applicable, the abbreviation "N/A" appears.

1989 DISK/TREND optical disk product groups

For the 1989 report, products are classified in three groups.

Group 10: Read-only optical disk drives.

Group 11: Read/write disk drives, less than 1 gigabyte.

Group 12: Read/write disk drives, more than 1 gigabyte.

MANUFACTURER	ATG GIGADISC	ATG GIGADISC	ATG GIGADISC	BERNOULLI OPTICAL SYSTEMS	CANON
DRIVE	GD1001	GD1002	GD6000	Preliminary	OM-500D
DISK/TREND GROUP	12	12	12	11	11
MARKET	OEM	OEM	OEM	OEM	Captive, OEM
MEDIA: Nominal disk diameter	12"	12"	12"	130 mm	130 mm
Recording medium	Au-Cr-Polymer	Au-Cr-Polymer	Au-Cr-Polymer	Dye Polymer	Bilayer RE-TM
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Write Once	Write Once	Rewritable-(MO)
Interface	SCSI, Prop.	SCSI	SCSI	SCSI	ESDI-like
Speed control	CAV	CAV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 1,000	F: 1,000	F: 3,200	F: 1,300	F: 256
Capacity per track (Bytes)	F: 25,600	F: 25,600	F: 51,200	F: 34,666	F: 16,384
Data surfaces per spindle	1	1	1	2	1
Tracks per surface	40000	40000	62500	18750	14848
Track density (TPI)	14514	14514	25400	15875	15875
Maximum linear density (BPI)	15200	15200	30400	35000	21082
Rotational speed (RPM)	1121.5	1121.5	1143	1900	3000
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Solenoid	Rotary, Voice Coil	Crs: Voice Coil Fine: Lens Actuator
Average positioning time (msec)	200	110	100	40	80
Within fine band (msec)	28	8	NA	N/A	18
Fine band capacity (Mbytes)	112 (tracks)	78	NA	N/A	2
Average rotational delay (msec)	26.7	26.7	26.2	15.8	10
Average access time (msec)	226.7	136.7	126.2	65.8	90
Data transfer rate (KBytes/sec)	480	480	1000	150	1138
FIRST CUSTOMER SHIPMENT	3Q84	2Q88	3Q89	1990	4Q88
U.S. OEM PRICE FOR 100 UNITS	$6,933	$8,900	$15,000	--	--
COMMENTS				41.3 mm high Preliminary specification	SCSI controller available Exchange coupled MO media

MANUFACTURER	CHEROKEE DATA SYSTEMS	CHEROKEE DATA SYSTEMS	CHINON	EASTMAN KODAK	FUJITSU
DRIVE	M600	Tracker	CDS-430 CDS-430i	6800	M2505B
DISK/TREND GROUP	11	11	10	12	11
MARKET	OEM	OEM	OEM	Captive, OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	120 mm	14"	130 mm
Recording medium	Te-Ox	Te-Ox	Aluminum	Dye Polymer	Te Alloy
Track format	Spiral,Concent.	Spiral,Concent.	Spiral	Spiral (Zone)	Spiral
DRIVE: Operating mode	Write Once	Write Once	Read Only	Write Once	Write Once
Interface	ESDI	ESDI	Proprietary	SCSI, IPI-3	ESDI, SCSI
Speed control	CAV	CAV	CLV	CLV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 308	F: 260	F: 550	F: 3,400	F: 300
Capacity per track (Bytes)	F: 17,375	F: 20,754	F: N/A	F: N/A	F: 16,325
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	17727	14178	20750	58200	18320
Track density (TPI)	15000	15000	15875	14111	15875
Maximum linear density (BPI)	15000	15000	27600	21000	24924
Rotational speed (RPM)	1620	1613	500-200	800-1600	1800
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Solenoid	Crs: Voice Coil Fine: Solenoid	Crs: Motor Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator	Crs: Stepping Motor Fine: Lens Actuator
Average positioning time (msec)	108.4	108.4	500	500	100
Within fine band (msec)	NA	NA	N/A	100	NA
Fine band capacity (Mbytes)	NA	NA	N/A	NA	NA
Average rotational delay (msec)	18.5	18.5	110	27	16.67
Average access time (msec)	126.9	126.9	610	527	116.67
Data transfer rate (KBytes/sec)	406.25	406.25	153.6	1000	693.6
FIRST CUSTOMER SHIPMENT	1Q88	1Q88	1988	1987	9/87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	$24,800	--
COMMENTS	Can be used in harsh environments	Can be used in harsh environments	41.3 mm high CDS-430 is external mount Audio output	$32,800 with controller	

MANUFACTURER	FUJITSU	FUJITSU	GOLDSTAR TELE-COMMUNICATION	HITACHI	HITACHI
DRIVE	F6441A1 F6441B1	M2502A/B	GCDR-200	CDR 1503S CDR 1553S	CDR 3500 CDR 3550
DISK/TREND GROUP	12	12	10	10	10
MARKET	Captive	OEM	OEM	Captive, OEM	OEM
MEDIA: Nominal disk diameter	12"	12"	120 mm	120 mm	120 mm
Recording medium	Te Alloy	Te Alloy	Aluminum	Aluminum	Aluminum
Track format	Concentric	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Read Only	Read Only	Read Only
Interface	Mod. 3350, SCSI	Mod. SMD, SCSI	Proprietary	SCSI, PC	SCSI, Prop.
Speed control	CAV	CAV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 1,376	F: 1,800	F: 552	F: 552	F: 552
Capacity per track (Bytes)	F: 30,720	F: 38,912	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	44800	46260	20750	20750	20750
Track density (TPI)	15875	16383	15875	15875	15475
Maximum linear density (BPI)	24144	25133	27600	27600	27600
Rotational speed (RPM)	900	900	535-200	535-200	535-200
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Motor Fine: Lens Actuator	Crs: Motor Fine: Lens Actuator
Average positioning time (msec)	216.7	190	600	690	690
Within fine band (msec)	NA	NA	N/A	N/A	N/A
Fine band capacity (Mbytes)	NA	NA	N/A	N/A	N/A
Average rotational delay (msec)	33.3	33.3	110	110	110
Average access time (msec)	250	223.3	710	800	800
Data transfer rate (KBytes/sec)	783	816	153.6	153.6	153.6
FIRST CUSTOMER SHIPMENT	3Q85	1Q89	--	2Q87	4Q87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	Available only in Japan F6441A1 has SCSI interface	M2502A has SCSI interface	Audio output	CDR 1553S has SCSI interface External mount	41.3 mm high CDR 3550 has SCSI interface

MANUFACTURER	HITACHI	HITACHI	HITACHI	HITACHI	HITACHI
DRIVE	CDR 3600 CDR 3650	M-301S	OD 101-1	OD 112-1	OD 301A-1
DISK/TREND GROUP	10	11	11	11	12
MARKET	Captive,OEM,PCM	OEM	Captive, OEM	Captive, OEM	Captive, OEM
MEDIA: Nominal disk diameter	120 mm	130 mm	130 mm	130 mm	300 mm
Recording medium	Aluminum	Various*	Te-Se-Pb	Tb-Fe-Co	Te-Se-Pb
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Read Only	Write Once	Write Once	Rewritable-(MO)	Write Once
Interface	SCSI, Prop.	SCSI	SCSI	SCSI	SCSI, GPIB, SMD
Speed control	CLV	CAV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 552	F: 320	F: 300	F: 322	F: 1,310
Capacity per track (Bytes)	F: N/A	F: 16,000	F: 16,400	F: 17,408	F: 31,700
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	20000	18624	18751	41300
Track density (TPI)	15475	16942	16000	16000	16000
Maximum linear density (BPI)	27600	24500	24000	24000	19500
Rotational speed (RPM)	535-200	1800	1800	2400	600
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.
Average positioning time (msec)	350	100	93	62.5	200
Within fine band (msec)	N/A	NA	NA	N/A	NA
Fine band capacity (Mbytes)	N/A	NA	NA	N/A	NA
Average rotational delay (msec)	110	16.7	16.7	12.5	50
Average access time (msec)	460	116.7	109.7	75	250
Data transfer rate (KBytes/sec)	153.6	487.5	690	925	440
FIRST CUSTOMER SHIPMENT	3Q89	1989	2Q87	7/89	3Q85
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	41.3 mm high CDR 3650 has SCSI interface	*Uses phase change or ablative media		ISO standard	

MANUFACTURER	IBM	INFORMATION STORAGE INC.	INFORMATION STORAGE INC.	JVC	KAWATETSU ADVANTECH
DRIVE	3363-A01 3363-A11 3363-B01 3363-8700	525 GB 525 GBX2	525 WC	XR-R100 XR-R1001	KL200S
DISK/TREND GROUP	11	11	11	10	11
MARKET	Captive	OEM, PCM	OEM, PCM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	130 mm	120 mm	130 mm
Recording medium	Doped Te-Ox	Te Alloy	Te Alloy	Aluminum	Te Alloy
Track format	Spiral	Concentric	Concentric	Spiral	Concentric
DRIVE: Operating mode	Write Once	Write Once	Write Once	Read Only	Write Once
Interface	IBM	SCSI, Prop., PC	ESDI, PC	SCSI	SCSI, PC
Speed control	CAV	CAV	CAV	CLV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 201.36	F: 640	F: 122	F: 540	F: 122
Capacity per track (Bytes)	F: 11,776	F: 20,000	F: 8,192	F: N/A	F: 8,192
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	17100	32000	14901	20750	14901
Track density (TPI)	15875	35000	15875	15875	15875
Maximum linear density (BPI)	21166	32000	11500	27600	11500
Rotational speed (RPM)	875	1800	1800	530-200	1800
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Galvonom.	Crs: Stepping Motor Fine: Lens Actuator	Crs: Stepping Motor Fine: Galvonom.	Crs: Voice Coil Fine: Lens Actuator	Crs: Stepping Motor Fine: Galvonom.
Average positioning time (msec)	230	90	135	300	135
Within fine band (msec)	NA	8	NA	N/A	21.6
Fine band capacity (Mbytes)	NA	4	NA	N/A	1.2
Average rotational delay (msec)	34.3	16.7	16.7	110	16.7
Average access time (msec)	264.3	106.7	151.7	410	151.7
Data transfer rate (KBytes/sec)	171	812.5	312.5	153.6	240
FIRST CUSTOMER SHIPMENT	2Q87	4/88	3Q85	3Q87	1Q87
U.S. OEM PRICE FOR 100 UNITS	--	$2,900	$1,400	--	--
COMMENTS	Mechanism by Matsushita Electric	525 GBX2 is external mount; dual drive available	Grooveless tracking system ISI will certify media	41.3 mm high XR-R100 is free standing	Grooveless tracking system Licensee of ISI

MANUFACTURER	KAWATETSU ADVANTECH	LASER MAGNETIC STORAGE	LASER MAGNETIC STORAGE	LASER MAGNETIC STORAGE	LASER MAGNETIC STORAGE
DRIVE	KL1200S	CM 121 CM 201	CM 131 CM 132	CM 210	CM 212
DISK/TREND GROUP	11	10	10	10	10
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	120 mm	120 mm	120 mm	120 mm
Recording medium	Te Alloy	Aluminum	Aluminum	Aluminum	Aluminum
Track format	Concentric	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Read Only	Read Only	Read Only	Read Only
Interface	SCSI, PC	Serial	SCSI	SCSI, PC XT	SCSI
Speed control	CAV	CLV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 630	F: 600	F: 600	F: 600	F: 600
Capacity per track (Bytes)	F: 20,480	F: N/A	F: N/A	F: N/A	F:
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	31500	20750	20750	20750	20750
Track density (TPI)	36000 max.	15875	15875	15875	15875
Maximum linear density (BPI)	27000 max.	27600	27600	27600	27600
Rotational speed (RPM)	1800	500-200	500-200	500-230	500-200
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Galvonom.	Rotary Galvonometer	Rotary Galvonometer	Rotary Galvonometer	Rotary Galvonometer
Average positioning time (msec)	90	500	500	415	290
Within fine band (msec)	8	N/A	N/A	N/A	N/A
Fine band capacity (Mbytes)	4	N/A	N/A	N/A	N/A
Average rotational delay (msec)	16.7	110	110	110	110
Average access time (msec)	106.7	610	610	525	400
Data transfer rate (KBytes/sec)	600	153.6	153.6	153.6	153.6
FIRST CUSTOMER SHIPMENT	3Q89	8/88	8/88	2Q87	2Q89
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	$875
COMMENTS	Grooveless tracking system Licensee of ISI	41.3 mm high CM 121 is external mount	CM 132 is 2 drive package		

MANUFACTURER	LASER MAGNETIC STORAGE	LASER MAGNETIC STORAGE	LASERDRIVE	LASERDRIVE	MATSUSHITA ELECTRIC INDUSTRIAL
DRIVE	510	1200E 1250E	M810 M820 M840 M850	Preliminary	EMI-103
DISK/TREND GROUP	11	12	11	11	10
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	12"	130 mm	96 mm	120 mm
Recording medium	Te Alloy	Te Alloy	Te-C, Te Alloy	Tb-Fe-Co	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Write Once	Rewritable-(MO)	Read Only
Interface	SCSI	SCSI, ISI	SCSI, Prop.	SCSI	Proprietary
Speed control	CAV	CAV	CLV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 327	F: 1,000	F: 405	F: 120	F: 540
Capacity per track (Bytes)	F: 16,384	F: 32,800	F: 22,016 avg.	F: 11,264	F: NA
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	19928	32000	18750	10653	20750
Track density (TPI)	NA	15875	15875	15875	15875
Maximum linear density (BPI)	NA	14111	20159	19050	27600
Rotational speed (RPM)	2160	480	1114-557	2400	500-200
PERFORMANCE					
Positioner type	Linear, Voice Coil	Linear, Voice Coil	Crs: Stepping Motor Fine: Galvonom.	Crs: Linear, Voice Coil Fine: Galvonom.	Crs: Geared Motor Fine: Lens Actuator
Average positioning time (msec)	61.3	150	135	30	2400
Within fine band (msec)	N/A	N/A	21	N/A	N/A
Fine band capacity (Mbytes)	N/A	N/A	3.2 avg.	N/A	N/A
Average rotational delay (msec)	13.7	62.5	40	12.5	110
Average access time (msec)	75	212.5	175	42.5	2510
Data transfer rate (KBytes/sec)	600	313	347	480	153.6
FIRST CUSTOMER SHIPMENT	4Q88	3Q83	4Q87	1990	3/89
U.S. OEM PRICE FOR 100 UNITS	$2,630	$11,250	$1,500	--	--
COMMENTS	Sampled servo format	Has Direct Read During Write 1250E is rack mounted	M810 for PC/AT M820 for Apple M840 for Microvax II M850 for PS/2	Preliminary specification	

MANUFACTURER	MATSUSHITA ELECTRIC INDUSTRIAL	MATSUSHITA ELECTRIC INDUSTRIAL	MATSUSHITA ELECTRIC INDUSTRIAL	MATSUSHITA ELECTRIC INDUSTRIAL	MATSUSHITA ELECTRIC INDUSTRIAL
DRIVE	JU-9400	JU-9500	LF-5000 LF-5001	LF-5010 LF-5014 LF-5110 LF-5210	Preliminary
DISK/TREND GROUP	11	11	11	11	11
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	130 mm	130 mm	86 mm
Recording medium	Te Alloy	Tb-Fe-Co*	Te-Ox	Te-Ox	Ge-Te-Sb
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Rewritable-(MO)	Write Once	Write Once-(PC)	Rewritable-(PC)
Interface	SCSI	SCSI	SCSI	SCSI-2	SCSI
Speed control	CAV	CAV	CAV	MCAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 300	F: 262*	F: 200	F: 470	F: 140
Capacity per track (Bytes)	F: 16,000	F: 16,000	F: 11,776	F: 25,600 avg.	F: NA
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	18598	16200*	17100	18360	NA
Track density (TPI)	15875	15875	15875	16925	16925
Maximum linear density (BPI)	24937	24937	21166	NA	NA
Rotational speed (RPM)	2400	2400	875	1200	2400
PERFORMANCE					
Positioner type	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: NA
Average positioning time (msec)	62.5	62.5	190	90	42
Within fine band (msec)	13	13	45	45	N/A
Fine band capacity (Mbytes)	1.6	1.6	.588	+/-50 (tracks)	N/A
Average rotational delay (msec)	12.5	12.5	34.3	25	12.5
Average access time (msec)	75	75	224.3	115	54.5
Data transfer rate (KBytes/sec)	925	925	171	861.25	750
FIRST CUSTOMER SHIPMENT	2Q87	4/88	2Q88	3Q89	--
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS		Glass substrate *Preliminary		LF-5010 is external mount. LF-51XX series sold in Japan. LF-52XX series sold in Europe.	Preliminary specification

MANUFACTURER	MATSUSHITA ELECTRONIC COMPONENTS	MATSUSHITA ELECTRONIC COMPONENTS	MATSUSHITA GRAPHIC COMMUNICATION	MAXIMUM STORAGE	MAXIMUM STORAGE
DRIVE	SQ-D1	SQ-D101	PF-10 PF-10B PF-3000	APX-3200	APX-4000
DISK/TREND GROUP	10	10	11	11	11
MARKET	Captive, OEM	Captive, OEM	Captive, OEM	OEM	OEM
MEDIA: Nominal disk diameter	120 mm	120 mm	200 mm	130 mm	130 mm
Recording medium	Aluminum	Aluminum	Te-Ox	Te Alloy	Te Alloy
Track format	Spiral	Spiral	Spiral	Concentric	Concentric
DRIVE: Operating mode	Read Only	Read Only	Write Once	Write Once	Write Once
Interface	SCSI, PC	SCSI, PC	Proprietary	Mod. ESDI, PC	
Speed control	CLV	CLV	CLV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 540	F: 540	F: 700	F: 122	F: 760
Capacity per track (Bytes)	F: N/A	F: N/A	F: 32,000	F: 8,192	F:
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	20750	23330	14901	23207
Track density (TPI)	15875	15875	23333	14100	NA
Maximum linear density (BPI)	27600	27600	15394	11400	NA
Rotational speed (RPM)	530-200	530-200	900	1800	1800
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Voice Coil	Crs: Voice Coil Fine: Voice Coil	Linear, Voice Coil	Crs: Stepping Motor Fine: Lens Actuator	Crs: Stepping Motor Fine: Lens Actuator
Average positioning time (msec)	540	540	200	118	NA
Within fine band (msec)	N/A	N/A	N/A	20	NA
Fine band capacity (Mbytes)	N/A	N/A	N/A	1.31	NA
Average rotational delay (msec)	110	110	33.3	16.7	16.7
Average access time (msec)	650	650	233.3	134.7	NA
Data transfer rate (KBytes/sec)	153.6	153.6	675	312.5	625
FIRST CUSTOMER SHIPMENT	1Q87	1Q87	2Q86	3Q87	--
U.S. OEM PRICE FOR 100 UNITS	--	--	--	$1,875	--
COMMENTS	41.3 mm high	Free standing	Available only in Japan 30 disk library available		

MANUFACTURER	MAXIMUM STORAGE	MAXIMUM STORAGE	MAXTOR	MITSUBISHI ELECTRIC CORPORATION	MITSUBISHI ELECTRIC CORPORATION
DRIVE	APX-4200	APX-4300	Tahiti	ME-5E1 ME-5U1	MW-5D1-11 MW-5U1
DISK/TREND GROUP	11	11	11	11	11
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	130 mm	130 mm	130 mm
Recording medium	Te Alloy	Te Alloy	RE-TM Alloy	Tb-Fe-Co	Te-Se
Track format	Concentric	Concentric	Spiral, (Zone)	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Rewritable-(MO)	Rewritable-(MO)	Write Once
Interface	Mod. ESDI, PC	SCSI, Sun	SCSI	ESDI, SCSI	ESDI, SCSI
Speed control	CAV	CAV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 500	F: 500	F: 512/326	F: 297/326	F: 300
Capacity per track (Bytes)	F: 16,384	F: 16,384	F: 25,000	F:15,872/17,408	F: 15,872
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	14901	14901	25000	18750	18750
Track density (TPI)	14100	14100	16933	15875	15875
Maximum linear density (BPI)	21069	21069	25000**	25400*	25400*
Rotational speed (RPM)	1800	1800	2200/1800	2400	1800
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Lens Actuator	Crs: Stepping Motor Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator
Average positioning time (msec)	NA	NA	30	35.5	63
Within fine band (msec)	NA	NA	26	1.5	1.5
Fine band capacity (Mbytes)	NA	NA	2	.317	.317
Average rotational delay (msec)	16.7	16.7	13.6/16.7	12.5	17
Average access time (msec)	NA	NA	43.6/46.7	48	80
Data transfer rate (KBytes/sec)	625	625	1250*	925	687.5
FIRST CUSTOMER SHIPMENT	3Q88	4Q88	9/88	1Q90	1Q88
U.S. OEM PRICE FOR 100 UNITS	$3,115	--	--	--	--
COMMENTS	Cartridges compatible with APX-3200, APX-4300	Cartridges compatible with APX-3200, APX-4200	*Average Actuator has split optics **2,7 RLL Code	ME-5U1 is external mount *2,7 RLL Code	MW-5U1 includes controller; free standing package *2,7 RLL Code

MANUFACTURER	MITSUBISHI ELECTRIC CORPORATION	MITSUMI ELECTRIC	NEC	NEC	NEC
DRIVE	MW-5E2 MW-5U2	CRMC-SR001N	CDR-30	CDR-75 CDR-77 CDR-80	N5267-31
DISK/TREND GROUP	11	10	10	10	10
MARKET	OEM	OEM	Captive	OEM	Captive
MEDIA: Nominal disk diameter	130 mm	120 mm	120 mm	120 mm	120 mm
Recording medium	Te-Se	Aluminum	Aluminum	Aluminum	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Read Only	Read Only	Read Only	Read Only
Interface	ESDI, SCSI	SCSI, Prop.	Proprietary	SCSI	SCSI
Speed control	CAV	CLV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 300	F: 540	F: 540	F: 540	F: 540
Capacity per track (Bytes)	F: 15,872	F: N/A	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	18750	20750	20750	20750	20750
Track density (TPI)	15875	15875	15875	15875	15875
Maximum linear density (BPI)	25400*	27600	27600	27600	27600
Rotational speed (RPM)	2400	500-200	535-200	535-200	530-200
PERFORMANCE					
Positioner type	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Motor Fine: Lens Actuator	Crs: Audio Mechanism Fine:	Crs: Stepping Motor Fine: Lens Actuator	Linear, Voice Coil
Average positioning time (msec)	35.5	500	1000	500	650
Within fine band (msec)	1.5	N/A	N/A	N/A	N/A
Fine band capacity (Mbytes)	.317	N/A	N/A	N/A	N/A
Average rotational delay (msec)	12.5	110	110	110	110
Average access time (msec)	48	610	1110	610	760
Data transfer rate (KBytes/sec)	925	153.6	153.6	153.6	153.6
FIRST CUSTOMER SHIPMENT	3Q89	--	4Q88	2Q88	2Q87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	MW-5U2 is external mount *2,7 RLL Code	41.3 mm high Preliminary specification	Used with NEC PC engine	41.3 mm high CDR-77 is external model	Stand alone type

MANUFACTURER	NEC	NEC	NEC	NIKON	NIPPON COLUMBIA
DRIVE	PC-CD102	N6329-21 N7911	N6513	MO-DD120C	DRD-251 DRD-253
DISK/TREND GROUP	10	12	12	12	10
MARKET	Captive	Captive	Captive	OEM	OEM
MEDIA: Nominal disk diameter	120 mm	12"	12"	12"	120 mm
Recording medium	Aluminum	Tri-layer	Te-Alloy	TbFe, GdFeCo	Aluminum
Track format	Spiral	Concentric	Spiral	Spiral	Spiral
DRIVE: Operating mode	Read Only	Write Once	Write Once	Rewritable-(MO)	Read Only
Interface	SCSI, Prop.	SCSI, Prop.	SCSI, Prop.	SCSI	SCSI
Speed control	CLV	CAV	Zone CLV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 540	F: 1,016	F: 1,800	F: 2,000	F: 553
Capacity per track (Bytes)	F: N/A	F: 32,768	F:29,500-56,500	F: 44,444	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	31000	41000	45000	20750
Track density (TPI)	15875	15900	15875	15875	15475
Maximum linear density (BPI)	27600	20000	20000	N/A	26008
Rotational speed (RPM)	535-200	900	600-330	1800	535-194
PERFORMANCE					
Positioner type	Crs: Stepping Motor Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Galvonom.	Linear, Voice Coil
Average positioning time (msec)	500	270	650	70	300
Within fine band (msec)	N/A	NA	NA	NA	N/A
Fine band capacity (Mbytes)	N/A	NA	NA	NA	N/A
Average rotational delay (msec)	110	33.3	50-90	16.7	110
Average access time (msec)	610	303.3	700-740	86.7	410
Data transfer rate (KBytes/sec)	153.6	785	452	1500	153.6
FIRST CUSTOMER SHIPMENT	1Q87	4Q83	1Q87	4Q89	3Q86
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	Mechanism from NEC Home Electronics For PC9800				41.3 mm high DRD-253 mounts externally

MANUFACTURER	NIPPON COLUMBIA	NIPPON COLUMBIA	NIPPON COLUMBIA	OPTIMEM	OPTIMEM
DRIVE	DRD-250 DRD-252	DRD-550 DRD-552 DRD-554	DRD-551 DRD-553 DRD-555	1000 1/2 1000 6/7	2400 1/2
DISK/TREND GROUP	10	10	10	12	12
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	120 mm	120 mm	120 mm	12"	12"
Recording medium	Aluminum	Aluminum	Aluminum	3M, Te Alloy	3M, Te Alloy
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Read Only	Read Only	Read Only	Write Once	Write Once
Interface	Proprietary	SASI, SCSI	Proprietary	SASI,SCSI,Prop.	SCSI
Speed control	CLV	CLV	CLV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 553	F: 553	F: 553	F: 1,000	F: 1,200
Capacity per track (Bytes)	F: N/A	F: N/A	F: N/A	F: 25,000	F: 25,000
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	20750	20750	40000	46900
Track density (TPI)	15475	15475	15475	14514	16933
Maximum linear density (BPI)	26008	26008	26008	15339	15339
Rotational speed (RPM)	535-194	535-194	535-194	1122	1122
PERFORMANCE					
Positioner type	Linear, Voice Coil	Linear, Voice Coil	Linear, Voice Coil	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.
Average positioning time (msec)	300	190	190	150	150
Within fine band (msec)	N/A	N/A	N/A	3	3
Fine band capacity (Mbytes)	N/A	N/A	N/A	8.3	8.3
Average rotational delay (msec)	110	110	110	26.7	26.7
Average access time (msec)	410	300	300	176.7	176.7
Data transfer rate (KBytes/sec)	153.6	153.6	153.6	625	625
FIRST CUSTOMER SHIPMENT	3Q86	4Q85	4Q85	2Q84	4Q87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	$6,900	$8,500
COMMENTS	41.3 mm high DRD-252 mounts externally	DRD-550 mounts in full height slot DRD-554 has audio output	External mount except for DRD-551 DRD-555 has audio output		2400 1 includes controller

MANUFACTURER	OPTIMEM	PENTAX TEKNOLOGIES	PIONEER	PIONEER	PIONEER
DRIVE	4000 4400	LW-S501	CDM-6	DD-8001/KU	DD-M5001
DISK/TREND GROUP	12	11	10	11	11
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	12"	130 mm	120 mm	203 mm	130 mm
Recording medium	3M, Te Alloy	Te Alloy	Aluminum	Cyanine Dye	Cyanine Dye
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Read Only	Write Once	Write Once
Interface	SCSI	SCSI	SCSI	SCSI	N/A
Speed control	CAV	CAV	CLV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 1,979	F: 326	F: 3,240	F: 750	F: 327
Capacity per track (Bytes)	F: 40,960	F: 17,386	F: N/A	F: 32,432	F: 16,384
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	48333	18751	20750	23125	19958
Track density (TPI)	16900	15875	15875	15875	15875
Maximum linear density (BPI)	22088	24923	27600	15875	15875
Rotational speed (RPM)	1122	1800	530-220	450	1800
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Galvonom.	Crs: Linear, Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.
Average positioning time (msec)	150	40	600	184	60
Within fine band (msec)		NA	NA	NA	NA
Fine band capacity (Mbytes)		NA	NA	NA	NA
Average rotational delay (msec)	26.7	16.7	110	66	16.7
Average access time (msec)	176.7	56.7	710	250	76.7
Data transfer rate (KBytes/sec)	723	530	153	308	742.5
FIRST CUSTOMER SHIPMENT	3Q89	1989	4Q89	4Q85	2Q88
U.S. OEM PRICE FOR 100 UNITS	--	--	$840	--	--
COMMENTS			Integral with 6 disk changer. Disk change time is 7 sec. Includes audio output.		41.3 mm high Mechanism only Sample servo format

MANUFACTURER	PIONEER	PIONEER	REFERENCE TECHNOLOGY	RICOH	RICOH
DRIVE	DD-U5001	DD-8002 DD-8002/KU	2000	RO-5030E	RO-5040WL
DISK/TREND GROUP	11	11	10	11	11
MARKET	OEM	OEM	OEM	OEM	Captive, OEM
MEDIA: Nominal disk diameter	130 mm	203 mm	12"	130 mm	130 mm
Recording medium	Cyanine Dye	Cyanine Dye	Aluminum	RE-TM(Tb-Fe-Co)	Cyanine Dye
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Write Once	Read Only	Rewritable-(MO)	Write Once
Interface	SCSI, Prop.	Prop.,IBM Ser.I	SCSI	SCSI	SCSI
Speed control	CAV	CAV	CAV	CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 327	F: 750	F: 1,000	F: 297.6	F: 400
Capacity per track (Bytes)	F: 16,384	F: 32,432	F: 19,600	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	19958	23125	51000	18750	18750
Track density (TPI)	15875	15875	14896	18875	15900
Maximum linear density (BPI)	15875	15875	24000	24902	32200
Rotational speed (RPM)	1800	450	1800	1800	668-334
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Galvonom.	Crs: Voice Coil Fine: Voice Coil	Crs: Voice Coil Fine: Voice Coil
Average positioning time (msec)	60	184	125	50	108
Within fine band (msec)	NA	NA	NA	NA	N/A
Fine band capacity (Mbytes)	NA	NA	NA	NA	N/A
Average rotational delay (msec)	16.7	66.7	16.7	16.7	60
Average access time (msec)	76.7	250.7	141.7	66.7	168
Data transfer rate (KBytes/sec)	742.5	307.5	1000	625	312.5
FIRST CUSTOMER SHIPMENT	2Q88	4Q86	4Q84	4Q88	4Q86
U.S. OEM PRICE FOR 100 UNITS	--	--	$8,900	--	--
COMMENTS	Sample servo format	8002 has IBM Series/1 interface		SCSI controller included in price	SCSI controller included in price

MANUFACTURER	RICOH	SANYO	SANYO	SANYO	SANYO
DRIVE	RO-5041WL	ROM-3000U ROM-3000US	ROM-3001U ROM-3001US	ROM-4005U	ROM-4006U
DISK/TREND GROUP	11	10	10	10	10
MARKET	Captive, OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	120 mm	120 mm	120 mm	120 mm
Recording medium	Cyanine Dye	Aluminum	Aluminum	Aluminum	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Write Once	Read Only	Read Only	Read Only	Read Only
Interface	SCSI	Proprietary	SCSI	Proprietary	SCSI
Speed control	CLV	CLV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 400	F: 540	F: 540	F: 540	F: 540
Capacity per track (Bytes)	F: N/A	F: N/A	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	18750	20750	20750	20750	20750
Track density (TPI)	15900	15875	15875	15875	15875
Maximum linear density (BPI)	32200	27600	27600	27600	27600
Rotational speed (RPM)	668-334	530-200	530-200	530-200	530-200
PERFORMANCE					
Positioner type	Crs: Voice Coil Fine: Voice Coil	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator
Average positioning time (msec)	108	500	500	500	500
Within fine band (msec)	N/A	N/A	N/A	N/A	N/A
Fine band capacity (Mbytes)	N/A	N/A	N/A	N/A	N/A
Average rotational delay (msec)	60	108	108	108	108
Average access time (msec)	168	608	608	608	608
Data transfer rate (KBytes/sec)	312.5	153	153	153	153
FIRST CUSTOMER SHIPMENT	2Q89	2/88	5/88	5/89	8/89
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS	41.3 mm high SCSI controller included in price	S models have audio output External mount	S models have audio output External mount	41.3 mm high Internal mount Includes audio output	41.3 mm high Internal mount Includes audio output

MANUFACTURER	SANYO	SANYO	SANYO	SANYO	SHARP
DRIVE	ROM-6000US	ROM-6001US	SOF-M90	SOF-8501	JY-500
DISK/TREND GROUP	10	10	11	12	11
MARKET	OEM	OEM	OEM	Captive	OEM
MEDIA: Nominal disk diameter	120 mm	120 mm	130 mm	300 mm	130 mm
Recording medium	Aluminum	Aluminum	Te Alloy	Te Alloy	RE-TM(Tb-Fe-Co)
Track format	Spiral	Spiral	Spiral	Concentric	Spiral
DRIVE: Operating mode	Read Only	Read Only	Write Once	Write Once	Rewritable-(MO)
Interface	Proprietary	SCSI	SCSI	Proprietary	SCSI
Speed control	CLV	CLV	CAV	CAV	CAV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 540	F: 540	F: 600	F: 1,100	F: 190
Capacity per track (Bytes)	F: N/A	F: N/A	F: 31,996	F: 25,000	F: 10,133
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	20750	18752	44000	18750
Track density (TPI)	15875	15875	16000	14100	15875
Maximum linear density (BPI)	27600	27600	24000	NA	NA
Rotational speed (RPM)	530-200	530-200	1800	690	900
PERFORMANCE					
Positioner type	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Lens Actuator	Crs: Linear Fine: Galvonom.	Crs: Linear, Voice Coil Fine: Lens Actuator
Average positioning time (msec)	500	500	93	255	150
Within fine band (msec)	NA	NA	NA	NA	NA
Fine band capacity (Mbytes)	NA	NA	NA	NA	NA
Average rotational delay (msec)	108	108	16.7	43.5	33.2
Average access time (msec)	608	608	109.7	298.5	183.2
Data transfer rate (KBytes/sec)	153.6	153.6	1500	125	150
FIRST CUSTOMER SHIPMENT	8/89	8/89	1987	1985	12/87
U.S. OEM PRICE FOR 100 UNITS	--	--	--	--	--
COMMENTS			Continuous servo format	Available only in Japan	Media uses glass or plastic substrate External mount

MANUFACTURER	SHARP	SHUGART	SONY	SONY	SONY
DRIVE	JY-700	5984 5984AT	CDU-510	CDU-541	CDU-6100 CDU-6101 CDU-6110 CDU-6111
DISK/TREND GROUP	11	11	10	10	10
MARKET	OEM	OEM	OEM	OEM	OEM
MEDIA: Nominal disk diameter	130 mm	130 mm	120 mm	120 mm	120 mm
Recording medium	RE-TM(Tb-Fe-Co)	Te-Se	Aluminum	Aluminum	Aluminum
Track format	Spiral	Spiral,Concent.	Spiral	Spiral	Spiral
DRIVE: Operating mode	Rewritable-(MO)	Write Once	Read Only	Read Only	Read Only
Interface	SCSI	SCSI, PC	SCSI	SCSI	SCSI, Prop.
Speed control	CAV	CAV	CLV	CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 297.4	F: 202	F: 540	F: 540	F: 540
Capacity per track (Bytes)	F: 15,872	F: 10,752	F: N/A	F: N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	18751	18826	20750	20750	20750
Track density (TPI)	15875	15625	15875	15875	15875
Maximum linear density (BPI)	24930*	14620	27600	27600	27600
Rotational speed (RPM)	2400	1200	500-200	500-200	500-200
PERFORMANCE					
Positioner type	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Stepping Motor Fine: Voice Coil	Linear, Voice Coil	Linear, Voice Coil	Linear, Voice Coil
Average positioning time (msec)	60	170	350	380	350
Within fine band (msec)	NA	NA	N/A	N/A	N/A
Fine band capacity (Mbytes)	NA	NA	N/A	N/A	N/A
Average rotational delay (msec)	12.5	25	150	150	150
Average access time (msec)	72.5	195	500	530	500
Data transfer rate (KBytes/sec)	925	275	153.6	150	153.6
FIRST CUSTOMER SHIPMENT	1989	3Q85	--	1989	--
U.S. OEM PRICE FOR 100 UNITS	--	$2,300	--	--	--
COMMENTS	512 byte sectors *2,7 RLL Code	AT version mounts in IBM PC/AT	41.3 mm high	Has audio output	External mount. CDU-6110 & 6111 have SCSI intf. CDU-6101 & 6111 have audio output.

MANUFACTURER	SONY	SONY	SONY	SONY	TOSHIBA
DRIVE	CDU-7101	SMO-D501	WDD 2000	WDD 3000	XM-2200A
DISK/TREND GROUP	10	11	11	12	10
MARKET	Captive	Captive, OEM	Captive, OEM	Captive, OEM	OEM
MEDIA: Nominal disk diameter	120 mm	130 mm	200 mm	300 mm	120 mm
Recording medium	Aluminum	Tb-Fe-Co	Se-Sb, Bi-Te	Se-Sb, Bi-Te	Aluminum
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Read Only	Rewritable-(MO)	Write Once	Write Once	Read Only
Interface	IBM PC XT	SCSI, ESDI	SCSI, Prop.	SCSI, Prop.	SCSI
Speed control	CLV	CAV	CLV	CAV, CLV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 540	F: 325	F: 500	F: 1,100/1,600	F: 599
Capacity per track (Bytes)	F: N/A	F: 17,408	F: N/A	F: 25,600/N/A	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	18751	18750	43750	20750
Track density (TPI)	15875	15875	12700	15875	15875
Maximum linear density (BPI)	27600	24902	25391	24937	27600
Rotational speed (RPM)	500-200	2400	900-535	720/720-360	530-200
PERFORMANCE					
Positioner type	Linear, Voice Coil	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator
Average positioning time (msec)	350	90	250	250/620	250
Within fine band (msec)	N/A	20	25	25	N/A
Fine band capacity (Mbytes)	N/A	22	1.25	1.25	+/-255(tracks)
Average rotational delay (msec)	150	12.5	44.7	42/62.5	110
Average access time (msec)	500	102.5	294.7	292/682.5	360
Data transfer rate (KBytes/sec)	153.6	680	300	300	153.6
FIRST CUSTOMER SHIPMENT	5/88	2Q88	4Q84	2Q85	4Q88
U.S. OEM PRICE FOR 100 UNITS	--	--	$5,300	$7,200	--
COMMENTS		ISO standard	Controller is $4,000	Controller is $4,000	Embedded SCSI controller and audio External mount

MANUFACTURER	TOSHIBA	TOSHIBA	TOSHIBA	TOSHIBA	TOSHIBA
DRIVE	XM-3201B	XM-5100A	WM-D050	WM-D070 WM-D071 WM-S070 WM-S071	DF-0450 DF-0460
DISK/TREND GROUP	10	10	11	11	12
MARKET	OEM	OEM	Captive, OEM	OEM	Captive, OEM
MEDIA: Nominal disk diameter	120 mm	120 mm	130 mm	130 mm	12"
Recording medium	Aluminum	Aluminum	Te-C	Te-C	Te-C
Track format	Spiral	Spiral	Spiral	Spiral	Spiral
DRIVE: Operating mode	Read Only	Read Only	Write Once	Write Once	Write Once
Interface	SCSI	SCSI	SCSI	SCSI, Prop.	GPIB, SCSI
Speed control	CLV	CLV	CAV, CLV	MCAV, CAV	CLV
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 599	F: 599	F: 250/400	F: 450/300	F: 1,800
Capacity per track (Bytes)	F: N/A	F: N/A	F: 14,336*	F: 17,000 CAV	F: N/A
Data surfaces per spindle	1	1	1	1	1
Tracks per surface	20750	20750	20000	18750	45000
Track density (TPI)	15875	15875	15875	15875	15875
Maximum linear density (BPI)	27600	27600	21900	24900	19450
Rotational speed (RPM)	530-200	530-200	925	900-1800	427-215
PERFORMANCE					
Positioner type	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator
Average positioning time (msec)	250	280	180	90	900
Within fine band (msec)	N/A	N/A	NA	.5	NA
Fine band capacity (Mbytes)	+/-255(tracks)	+/-255(tracks)	NA	50 (tracks)	NA
Average rotational delay (msec)	110	110	32	16.7 (CAV)	105
Average access time (msec)	360	390	212	106.7 (CAV)	1005
Data transfer rate (KBytes/sec)	153.6	153.6	120	528 (CAV)	313
FIRST CUSTOMER SHIPMENT	4Q88	4Q88	4Q86	1Q89	4Q84
U.S. OEM PRICE FOR 100 UNITS	--	--	$4,500	--	$11,000/12,000
COMMENTS	41.3 mm high Embedded SCSI controller and audio	External mount Embedded SCSI controller and audio	*Not applicable for CLV mode	WM-D071 includes SCSI controller WM-S series is external mount	DF-0460 has SCSI interface

MANUFACTURER	TOSHIBA	YAMAHA			
DRIVE	WM-S500 WM-S500A	YPR-1			
DISK/TREND GROUP	12	11			
MARKET	OEM	Captive			
MEDIA: Nominal disk diameter	12"	120 mm			
Recording medium	Te-C	In-Ge			
Track format	Spiral	Spiral			
DRIVE: Operating mode	Write Once	Write Once			
Interface	SCSI, Prop.	Proprietary			
Speed control	MCAV	CLV			
CAPACITY/RECORDING DENSITY					
Total capacity (Mbytes)	F: 2,500	F: 540			
Capacity per track (Bytes)	F: 53,000 avg.	F: N/A			
Data surfaces per spindle	1	1			
Tracks per surface	45000	20750			
Track density (TPI)	15875	15875			
Maximum linear density (BPI)	22400*	27600			
Rotational speed (RPM)	617	530-200			
PERFORMANCE					
Positioner type	Crs: Linear, Voice Coil Fine: Lens Actuator	Crs: Linear, Voice Coil Fine: Lens Actuator			
Average positioning time (msec)	160	NA			
Within fine band (msec)	2	N/A			
Fine band capacity (Mbytes)	60 (tracks)	N/A			
Average rotational delay (msec)	48.8	110			
Average access time (msec)	208.8	NA			
Data transfer rate (KBytes/sec)	500-1000	153.6			
FIRST CUSTOMER SHIPMENT	4Q88	1989			
U.S. OEM PRICE FOR 100 UNITS	--	--			
COMMENTS	*2,7 RLL Code WM-S500A includes SCSI controller	Sold only as part of PDS system			

MANUFACTURER PROFILES

1989 DISK/TREND REPORT

MANUFACTURER PROFILES

All manufacturers now producing optical disk drives, or those which are expected to eventually enter the market, are listed in this section. DISK/TREND normally estimates the annual volume of disk drive sales by manufacturers. Because few companies had a high level of optical disk drive sales in 1988, this figure is reported explicitly only for firms with major 1988 sales. "1988 total net sales" covers the fiscal year ending in 1988 for each firm unless noted otherwise, or for the parent company if the disk drive manufacturer is a subsidiary. The fiscal year of listed firms ends on December 31, 1988, unless otherwise noted.

Manufacturers located in the United States that have majority owners headquartered in another country are grouped in the geographical area covering the owner's home office.

Exchange rates

The exchange rates used in converting the financial data of non-U.S. manufacturers to dollars are given below. The average exchange rate for 1988 is used, as cited by the Federal Reserve Bulletin and rounded to 3 significant figures.

Country	Currency	Currency units/U.S. dollar
France	Franc	5.96
Japan	Yen	128.0
Italy	Lira	1302.0
South Korea	Won	735.0
Netherlands	Guilder	1.98

Use caution in making year-to-year comparisons of revenue and income figures, as they are significantly impacted by exchange rate changes.

U.S. Manufacturers

BERNOULLI OPTICAL SYSTEMS CO.
Subsidiary of Iomega Corporation
5700 Flatiron Parkway
Boulder, CO 80301

BOSCO, as it is familiarly known, is developing a 5.25", half-high write-once drive using flexible media. Target capacity is 1.3 gigabyte on two sides of the cartridge. Average access time will be in the 40-50 millisecond range. This will be the first drive to have dual optical heads and independent actuators. It is scheduled to be available in 1990. Media is being supplied by ICI, which has an investment position in BOSCO. A prototype drive and media were shown at the 1989 AIIM show.

CHEROKEE DATA SYSTEMS
1880 S. Flatiron Court
Boulder, CO 80301

Cherokee was founded in March, 1984. Key founders include managers previously with Storage Technology Corporation and Sperry Corporation. The firm has designed a 300 megabyte ruggedized 5.25" write-once drive that it expects to supply to customers in the defense and mineral resources industries. Volume shipments began in 1988. The first major customer for the Cherokee product appears to be Lockheed Corporation, which announced in April of 1986 that it had invested $2,000,000 in Cherokee and intended to modify the product for potential use in airborne electronic navigation systems for fighter aircraft. Later investments have brought Lockheed's share of ownership to 36%. Cherokee began to ship small amounts of product in the first half of 1988, and 1989 shipments will be modest. Increasing government procurement activity is expected by Cherokee to improve shipment levels next year. A non-ruggedized version of the product will become available in late 1989, which should also improve 1990 results.

DIGITAL EQUIPMENT CORPORATION
146 Main Street
Maynard, MA 01754

1988 total net sales: $7,541,241,000 (FY ending 7/02/88) Net income: $1,305,633,000

DEC was the first major system supplier to offer the CD-ROM as a system peripheral. The CD-ROM product is based upon a drive supplied by Philips, and is interfaced and supported on the highly successful Micro-VAX product line. A long-time manufacturer of both rigid and floppy magnetic disk drives, DEC is a logical candidate for internal production of its own optical drives at some future time. In 1988, DEC announced the RV20, which incorporates a 12", 1 gigabyte per side write-once drive supplied by Laser Magnetic Storage. DEC also announced the RV64 jukebox, which can handle up to four drives, in early 1989.

EASTMAN KODAK COMPANY
343 State Street
Rochester, NY 14650

1988 total net sales: $17,034,000,000 Net income: $1,397,000,000

Eastman Kodak has at least two optical disk drives, one a very high capacity 14" write-once optical disk drive and the other a low-end 3.5" magneto-optical drive. The latter product originated at Verbatim Corporation, acquired by Eastman Kodak in 1985, and is not yet in production. The 14" drive began its production run in 1987, but relatively few have been shipped to date. It uses a 14" diameter format and employs proprietary dye/polymer media. The drive is used in Eastman Kodak's KIMS series image storage product lines and is also offered on an OEM basis as a computer peripheral. Media will be made by Verbatim at its North Carolina facility. The company also purchases 12" optical drives from Hitachi and 5.25" optical drives from ISI for use in the KIMS product line. Eastman Kodak produces an automated library unit for use with its own drive and purchases library units for systems using drives from other manufacturers. In the spring of 1989, Eastman Kodak purchased a 40% ownership in Laserdrive and transferred the 3.5" drive development to Laserdrive. Verbatim retains optical media and head development responsibilities.

HEWLETT-PACKARD COMPANY
3000 Hanover Street
Palo Alto, CA 94303

1988 total net sales: $9,831,000,000 (FY ending 10/31/88) Net income: $816,000,000

Hewlett-Packard does not currently produce optical disk drives, but has an active technology evaluation program at its Boise, Idaho facilities. Boise is also the firm's development facility for its advanced rigid disk technology. Some related work on optical and rigid drive technology is being done at HP Laboratories. In September, 1987, The firm announced it would distribute technical documentation for its computer systems on CD-ROM, and followed that up in June of 1988 by commencing distribution of UNIX support information on CD-ROM. At the 1989 Spring Comdex show, HP announced that it would sell the Sony 5.25" rewritable drive as an OEM or end user system peripheral in both standalone and jukebox configurations. This is the end result of a development effort using Sony rewritable technology that began in 1985. HP manufactures its own jukebox.

HONEYWELL, INC.
Optical Storage Systems Operation
19019 North 59th Avenue
Glendale, AZ 85308

Honeywell purchased Sperry's Optical Products Group and Aerospace Group at the time that Sperry and Burroughs merged to form Unisys, and combined them to form the Sperry Space Division. At the same time, Honeywell obtained Sperry's 9% share of ownership in ISI. Honeywell is continuing development of a militarized drive based on ISI technology. Small quantities of a 300 megabyte 5.25" write-once drive began shipping in 1989 for use in a USAF system.

INFORMATION STORAGE, INC.
2768 Janitell Road
Colorado Springs, CO 80906

ISI was started in 1983 by executives from Optical Peripherals Laboratory, the Philips and Control Data joint venture for optical drive development which later became part of Optical Storage International. Among the early investors in ISI were CPT (20%) and Tallgrass (20%). Sperry, now incorporated into Unisys, also became a significant investor, and acquired rights to ISI technology for use in military systems. This product area, along with Sperry's investment, was subsequently sold to Honeywell.

The initial ISI product was a 5.25" write-once drive of 122 megabyte capacity, aimed at the personal computer and small system peripherals market. Limited production began in the fourth quarter of 1985. A funds shortage in early 1986 required scaling back the size of the company, but ISI was successful in attracting additional investment from local and foreign sources, in some cases by licensing its design. Single sided media for the ISI drive is being supplied by Sumitomo Chemical. Daicel will supply double sided media. In February, 1988 ISI announced a 600 megabyte per side, 5.25" write-once drive for volume delivery in late 1988. The drive uses a technique called track compression to achieve the higher capacity. In 1986, ISI licensed two other firms, Maximum Storage Inc. and Kawatetsu Instruments, to use ISI technology and designs. Both firms are currently in low volume production.

ISI's current efforts are heavily oriented to ramping up production on the newer optical drives and developing device drivers for various operating systems.

INTERNATIONAL BUSINESS MACHINES CORPORATION
Route 22
Armonk, NY 10504

1988 total net sales: $59,681,000,000 Net income: $5,806,000,000

Since May, 1986, IBM has demonstrated CD-ROM subsystems with various personal computers. A CD-ROM subsystem for use with IBM's PS/2 personal

computer family may appear in the future, but it is expected that these requirements will be filled with outside purchases of OEM CD-ROM drives. At the 1989 Microsoft CD-ROM conference, IBM indicated support of both the XA architecture and the Intel DVI format.

In April, 1987, IBM announced the model 3363 write-once drive for use with its personal computers. The mechanism for this drive was obtained from Matsushita Electric; IBM supplied the electronics, software, and final assembly and test. The product has been unsuccessful, and shipments of mechanisms to IBM ceased in 1988. While IBM has not revealed its future product plans, it is widely believed in the industry that IBM is working on 3.5" and 5.25" erasable optical technology for use with workstations, desktop computers, and mass storage subsystems. As a result of a mid-1988 reorganization, IBM's future optical products may be made in a location other than Tucson, but development staff and laboratories remained in Tucson. Development of 3.5" drives is also underway at IBM's facility in Fujisawa, Japan.

IBM has been purchasing 12" optical drives and library modules for integration into subsystems since 1988, and now offers optical library systems as attachments to large and mid-range systems.

LASERDRIVE, LTD.
1101 Space Park Drive
Santa Clara, CA 95054

Laserdrive was founded in 1984 with financial support from Acorn Computer and BSR International. Olivetti also acquired about 25% of ownership at that time. The firm's first product, a 5.25" write-once drive with 400 megabyte capacity, was formally introduced in 1987. Laserdrive has invested substantially in software that permits the optical drive to appear to the using system as a standard rigid drive and has developed special hardware for on-the-fly ECC. Production of the drive mechanism is done in Japan by Sansui, but the electronics and final assembly is done in the U.S., where the research and engineering functions are located. Media is provided by Daicel Chemical Industries or Sumitomo Chemical.

Laserdrive obtained considerable financial and management support from Olivetti, which purchased 80% of Acorn Computer in mid-1985 and as a result, obtained an 80% position in Laserdrive. In the second quarter of 1989, Eastman Kodak purchased half of Olivetti's interest and transferred its 3.5" magneto-optic drive development program to Laserdrive.

The firm has developed interfaces for a variety of small systems, including the Apple Macintosh, DEC MicroVax, and IBM compatible PCs, and has a modest, but profitable business in drive test equipment.

MAXIMUM STORAGE, INC.
5025 Centennial Boulevard
Colorado Springs, CO 80919

Privately held, MSI was founded in September, 1986, by Paul Schroeder, one of the founders of INMOS. Start-up has been rapid, as MSI licensed technology from ISI and began producing a 5.25" write-once drive having specifications similar to the ISI drive in early 1987. The firm is also working on a higher capacity write-once drive of its own design for future release. MSI has designed its drives for use with IBM PC and PC-compatible computers, and has developed its own software to optimize data throughput in write-once drives.

MAXOPTIX CORPORATION
Joint venture between Maxtor Corporation and Kubota, Ltd.
281 River Oaks Parkway
San Jose, CA 95134

1988 total net sales: $351,000,000 (FY ending 3/29/89) Net income: $14,100,000

In March of 1989, Maxtor and Kubota, Ltd. formed Maxoptix, a joint venture 75% owned by Maxtor. Maxoptix will design, produce and market rewritable optical disk drives. Kubota has worldwide manufacturing rights and exclusive sales rights in Japan for Maxoptics products.

Maxtor, with manufacturing facilities in California and Singapore, is a supplier of high performance, high capacity 5.25" rigid disk drives. In 1986, Maxtor entered into an agreement with Ricoh in which Maxtor acquired exclusive U.S. OEM marketing rights for the Ricoh 5.25" write-once optical disk drive. Because of Maxtor's strong market penetration in the OEM community, this was a successful effort for both parties.

In May, 1988, Maxtor announced a 5.25" magneto-optic rewritable drive offering 35 millisecond average seek time, the industry's fastest. Evaluation units began shipping in late 1988, and volume production is anticipated in late 1989. Maxtor also annnounced a 3.5" erasable drive to be supplied by Seiko Epson, but this product was later withdrawn. The rewritable drive program has been turned over to Maxoptix for further development and eventual manufacturing.

Maxoptix will leverage its optical program through Maxtor's sub-system subsidiary Storage Dimensions, which serves the personal computer and system integrator markets. U.S. Design, a firm specializing in storage sub-systems for the DEC market was also acquired by Maxtor and subsequently merged into Storage Dimensions. Storage Dimensions accounts for a substantial fraction of Maxtor's sales of write-once optical disk drives and is expected to be successful with Maxoptix products when they become available in 1989.

OPTIMEM
Subsidiary of Cipher Data Products, Inc.
435 Oakmead Parkway
Sunnyvale, CA 94086

1988 total net sales: $185,373,000 Net income: $10,443,000

Optimem began in 1980 as a development program managed by Shugart Associates based on Xerox technology, and functioned as the Optimem Division of Shugart until Shugart ceased operations, at which time it became a Xerox subsidiary company. In mid-1986, control of Optimem was acquired from Xerox by Cipher Data Products. Xerox retains a 10% minority ownership position. 3M Company subsequently acquired a small ownership position.

Optimem is one of the few U.S. based firms that is shipping a production version of an optical disk drive. 3M and Art Tech Gigadisc are sources for media. The Optimem products are 12", 1 and 1.2 gigabyte drives. Work on a 5.25" drive capable of using read-only, write-once or magneto-optical erasable media was discontinued in 1987. The 12" Optimem drive has found applications in image processing and in document storage and retrieval systems.

Optimem was hurt in 1987 by the departure of most of its senior management, and while the firm weathered the changes, additional disruption may occur as the result of continuing management changes in 1989.

OPTOTECH, INC.
770 Wooten Road
Colorado Springs, CO 80915

Founded in 1984, Optotech was one of the early suppliers of 5.25", 400 megabyte write-once drives. Initial production began in mid-1986 in Colorado, but Optotech, expecting a rapid ramp up, stated that its eventual plan was to manufacture offshore in Taiwan. Slow market growth and product problems limited production, however, and after a period of management instability, in mid-1988 Optotech announced that it was selling its write-once drive product line to Shugart Corporation. While no new product announcements have been made, Optotech is concentrating upon a line of erasable drives.

REFERENCE TECHNOLOGY, INC
1832 North 55th Street
Boulder, CO 80301

Reference Technology's products include a 12" read-only unit, but the firm has also begun to remarket the Hitachi CD-ROM. Replication services for media are available through 3M. Reference Technology has entered into marketing agreements with database publishers aimed at providing complete subsystem packages to the ultimate end users. The 12" media used is a video laserdisk which can be used for either data or images. Reference Technology has shifted its emphasis to system integration; its product

line now includes hardware and software to interface optical disk drives to small systems. Only a few drives were made by the firm after 1987, mostly to service existing customer accounts.

SEAGATE TECHNOLOGY
920 Disc Drive
Scotts Valley, CA 95066

1988 total net sales: $1,265,966,000 (FY ending 6/30/88) Net income: $77,317,000

Seagate is one of the world's largest suppliers of small rigid disk drives and is highly vertically integrated. The company has begun development of optical drives including a high performance CD-ROM and a CD format read/write drive. The project remains in an experimental stage; products will not be available for some time. In 1989, Seagate and Imprimis signed a letter of intent for Seagate to acquire Imprimis in a deal worth $450,000,000. However, this does not include Control Data's ownership in Laser Magnetic Storage.

SHUGART CORPORATION
9292 Jeronimo
Irvine, CA 92718

Shugart Corporation, formerly the Narlinger Group, acquired the rights to the Shugart name in 1986 from Xerox Corporation, along with manufacturing rights to the 8" floppy drive product line. The firm has since acquired manufacturing rights and certain assets of other storage products companies including Tandon, Control Data, Kennedy and Optotech. In general, these have been obsolescent products that the firm continues to make (in small numbers) and service for existing customers. In 1988, Optotech sold its write-once optical drive product line to Shugart, which continues to supply products and maintenance services to Optotech's former customers.

VERBATIM CORPORATION
Subsidiary of Eastman Kodak
1200 W. T. Harris Boulevard
Charlotte, NC 28213

Verbatim, known primarily as a maker of floppy disk media, began developing an erasable optical disk drive in early 1983. Based upon technology developed at Philips, the Verbatim design, a 3.5" magneto-optical erasable drive, was announced in preliminary form at the NCC in 1985. In its final form, the drive was expected to be a low cost, moderately fast drive that would offer at least 50 megabytes of capacity. Eastman Kodak, which acquired Verbatim in 1985, continued to support the development of the product at a high level, and brought in several key employees from its operations in Rochester, New York, to strengthen the program. A non-operating prototype was demonstrated at the 1986 NCC and several later shows. The

drive was to be produced by Eastman Kodak; media for the drive was to be produced by Verbatim at its Charlotte facilities. However, the firm was unable to move the drive into manufacturing status, and in 1989 Eastman Kodak transferred the 3.5" program to Laserdrive as part of Kodak's deal to acquire 40% of Laserdrive from Olivetti.

Kasei Verbatim, a Japanese joint venture between Verbatim and Mitsubishi Chemical, announced in 1987 that it would also make 3.5" magneto-optical media.

Asian Manufacturers

(All fiscal years end in March, 1988, unless otherwise noted. All firms are in Japan unless otherwise noted.)

ALPS ELECTRIC CO., LTD
1-7, Yukigaya Otsuka-cho
Ohta-ku, Tokyo 145

1988 total net sales: $2,894,328,000 Net income: $64,664,000

Alps Electric is a high growth manufacturer of electronic components and sub-assemblies for audio, television, instrument and computer applications. The firm's product line includes floppy and rigid disk drives. Alps has been working with other companies wishing to supply CD-ROMs and is able to supply design assistance, components, and to manufacture on a contract basis.

CANON INC.
2-7-1 Nishi-Shinjuku
Shinjuku-ku, Tokyo 163

1988 total net sales: $8,640,703,000 Net income: $289,844,000
(FY ending 12/31/88)

Canon is a major supplier of business machines, copiers, and cameras. Disk drive products include flexible and erasable optical drives. Canon's rewritable drive and media were announced in 1988 when it was revealed that Canon had an exclusive agreement with NeXT to supply a 256 megabyte 5.25" magneto-optic drive. Shipments began in 1988, making Canon, along with Sony, one of the few major suppliers of rewritable drives in 1988. In 1989, Canon acquired a 16% interest in NeXT.

CHINON INDUSTRIES INC.
21-17 1 Chome, Takashima
Suwa City, Nagano 392

1987 total net sales: $375,117,000 Net income $9,008,000
(FY ending 9/30/87)

Chinon is best known for its cameras and audio equipment, but 35% of its sales come from floppy disk drives and printers. Eastman Kodak holds approximately 15% ownership through Kodak Japan. Chinon has been producing head assemblies for CD equipment and in 1988 began supplying CD-ROM drives to Atari as a custom product. A similar drive has since appeared under Chinon's own label.

FUJITSU, LTD.
1-6-1, Marunouchi
Chiyoda-ku, Tokyo 100

1988 total net sales: $15,990,641,000 Net income: $329,023,000

Fujitsu is Japan's largest producer of computer systems and also manufactures a wide variety of other electronic equipment. Computer products represent about 68% of Fujitsu's sales. The firm announced a write-once 12" drive for use in document storage systems in 1984. The product is currently marketed only in Japan. In 1986, the company added a similar product for sale in Japan on an OEM basis. The head for the drive was developed in a joint effort with Olympus Optical Company, the industry's leading supplier of optical read/write heads. Media was developed in a joint program with Asahi Chemical. In October, 1986, Fujitsu announced a 5.25" write-once drive with 300 megabyte capacity for delivery in mid-1987. Fujitsu has a development program for erasable optical disk drives and media, and has made a technology announcement of rewritable media using phase change techniques, but has not announced a rewritable drive as of mid-1989. In 1989, Fujitsu began to ship a computer system with a bundled CD-ROM drive, one of the first companies anywhere to take such a step. It is currently available only in Japan, but has been displayed in the U.S. and elsewhere. The CD-ROM drive is purchased from another firm.

GOLDSTAR TELECOMMUNICATION CO., LTD.
20, Yoido-dong
Yongdungpogu, Seoul
Korea

Goldstar Telecommunications is a joint venture between the Lucky Goldstar Group and several other firms, including Fuji Electric and the German firms Siemens and DEG. About 11% of total sales is computer related equipment. Goldstar has announced a CD-ROM drive that is scheduled to begin shipping in 1990. An internal development program targeted at read/write drives exists has been reported in the trade press.

HITACHI, LTD.
6-2, Otemachi 2-chome
Chiyoda-ku, Tokyo 100

1988 total net sales: $38,868,016,000 Net income: $1,068,797,000

Hitachi remains Japan's largest manufacturer of electrical and electronic equipment and the third largest Japanese producer of computer systems, which account for about 10% of sales. It manufactures rigid disk drives and other peripherals as well as processors. Hitachi is one of the earlier entrants in the optical disk drive market. CD-ROM and write-once products are available in the U.S. as well as in Japan. Hitachi's first write-once 12" optical disk drive has a capacity of 1.3 gigabytes,

and began shipping in 1984. The CD-ROM products began shipping in 1985, and in 1987 and 1988 Hitachi was the leading CD-ROM drive producer. In early 1986, Sperry announced that the Hitachi 12" write-once optical drive was available as a peripheral device on its mainframes--the first optical drive offered by a mainframe vendor. A 5.25" continuous servo write-once drive with a capacity of 300 megabytes was announced at COMDEX in 1986. A sampled servo version offering 320 megabytes per side was introduced in late 1987. The CD-ROM product line was expanded in 1986 and 1987 to include 5.25" form factor drive packaging and some new features. In early 1988, Hitachi made a technology announcement of a 3.5" erasable drive under development in its Central Research Laboratory, but the first rewritable drive to be announced was a 322 megabyte, 5.25" model in March, 1989. Hitachi also offers automated library storage units based upon its 12" and 5.25" drive designs. Media for the Hitachi drives is made by Hitachi Maxell.

JVC (VICTOR COMPANY OF JAPAN, LTD.)
1-4 Nihonbashi-Honcho
Chuo-ku, 103 Tokyo

1988 total net sales: $5,605,227,000 Net profit: $70,461,000

JVC, as it is commonly known, is a major producer of consumer audio equipment, including CD players. Video tape recorders accounted for 65% of JVC sales in 1986, but JVC has been expanding into computer peripherals and has been shipping rigid disk drives since 1985. The firm has introduced CD-ROM drives and went into low volume production in the last half of 1987. 1988 shipments were nominal.

KAWATETSU ADVANTECH CO. LTD.
Subsidiary of Kawasaki Steel Corporation
14-4 Nihonbashi Kodemma-cho
Chuo-ku, Tokyo 103

1988 total net sales: $7,924,461,000 Net income: $68,094,000

Kawatetsu Advantech is a smaller company specializing in electronic instrumentation. The firm began producing 5.25" write-once optical disk drives at its Nishinomiya plant in December of 1986 under license from ISI. Kawatetsu Advantech will market the drives to OEM customers in Asian markets through Kanto Denshi, a trading company, and may act as a second source of supply to ISI if demand warrants. As of mid-1988, sales were entirely in Japan, mostly through distributors. In 1988, Kawatetsu Advantech, Kawasaki Steel and four private investors established Advansys Corporation, which is chartered to develop components for optical disk drives. Advantech holds 50% ownership and Kawasaki Steel an additional 25%. Kawatetsu Advantech is maintaining its relationship with ISI, and will begin shipping 5.25" drives based on the ISI 600 megabyte design in the last half of 1989.

MATSUSHITA COMMUNICATION INDUSTRIAL CO., LTD.
4-3-1, Tsunashima-Higashi
Kohoku-ku, Yokohama 223

1988 total net sales: $2,633,336,000 Net income: $64,633,000

The primary products of MCI include key telephones, car audio equipment and floppy disk drives. Disk drives are made at a highly automated plant in Hanamaki and in the Philippines. In 1987, MCI announced a 5.25" 300 megabyte write-once optical disk drive offering 75 millisecond average access time and 925 kilobyte per second data transfer rate. A rewritable drive having similar specifications began shipping in late 1988. In 1989, responsibility for the MCI optical disk drive products was transferred to Matsushita Electric Industrial Company.

MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
1006, Kadoma City
Osaka, 571

1988 total net sales: $37,648,531,000 Net income: $1,272,141,000

MEI's Panasonic, National, Technics, and Quasar brands are among the most widely known in the world for appliances, consumer electronics, and communications equipment. The MEI High Fidelity/Audio division is offering CD-ROM products, including half-high models that became available in late 1987. The parent firm has also developed an 8" write-once drive that is now manufactured by Matsushita Graphics Communication Systems and used in captive document storage systems. In April, 1987, IBM announced a 200 megabyte write-once disk drive whose mechanism is made for IBM by Matsushita Electric's Disk Division. The product was not a commercial success, although MEI is offering a similar product under its own brand. The company also has an active program in rewritable optical drives and media, and is noted for its advanced work in rewritable phase change media and has made several technology announcements regarding phase change media and related drives. In 1989, the Disk Division of MEI acquired the responsibility for manufacturing and marketing of the MCI optical disk drive product line.

MATSUSHITA GRAPHIC COMMUNICATION SYSTEMS
3-8 Shimomeguro 2-chome
Meguro-ku, Tokyo 104

MGCS is best known for facsimile systems, but has, for the past three years, marketed a line of office automation equipment. These include document storage systems using an 8" write-once optical drive developed by MGCS' parent, Matsushita Electric Industrial Company. MGCS now manufactures the drive itself for use in the Panafile series of document storage systems. As of mid-1989, these systems were marketed only in Japan.

MITSUBISHI ELECTRIC CORPORATION
2-2-3, Marunouchi
Chiyoda-ku, Tokyo 100

1988 total net sales: $18,502,180,000 Net income: $173,539,000

This company is most noted for heavy machinery production, but is also quite active in defense electronics and consumer electronics. Data and communication systems represent 28% of sales. In 1987, Mitsubishi introduced a 5.25" 300 megabyte write-once optical drive with 80 millisecond average access time. The drive is sold as part of an optical storage library system that can contain as many as two drives and 152 disks. Higher performance 5.25" write-once and rewritable drives are scheduled to be shipped in the fourth quarter of 1989 and the first quarter of 1990, respectively.

NAKAMICHI CORPORATION
1-153, Suzuki-cho
Kodaira City, Tokyo 187

1988 total net sales: $97,438,000 (FY ending 2/28/88) Net income: $1,281,000

Best known for its top of the line audio equipment, Nakamichi has had an optical disk drive development program for several years, and is currently selling laboratory equipment for optical disk drive development. About 17% of sales are computer related items. Nakamichi has established or purchased several organizations in the United States, including Mountain Computer, Caliper, and Ocean Micro, in which Mountain has a 20% interest. Responsibility for Nakamichi's line of optical disk test equipment has been transferred to Mountain Computer, which manufactures a variety of test and certification equipment. A 100 megabyte 3.5" rewritable drive, developed by MOST, another U.S. Nakamichi operation, is scheduled to be added to Mountain's manufacturing responsibilities in late 1989.

NEC CORPORATION
5-33-1, Shiba
Minato-ku, Tokyo 108

1988 total net sales: $21,208,875,000 Net income: $198,148,000

NEC has defined its product area as communications and computers, with computer products accounting for about 43% of annual revenues. The firm has the largest share of the Japanese personal computer market. NEC makes a variety of disk products, including floppy, rigid and optical disk drives. The firm's first optical drive, introduced in 1983, was a 1 gigabyte, 12" unit used primarily for NEC captive document storage systems but also sold on an OEM basis. A fingerprint tracking system using optical storage is sold by NEC and has achieved some success in the

U.S. The largest such system installed has 28 NEC optical drives and may be further expanded.

NEC Home Electronics is producing CD-ROM drives for both captive use and worldwide OEM sale, but has had its greatest success with a modified CD audio drive as a CD-ROM add on to its popular PC Engine consumer system.

NIKON CORPORATION
3-2-3, Marunouchi
Chiyoda-ku, Tokyo 100

1988 total net sales: $1,548,617,000 Net income: ($9,930,000)

Nikon, a member of the Mitsubishi group, is best known for its popular line of cameras and other optical equipment. The firm is also a significant supplier of semiconductor production equipment, medical optical instruments, microscopes and telescopes, and other optical instruments. As a way of expanding its scope of business, Nikon is developing a 12" erasable optical drive. Limited quantities will be available in 1989, but the real opportunity for Nikon may lie in an innovative media design that solves the overwrite problem experienced by current magneto-optic media designs. However, it will take several years for Nikon to fully commercialize the technology.

NIPPON COLUMBIA CO., LTD.
4-14-14, Akasaka
Minato-ku, Tokyo 107

1988 total net sales: $762,961,000 Net income: $4,297,000

Primarily known as a producer of CD disks, phonograph records, consumer electronics and audio equipment, Nippon Columbia is leveraging its CD audio player experience to gain an entry in the CD-ROM market. CD-ROM hardware production in limited quantities began in the fourth quarter of 1985, and half high models are now available. The firm has yet to establish strong marketing channels for the drives and shipments remain at moderate levels. The company is also developing phase change technology media, but has not yet committed to development of a write-once or rewritable drive.

OLYMPUS OPTICAL CO., LTD.
22-2, Nishi-Shinjuku 1-chome
Shinjuku-ku, Tokyo

1987 total net sales: $1,290,258,000 (FY ending 9/30/87) Net income: $40,617,000

Founded 1n 1919, Olympus Optical company is known primarily for its cameras and optical instruments. In recent years the company has broadened its activities to include electronics and some specialty products, including optical heads for disk drives. Development of optical disk drive technology began in 1981 when Olympus and Fujitsu began a joint project that resulted in one of the first commercial write-once optical disk drives. The firm's optical electronic products include optical heads, an optical card reader compatible with the Drexler Lasercard and a 5.25" erasable optical disk drive announced in November, 1987. The disk drive, which has a capacity of 326 megabytes per side, was provided in sample quantities as of mid-1988, and the mechanism was adopted by Ricoh as the basis of its own rewritable drive. Olympus has an exclusive agreement with Ricoh to provide drive mechanisms to which Ricoh then adds the electronics.

PENTAX TEKNOLOGIES CORPORATION
Subsidiary of Asahi Optical Co., Ltd.
880 Interlocken Parkway
Broomfield, CO 80020

Pentax Teknologies was founded in 1985. Products include optical components, heads and a write-once drive, a 5.25" 326 megabyte per side unit introduced in late 1988. Deliveries started in 1989. The drive is unusually fast for a write-once drive, having a specified average seek time of 40 milliseconds.

PIONEER ELECTRONIC CORPORATION
4-1, Meguro 1-chome
Meguro-ku, Tokyo 153

1988 total net sales: $3,156,609,000 (FY ending 9/30/87) Net income: $143,820,000

Pioneer and Ricoh have had a joint development program on an 8" 750 megabyte optical write-once disk drive, with Ricoh being Pioneer's most significant customer for the product. First shipments began in late 1985, and Pioneer has established a separate division to make and sell the product. Pioneer has also developed a 5.25" write-once drive and displayed media for it at the Japan COMDEX show in early 1986. Drive shipments commenced in mid-1988. The media used in these drives is a cyanine dye based type that appears to offer superior resistance to corrosion. The active layer is placed on the PMMA substrate by spin

coating, a relatively inexpensive production process. Pioneer's media is the first commercial version of dye based media to be brought to market. In 1989, Pioneer introduced a CD-ROM drive integral to an automatic library mechanism. The library contains up to six disks and is derived from a design developed for use with audio CD players and disks.

RICOH CO., LTD.
15-1, Minami-Aoyama 1-chome
Minato-ku, Tokyo 107

1988 total net sales: $5,267,328,000 Net income: $132,938,000

Copiers, photographic equipment, and sensitized papers provide most of Ricoh's revenues, but the firm also produces a growing line of data processing equipment. This product line, which was started in 1979, includes floppy disks and a cartridge-type rigid disk licensed from DMA Systems. Ricoh has been Pioneer's partner in the development of an 8" write-once optical drive which Ricoh uses in a document storage system, and the firm showed a prototype OEM 8" write-once drive at the 1986 NCC show. However, Ricoh has concentrated upon developing optical disk drives in the 5.25" form factor, rather than expending further effort on an 8" product. In early 1987, Ricoh and Maxtor entered an agreement whereby Maxtor is the exclusive marketing agent for Ricoh OEM 5.25" write-once optical disk drives in the United States. Ricoh is marketing subsystems containing optical drives in the U.S., an activity permitted under the terms of the Ricoh-Maxtor agreement. In 1987, Ricoh supplied more write-once drives than any other manufacturer, largely as a result of its collaboration with Maxtor. The Maxtor-Ricoh agreement for write-once drives continues, even though Maxtor has gone its own way with rewritable drives.

Ricoh has also announced a jukebox for 5.25" drives and, in 1988, a half high version of its original 5.25" optical disk drive design. In 1988, Ricoh adopted a rewritable drive mechanism supplied by Olympus on an exclusive basis, and, supplying the required electronics and packaging, began shipping a rewritable 5.25" 300 megabyte per side optical drive in the second quarter of 1989.

SANYO ELECTRIC CO., LTD.
2-18 Keihan-Hondori
Moriguchi, Osaka 570

1988 total net sales: $9,811,797,000 (FY ending 11/30/88) Net income: $47,930,000

Sanyo is a major supplier of facsimile equipment, consumer electronics, appliances, batteries and components such as solar cells, and is one of Japan's more active offshore manufacturers. The firm is moving into development of DRAM in 1989. About 25% of sales are computing and business equipment. Sanyo is actively involved in CD equipment and media

production and introduced a CD-ROM drive in 1987. Shipments began in 1988. Half high drives will begin shipping in 1989. The firm also makes 5.25" and 12" write-once optical drives for use in its own line of office equipment.

SEIKO EPSON CORPORATION
80 Hirooka
Shiojiri-shi, Nagano 399-07

Epson is a member of the privately held Suwa Seikosha/Epson group owned by members of the Hattori family, which also control Japan's Seiko companies, known for watches and electronics. Epson is best known for its line of printers, but also manufactures a portable computer, displays, paper tape equipment, and floppy and rigid disk drives. In 1988, Epson agreed to supply Maxtor with a 160 megabyte 3.5" erasable optical disk drive and media then under development. However, plans to deliver such a drive to Maxtor have been terminated.

SHARP CORPORATION
22-22 Nagaike-cho
Abeno-ku, Osaka 545

1988 total net sales: $9,571,766,000 Net income: $158,914,000

Sharp is a supplier of electrical and electronic equipment. About 41% of sales are derived from computer or computer related products, including desktop and transportable personal computers. Sharp has been actively developing magneto-optic disk drives and media for several years and has made several technology announcements during this period. In mid-1987, the firm announced a 5.25" 190 megabyte erasable optical drive. An improved 300 megabyte version is scheduled to be available in production quantities in 1989.

SONY CORPORATION
6-7-35, Kitashinagawa
Shinagawa-ku, Tokyo 141

1988 total net sales: $11,381,828,000 (FY ending 10/31/87) Net income: $286,984,000

Sony is a leader in consumer electronics and has also earned a position as the major supplier of 3.5" floppy disk drives. Sony is fielding a product line of CD-ROM, write-once and rewritable optical drives. The write-once products are available in 8" and 12" sizes, while the rewritable drive is a 5.25" model. Sony is vertically integrated and supplies its own media. Because of its strong position in the audio CD player market, Sony is very competitive in the CD-ROM marketplace with products

aimed at the personal computer and small systems market. Sony, together with Philips, has been a moving force in establishing standards for CD and CD-ROM devices. Sony's latest CD-ROM products conform to the commonly used 5.25" form factor used by floppy and small rigid disk drives, thus making them physically compatible with personal computer packaging. To support its write-once drives, Sony offers an automated library unit, first shown at COMDEX in the fall of 1985. In 1987, Sony announced an erasable 5.25" optical drive using magneto-optical technology. Evaluation units were first shipped in late 1987, and additional improved evaluation units were shipped in mid-1988. Production units were shipped in late 1988, and Sony has been successful in capturing several OEM accounts for its rewritable drive. In 1989, Sony is expected to be among the major suppliers of rewritable optical disk drives.

TOSHIBA CORPORATION
1-1-1, Shibaura
Minato-ku, Tokyo 105

1988 total net sales: $27,909,648,000 Net income: $474,305,000

Toshiba is a major factor in consumer electric and electronic products, and also has a leading position in the office computer market in Japan. Floppy, rigid, and optical drives are produced by Toshiba; the firm was one of the first to offer a commercial 12" write-once drive. A 12" 2.5 gigabyte drive began shipments in 1988. Toshiba has also made product announcements of CD-ROM and 5.25" write-once optical disk drives, and began shipping samples of its 400 megabyte 5.25" write-once drive in 1986. CD-ROM shipments also began in 1986, with half high drives scheduled for the latter half of 1987. Toshiba's later CD-ROM models have unusually short seek times for CD-ROM drives, and this has helped Toshiba capture a significant and growing market share. The drives are particularly favored by system integrators building file servers incorporating CD-ROM.

YAMAHA CORPORATION
10-1 Nakazawa-machi
Hamamatsu, Shizuoka

1988 total net sales: $3,648,516,000 Net income: $65,383,000

Yamaha is the world's largest manufacturer of musical instruments, which account for 62% of the firm's sales. Among more recent activities is the development of a CD format system capable of recording on write-once media. The media is supplied by Fuji Photo Film. The Yamaha system is intended for use in situations where fast preparation of a master disk is required or where relatively few copies are needed. It contains the first commercial write-once CD format drive. The drive is not available as a separate item.

European Manufacturers

ATG GIGADISC
1270 Avenue General Eisenhower
31047 Toulouse
France

Beginning as the optical disk operation of Thomson-CSF, ATG was formed as a joint venture in 1984 when CIT-Alcatel, a maker of image processing systems, joined with Thomson-CSF, Rhone-Poulenc, Bull, and several other French companies to form Alcatel-Thomson-Gigadisc. A major drive and media production facility in Toulouse was brought on-stream in early 1986. ATG was one of the first firms to get into limited production of optical drives, but media shortages hampered its growth. A new facility alleviated this problem, but disappointing sales caused Alcatel to decide to withdraw from the venture, and for a short time ATG was dormant while new investors were found. Now officially Art Tech Gigadisc, the firm prefers to be known as ATG Gigadisc. While ATG Gigadisc markets its products internationally, it has its strongest market presence in Europe.

ATG and Optimem share technology; the two firms' drives can use the same media. The current product line is based upon 12" write-once products using an unusual media developed by ATG. The drive will also operate with 3M or LMS media if properly adjusted. New products include 3.2 gigabyte write-once drives; a 5.25" drive is also under development with a 1990 introduction target. ATG also designed a library storage unit for 12" media, but has elected to market Cygnet's line of library units in order to concentrate its resources on drive development and manufacturing.

LASER MAGNETIC STORAGE INTERNATIONAL
Joint venture of N. V. Philips and Control Data
4425 ArrowsWest Drive
Colorado Springs, CO 80907

LMS was formed in 1986 through the combination of Optical Storage International, Computer Peripherals International, and Philips' CD-ROM operations. Philips owns 51% of the company. CPI was a CDC and NCR joint venture that produced tape drives. OSI, formed in 1984, was a joint venture of Philips and Control Data. While Philips now holds the majority interest, the organization originally was managed by Control Data. OSI combined two earlier joint ventures, Optical Peripherals Laboratory in Colorado and Optical Media Laboratory in the Netherlands. The entire U.S. operation, at one time split between California and Colorado, was consolidated at the Colorado facility in early 1986. In the spring of 1986, Philips assumed management responsibility for LMS.

LMS optical disk drives currently include CD-ROM drives, a 12" write once drive, 12" automated libraries, and a 5.25" write-once drive using sampled servo tracking. The 5.25" drive was introduced at the fall Com-

dex conference in 1987 and went into production in late 1988. LMS continues to also produce tape drives, which are the firm's most profitable products. Image processing has been the most significant application to date for the company's write-once products. Media is obtained from an LMS manufacturing operation sharing Philips media manufacturing facilities at Blackburn in the UK. PDO also is a qualified media supplier.

ING. C. OLIVETTI & C., S.P.A.
Via G. Jervis 77
10015 Ivrea
Italy

1988 total net sales: $6,100,000,000 Net income: $254,000,000

Olivetti's major participation in the optical drive business is through its 40% equity in Laserdrive. The firm had held an 80% share, but sold half of its holdings to Eastman Kodak in 1989. While Olivetti had major internal disk storage projects under development, a change of emphasis in 1988 resulted in the formation of joint ventures with other firms. A joint venture with Conner Peripherals has absorbed Olivetti's magnetic disk drive manufacturing and development in Italy. Some optical recording research projects have been continued. Olivetti has negotiated some optical technology sharing agreements with Toshiba.

N. V. PHILIPS
5600 MD Eindhoven
The Netherlands

1988 total net sales: $28,322,727,000 Net income: $533,333,000

The Philips organization, established in 1891 as a manufacturer of electrical equipment, has been active for many years in the development of optically based information systems. Initial development work was spun off to joint ventures with Control Data. Philips' initial digital optical developments were a 12" write-once drive and the CD-ROM. Philips, together with Sony, has been instrumental in establishing standards for CD and CD-ROM drives. The Philips CD-ROM has the distinction of being the first CD-ROM to be accepted by a major system OEM: Digital Equipment Corporation offered it as a peripheral on its Micro-Vax line. Philips and Sony have continued to innovate standards for CD-ROM, including CD-I and CD-ROM XA.

In 1986, OSI, a joint venture between Philips and Control Data, was reorganized as Laser Magnetic Storage and charged with the responsibility of manufacturing and marketing the Philips CD-ROM, write once optical disk drives designed by OSI using Philips-developed technology, and magnetic tape drives previously produced by another CDC joint venture. Philips owns 51% of LMS; Control Data has the other 49%. Philips is also involved in a joint venture with Sun Microsystems to develop CD-ROM

and CD-I authoring systems using Sun workstations. Philips is a producer of CD media through its Polygram operation and several joint ventures with Japanese companies. In 1985, Philips also entered into a joint venture with DuPont named Philips and DuPont Optical to produce optical media of various types in large quantities.

1989 DISK/TREND REPORT

DISK/TREND ON DISK

INTRODUCTION

DISK/TREND ON DISK is a set of floppy disks containing the statistical tables and specification tables from the annual DISK/TREND reports. The disk files have been prepared in a format usable by Lotus 1-2-3 on IBM or IBM-compatible computers running under the MS-DOS or PC-DOS operating system. All files contain data only: Manipulation of the data is the user's responsibility. Because some of the files can be very large, system memory of 640K or more is recommended. While the files supplied can be used with Lotus 1-2-3 versions 1A and up, we recommend the use of versions 2.0 and up in order to be able to take advantage of Lotus advanced features to manipulate data.

Two disks are available for each DISK/TREND disk drive report. The first disk contains the statistical tables. File names are keyed to the table numbers in the report for easy identification. The second disk contains the specification tables in a data base format. Both types of data are directly loadable by Lotus 1-2-3. The color used on the label of each floppy disk is similar to the color used on the cover of the corresponding report for ease in identification. Because the statistical tables are provided in ASCII form, they can be used with any spreadsheet program that can import ASCII text files. However, the specification tables have been prepared specifically in Lotus 1-2-3 format to allow them to be searchable using Lotus 1-2-3 database commands. If you use a spreadsheet program other than Lotus 1-2-3 that can translate Lotus WK1 formatted files to its own format, it may be able to import the specification tables.

The authors of this manual assume that you are familiar with personal computers, Lotus 1-2-3, and MS-DOS, and do not cover their operation in this manual. This manual deals specifically with how to load and use the files supplied on the floppy disks.

Note: Please read the license information on the following page.

DISK/TREND ON DISK
Information License

DISK/TREND is supplying diskettes containing selected information from the 1989 reports for your convenience.

YOU MAY:

1. Install and use the information on a single computer system, provided that you or the organization by which you are employed has purchased at least one copy of the DISK/TREND report volume associated with the information.

2. Make backup copies of the information for your own use. Such backup copies may be used only on the computer on which the information is installed. You must reproduce the copyright notice on any copies.

3. Reproduce the information, but not the associated programs or documentation, contained in the Product for use within internal documents distributed within the organization by which you are employed.

YOU MAY NOT:

1. Install, or allow the use of, the information on more than a single computer system.

2. Transfer the information through or within a computer network.

3. Distribute the information or any portion thereof in any form outside the organization by which you are employed or modify the information for purposes of distribution.

4. Transfer this license to another party.

Trademarks:

IBM is a trademark of International Business Machines Corporation.

Lotus and Lotus 1-2-3 are trademarks of Lotus Development Corporation.

MS-DOS is a trademark of Microsoft Corporation.

Getting Started

The first thing you should do is to make working copies of the DISK/TREND diskettes. Place the originals in a safe location and use only the working copies for day-to-day operations. This procedure will help to protect your data from inadvertent destruction or loss due to a malfunction of the computer or its operator. We also recommend that you place a write protect tab on the working copies (after you create them) for the same reason. Use the hard disk or another floppy disk copy for day-to-day manipulations of the files.

The statistical tables are provided in ASCII text format. This allows you to use any word processor to edit the file prior to importing it into Lotus 1-2-3. Appropriate editing removes any material you don't wish to work with and allows you to add figures or text to the data tables. You may also embed the data in internal documents or reports you are preparing for use within your company.

STATISTICAL TABLES

Loading

1. Place the floppy disk marked 'Tables' in a floppy disk drive able to read 5.25", 360 KB disks. This is usually drive A, but if you are using a dual floppy only system, use drive B and put the Lotus 1-2-3 system disk in drive A. Use the DOS 'DIR' command to examine the file directory on the 'Tables' disk. If there are any special instructions, they will be in a file named READ.ME. To see these instructions, at the DOS prompt type:

   TYPE A:READ.ME (Use the appropriate drive letter if not A)

   If you wish to print the instructions, turn on your printer and type:

   TYPE A:READ.ME>PRN

2. Do this step if you have a hard disk. Log into the hard disk directory in which Lotus 1-2-3 normally stores worksheet files. Using the DOS 'COPY' command, copy all the statistical table files to the hard disk. This can be done in one step using the copy command as follows:

   COPY A:?T*.*

   Several utility files should also be copied. The command is:

   COPY A:*.PRN

3. Now you are ready to start Lotus 1-2-3. If you are using a two floppy system, place the DISK/TREND disk in drive B and the Lotus 1-2-3 system disk in drive A. If you are using a rigid disk system, place the Lotus 1-2-3 system disk in floppy drive A. Now start Lotus 1-2-3 as usual. After obtaining the blank spreadsheet image on the screen, use the Lotus File Import Text command to select a file. The command is:

   /FIT<filename>

   The file names are in the format XTYY.ZZX, where:

   X= Type of data
   - F (Flexible disk drive data)
   - R (Rigid disk drive data)
   - O (Optical disk drive data)

   YY= Table number, as shown in the appropriate report volume

   ZZ= Year of report.

   Examples: File RT10.89R is 1989 Rigid Disk Drive Report Table 10
   File OT2.890 is 1989 Optical Disk Drive Report Table 2

The file selected will be loaded as a worksheet in text block format. You can use Lotus 1-2-3 commands to edit the worksheet and embed it in some other document or, using the Lotus 1-2-3 Data Parse commands, you can convert the numeric content to individual cells which can be manipulated or graphed using Lotus 1-2-3 commands.

Data Parsing made easy

Most Lotus 1-2-3 users are not familiar with the Data Parse commands. They allow the user to convert a table which has been imported in the form of a block of text to a form in which the individual numbers and labels can be manipulated as spreadsheet elements or used to prepare graphics.

Before starting, it would be useful to read the Lotus reference manual on this subject if you are not a regular user of the Data Parse commands. The trickiest and most time-consuming part of using the Data Parse commands is setting up the format line. Several utility files have been provided on the tables disk to make this process easier. These are used with various table formats encountered in the DISK/TREND Reports:

- o FORMLINA.PRN — Used with Table 1 and the Revenue and Unit Shipment tables found in the product group sections of the reports.
- o FORMLINB.PRN — Used with table 2.
- o FORMLINC.PRN — Used with tables 3 through 6.
- o FORMLIND.PRN — Used with Application tables.

There are no FORMLIN format files for disk diameter tables or market share tables (if any), as these are variable in format. You will have to construct the format line directly, but after you have seen how it is done in the other tables, this should not be too big a job.

A step-by-step process for parsing and an example are shown on the following pages.

The Parsing Process

The basic process of parsing the data table goes like this:

1. Enter Lotus 1-2-3 and obtain the blank spreadsheet screen.
2. Import the file to be parsed using the /FIT<filename> command.
3. Move the cursor in the A column to the blank row just above the first line of numbers.
4. Import the Formline file.

   Example: /FIT FORMLINA.PRN

   A sample format line will appear in the row. See Figure 1 below.

Figure 1. Portion of sample file with sample format line imported

TABLE 1

CONSOLIDATED WORLDWIDE REVENUES

ALL EXISTING MOVING HEAD DISK DRIVE GROUPS

REVENUE SUMMARY

	1988 ----Revenues--- U.S.	WW	------1989----- U.S.	WW	------1990--- U.S.	WW
U.S. Manufacturers						
L>>>>>>>>>>>>>>>>>>>>>>>>*V>>>>>>>*V>>>>>>>*V>>>>>>>*V>>>>>>>*V>>>>>>>*V>>>>>>						
IBM Captive	3,810.3	6,412.0	4,791.9	7,707.0	4,987.9	8,039.
Other U.S. Captive	1,123.8	1,902.8	1,355.0	2,059.3	1,808.9	2,649.
TOTAL U.S. CAPTIVE	4,934.1	8,314.8	6,146.9	9,766.3	6,796.8	10,688.

---

5. Move the cursor down one row to the first row of numbers. In the example above, this will place it on the 'IBM Captive' label.
6. Use the Data Parse format command /DPFCFE. This creates the actual format line and puts it into EDIT mode. You will now see two format lines: the sample format line (above) and the actual format line (below).

7. Now edit the actual format line until it is identical to the sample format line.

   Optional: The sample format line can now be deleted if you wish. It is not needed for further operations. You will have to Quit the Data Parse mode, delete the line, and reenter Data Parse mode.

8. Create the input range. Select the Input-Column command and then move the cursor to column 'A' of the format line. Anchor the cursor with a period and then set the range to include all columns from 'A' to the right side of the table and all rows from the format line to the bottom of the table by using the arrow keys.

   Be careful not to include footnotes or other similar material in the input range, because the parsing process will cause unusual spacing to appear in text sentences or paragraphs.

9. Create the output range. This is where the parsed data will appear. It is convenient to locate it a few rows below the input range and directly in line with the input range. Select the Output-Range command and locate the cursor in the 'A' column a few rows below the input range, then hit 'Return'. Now expand the 'A' column to 27 spaces in width to accommodate the left margin labels. (You will have to leave the parse mode to do this.)

10. Return to the parse mode. Select the GO command. The parsed data will appear in the output range. You will have to use the /RF (range format) command on the output data to obtain a consistent format because figures terminating in .0 will drop the decimal places unless the format is prescribed with a decimal place. You may also have to reformat some lines containing percentages in some tables.

11. You now have a table in which all of the elements may be manipulated, but there are no formulas. You must create your own formulas if you intend to change the numbers and want automatic recalculation to occur.

    Optional: You can delete the input range now if you wish. This will bring the newly parsed date up to the headers at the top of the page for easier reading.

While the procedure described above seems complex, it is not difficult or time-consuming in practice. After you have done it once or twice, it will take only two or three minutes per table to do data parsing.

SPECIFICATION TABLES

Loading

1. Place the floppy disk marked 'Specifications' in a floppy disk drive able to read 5.25", 360 KB disks. This is usually drive A, but if you are using a dual floppy only system, use drive B and put the Lotus 1-2-3 system disk in drive A. Use the DOS 'DIR' command to examine the file directory on the 'Tables' disk. If there are any special instructions, they will be in a file named READ.ME. To see these instructions, at the DOS prompt type:

   TYPE A:READ.ME (Use the appropriate drive letter if not A)

   If you wish to print the instructions, turn on your printer and type:

   TYPE A:READ.ME>PRN

2. Do this step if you have a hard disk. Log into the hard disk directory in which Lotus 1-2-3 normally stores worksheet files. Using the DOS 'COPY' command, copy all the specification table files to the hard disk. This can be done in one step using the copy command as follows:

   COPY A:?S*.*

3. Now you are ready to start Lotus 1-2-3. If you are using a two floppy system, place the DISK/TREND disk in drive B and the Lotus 1-2-3 system disk in drive A. If you are using a rigid disk system, place the Lotus 1-2-3 system disk in floppy drive A. Now start Lotus 1-2-3 as usual. After obtaining the blank spreadsheet image on the screen, use the Lotus File Retrieve command to select a file. The command is:

   /FR<filename>

   The file names are in the format XSYZZ.WK1 or XSYZZ.WKS, depending upon which version of Lotus 1-2-3 you are using. X,Y, and Z are:

   X= Type of data
   - F (Flexible disk drive data)
   - O (Optical disk drive data)
   - R (Rigid disk drive data)

   Y= Table number. Usually, there is only one table, but if the specification file is so large as to need multiple disks to hold it, there may be several.

   ZZ= Year of report.

   Example: OS189.WK1 Optical specification table for 1989

Note that the specification tables load directly as a database. You can use the database functions of Lotus 1-2-3 to sort, count or otherwise manipulate the data for purposes of special analysis.

Using the specification data base

Introduction: If you have not used the Lotus 1-2-3 /DATA QUERY commands, it will be helpful for you to review the sections of the Lotus 1-2-3 reference manual that pertain to their use before proceeding further.

The specification data base fits into a worksheet format of 25 to 30 columns, depending upon whether rigid, optical or floppy drives are involved, and a row count of up to 500 rows. Each row represents a specific record, and is equivalent to a column in the Specifications section of the DISK/TREND report. Each column represents a specific specification parameter, and is equivalent to one row of the DISK/TREND report.

The data base has been set up for data extraction using Lotus 1-2-3 commands. The Input, Output and Criterion ranges have been predefined, but you, the user, will have to decide how you want the extracted data manipulated and place the appropriate Lotus functions, such as @COUNT, in the appropriate cells. Some rows between the bottom of the input range and the top of the output range have been left empty so that you can do this easily. When the data base is first loaded, you will see the top of the input range, showing the first column (manufacturer name) for the first several manufacturers. Use the arrow keys to find other manufacturers or specific product specifications.

Operating tips

Expanding the input or output ranges: The predefined output range is of a nominal size, and a search with broad parameters may result in overflowing the output range. In such a case, merely extend the output range (add more rows) using the Lotus 1-2-3 /DQEO command. Similarly, it is possible to extend the input range to add more products, but be sure you move the output range so that there is no overlap.

Memory overflow: If you should receive a memory overflow message while manipulating the specification data, it is usually because:

- There are other 'pop-up' programs resident in the memory of your computer. These should be removed.
- You have selected too large an output range. Use a smaller output range or delete some of the columns that contain data not relevant to your analysis. If you delete data, be sure that if you save your spreadsheet you use a different file name, otherwise you will overwrite the original file with the modified spreadsheet.
- If you receive a memory overflow message while loading the data base, you probably will have to remove other memory-resident programs, reload Lotus 1-2-3 and try again. If your computer has less than 640K memory, you are more likely to get this message.

Saving time

Make sure that when you save a worksheet using the /FS command that you save it under a new file name. If you save it in the file name from which it was loaded, the original file will be overwritten. If a file is overwritten unintentionally, it can take a long time to recreate.

Use the SORT capabilities of Lotus 1-2-3 to organize the data the way you find it most useful. The sorts most frequently done are by manufacturer name and by DISK/TREND product group, but it would also be possible to sort by average seek time, price, etc.

If you are interested only in a subset of product groups, use the FILE EXTRACT and the FILE COMBINE commands to move these records to another file and use the second file for analysis. The smaller file will take less time to process

Technical Support

Just about all of your questions regarding the use of DISK/TREND ON DISK should be answered in this manual or in the Lotus 1-2-3 reference manual. However, if you need to contact us to resolve any points of confusion, report errors, or otherwise receive comfort:

Call us at: 415-961-6209

Ask for Technical Support

In order to make this process efficient, when you call--

1. Tell us what is on the diskette label.

2. Have your computer up and displaying the data or operation that is the subject of your call.

3. Have this manual and the Lotus 1-2-3 reference manual handy.