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The microstructure of thin-film magnetic recording disks

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The microstructure of two rigid thin-film magnetic disks has been investigated using transmission electron microscopy. The disks consisted of a rigid textured substrate, a magnetic medium (either electrolessly plated CoP or sputtered CoNiPt) and an overlayer. Both cross-section and planar specimens were prepared. Magnetic measurements showed that both disks are isotropic within their plane. We believe this result is consistent with the noted absence of either preferred crystallographic orientation or columnar growth within the magnetic medium.

1. Introduction

Magnetic disks are the commonest means used for the storage of high-density digital information. The structure of such a disk basically comprises a number (up to five) of thin films deposited sequentially on to a rigid substrate. One of these films is the magnetic medium itself: in addition there may be an underlayer (usually chromium) an overlayer and a lubricant. The substrate consists of a disk of aluminium magnesium alloy some 1.25 mm thick, electroplated with an amorphous layer (~ 10 μm thick) of non-magnetic NiP. The plane surfaces of the disk are textured (abraded) circumferentially to improve both magnetic properties [1] and aerodynamic stability of the head–disk system.

It is apparent that the number of physical parameters which could ultimately affect the magnetic performance of the disk is very large. In this paper we concentrate on an investigation of the microstructure and some related magnetic properties of two types of commercial thin-film disks. In one disk (designated AMG1) the magnetic medium consisted of a sputtered layer of CoNiPt: the other (9B05) had an electrolessly plated CoP magnetic layer. On account of proprietary restrictions pertaining to the disks we are uncertain of their detailed preparation conditions.

We have prepared both planar and cross-section samples from the region near to or containing a disk surface. These were subsequently studied with transmission electron microscopy.

2. Experimental procedure

Cross-sections were prepared using ultramicrotomy. This entailed the initial cutting of small wedge-shaped sections from the complete disk which were embedded in a pyramid of resin and allowed to set. The finished block was then mounted in the ultramicrotome. After much trial and error, involving variations in cutting speed, knife and clearance angles, reproducible sections between 50 and 100 nm thickness were obtained. These were floated into a water bath and retrieved on copper grids for microscope examination. Specimens of disk B905 proved particularly difficult to prepare insofar as the electroless layer seemed brittle and easily peeled away from the underlying NiP.

To obtain planar or plan-view sections, 3 mm disks were first cut from the main disk in a spark erosion machine. After flat grinding to a thickness of 100 μm the thinned disk was transferred to a proprietary dimpling device which abraded a flat-bottomed crater in the sample to a depth of some 60 μm. Ion thinning was used as the last stage of the preparation procedure. The samples were self-supporting and could be mounted directly in the electron microscope. It should be emphasized that the task of making both types of sample is a difficult one, requiring considerable time and patience.

A vibrating sample magnetometer was used to measure the hysteresis loops within the disk plane. For this purpose small rectangular pieces (measuring 5 mm × 2 mm × disk thickness) were cut with the substrate texture lines, clearly visible to the naked eye on the disk surface, oriented either parallel or perpendicular to the longer edge. In this way the circumferential and radial loops could be plotted. From these loops the orientation ratio (OR), defined as the ratio of the coercivities measured in the circumferential and radial directions, respectively, could be found. The ratio of remanent magnetization values in the two directions (M_{rc}/M_{rr}) was also calculated. Owing to intrinsic difficulties with calibration, we do not put undue reliance on the absolute values of saturation magnetization, M_s.

3. Results

3.1. Magnetic properties

The hysteresis loops of either disk, measured in radial and circumferential directions, were virtually identical. The latter is illustrated in Fig. 1 for disk 9B05. The salient features for both disks are summarized in Table I where the absence of anisotropy is obvious in that the values of H_{cc}/H_{cr} (=OR) and M_{rc}/M_{rr} are

TABLE I Physical and magnetic parameters of disks studied. Substrate: Al–Mg alloy (1.25 mm)–NiP (10 μm) textured disk

Sample Code	Measured film thickness (nm)	M_s (G)	H_{cc} (Oe)	H_{cr} (Oe)	$\frac{H_{cc}}{H_{cr}}$	$\frac{M_{rc}}{M_{rr}}$	Remarks
9B05	CoP (85) C (20–40) overlay	1257	797	793	1.01	0.99	Electrolessly plated
AMG1	CoNiPt (50) C/Zirconia (40) overlay	930	719	727	0.99	1.1	Sputtered

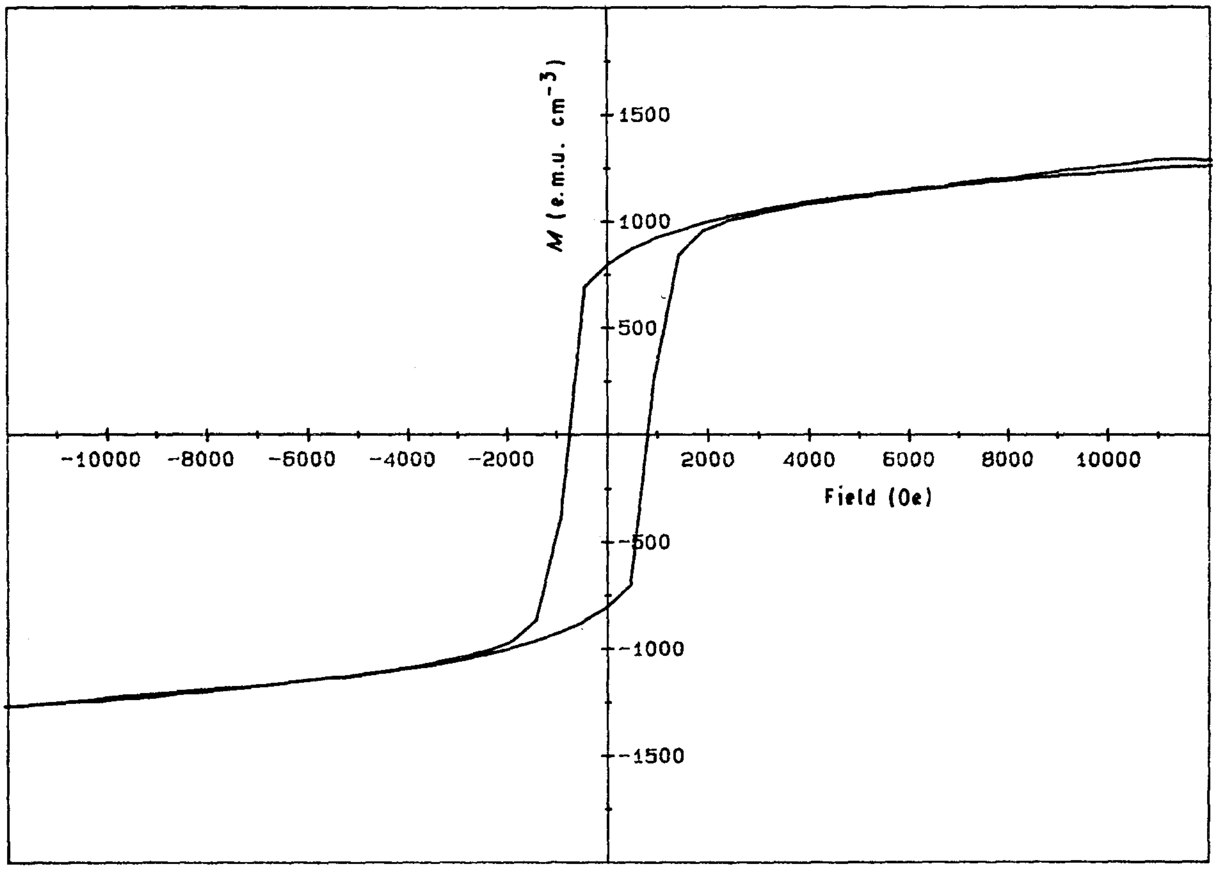

Figure 1 Circumferential hysteresis loop from disk 9B05.

both close to unity. The saturation magnetization of the electrolessly plated disk is noticeably higher than that of the sputtered disk, but all coercivity values lie in the range 700–800 Oe.

3.2. Microstructural properties
3.2.1. Disk 9B05

Fig. 2 shows three cross-sections taken from different depths of the disk. At the lowest depth (Fig. 2a) the interface between the aluminium alloy and the electroplated layer of NiP may be seen. In this disk the surface of the aluminium was unusually rough, the crest to valley distance being of the order of 300 nm. What is presumed to be damage caused by the microtome knife is particularly noticeable in the amorphous layer and tends to obscure faint bands running parallel to the disk surface. These bands are more obvious in Fig. 2b which is a section from the NiP layer. They represent slight variations in plating conditions as the layer is deposited [2]. What is remarkable here is their absence from the comparatively large thickness on the right side of the micrograph. It is also apparent that the configuration of damage suffered by the plated layer is influenced by the band structure: this may reflect a local difference in mechanical properties. Fig. 2c is a micrograph of the cross-section of the electroless magnetic medium together with the carbon overlayer. The layer of CoP does not possess the desired uniform thickness, although this could be attributed in part to the effect of the knife breaking off some material. More significantly there is very little manifestation of columnar growth or even of a well-developed grain structure. These features have certainly been observed in other media, e.g. in films of CoCrTa and CoNiCr sputtered on a chromium underlayer [3].

The magnetic medium here is nevertheless crystalline as demonstrated by the transmission electron diffraction pattern taken from a plan view sample

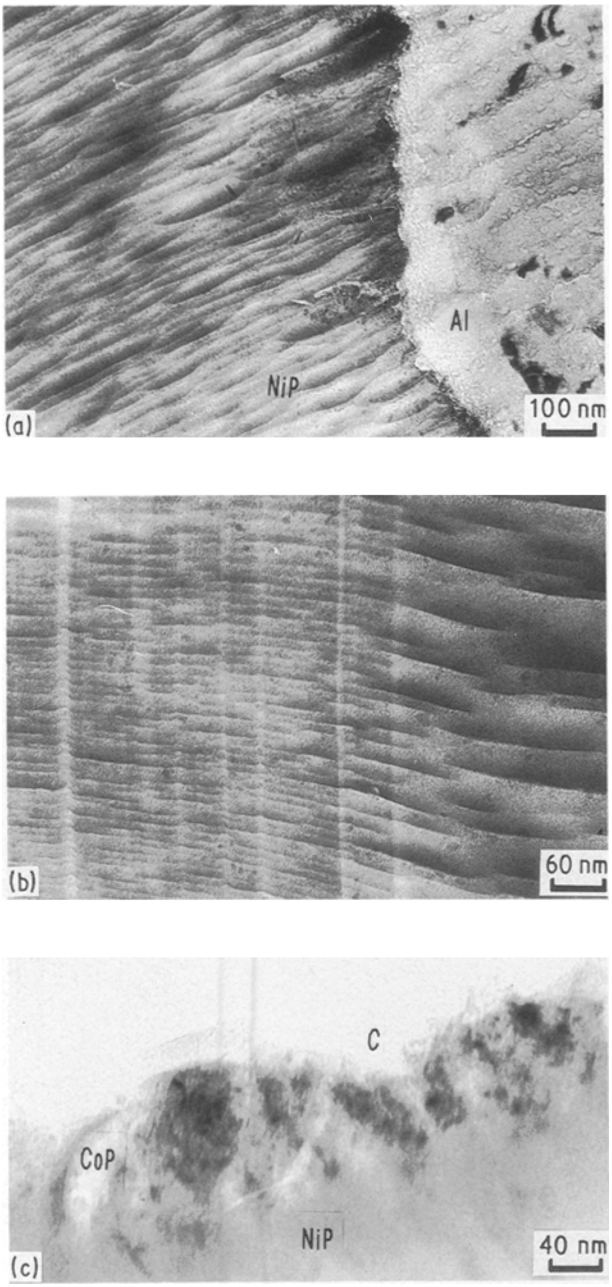

Figure 2 Cross-sections from disk 9B05: (a) Al-alloy/NiP/ interface; (b) NiP showing growth bands; (c) NiP/CoP/overlayer interfaces.

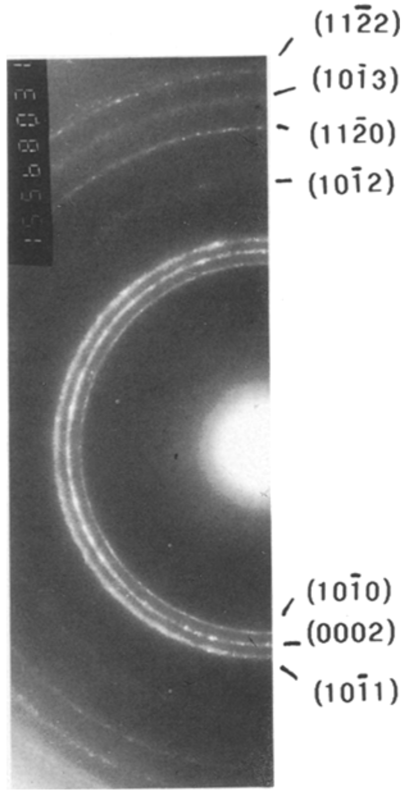

Figure 3 Diffraction pattern from surface planar section of disk 9B05.

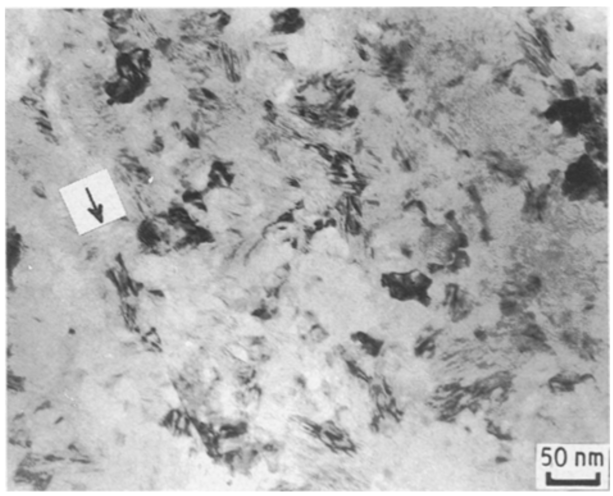

Figure 4 Plan view micrograph from surface planar section of disk 9B05. Arrow marks direction of substrate texture lines.

(Fig. 3). The diffraction rings are consistent with an h c p structure as might be expected from CoP. Because the three lowest index reflections, namely $(1 0 \bar{1} 0)$, $(0 0 0 2)$ and $(1 0 \bar{1} 1)$ are equally intense, we conclude that the CoP layer is polycrystalline with no preferred orientation. This would appear to be in agreement with previous work on electroless media and again differs from that reported for sputtered media [3]. Fig. 4 is a bright-field micrograph of a planar section from the disk. Several points are noteworthy. The grain-size distribution is wide with individual crystallites ranging from 10 nm to > 100 nm (best seen in dark-field micrographs). Moreover, there is no obvious intergranular spacing. Some of the grains are heavily faulted, probably due to the presence of stacking faults in crystallites where the c-planes are suitably oriented with respect to the incident beam [4]. Finally there is only the slightest evidence that the substrate texture lines have influenced the grain structure of the CoP layer. The known direction of the lines is indicated by an arrow and at the location shown it can be seen that one or two grains terminate along this line.

3.2.2. *Disk AMG1*

A cross-section of the disk surface is shown in Fig. 5. The CoNiPt is clearly seen but again the thickness is not especially uniform varying between 25 and 48 nm. The overlayer is also visible: we believe it to comprise

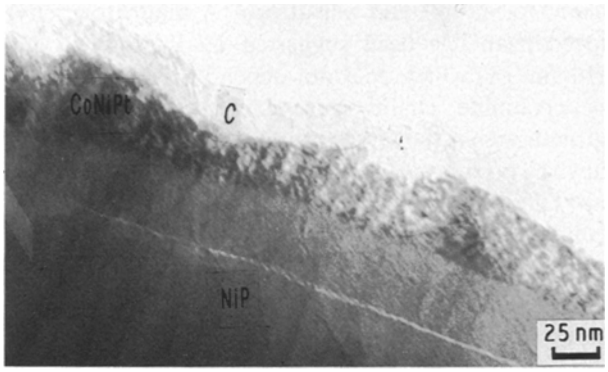

Figure 5 Cross-section of NiP/CoNiPt/overlayer in disk AMG1.

zirconia and carbon [5]. Despite taking micrographs from many samples, the magnetic layer invariably presents a mottled appearance which we conclude must constitute a faithful representation of the structure. In most respects the microstructure or lack of it is similar to that from disk 9B05, i.e. there is no well-defined grain or columnar structure. The Al–NiP interface and the NiP-plated layer showed no remarkable features in cross-section.

A diffraction pattern from a planar section of the disk is given in Fig. 6. Again it resembles that of disk 9B05 except for the comparative weakness of the $(1\,0\,\bar{1}\,3)$ reflection and the appearance of an extra ring lying just outside the $(1\,0\,\bar{1}\,1)$ reflection of the h c p phase. We have not been able to identify the origin of this reflection whose *d* spacing corresponds to 0.177 nm. It may be associated with the putative presence of zirconia but all common phases of ZrO_2 have stronger reflections at higher *d* spacing which are conspicuously absent.

Fig. 7 shows bright- and dark-field micrographs of a plan view specimen although not of the same area. Differences are noted compared with the CoP disk: there is a narrower distribution of grain size (more clearly seen in Fig. 7b) with the mean value of ~ 30 nm. The effects of the substrate texture are also now more prominent (Fig. 7a): the direction of the lines is marked with the arrow. There is also evidence of some intergranular channelling emphasized by the slight defocusing of the micrograph.

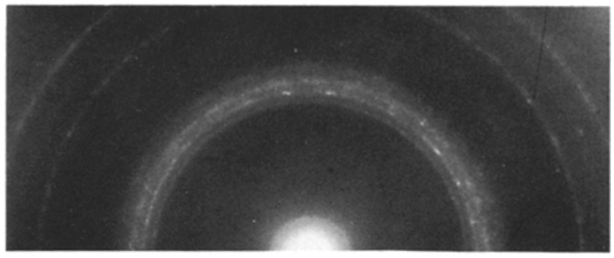

Figure 6 Diffraction pattern from surface planar section of disk AMG1.

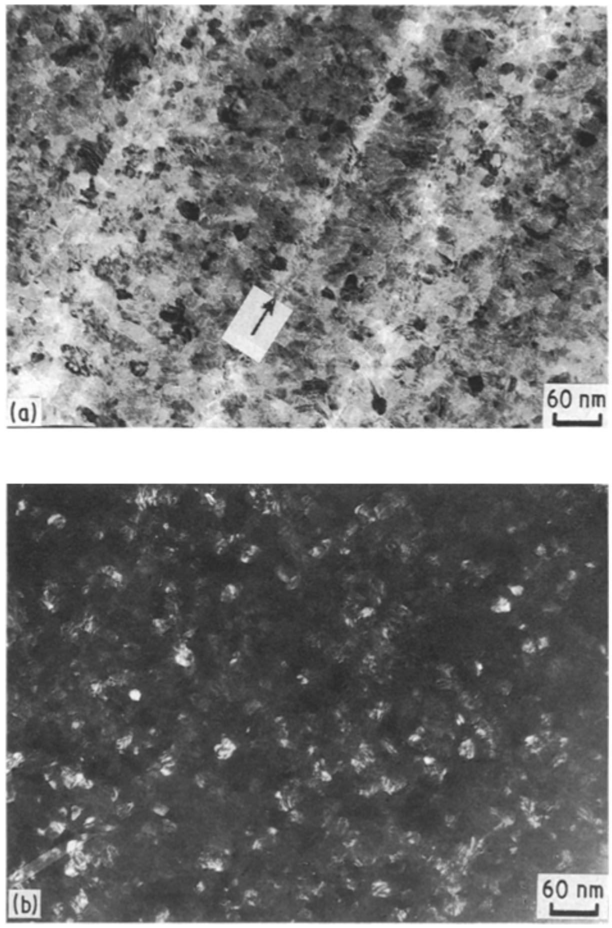

Figure 7 Micrographs of plan view section of disk AMG1. (a) Bright field; arrow marks direction of texture lines. (b) Dark field.

4. Discussion and conclusions

Two conclusions concerning the magnetic properties of the disks under review can be drawn immediately: (i) the coercivities of both media are similar despite their differing composition and method of fabrication; (ii) there is no sign of significant anisotropy within the disk plane. A high coercivity ($>$ 600 Oe) is an essential prerequisite for good disk performance and this criterion is fulfilled by both media.

The origin of high coercivity in longitudinal media is not completely understood, but physical factors relating to the constituent grains, e.g. size, separation and perfection, are considered to be important. In principle, grain separation should inhibit inter-particle exchange coupling and so give rise to higher coercivity at the expense of squareness of the hysteresis loop. On the other hand, the intrinsic high coercivities associated with single domain behaviour of particles with large magnetocrystalline anisotropy (a characteristic of h c p phases) are more probable at smaller grain sizes. Experimentally the evidence is somewhat confusing as to whether grain size or grain separation is the more important factor in determining coercivity. Johnson *et al.* [6] find that the coercivity of sputtered CoPtCr films with larger well-separated grains is higher than films with smaller "continuous" grains. However, Pressesky *et al.* [7] indicate the opposite behaviour in sputtered films of CoCrTa. Unfortunately, our results do not resolve this conflict. Disk AMG1 has a narrower distribution of smaller grain sizes than 9B05 but intergranular channelling is more obvious in the latter. As mentioned above, the coercivities are very similar. In any case, Tang *et al.* [4] have suggested that grain size is less relevant in determining the coercivity than stacking fault density. The mechanism of domain-wall pinning is seen as decisive in contributing to elevated coercivity. Both media in our study display grains with stacking faults but it is impossible to state that the density is higher in one disk than the other. Because we have been unable to observe the presence of a magnetic domain structure in our specimens, the precise origin of the coercivity must still remain open to question.

The presence of anisotropy within the disk plane (i.e. an OR > 1) leads to a better read/write performance compared with an isotropic medium [8] and is therefore desirable. As far as we are aware, anisotropy has never been detected in sputtered or electrolessly plated disks without a textured substrate: the results of this study show that texture, though a necessary condition, is in itself insufficient to procure anisotropy. The reason for this seems clear. Unless the influence of the textured substrate is transmitted in some way (via microstructure) to the magnetic medium, it will play no role in determining anisotropic properties. There are only minimal signs of the effects of texture in the magnetic medium of disk 9B05 and hence it is not surprising that the disk is isotropic. By contrast the sputtered magnetic medium (disk AMG1) does reveal (Fig. 7a) effects due to the substrate texture: nonetheless this disk is also isotropic. This negative result may shed some light on the origin of anisotropy.

Several mechanisms have been proposed for the development of anisotropy in longitudinal media. It has been suggested [9] that the texture lines replicated in the medium preferentially break down the exchange coupling in a direction normal to the lines. In the case of disk AMG1, we must conclude that the mechanism is either wrong in principle (unlikely) or that the microstructural changes induced in the medium, although clearly visible, are not of sufficient magnitude to render them effective as regards anisotropy.

It is well established [10] that substrate texture can give rise to the formation of crystallite chains in the overlying deposited media and it has been proposed that these are responsible for the development of planar anisotropy [11]. There is, perhaps, evidence of incipient chain formation in bright-field micrographs taken of disk AMG1. However, they are not visible in dark-field images (Fig. 7b) where the diffracting grains seem to be at random. It is possible, therefore, that to be effective in creating anisotropy, the chains must possess some common crystallographic texture. Some authors have disputed entirely the nexus between chain formation and anisotropy. A magnetostrictive mechanism has been suggested by Kawamoto and Hikami [8] which does not depend on the formation of crystallite chains but requires some epitaxial growth within the film medium. Mirzamaani *et al.* [1] have also reported disks with OR > 1; their films had no chains but possessed a preferred orientation. Neither of our disks has a chromium underlayer whose role is normally understood to promote a preferred crystallographic orientation in the magnetic medium [12]. It is, therefore, not surprising that the media in our disks are polycrystalline and that no preferred texture is visible via columnar growth or, as it would appear in a planar section, bands of textured crystallites. From our results it would seem that both a textured substrate and a preferred crystallographic orientation in the medium are conditions necessary for the fabrication of an anisotropic disk.

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