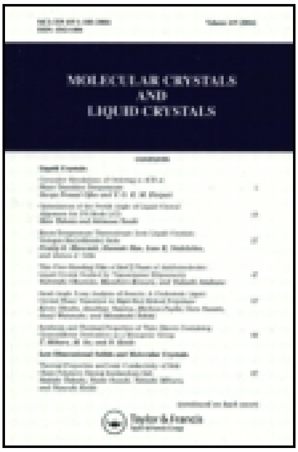

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Cholesteric Liquid Crystal Based Multi-Layer Optical Storage Technology

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CHOLESTERIC LIQUID CRYSTAL BASED MULTI-LAYER OPTICAL STORAGE TECHNOLOGY

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Abstract A novel approach to optical storage based on layering of cholesteric liquid crystal (CLC) media has been proposed. CLC media have been chosen due to their unique property of selective reflection, wherein a CLC film reflects light of its characteristic wavelength and polarization handedness at near-zero loss while transmitting all other light. High contrast data patterns are created by selectively crosslinking 1 μm size "1" and "0" data marks in the planar and the isotropic states, respectively. Recording "1" marks is accomplished by scanning a modulated UV laser beam over the CLC disk which is heated to 90 °C. The "0" marks are then crosslinked in the isotropic state. Up to 400 CLC layers can potentially be stacked on a single disk, which leads ultimately to a single disk capacity of one terabyte. The novel concept has been demonstrated in a 6-layer experiment.

INTRODUCTION

Numerous applications including video-on-demand, bank and insurance data bases, weather forecasting and supercomputers demand Terabyte (TB) data storage capacities and data rates exceeding 1 Giga-Byte/sec (GB/s). Therefore, quest for high density, low cost mass storage technologies is being pursued at a rapid pace. The leading removable mass storage technology, at present, is based on single layer optical disks. However, the areal capacity of this technology is limited by the finite size of the focused read-laser beam, which is referred to as the wavelength bottleneck.

The logical means of avoiding the wavelength bottleneck is by layering. In fact we have already seen the emergence of a layered disk by IBM, using semi-reflective-layers and depth of focus for addressing.[1] But the inherent problem with this approach is a loss of light, as high as 70% per semi-reflective layer.

A novel approach to creating a multilayer optical disk is being pioneered by Reveo Inc.[2, 3], which utilizes cholesteric liquid crystal (CLC) polymers. CLC media have the unique property of selectively reflecting light that matches the polarization state and characteristic wavelength of the layer while transmitting all other light at near-zero loss, substantially minimizing the limitations associated with semi-reflective layering techniques. As a result, the CLC-based multi-layer disk concept is very promising and could be introduced to market in just 2 to 3 years.

FIGURE 1 shows an example of reading from layer *4* of a multi-layer disk. The information is stored as reflecting regions representing the "1" state or transmitting regions representing the "0" state. The reflecting regions of each layer are tuned to a selective reflection wavelength and polarization state. In this example the read light beam is right-handed (RH) circular polarized, and tuned to reflect λ_1. Therefore, it is transmitted by all the top 3 layers and is also transmitted by layers 5 through 2*N*. Because only layer *4* is tuned to λ_1, and has RH chirality the "1" bits reflect the incident light, whereas the "0" bits are transparent

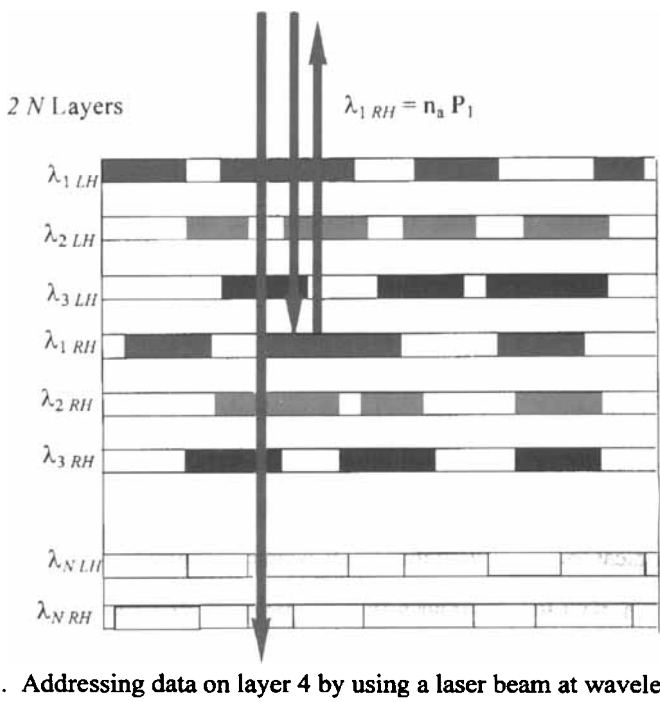

FIGURE 1. Addressing data on layer 4 by using a laser beam at wavelength $\lambda_{1\,RH}$.

PROPERTIES OF CHOLESTERIC LIQUID CRYSTAL POLYMERS

Cholesteric liquid crystal films are characterized as being either left-handed (LH) or right-handed (RH) and as having a helical pitch *P*. The helical structure of CLCs leads to their unique optical properties. Light incident on a CLC film, in a direction parallel to the CLC helix axis, will be reflected if the polarization sense matches the CLC handedness and the incident wavelength matches the characteristic wavelength λ_C according to Equation (1):

$$\lambda_C = n_a P \quad , \tag{1}$$

where n_a is the average refractive index of the CLC. All other light will be transmitted with near zero loss. Reveo fabricates such films down to 1 micron in thickness while tuning them to reflect light over a range of 400 nm to several microns. Typical spectra of a CLC film are shown in FIGURE 2

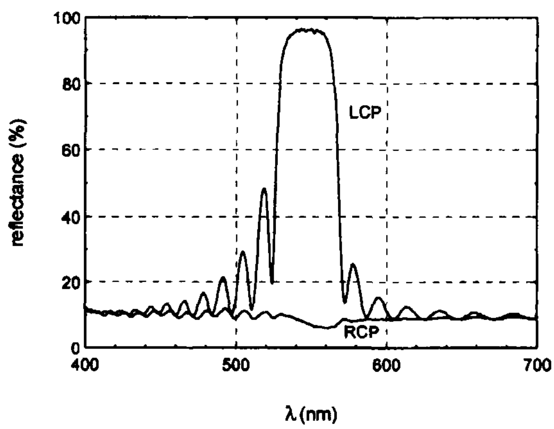

FIGURE 2. Typical reflection spectra of a left handed CLC film with LCP and RCP light incident

The CLC media employed in the present work have another important characteristic. The individual CLC molecules can be crosslinked to create a CLC polymer by an irreversible free radical reaction. Crosslinking is effected by exposure to near UV radiation. After crosslinking, the CLC polymer is monolithic and its pitch does not change with temperature or other environmental conditions.

The number of layers, N, is determined by the spectral width, $\Delta\lambda$, of selective reflection of each CLC layer (see FIGURE 2) which is governed by its birefringence $\Delta n = n_e - n_o$, where n_e and n_o are the indices of refraction for the extraordinary and ordinary direction with respect to the optical axis:[4] Thus

$$\Delta\lambda = \frac{\Delta n \lambda_0}{n_a} \tag{2}$$

N is limited by the bandwidth in spectral regions which have widths given by Equation (2) plus an appropriate separation to insure minimum cross-talk between layers.

THE 2*MN* DENSITY ENHANCEMENT CONCEPT

Three physical mechanisms for layer addressing must be distinguished: Depth-of-focus, wavelength and polarization. The depth of focus method is based on the fact that a random pattern such as a semitransparent layer with data marks, does not significantly disturb a laser beam that is outside the depth of focus.[5] Therefore, data layers spaced by appropriately can be read-out without significant crosstalk. Data layers can therefore be arranged in M decks, selectable by physically changing the focus position.

The second method used to address a CLC layer is wavelength selective reflection described above. $2N$ CLC films tuned to N unique-wavelengths separated by $\Delta\lambda$ can be placed within each deck. The factor *2* is due to the third method of layer selection: polarization. FIGURE 3 illustrates the arrangement on a CLC multilayer disk. Such an approach yields impressive numbers, ranging from a relatively simple 10-layer disk (M=1,N=5) up to a realizable 400 layers (M=10,N=20), each capable of supporting a multi-GB layer.

It is, therefore, possible to break the wavelength bottleneck of conventional optical storage technology by extending the ultimate areal bit density to $2MN/\lambda^2$. This leads to the possibility to store one TB on a single disk.

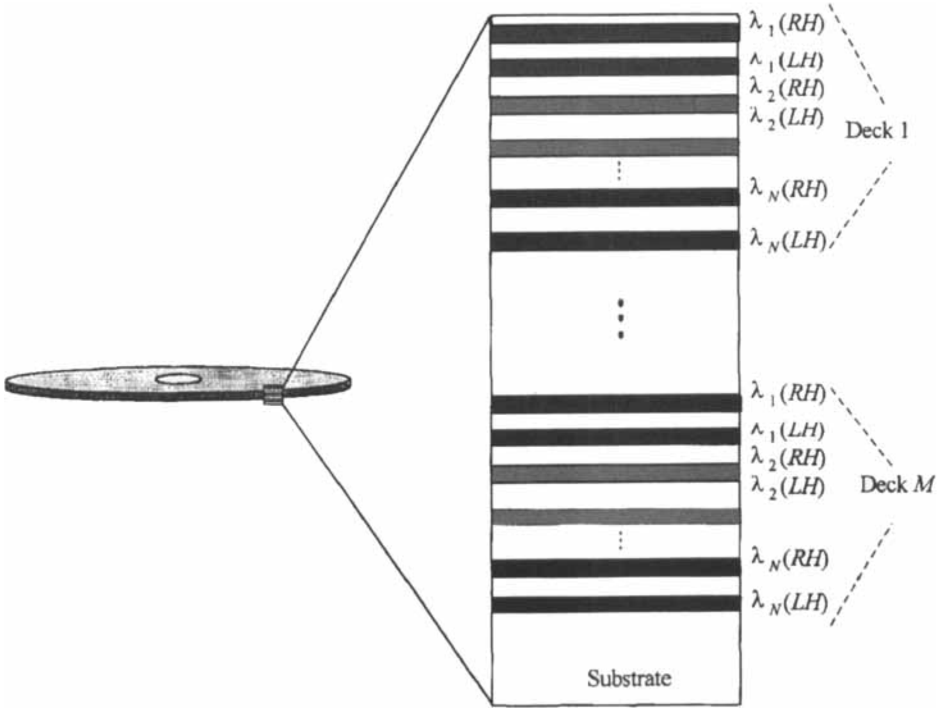

FIGURE 3. CLC layer ordering

RECORDING

Recording data on a CLC layer can be accomplished by tuning its pitch to reflect λ_1. This is done by setting the temperature to T_1 and scanning a modulated UV laser beam over the media, thereby selectively crosslinking the data bits. Then the temperature is increased to above the glass transition temperature. This changes the uncured areas to the isotropic state. The layer is subsequently flooded with UV radiation to cure clear regions, thereby creating contrast between reflecting data bits and clear background.

To verify this technique, several CLC disks were fabricated. Before recording two glass substrates are cleaned and coated with an alignment layer. CLC material is then sandwiched in-between the two substrates and annealed to create a uniform CLC film. After this preparation, the disks are recorded, as described above.

Reveo stacked two layers (M=1, N=1). with digital data to create dual-layer disk. FIGURE 4 shows a micrograph of the disks with 5 μm data mark. For this micrograph the disks are placed between crossed polarizers . The isotropic background appears therefore black and the marks appear bright. The disk is then illuminated with polarized light to verify that the data marks on the selected layer are visible, whereas the data marks form the other layers are not visible, as shown in FIGURE **4**B and C. Thus a prove-of-concept for crosstalk-free read-out is demonstrated. Also, a six storage layers(M=1, N=3). sample with analog data was prepared. The peak reflectivities are in the red, green and blue wavelengths band.

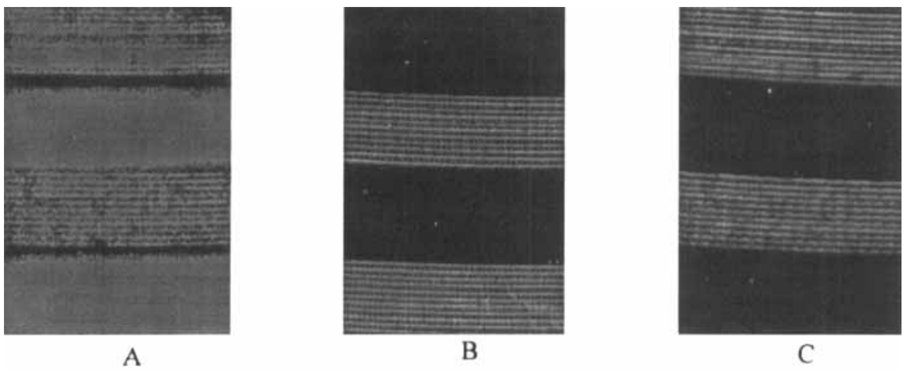

FIGURE 4. Data seen through linear (A), LCP (B) and RCP (C) polarizers.

CONCLUSIONS

We have shown the proof-of-concept demonstration of a novel CLC based multilayer optical disk technology. This technology is capable of increasing the capacity and data rate by a factor of 2MN over existing optical disk technology. This opens the possibility of storing one TB on a single disk.

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