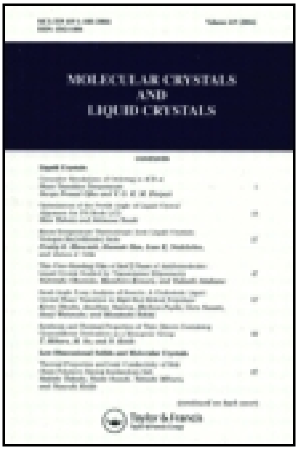

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PHOTOCHROMISM AND ITS APPLICATION TO A HIGH-DENSITY OPTICAL MEMORY

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Abstract In order to solve problems of photochromic memory, a super-low power readout method and a crosstalk reduction method for multi-wavelength recording were proposed. In the demonstration of 2-wavelength recording using photochromic diarylethenes, the crosstalk between multiplexed channels, which is caused from broad absorption bands of compounds, was effectively reduced by the method. A new high density optical memory, a super-resolution disk with a photochromic mask layer, was also introduced. The super-resolution method has enabled us to increase the recording density of conventional optical disks.

Keywords: photochromism, diarylethene, optical memory, multi-wavelength recording, super-resolution

INTRODUCTION

Photochromic compounds have been studied for application to optical memories. Recently a new type of photochromic compounds, diarylethene derivatives which have excellent durability and stability, has been developed[1]. Consequently, remaining principal problems for practical application to optical memory have been reduced. Some that remains are studying how to use it in high density optical memories. Many applications of photochromism to high density optical memories have been proposed. Some of them contain wavelength-multiplexed (multi-wavelength) memory[2][3], three-dimensional volume memory[4][5], and near-field optical memory[6][7] and a super-resolution disk using a photochromic mask layer[8][9][10]. In this paper, we introduce our recent studies about super-low power readout to minimize the destruction of recorded information on the photochromic memory, a crosstalk reduction method of multi-wavelength recording and a photochromic super-resolution disk.

PHOTOCHROMIC MEMORY

Super-low Power Readout Method of Photochromic Memory

One of the problems of the photon-mode photochromic recording is that the recorded information is destroyed during readout operations. To solve this problem, we have proposed a method which uses a superlow-power laser (superlow-power (SLP) readout method). The SLP readout method uses a minimum readout laser power which satisfy sufficient signal-to-noise ratio required for the system and a photodetection method having a photocurrent self-amplification function (e.g., avalanche photodiode). Our theoretical estimate predicted 10^5-10^6 readout cycles for a superlow laser power (about 10^{-9}-10^{-7} (W)) .[11]

In order to demonstrate the theoretical expectations, experiments were carried out as follows. The recording layer containing polystyrene and photochromic diarylethene, 2-(1-octyl-2-methyl-3-indolyl)-3-(2,3,5-trimethyl-3-thyenyl) maleic anhydride was prepared by spin coating a cyclohexanone solution onto a glass disc substrate. The colored form of this photochromic compound converts to the open ring form upon irradiation with 550-700 nm light. We therefore carried out recording by photobleaching of the precolored state and reading by detecting the reflectance changes with a 633 nm HeNe laser.

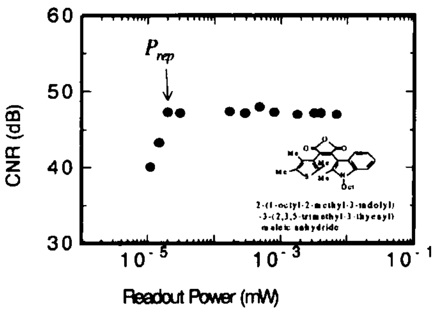

FIGURE 1. Readout laser power dependence of carrier to noise ratio (CNR).

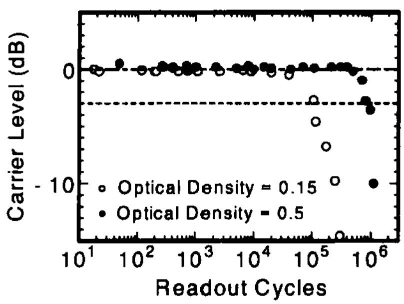

FIGURE 2. Readout cycle dependence of carrier levels.

Figure 1 shows the readout laser power dependence of the carrier-to-noise ratio (CNR). The CNR is constant when the readout laser power is greater than 20 nW, and it is restricted by the media noise. On the other hand, the CNR decreases rapidly when the power is less than 20 nW, and it is restricted by the shot noise (quantum noise of light). Therefore, to obtain CNR of 45 dB in the system, a super-low minimum laser power is around 20 nW. Figure 2 shows the readout cycle dependence of carrier levels by the SLP readout method. The readout power was 20 nW. On condition of keeping the carrier level decrease less than 3 dB, the 10^5-10^6 cycle readout operation was possible by the SLP readout method.[12]

A Crosstalk Reduction Method of Multi-wavelength Recording

Multi-wavelength recording is one of the candidate of high density recording using photochromic compounds. In the multi-wavelength recording, the memory medium contains plural compounds which have different wavelength bands and compounds are reacted by irradiation of corresponding plural light. As a result, much information can be recorded in a single laser light spot. However, the crosstalk between

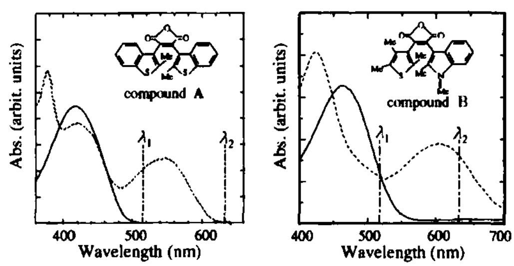

FIGURE 3. Absorption spectra of the compound **A** and the compound **B**.

multiplexed channels due to broad absorption bands of compounds is a problem for practical use. We have proposed a new crosstalk reduction method.[2] In this method, the cross-talk can be reduced by operations between multiplexed readout signals.

Two kinds of diarylethenes, 2,3-bis(2-methylbenzo[b]thiophen-3-yl) maleic anhydride (compound A) and 2-(1,2-dimethyl-3-indolyl)-3-(2,3,5-trimethyl-3-thienyl) maleic anhydride (compound B) (as shown in Figure 3), were dispersed in poly(vinyl butyral) (15 wt.%) and used for the recording media.

The colored form of the compound A converts to the bleached form upon irradiation with light of wavelength longer than 500 nm. Bleaching of the longer-wavelength absorption can also be induced by irradiation with the 515 nm Ar ion laser. On the other hand, the colored form of the compound B converts to the bleached form upon irradiation with light longer than 550nm. Bleaching can also be induced with the 633nm He-Ne laser. At 515nm, both compounds A and B show absorption. The crosstalk induced in the writing process by 515nm light is as large as the main signal written by 633nm light.

The 515nm (CH1) and 633nm (CH2) lasers were used for recording and reading in our two-wavelength recording. The readout signals before and after the crosstalk reduction operations were compared using a spectrum analyzer. Figure 4 shows the power spectra of CH1 signal and CH2 signal. The crosstalk (100 kHz) in CH1 is as small as about -24 dB. The crosstalk in CH2 has linear (80 kHz) and

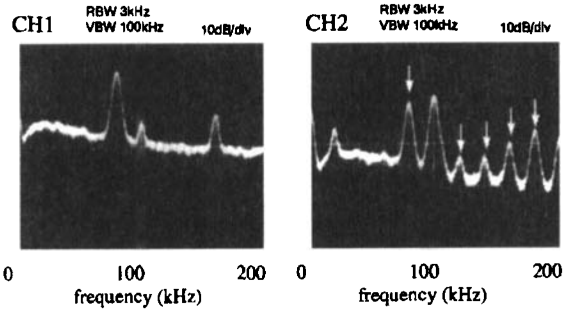

FIGURE 4. Signal power spectra of CH1 and CH2 before crosstalk reduction operations.

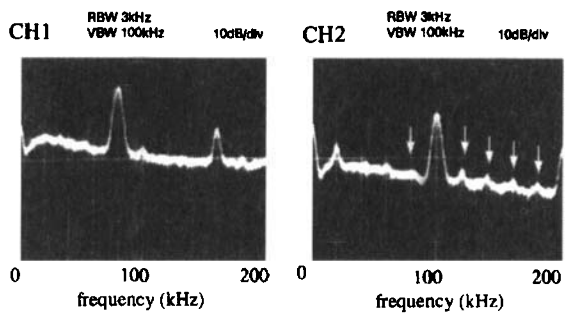

FIGURE 5. Signal power spectra of CH1 and CH2 after crosstalk reduction operations.

nonlinear (20 kHz, 180 kHz) components due to intermodulation, whose values are -2 dB and -14 dB, respectively. After the operations using the circuit for crosstalk reduction, we obtained the power spectra shown in Fig. 5. The crosstalk (indicated by arrows) was considerably reduced to less than -25 dB by the operation. The crosstalk reduction method is a promising method to use actual multi-wavelength recording.

PHOTOCHROMIC SUPER-RESOLUTION DISK

Figure 6 illustrates the concept of photochromic super-resolution readout. When the readout spot scans the precolored (initialized) mask layer of a super-resolution disk, only the restricted mask area corresponding to the backward portion of the spot is bleached by the photo-reaction, because the irradiated light quantity is integrated in this area. Therefore, a smaller effective super-resolution spot can be formed by overlapping the area of the readout spot and the bleached mask area.

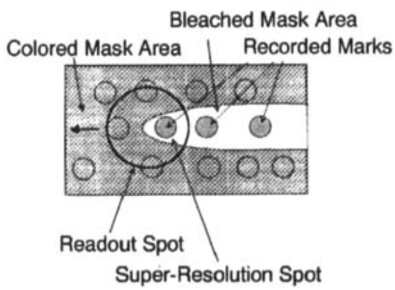

FIGURE 6 Concept of super-resolution readout.

Figure 7 shows the molecular structure and absorption spectrum of the photochromic material used in our experiment. The bleached state converts to the colored state by irradiation of ultraviolet light and the absorption in the red wavelength region increases. On the other hand, the colored state converts to the bleached state by irradiation of red light and the absorption in the red wavelength region decreases. Therefore, a

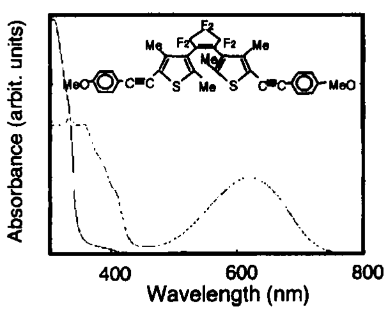

FIGURE 7 Absorption spectrum of photochromic diarylethene.

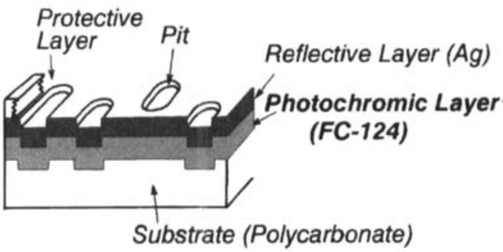

FIGURE 8 Structure of super-resolution disk with a photochromic mask layer.

red laser beam can be used for super-resolution readout. This material has a high iso-merization ratio, enabling a high optical density to be achieved in the thin film state.

Super-resolution readout was examined for two types of read-only optical disks[8]. Disk sub-strate 1 has a recording density similar to the conventional compact disk (CD), and disk substrate 2 has higher density (3T (shortest) pit: 0.48mm, track pitch: 0.85mm). Figure 8 shows the super-resolution disk structure. The photochromic mask layer, which was amorphous state, was prepared on disks by a vacuum evaporation method, and the Ag reflective layer was overcoated on it by the same method. The readout pickup had a laser diode ($\lambda = 685\,(\mathrm{nm})$) and an objective lens (NA=0.55). The mask layer was initialized by irradiation of ultraviolet (UV) light before readout.

Figure 9 shows reproducing signal comparisons between the disks with a mask layer and without mask layer. Upper figure shows the amount of crosstalk between adjacent trucks. The crosstalk was reduced to 18% from 42% by forming the mask layer. Lower figure shows the comparison of readout eye patterns between the disks with a mask layer and without mask layer. The amplitude of the shortest pit. was increased from 29% to 45% by forming the mask layer. These results indicate that a higher track density and a higher linear density can be expected by using a photochromic mask layer. From these results, about three-fold recording density of conventional optical disks can be expected.

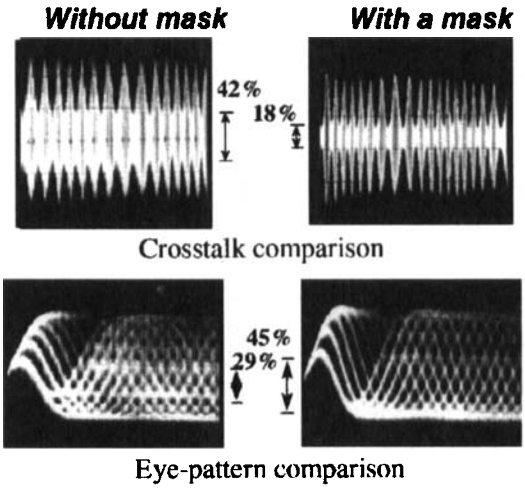

FIGURE 9 The upper figures show the comparison of crosstalk between adjacent trucks, and the lower figures show the readout eye-patterns.

CONCULUSION

The super-low power readout method and the crosstalk reduction method were proposed for solving problems of photon-mode photochromic memory, that is, the destruction of the information by readout light and a crosstalk in multi-wavelength recording. About one million readout cycles without decrease of the signal level and considerable reduction of the crosstalk in two-wavelength recording for photochromic media using diarylethene derivatives were demonstrated. The super-resolution disk with a photochromic mask layer was also demonstrated. About three-fold recording density for conventional optical disks, such as DVD, can be expected.

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