IMPROVED METHODS OF DIRECT OVERWRITE IN MAGNETO-OPTICAL RECORDING MEDIA

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Abstract

Two improved methods of achieving direct overwrite without a pulsed magnetic field to write or erase domains, are described. Both were demonstrated in special single-layer magneto-optical media with a compensation point of 125-130°C and a Curie temperature of about 310°C.

One of these methods uses two laser beams at different power levels. The first laser beam is set at a low power level which is adequate for erasure, but not for writing. This is possible since the laser energy required for erasure of written domains does not overlap with that for writing. The second beam can then be fired at a higher pulse power required for writing to put in the new data.

The second method uses only a single laser beam. Since the pulse energy required to erase data is less than that required to write new data, a single beam, in which the pulse energy of the laser is modulated between a low level for erasure of previously written domains and a higher level for writing of new domains, may be used to directly overwrite old data.

Both methods have been experimentally demonstrated for variable-length domains so that the use of pulse width modulation codes is possible. Scanning speeds as high as 15 m/sec have been demonstrated.

Introduction

Direct overwrite of magneto-optical (MO) recording in a manner similar to that used in present-day magnetic recording technology would greatly enhance the market potential for MO recording in data storage applications. Present MO drives offer higher areal storage density than magnetic drives and a removable medium, something which cannot be achieved with high density magnetic disks. On the other hand, present MO drives have longer access times and are not capable of directly overwriting previously written data on a disk. Solution of the direct overwrite problem would go a long way toward making MO drives a direct replacement for rigid magnetic disk drives.

The MO drives appearing on the market today use, in general, two-passes of the laser beam to overwrite data -- whole blocks of data are erased on the first pass, then the new data are written on the second pass. This scheme greatly increases the time required to update data.

One method of directly overwriting MO recordings is to use the so-called field modulation approach. With this method, the MO layer is heated with a continuous laser beam and a magnetic field whose direction is modulated between up and down is used to record data on the material. Obtaining a sufficiently large amplitude magnetic field which can be varied in direction at the several megahertz data rates desired is not an easy engineering task, however. Reports in the literature[1] indicate that to achieve a pulsed magnetic field of 500 Oe at 5 MHz data rates, the head must be only a few micrometers from the MO material. This precludes putting the head on the substrate side of the disk where the optical head is typically located and makes recording on both sides of a disk impossible. To achieve direct overwrite using the field modulation approach and large head-to-media spacings, a resonant bias coil was used[2]. This method, however, places restrictions on the modulation codes which may be utilized.

To overcome the difficulties in implementing the field modulation method, several alternative approaches which utilize special media have been proposed. The original direct overwrite method described by Shieh and Kryder[3,4] used media with a compensation point well above room temperature and a moderate Curie temperature. This method did not require a pulsed magnetic field, but utilized two laser beams spaced a few micrometers apart on a data track to overwrite old data. The first beam was used to read the old data bits and the second was used to alter any bits which did not correspond to the desired new data pattern. It was initially not clear whether this technique could be used for only pulse position modulation codes or for pulse width modulation codes as well, although data presented later by Schultz et al[5], confirmed that pulse width modulation codes were possible.

Rugar et al[6] also demonstrated the ability to erase domains with no pulsed magnetic field. The materials they chose were significantly different from those of Shieh and Kryder and had compensation points below room temperature and a low Curie temperature. The erasure process required multiple short duration pulses, rather than a single pulse. They suggested direct overwrite could be achieved by using an optical head with two laser beams. The first beam would fire closely spaced short pulses and the second would write new data.

Other direct overwrite techniques utilize multi-layer media, but require only a single laser beam for overwrite. In one approach[7], one layer having high room temperature coercivity and a low Curie temperature is used for storing the data. A second bias layer having low room temperature coercivity and a high Curie temperature is exchange coupled to the first layer. The second layer having a low room temperature coercivity is premagnetized in one direction by a dc magnet having insufficient field to switch the data storage layer. A second dc magnet which produces a magnetic field insufficient to switch either layer at room temperature and opposite in direction to the first magnet, is located where the writing is performed. If the coupled films are heated with a low energy laser pulse which is sufficient to heat the storage layer to its Curie temperature but insufficient to heat the bias laser to its Curie temperature, the exchange coupling from the high Curie temperature bias layer determines the direction of magnetization in the storage layer. If the coupled films are heated with a high energy laser pulse, however, the Curie temperature of both layers is exceeded and both layers switch to the direction dictated by the second magnet. Thus, by modulating the power of the laser beam, domains may be directly written into the data storage layer, independent of its original magnetization direction.

To make this exchange coupled multi-layer medium approach practical, Aratani et al[8] found it necessary to insert a third intermediate layer, having an in-plane magnetization. This intermediate layer has a reduced domain wall energy due to the reduced perpendicular anisotropy and allows the bias layer to be switched with a lower field than if the interfacial domain wall energy is large. As a result, the field of the magnet used to preset the bias layer can be reduced so it has a smaller effect on the previously written data. They report a carrier-to-noise ratio of 50 dB at data rates up to 10 MHz, corresponding to bit lengths down to 0.75 μm.

The technology described in this paper does not require a pulsed magnetic field to write or erase data and needs only a single layer MO material. It therefore is an attractive candidate for the desired MO direct overwrite technology. Magnetic domains of micrometer size can be written and erased without the presence of an external magnetic field in MO media such as TbCo, TbGdCo, TbFeCo, and GdTbFeCo thin films when they have suitable compensation and Curie temperatures and the proper

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coercivity versus temperature dependence. A laser pulse power on the MO film of about 7 to 11 mw will write 1 micrometer size domains while a laser pulse of 3 to 6 mw will erase the domains without an external magnetic field. Domains of variable length can also be written and erased with these pulse power levels and therefore the pulse width modulation codes typically used in magnetic recording can be used in MO recording to achieve high storage densities.

Experiments are described on the writing and erasing of both circular and elongated domains at velocities up to 15 meters/second. Successful experiments on the single beam direct overwrite of a "dot-dash" domain pattern are also described.

Film Preparation and Test Equipment

Small glass coupons were used for the experiments. Quaternary alloy films with the average composition of $Gd_{13}Tb_{13}Fe_{59}Co_{15}$ and thickness of 120-180 nm were deposited directly on the glass substrates. Selection of this material was primarily based on static tests. A silicon dioxide film, nominally 100 nm thick, was used as the overcoat material to provide some protection from oxidation.

The thin films were deposited in a Leybold Z-650 sputtering machine. This machine has a loading chamber and two deposition chambers, each employing an 8 in. diameter target. The MO film was sputtered with the dc-magnetron process from a mosaic target with the areal composition of $(GdTb)_{28}(Fe_4Co)_{72}$. The target was fabricated by bonding a Fe-Co alloy layer, about 1.5 mm thick, onto the target backing plate, and then bonding wedge-shaped rare-earth foils onto the Fe-Co layer with silver epoxy.

The standard sputtering process used for this project was as follows: The deposition chambers were first evacuated to $2X10^{-7}$ Torr prior to introducing a dry argon gas to a predetermined dynamic pressure monitored by a capacitance monometer. To achieve a smooth surface with a dense and featureless microstructure, low argon bleeding pressure of 5 mTorr was used. The substrate was positioned on the turntable and turned at a rate ranging from 15 to 60 rpm under the target during deposition. The deposition rate was about 100 nm/min. at a target power density of 1.5 W/sq. cm.

The dielectric film was rf-diode sputtered from a hot-pressed-powder silicon dioxide target, with a target power of 500 W, argon pressure of 10 mTorr and a deposition rate of 15 nm/sec.

A magneto-optic hysteresigraph was used to determine the coercive force as a function of temperature, the Kerr rotation angle as a function of temperature, the compensation temperature and the Curie temperature of the films. A vibrating sample magnetometer was used to measure the saturation magnetization, the bulk coercive force and the in-plane hysteresis of the prepared films.

A profilometer was used to measure the film thickness and X-ray fluorescence was used to determine the average composition of a 0.5 in. diameter area of the MO film.

The more important nominal characteristics so determined for media samples showed T_{comp} to be 125-130°C, and room-temperature H_c in the range of 2.4 KOe to 3.0 KOe, and Curie temperature of 310°C, which were within the range of characteristics for single-layer direct-overwrite materials.

A polarized light microscope with a mercury arc light source was used for domain observation, and a scanning galvanometer system was utilized to scan the writing/erasing laser beam at high speeds across the sample in the microscope. A simplified schematic diagram of the system is shown in Fig. 1. The laser beam used to write and erase domains emanates from a 20 mw laser with corrective optics necessary to form a circular beam and passes through two lenses and is reflected off a galvanometer mirror and through an aperture in the microscope nose piece. A 45° dielectric mirror located in the nose piece of the microscope reflects the laser beam through the objective lens and onto the MO film. The band pass frequency of the mirror film is such that it reflects the laser beam but passes the mercury arc beam used to observe the domains written in the film. The galvanometer mirror is driven by a CX-660 control amplifier from General Scanning Inc. The galvanometer mirror can be oscillated at frequencies up to 220 cycles per second or can be triggered for only one oscillation. The amplitude of oscillation can be varied from zero up to a total angle of 40°.

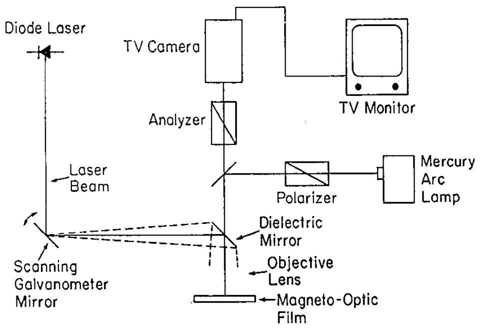


Figure 1

A schematic diagram of the laser beam path and the scanning galvanometer mirror used in conducting the dynamic write-erase experiments.

The velocity of the laser beam scan on the sample is limited by the laser beam velocity achieved on the back of the objective and the demagnification produced by the objective. Although the scanning galvanometer mirror could produce a laser beam velocity of 30 m/sec across the back of the objective lens, the velocity of the beam on the MO film is only 0.3 m/sec when a 100 X objective lens is used, due to the demagnification of the lens. To achieve slightly higher scan rates, some experiments were performed with a 50 X objective lens, yielding a scan rate of 0.6 m/sec.

To achieve significantly higher scan rates, recording and erasing were done during the retrace of the scanning galvanometer system when the velocity across the back side of the objective is 25 times faster than during the initial trace. By using a 50 X objective lens, a laser beam velocity on the MO film of 15 m/sec could be achieved.

Erase-Before-Write Experiments

Although information obtained from tests on a disk spin stand are necessary to completely evaluate the ability to erase recorded magnetic domains and to overwrite recorded magnetic domains without the use of a magnetic field, we used a scanning galvanometer in conjunction with a Leitz polarizing microscope to obtain much of the same information, and, in addition, we could observe the written domains to determine their uniformity and completeness of erasure. The use of the scanning galvanometer allowed us to obtain some dynamic performance data on small glass coupons which could be made in small scale laboratory deposition equipment.

Erasure of Circular Magnetic Domains

Previous work[4] on the erasure of magnetic domains without the use of an external magnetic field focused mainly on the static erasure of circular magnetic domains in MO materials, although some quasi-static work on high frequency pulse erasure of domains was reported[5]. The work demonstrated that circular domains could be erased by hitting the recorded domain with a reduced length laser pulse of about one-half that used for writing the domain. It was also determined that erasure would occur if the center of the laser beam hit the recorded domain within a circle about the domain center of radius equal to about 75% of the domain radius.

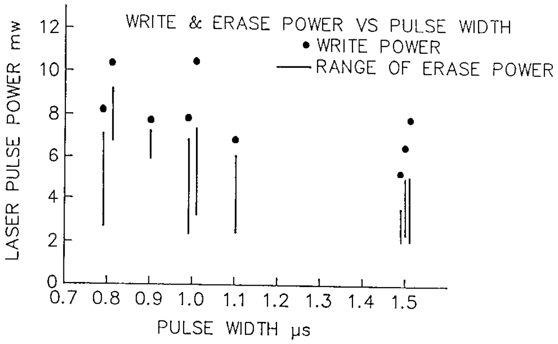


Figure 2

Laser beam power required to write and erase circular magnetic domains as a function of the write and erase beam pulse width.

Since a MO recording system would probably make use of a reduced power pulse for erasing instead of a shorter duration pulse, this method of erasure was investigated. It was found that the domain could be erased by using a pulse power in the range of 50% to 70% of the record pulse power for a GdTbFeCo film as shown in Fig. 2. The test consisted of writing domains at a particular power level as shown by the solid circle and then determining the range of power levels that would erase the written domain. This range of power levels is shown by the solid vertical line. All of the measurements grouped around a particular pulse width were made at the center pulse width. The recorded domain size depended on pulse width and power and varied from 0.5 to 1.2 micrometers. The data taken for a 1.0 microsecond pulse width shows that domains recorded with pulse powers between 7.9 mw and 10.5 mw can consistently be erased with pulse powers between 3.3 mw and 6.9 mw. In this particular case, the record power margins are plus or minus 14% from the mean power, while the erase power margins are plus or minus 35% from the mean power. Note that, in general, there is no overlap of the erase power level with the write power level, at a given pulse width, except in the one case at the domain size of 0.8 micrometer. Even at the 0.8 micrometer domain size, an erase power level exists that is below the write power level for the two experiments.

High frequency pulse erasure of circular domains was performed by using the scanning galvanometer to sweep the laser beam across the MO film placed on the stage of the polarizing microscope. Initial experiments were performed at a low scanning velocity of the laser beam on the MO film of $3X10^{-4}$ meter/second. The recording of 1 micrometer diameter circular domains in a GdTbFeCo MO film was accomplished by triggering the scanning galvanometer for one cycle while a continuously pulsed laser beam was reflected from the mirror of the galvanometer. The laser was pulsed with a 50% duty cycle at a rate of 50 pulses/second with a pulse width of 500 nanoseconds. The domains were observed to the limits of the resolution of the objective lens used (0.95 NA) to have excellent uniformity and no noticeable irregularity in shape.

In order to erase each domain in the pulse mode, it was previously determined[5] to be adequate to hit each domain, within a 75% radius, with the proper erase energy in the laser beam. In order to insure that this happens, the frequency of the erase pulses must be at least equal to the velocity of the laser beam during recording divided by 75% of the diameter of the magnetic domain or 400 pulses/sec in this case. Erasure of the recorded domains was accomplished in this experiment even at 300 pulses/sec, which insured that each domain would be hit at least once, suggesting the margin for error is even wider than 75% of the domain diameter.

As a precursor to the feasibility of erasing elongated domains, the erase pulse frequency was increased so that each circular domain would be hit more than once during the beam scan at a velocity of $3X10^{-4}$ meters/second. The 1 micrometer diameter domains were scanned with 250 nanosecond width pulses at a frequency of 5 KHz and appeared to be completely erased. The distance between pulses was 0.06 micrometers indicating that each circular domain was hit with the erase pulse laser beam about 16 times. This experiment indicates that excessively large numbers of erase pulses do not rewrite domains.

Erasure of circular magnetic domains at higher velocities and at higher frequencies was also investigated. Experiments at laser beam velocities of 0.6 meter/second and a pulse frequency of 1 MHz resulted in what appeared to be complete erasure of 1 micrometer magnetic domains.

Continuous wave (CW) erasure of the circular magnetic domains was investigated by increasing the pulse width to the extent that the laser was continuously emitting during the time that the beam was traversing the objective lens of the Leitz polarizing microscope. This arrangement allowed the operation of the laser at a 50% duty cycle and therefore a higher power level than could be continuously obtained by applying a dc voltage to the laser. Arrangements were made to gate the laser on at the appropriate time during one sweep of the laser beam past the entrance port to the microscope objective lens.

CW erasure experiments of 1 micrometer diameter circular magnetic domains were conducted at a laser beam velocity of 0.14 meters/second across the MO film with the appropriate laser power. The domains appeared to be completely erased, as determined by the visual image on the TV monitor.

Erasure of Elongated Magnetic Domains

Experiments were conducted on the high frequency erasure of elongated domains. Elongated domains of about 5 micrometers in length were recorded by scanning a laser beam across the specimen at a velocity of 0.3 meter/second. A laser beam with reduced energy pulses of 150 nanosecond duration and 1 MHz frequency was swept across the MO film at a velocity of 0.3 meter/second and erased the elongated magnetic domains. The 5 micrometer long domains were hit with about 16 pulses which were sufficient to totally erase them.

In a subsequent experiment, a mixture of circular and elongated domains of various lengths were erased by sweeping a pulsed laser beam having a frequency of 1 MHz, and a pulse width of 150 nanoseconds across the MO film at a velocity of 0.3 meter/second.

CW erasure of elongated magnetic domains was also demonstrated. As in the previous experiments on the CW erasure of circular magnetic domains, 50% duty cycle low frequency pulses having a long pulse width were used for erasure. The laser beam was gated so that the laser was continuously emitting during the time the beam passed through the aperture into the Leitz polarizing microscope. The elongated domains recorded in the MO film were erased by sweeping a reduced energy beam across the film at a velocity of 0.3 meter/second.

CW erasure of a 15 micrometer magnetic domain was accomplished at a laser beam velocity of 15 meters/second. In order to obtain this higher velocity of the laser beam on the MO film, it was necessary to erase during the retrace of the laser beam, as described above. We were able to repeatedly CW record and erase a 15 micrometer long magnetic domain at a beam velocity across the MO film of 15 meters/sec.

Single Laser Beam CW Overwrite of a Pulse Width Modulated Magnetic Domain Pattern

The feasibility of directly overwriting pulse width modulated data with a single laser beam was also demonstrated. To perform this experiment, two pulsers and two word generators were used to trigger a laser to successively overwrite dot-dash domains and dash-dot domains on the MO film. The domains were recorded at the same location on the film by using the position output signal from the scanning galvanometer in conjunction with a trigger level and delay signal from the oscilloscope.

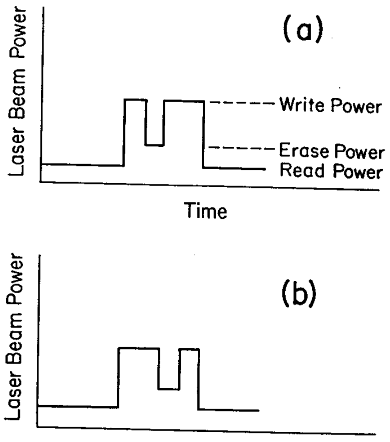


Figure 3

Laser beam power modulation used to write a dot-dash magnetic domain pattern and overwrite in the same spot on the MO film with a dash-dot magnetic domain pattern.

The pattern of modulation of the CW laser beam for overwriting the dot-dash and dash-dot patterns is shown in Fig. 3. The laser beam is on continuously at the read power level and modulated to the high power level to write a domain or write a "1", or modulated to a lower power level to erase domains or write a "0".

A dot, about 1 micrometer in diameter, and a dash, about 3 micrometers long, were recorded by the laser current dictated by one word generator. The second word generator was then triggered to write a dash-dot pattern in the same spot on the MO film. This experiment repeatedly demonstrated that direct overwrite of pulse width modulation codes could be achieved by using only a single laser beam.

Write-Erase Life Tests

Tests showed that recording and erasing of magnetic domains in the same spot on a GdTbFeCo film can be made up to 10^8 cycles without any apparent diminution of the write and erase capability of the MO film. The test was performed using the scanning galvanometer. Recording was performed during one cycle and erased during the next cycle. The time between recording pulses measured on the cathode ray tube was 11 ms, yielding a record-erase frequency of 90.9 Hz. This frequency results in $7.9\text{X}10^6$ record-erase cycles per 24 hours or $1\text{X}10^8$ record-erase cycles in 14 days. The test was run continuously for 14 days or $1\text{X}10^8$ record-erase cycles with no apparent diminution of the record-erase capability of the MO film.

Direct Overwrite Methods

Although the above described experiments indicate that the originally proposed[3] read-before-overwrite method of direct overwrite should work, they indicate two simpler techniques may be used. We refer to these two techniques as erase-before-write and single-beam direct overwrite.

The erase-before-write scheme is illustrated in Fig. 4. There two laser beams are shown focussed through a single lens onto the recording medium. The medium moves from left to right and encounters the erase beam first. The erase beam is operated at a power level which is adequate to erase written domains, but inadequate to write new domains. As described above, this erasure can be accomplished with either a constant intensity laser beam or a laser beam which is pulsed at a sufficiently high rate to ensure that each domain is hit at least once by a laser pulse adequate to cause erasure. The second beam encountered (the write beam) is then pulsed at a power level adequate for writing to record the new data.

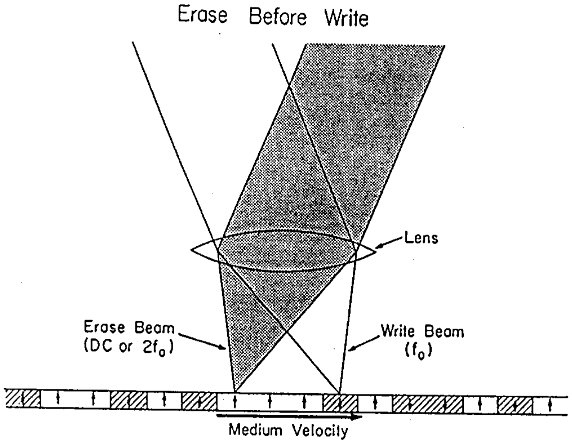


Figure 4

The erase-before-overwrite technique uses the first laser beam to erase old data and the second to write new data.

The use of such an erase-before-write scheme has been previously proposed for direct overwrite in phase change materials and was also previously discussed by Rugar et al[6] for magneto-optic recording. However, here we have shown that with suitable materials it is possible to achieve high scanning speeds and that a single pulse is adequate for complete erasure.

The single-beam direct overwrite technique is illustrated in Fig. 5. With this technique, the laser is simply pulsed between the erase level and the write level to control the direction of magnetization in the medium. As illustrated in the inset in Fig. 5, an existing domain pattern can be overwritten with a new pattern by modulating the output of a single laser beam. The overwriting of dot-dash and dash-dot patterns described above demonstrates this technique.

Conclusions

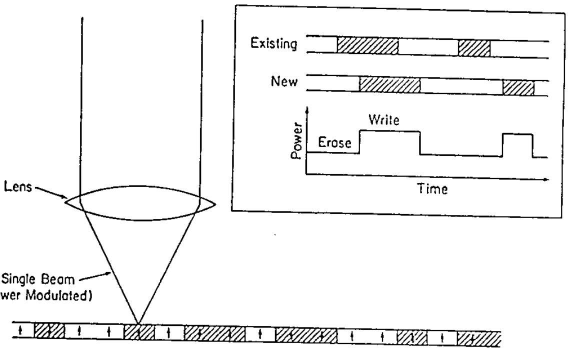
Two new methods of achieving direct overwrite in magneto-optical recording media have been described. Both utilize a single layer GdTbFeCo magneto-optic recording medium with a compensation temperature of 125°-130°C and a Curie temperature of 310°C.

In one method, two laser beams are used. The first is operated at a low power level and utilized to erase any written domains. The second is pulsed at a higher power level to write either circular or elongated domains as the modulation code requires.

In the second preferred method, a single laser beam is used. Its output power is modulated between the write power level used to record a reverse domain and the erase power level used to erase domains. This method, too, was demonstrated with both circular and elongated domains.

Both the two-laser and single-laser techniques have been shown to work without the need for careful timing of the laser pulses with respect to the previously written data.

Neither of these overwrite techniques require a pulsed magnetic field. Hence, high data rates are potentially achievable. Here, write-erase experiments were successful at scanning rates up to 15 m/sec. There is no technical reason why even higher write-erase velocities cannot be achieved.



Single Beam Direct Overwrite

Figure 5

The single beam direct overwrite technique requires only that the laser beam power be modulated between the erase and write levels to achieve true direct overwrite.

The measurement of the write-erase power requirements of an MO film shows good operating margins, in one particular case being plus or minus 14% during write and plus or minus 35% during erase.

The write and erase of a dot-dash domain pattern 10^8 times in the same spot on a MO film, without any apparent degradation of the domain pattern, demonstrates good stability of the medium against annealing.

References

[1] F. Tanaka, S. Tanaka and N. Imamura, *Jap. J. Appl. Phys.* 26, 231 (1987).

[2] D. Rugar, *IEEE Trans. Magn.*, MAG-24, 666 (1988).

[3] H-P. D. Sheih and M. H. Kryder, *Appl. Phys. Lett.* 49, 473 (1986).

[4] H-P. D. Shieh and M. H. Kryder, *IEEE Trans. Mag.*, Vol. MAG-23, 171 (1987).

[5] M. D. Schultz, H-P. D. Shieh and M. H. Kryder, *J. Appl. Phys.* 63, 3844 (1988).

[6] D. Rugar, J. C. Suits and C-J. Lin, *Appl. Phys. Lett.*, 52, 1537 (1988).

[7] J. Saito, M. Sato, H. Matsumoto and H. Akasaka, Proc. Int. Symp. on Optical Memory, Kyoto, Japan, p. 149 (1987).

[8] K. Aratani, Y. Mutoh, M. Kaneko, K. Watanabe and H. Makino, Technical Digest of "Topical Meeting on Optical Data Storage", Los Angeles, CA p. 154 (1989).