Operating Margins for Magneto-Optic Recording Materials with Direct Overwrite Capability

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ABSTRACT

The possibility of achieving direct overwrite in magneto-optic thin films is demonstrated. By using films having a compensation temperature tens of degrees higher than room temperature, writing and erasing of domains thermomagnetically can be accomplished in the absence of a magnetic field. The device operating margins were measured in GdTbCo and TbFeCo films, and it was found that write and erasure pulses have wide margins in duration and amplitude while the ambient temperature is varied from room temperature to 80 °C. Data rates higher than 10 MHz are shown feasible with this direct overwrite scheme.

INTRODUCTION Amorphous ferrimagnetic rare earth-transition metal (RE-TM) thin films have been demonstrated for high-density magneto-optical (M-O) recording media.[1,2] Such materials have erasure and rewrite capabilities like conventional magnetic recording media, yet can achieve recording densities comparable to those of optical disks. Carrier-to-noise ratio has been improved to about 52 dB, and bit error rate can be lower than 10^{-12} with existing error detection and correction codes.[3] Expected lifetime of greater than 10 years indicates that these materials can be used for long term data storage.[4]

M-O recording media are typically chosen to have a high coercivity (H_c) at room temperature and low coercivity at high temperatures. This temperature dependent coercivity is achieved by utilizing alloys exhibiting ferrimagnetic behavior and having a compensation temperature (T_{comp}) near room temperature. Local heating by a focussed laser beam raises the temperature and consequently causes a localized decrease in H_c. At this moment, if a high enough magnetic field is applied antiparallel to the direction of magnetization, the magnetization can be reversed locally to form a cylindrical reverse domain. After subsequent wall motion and cooling processes, the domain is stabilized by the high H_c of the medium at ambient temperature (T_A). The erasure mechanism is very similar to that of writing. By pulsing a focussed laser beam with an energy level comparable to that used in writing, but with a magnetic field opposite to the direction of magnetization in the domain, the domain can be made to vanish.

This erasure scheme does not provide for direct overwrite as conventional magnetic recording does, unless the applied magnetic field can be switched at the data rate. Instead, a sector of data must be totally erased before the new data can be rewritten in that sector. Implementation of such a high speed switching magnetic field is challenging whereas the scheme of erasing an entire sector before writing slows down the read-write time in the system.

This paper reports the successful demonstration of writing and erasing micrometer size domains without a magnetic field by using M-O media with $T_{comp} > T_A$. The device operating margins obtained are shown to be adequate for practical applications. Coupled with a Read-Before-Write scheme, it is possible to achieve direct overwrite.

SAMPLE PREPARATION & EXPERIMENTAL METHOD
Amorphous films of RE-TM (RE = Gd, Tb, TM = Co, Fe) were prepared by r.f. sputtering from composite targets onto Corning 0211 glass substrates. The magnetic layer was coated with 25 nm of SiO_2 in situ. The temperature dependence of the M-O hysteresis loops were measured by a Kerr M-O hysteresis loop tracer from which the temperature dependences of coercivity and polar Kerr rotation angle, $H_c(T)$ and $\theta_k(T)$ respectively, and T_{comp} were derived. Film composition was determined by x-ray fluorescence analysis. Static thermomagnetic writing was performed using a polarized microscope/photometry system with a 25 mW GaAlAs laser diode (λ = 780 nm) as a writing/erasing source and a 100x/0.90 lens as a focus/observation lens.

RESULTS M-O hysteresis loops of GdTbCo and TbFeCo films and their $H_c(T)$ and $\theta_k(T)$ are shown in Fig. 1. The H_c of the GdTbCo film is over 2 KOe at room temperature, diverges at T_{comp} above room

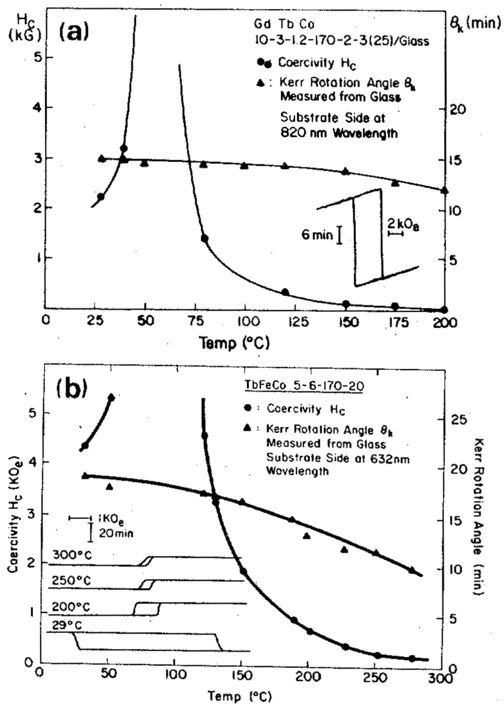

Fig. 1: The temperature dependences of coercivity and Kerr rotation angle for (a) a GdTbCo film, and (b) a TbFeCo film. The inserts are the M-O hysteresis loops measured at different temperatures.

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temperature, but drops below 200 Oe at 150 °C. The room temperature H_c of the TbFeCo film is over 4 KOe. It diverges at about 80 °C, then drops below 1 KOe above 180 °C. The M-O hysteresis loops shown in Fig. 1 indicate that squareness = 1 is maintained at least up to 225 °C for the TbFeCo film. Squareness < 1 is obtained at about 300 °C.

We successfully nucleated micrometer size domains in both films by locally heating the film with a laser pulse of 12 mW amplitude, 80 and 100 nsec duration, respectively, and no externally applied magnetic fields. To erase the written domain a second laser pulse is used, again with no applied fields. Typically, this erasure pulse is of shorter duration than the write pulse. For example, a domain written with a pulse of 100 nsec duration in the GdTbCo film can be completely erased by a succeeding pulse ranging in duration from 35 - 90 nsec at the same power level. A succeeding pulse can nucleate a domain again, and the following pulse of shorter duration again erases the domain. A single isolated domain or domains within a 8x8 matrix of 1 μm size domains with micrometer spacing have been written and erased successfully with no external magnetic field without altering the surrounding domains. Figure 2 is a photograph of domains written/erased without a magnetic field where domains are shown quite reproducible in size and shape.

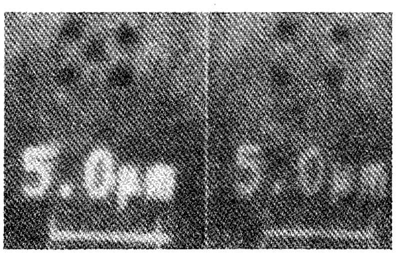
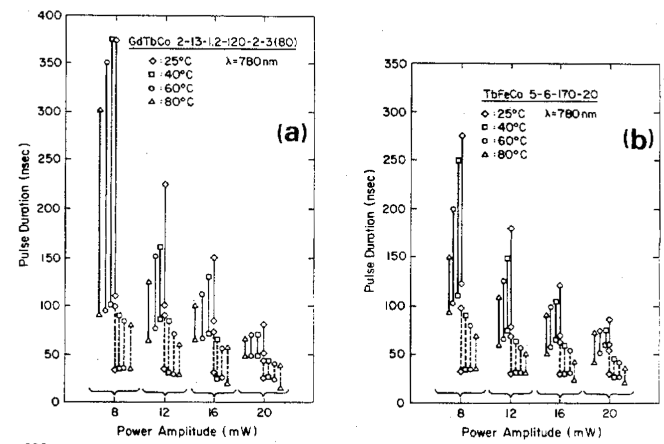


Fig. 2: A photograph of domains nucleated without a magnetic field at power amplitude of 8 mW, 250 nsec of duration in the TbFeCo film. The domain at the center was then erased with a pulse of 80 nsec duration at the same power level.

For the given GdTbCo and TbFeCo films, pulse duration margins to nucleate erasable domains as functions of pulse amplitude and T_A are plotted in Fig. 3 as solid lines. The dotted lines are the pulse duration margins to erase the domain written by the minimum pulse length at the same power level. Upper limits of the write pulse durations are constrained by the nucleated domain size which may become too large (> 2 μm) to be completely erased; while the lower bound is limited by the minimum stable domain size in the media. Pulse duration margins are quite wide for a given power level and are not very sensitive to temperature variations. For example, at a power level of 12 mW and T_A of 25 °C, the domains written in the TbFeCo film by pulse durations ranging from 80 - 180 nsec all can be erased by a subsequent shorter pulse at the same power amplitude without the presence of a magnetic field. If the minimum pulse duration of 80 nsec is used, erasure can be accomplished with pulses of 30 - 70 nsec at 25 °C. When the temperature increases, the required write/erasure pulse durations decrease, and their margins become smaller. As shown in Fig. 3, a temperature change from 25 to 80 °C decreases the minimum pulse duration to nucleate an erasable domain from 80 to 60 nsec for the TbFeCo film, and from 90 to 65 nsec for the GdTbCo film at 12 mW power level. At room temperature, a 4 mW power amplitude variation (16 mW to 12 mW) only causes the minimum write and erasure pulse duration margins to change by about 10 nsec for both films.

Erasure pulse duration margins for the domains written by different pulse durations and power levels in the GdTbCo film are plotted in Fig. 3(c). The erasure pulse duration is constrained such that a local heating can completely erase the domain at the lower bound, and will not result in renucleating a domain at the upper bound. The lower bounds of the erasure pulse duration can be as short as 25 nsec and are relatively independent of the writing parameters; while the upper bounds increase as the write pulse durations increase at the given power levels. The margins, as shown in Fig. 3(c), of at least 45 nsec to more than 130 nsec, are adequately wide for practical applications.

Similar results for writing/erasing domains without a magnetic field were also found in other RE-TM alloys such as TbCo, and GdTbFeCo with $T_{comp} > T_A$ by tens of degrees. Writing conditions vary slightly from film to film, depending on the properties of the films.



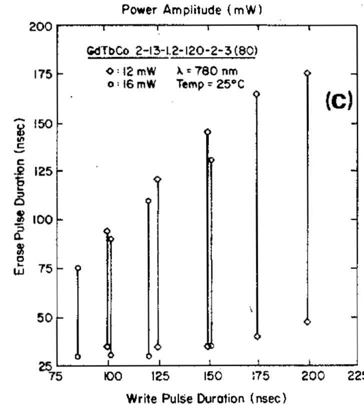


Fig. 3: The laser pulse duration and amplitude margins at different temperatures for nucleation and erasure of domains in (a) the GdTbCo and (b) TbFeCo films without an applied magnetic field. (c) The erasure pulse duration margins for the domains written by different pulse durations at different power levels for the GdTbCo film.

DISCUSSION To nucleate domains with no external magnetic fields applied, it is necessary to make use of the demagnetizing fields.[5] In a thin film with uniform magnetic properties the demagnetizing fields are equal in magnitude to $4\pi M$ and antiparallel to the net magnetization. Figure 4 summarizes the details of thermomagnetic writing by a demagnetizing field in a film in which $T_{comp} > T_A$. When the temperature is raised locally above T_{comp} by a laser pulse, the net magnetization direction reverses, because of the relative change in the subnetwork magnetizations; however, no domain wall involving exchange energy results, since the spins contributing to a given subnetwork magnetization are still aligned (state B). This local heating results in a non-uniform magnetization distribution in the heated region. Since the heated spot size is large compared to the film thickness, at the center of the spot the self-demagnetizing field is opposite to the net magnetization. If the temperature is high enough that H_c is low, then the magnetization at the center of the spot can be reversed, forming a domain wall (state C). After magnetization reversal, the self-demagnetizing field becomes smaller because of the lower magneto-static energy state. This helps to prevent another possible magnetization reversal. When the temperature drops through T_{comp} to T_A, the magnetization becomes uniform in magnitude, but the domain wall is frozen in by the high coercivity and a reverse domain results (state D).

To erase the written domain, a shorter pulse duration than that for writing is used. This again causes the net magnetization to reverse sign in the heated region when the temperature passes through T_{comp} (state E). The self-demagnetizing field at the center of the domain now causes the magnetization at the center of the original domain to reverse, forming a ring-shaped domain (state F). Subsequent domain wall motion causes the inner wall to move outward and annihilates with the outer wall which effectively erases the domain (state G). Finally when the temperature cools back through T_{comp} to T_A, the magnetization becomes uniform (state H).

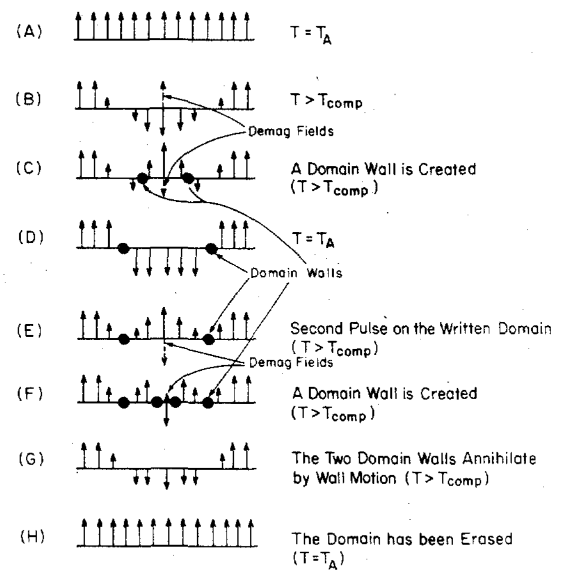


Fig. 4: The states of net magnetization for a M-O film with $T_{comp} > T_A$ during a local laser heating.

To achieve erasure with the above process, it seems that the erasure pulse should be approximately centered with respect to the original domain. However, we have found that erasure will still occur when the erasure pulse is shifted by half the radius of the written domain from the center. This suggests that adequate timing windows may be available for using this erasure scheme at high data rates on a rotating disc.

The minimum pulse durations for writing/erasing of domains in the GdTbCo film are slightly shorter than those for the TbFeCo film. This is believed to be due to the higher T_{comp} and H_c of the TbFeCo film. Nevertheless, at 12 mW power level, only 100/50 nsec are required to write/erase micrometer size domains, respectively. Thus, data rates over 10 MHz are possible.

We have found that the location of T_{comp} is important to the erasability of domains by this process. Erasure does not work well in the films with $T_{comp} < 40$ °C or $T_{comp} > 130$ °C. Generally good performance was obtained in films with T_{comp} tens of degrees higher than room temperature (for example 60 and 80 °C) for the films shown in Fig. 4. The precise reason that T_{comp} must be in this region is not well understood at this time, and investigations are underway.

To selectively erase written domains in tracks or sections, a Read-Before-Write scheme is proposed. A section of data (recorded bits) is read into a buffer by a read laser and logically coupled with the input data stream which is going to be stored onto the M-O disc; the logic results are used to trigger a write laser which overwrites domains on the M-O disc if the domain pattern needs to be reversed. The logic operation is simply a toggle flip-flop whose output is changed when the input data and buffered data from the M-O disc are different, but whose output is unchanged when they are the same. By using two laser diodes or by splitting the write laser beam into multiple beams with a grating, multiple laser beams for the Read-Before-Write scheme can be provided.

CONCLUSIONS M-O recording media with T_{comp} tens of degrees above room temperature have been found to provide direct overwrite capability. Domain nucleation and erasure can be realized by ordinary thermomagnetic writing, typically with a shorter pulse used to erase the nucleated domains than that used for writing. The "field" used to reverse the direction of magnetization is the demagnetizing field of the thin magnetic films at elevated temperatures. A single isolated domain or domains within a matrix of micrometer size domains with micrometer spacing can be written/erased without an external magnetic field with good margins for laser pulse energy, laser beam positioning and temperature. The nucleated domains exhibit good regularity. Over 10 MHz data rates have been shown to be feasible. This has been demonstrated in several RE-TM thin films. This mechanism makes the bias magnetic field required for existing M-O recording systems unnecessary, and provides for direct overwriting capability compatible with existing magnetic recording systems.

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