OPERATIONAL PRINCIPLE AND CONSTRUCTIONAL BASES OF A MAGNETOOPTICAL DATA MEDIUM DISC*

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Abstract

This communication will review the purpose of development of the magnetooptical data medium. The physical principle of recording, reading and erasing is described in this paper. The authors summarize the possible materials of the magnetooptical layers and two basic structures has been studied.

Our group has been developing magnetooptical (MO) data media since the midst of 1988 at the Department of Atomic Physics, Technical University of Budapest. The work was initiated and directed by Prof. János Giber. We have aimed at developing an on-line memory with high store capacity and rapid access. This memory would integrate the features of traditional magnetic data recorders (floppies, winchesters), such as erasing and rewriting with the high signal density characterizing the optical discs, and in addition, it would have long lifetime and many erase-rewrite cycles without the need of using a magnetic head near the disc, which is exposed to mechanical injuries and is sensitive to dirt.

The theoretical limit of the storing density resulting from the transformation of light equals to 10^7 bits/mm^2, hence, on one side of a 130 mm diameter disc 250 MB information may be stored.

A few data for comparison

	MO	Floppy	Winchester	WORM
Capacity	200—700	1.2	10—180	200—1000 Mbyte
Signal density	40	0.06	5	40 Mbit/cm^2
Access time	70—100	150—200	10—90	70—100 ms
Lifetime	>10	>5	>10	>10 year
Data transmission velocity	1	0.5	2	0.5—1 Mbyte/s
Multiple writing	×	×	×	—
Real write cycle	$>10^8$	$>10^8$	$>10^8$	0

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* Dedicated to Prof. J. Giber on the occasion of his 60th birthday.

I. Mechanism of writing, reading and erasing of magnetooptical memories

At room temperature the reversible memory materials must have two stable states so that the focused reader's laser beam could distinguish them. On the other hand the reading beam must not affect the memory material, i.e. it should not change the stable state. And, at last, the material should overturn between the two optically distinguishable states under the influence of the writing and erasing laser beams. The latter, as a rule, is of greater intensity.

Magnetooptical materials are possessed of these properties. Distinction of the stable states, i.e. readout is based on the Kerr or the Faraday effects. If a linearly polarized light falls on a magnetic material the magnetooptical interaction would result in elliptically polarized states both in the reflected and in the transmitted beams. The linearly polarized beam may be broken into two circularly polarized lights rotating in opposite directions since their direction of propagation in the magnetic material is different, so passing through the material the plane of polarization of the linearly polarized light would deviate. If the absorptions of the two circularly polarized beams, rotating in opposite directions, are different, then the reflected (Kerr effect) and transmitted (Faraday effect) light would be elliptically polarized. The major axis of the ellipse is deviated in relation to the plane of polarization of the original linearly polarized light. The degree of deviation of the plane of polarization is characteristic of the magnetooptical interaction, is dependent

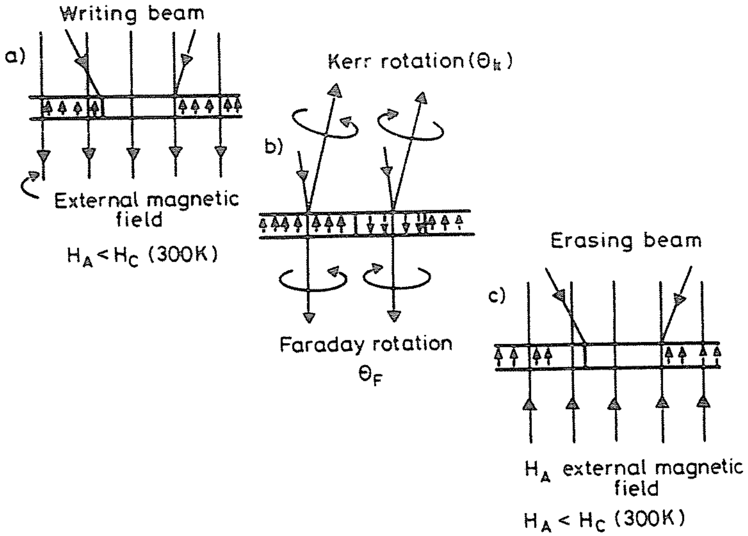

Fig. 1. Magnetooptic recording, reading and erasing processes

both on the direction of magnetization in relation to the direction of incidence and the original direction of polarization of the incident light. The greatest effect may be achieved if the incident light beam is perpendicular to the surface and the direction of magnetization in the material is parallel or antiparallel with the direction of propagation of the light. Changing the direction of magnetization in the material to the opposite the direction of Kerr deviation will change to the opposite as well.

Thus the two optically distinguishable stable states of magnetooptical materials result from the opposite of magnetization perpendicular to the surface of the magnetooptical film.

The optical distinction (readout) is carried out by the Kerr-effect.

The process of writing, reading and erasing is illustrated in Fig. 1.

The magnetooptical films in the ground state (before writing) are entirely magnetized perpendicularly to the surface.

Two ways of writing are known: Curie-point and compensation-point ones.

Curie-point writing

The absorbed energy of the writing laser light beam alters the film temperature above the Curie-point at the areas to be written thus at these places magnetic ordering disappears.

During writing a magnetic field opposite to the original direction of magnetization of the film is applied. At the end of writing light impulse the radiated part is cooled down, the direction of magnetization of the written-in areas is opposite to the direction of that of the non-written areas. Since the applied field cannot be localized on the area heated by the beam, the coercivity of the film must be higher than the applied field. (Otherwise the non written-in areas would be reserved magnetized).

Compensation-point writing

Rare-earth-transition metal (RE-TM) magnetic materials are amorphous ferrimagnetic materials. (The ferrimagnetic materials are made up of two sublattices wherein magnetic momenta are in antiparallel directions, and the absolute values of those are unequal [1].) These materials may have a compensation temperature (T_{comp}) at which the magnetization of the two sublattices are equal. The coercive force (H_c) may reach a great value near T_{comp}, and would rapidly decrease with increasing or decreasing temperature.

As an illustration in Fig. 2 are shown the variation of the coercive force of a GdTbCo film over temperature, the magnitude and direction of

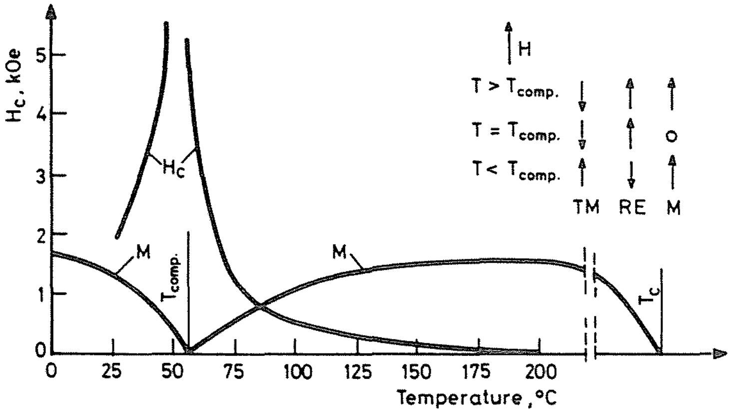

Fig. 2. Coercive force (H_c) and magnetization (M) as a function of temperature

magnetization in the transition metal (TM) and the rare earth metal (RE) subcircuit, and the resultant magnetization of the film. At T_{comp} the magnitudes of magnetization of the two subcircuits are equal and their directions are opposite, thus the resultant will be zero. While under the compensation temperature the RE magnetization will be greater, above T_{comp} on the contrary, TM is the greater.

Magnetic field is in the direction of the magnetization of the greater sublattice, and, taking into account that there is a negative exchange between the two sublattices the direction of magnetization of the other sublattice will be opposite.

If the compensation temperature of the above described amorphous ferrimagnetic film is in the vicinity of room temperature writing may be carried out under Curie-point temperatures as well. That is to say, if the applied field is greater than the coercive force (H_c) of the radiated part but smaller than the coercive force of the surrounding room temperature parts, the applied field will magnetize to the opposite direction only those parts which are heated by the laser beam.

At erasing a magnetic field coinciding with the direction of the original magnetization of the film is applied. The erasing laser beam alters the temperature of the radiated part above the Curie-point and at the written parts the applied magnetic field restores the direction of original magnetization.

Construction of the MO disc

There are two groups of materials wherein the above described physical phenomena may emerge, operate and have their effect, namely the polycrystalline metallic compounds and amorphous metallic films.

A typical representant of the first group is MnBi. It is characterized by a high coercive force. At writing it has to be heated to the Curie-point which is in the close vicinity of its decomposition temperature. This is the reason why a multiple writing-erasing cycle is not achievable with this material.

Though they have advantageous magnetic properties the application of the polycrystalline materials as magnetooptical media is complicated since they have to be produced in an accurate stoichiometric composition. This requirement is hard to meet technically. Another disadvantage of them is that the dimensions of their microcrystals are commensurate with the wavelength of the commonly used laser beam so they have a great material-noise.

The other group is formed by the ferrimagnetic (antiferromagnetic) amorphous metallic films displaying a great magnetic anisotropy perpendicular to the surface. These films, as a rule are compounds of rare earth metals, such as gadolinium (Gd), terbium (Tb), in some cases dysprosium (Dy), holmium (Ho), erbium (Er), or of *transition metals* as iron, cobalt.

These alloys are used as magnetic data media for the following reasons:

- Since in the case of Gd and Tb there are 6 or 7 electrons with uncompensated spins on the 4f trajectory, and, similarly, the iron and cobalt have 4 or 3 unpaired electrons on the 3d trajectory, thus both the rare earth metal and the transition metal components have magnetic momenta at the atomic level, so they behave as a ferromagnetic material. Since the alloy is amorphous there is no reason to speak about sublattices, but, as a result of the short-range ordering some kind of "subcircuit" is generated according to the two components (rare earth metal—transition metal.)
  The temperature dependence of these materials is of opposite run. This way, depending on the composition, one may find a temperature the so-called compensation temperature, at which the resultant magnetization equals zero.
- The compensation temperature or the Curie-point is relatively low, so the sensitivity of writing is high, a 10^6 order of magnitude of writing and reading cycle may be achieved without the ageing or alteration of material.
- The desired composition and the perpendicularly directed anisotropy can be produced by evaporation or pulverization.
- This way the light magnetization axis is perpendicular to the surface, therefore the information may be written in with great density.
- Resulting from the amorphous structure the short-range ordering is by some orders of magnitude smaller than the wavelength of the laser beam, so the material-noise is negligible. The signal/noise ratio is good because of the fact that the Kerr-rotation is high enough, typically 0.3—0.5°.

One may choose a great number of compositions of rare earth and transition metals having the above described properties and applicable to producing magnetooptical information media.

Table 1

Composition of magnetooptical materials in at %

Gd	Tb	Fe	Co	Other	Literature
20	—	—	80	—	3
25	—	75	—	—	4
26	—	74	—	—	4
23,14	—	65,86	—	Bi : 11	10
23,4	—	66,6	—	Sn : 10	10
25	5	70	—	—	Personal information
22,8	1,2	76	—	—	5
26	—	66,6	7,4	—	6
—	28	60	12	—	7
—	22	68	10	—	7
22,8	1,2	72,2	3,8	—	9
—	22	57	13	Dy : 8	8
—	22	61	7	Dy : 10	8
—	21	46	21	Ho : 12	8

Table 2

Composition of magnetooptical data medium layers

Firm	Composition
NEC Corp.	TbFeCo
NHK Labs.	GdFeCo Tb $^{+}$Fe
Arizona Univ. Tucson	TbFe
NTT El. Communs. Labs.	TbFeCo
3M	TbFeCo GdTbCo
Ibm Corp.	TbFe TbFeCo
Toshiba	TbCo
ATT Bell	Fe és amorphous $Tb_{21}(Fe_{1-x}Co_x)_{79}$
Hewlett Packard	$Tb_{30}Fe_{32}Co_{38}$ $Tb_{24}Fe_{35}Co_{41}$
Thompson-CSF	TbFeCo
Fujitsu Labs.	$Tb_{23}Fe_{66}Co_{11}$
Philips	GdTbCo (GdTbFe)
Eastman Kodak	TbFe

The known accurate compositional data are summarized in Table 1. Summarizing we can state:

- The rare-earth content of the usable compositions must not exceed 20—30 atomic percent.
- The most frequently applied rare-earth components are as follows: gadolinium and terbium. They are commonly used since they have the most electrons with uncompensated spins on their electron shell, so their magnetic properties are the best.
- As the X-ray diffraction pattern shows layers containing less than 15% Tb are crystalline. If the Tb content is between 15 and 30%, the anisotropy perpendicular to the desired surface is established.
- Increasing the concentration of Tb the coercive force increases as well, thus the layer gets more sensitive to oxidation and the ageing properties are worse [4]
- From among the transition metals exclusively the iron and cobalt are used, since the magnetic momenta and the saturation magnetization for these materials are the highest.
- When Fe and Co are used together — that is with the three-component alloys — with the increasing of the Co-content the stability of the writer — in bits and the magnitude of the Kerr-deviation may be increased. The increase of Co concentration is limited by the fact that the addition enhances the temperature required to writing.

  Studying the experimental literature reveals that the requirements of magnetooptical signal-recording can be met by different material compositions with more or less compromise. Table 2 shows, however, that great firms, making experiments in the field of magnetooptical data recording most commonly use Tb-Fe-Co three-component alloys. According to that the Tb content is between 18 and 28 at%, Co — as a rule — is 8—15 at% and the rest is Fe. (The only exclusion of the layer of the Hewlett-Packard, wherein the ratio of Fe and Co is approximately equal.)

In our experiments we have used TbFeCo target because of its advantageous properties.

The layer structure of the MO disc

Besides the magnetooptical layer there is at least a three-layer structure on the substrate of the magnetooptical disc. The multiple layer construction is mainly based on the fact that the rare earth metal components of the information carrying medium, i.e. terbium and gadolinium are sensitive to corrosion. This way the layers encasing the MO layer have a protecting role, eliminating oxidation and other effects which cause ageing of the layer. Another very important task of them is to enhance the signal/noise ratio.

Against corrosion it is common to use additional materials in the alloy besides the covering layers [10, 11]. This procedure is based on the fact that protective layers themselves may not prevent neither oxidation of the information medium nor corrosion for a long time, 5—10 years.

Introducing some percent of Pt, Au, Ag, Ti will prevent harmful chemical reactions without the risk of destroying magnetooptical properties. This procedure is not widespread since the production of the target is sophisticated due to the high homogeneity requirements.

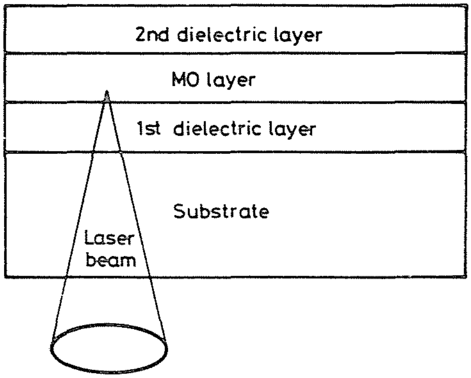

Fig. 3. The layer structure of the MO disc

On the basis of the above it is understandable that the magnetooptical data medium layers are encased in between two dielectrics, having the same material characteristics. Their materials, as a rule are Si_3N_4, or AlN, scarcely SiO_2. The fundamental structure may have two substructures depending on the width of the MO-layer: (Fig. 3)

- If the MO layer is 80 nm — which is considered to be thick and the tolerance is not critical — then the reading laser practically does not penetrate the MO layer. In this case the width of the 1st dielectric (80 nm) must be held within $\pm 2\%$.
- In the case of the second version, the MO layer is much thinner, as a rule 10 nm thick, so the laser light penetrates the magnetooptical layer. Since the detector is on the side of the laser source, it is necessary to put an Al mirror after — or, in some cases instead of — the 2nd dielectrics to enhance reflection.

With some experimental realization the above described layer-structure is the base for the double-side final-product disc in the manner that the two half discs are stuck together.

Acknowledgement

The theory and development of magnetooptical discs have emerged and become in all its depth as a development programme at the VIDEOTON thanks to the activity of Prof. János Giber. Thanks to Prof. Giber besides the magnetooptical layers described in the paper we have had the chance to deal with all the theoretical and technological problems beginning at the production of the substrate and ending at the final product. This way we could get an insight into the latest results of the high technology.

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