

Description

Technical field

This invention relates to a magneto-optical recording medium including an amorphous thin film having magnetic anisotropy, whereby the thin film possesses a stable magnetic easy axis perpendicular to the plane of the film itself. The composition of the thin film is used as a light modulator, in which light interacting with the thin film is affected by the presence of a magnetic domain at the incident spot.

Background

Magneto-optic recording media are also known by several other names: thermomagnetic media, beam addressable files, and photo-magnetic memories. All of these terms apply to a storage medium or memory element which responds to radiant energy permitting the use of such energy sources as laser beams for both recording and interrogation. Such media modify the character of an incident polarized light beam so that the modification can be detected by an electronic device such as a photodiode.

This modification is usually a manifestation of either the Faraday effect or the Kerr effect on polarized light. The Faraday effect is the rotation of the polarization plane of polarized light which passes through certain magnetized media. The Kerr effect is the rotation of the plane of polarization of a light beam when it is reflected at the surface of certain magnetized media.

Magneto optic recording media have several advantages over known magnetic recording media:

1. The spacing between the medium and the recording head is greater, thus reducing potential for contact and wear;

2. Using a pulsed laser beam as the writing means, very high density data storage is possible.

3. With an interference layer on top of a magneto optic layer, the medium is affected less by dust than magnetic media.

In magneto optical recording, data is written into a medium having a preferentially directed remanent magnetization by exposing a localized area (spot or bit) on the recording media to an electromagnetic or other energy source of sufficient intensity to heat the recording medium above its compensation or Curie point temperature and simultaneously biasing the medium with a magnetic field. Preferably, the energy source is a laser which produces a monochromatic output beam. The magnetic field required to reverse the magnetization of the recording medium varies with the temperature to which the recording medium is brought. Generally speaking for a given material, the higher the temperature, the smaller the required magnetic field coercive force.

The write or record operation for both Curie point and compensation point writing is as follows:

1. The medium is initially in a demagnetized state having about equal numbers of magnetic domains with magnetization oppositely directed and perpendicular to the surface of the film. A domain will herein refer to the smallest stable magnetizable region; although, in common usage a domain is a uniformly magnetized region of any size. The medium may be subjected to a saturation magnetic bias field normal to the surface of the film in order to magnetize all the domains in one direction. Alternatively, a selected area of the medium may be magnetized by exposing said area to a continuous light beam and a small magnetic bias field.

2. A small magnetic bias field oriented perpendicular to the surface or plane of the film, but oppositely directed to the magnetic field applied earlier is applied over the entire thin film medium.

3. With the biasing field in place, a light beam from a radiant energy source such as a laser beam is directed toward a selected location or bit on the film where it causes localized heating of the film to a temperature at or above the compensation temperature. When the laser beam is removed, the bit cools in the presence of the biasing magnetic field and has its magnetization switched to that direction. The medium, in effect, has a magnetic switching field which is temperature dependent. The magnetic biasing field applied to the irradiated bit selectively switches the bit magnetization, with the bit momentarily near its compensation temperature under the influence of the laser. The momentary temperature rise reduces the bit coercive force.

In the write operation, the write laser beam (e.g. about 8—12 mW) is focused to the desired diameter (e.g. 10^{-6} m (1.0 microns)) onto the surface of the recording medium by an objective lens.

The memory element or recorded bit is interrogated, or read, nondestructively by passing a low-power (e.g. 1—3 mW) beam of polarized light (e.g. a laser beam) through the bit storage site for a sufficiently short time so as not to heat the medium to change its magnetic state. The read laser beam is normally shaped to a circular cross-section by a prism, polarized and focused to some small diameter (e.g. 10^{-6} (1.0 microns)) onto the recording medium by a lens. When the read beam has passed through the recorded spot, it is sent through an optical analyzer, and then a detector such as a photodiode, for detection of any change or lack of change in the polarization.

A change in orientation of polarization of the light is caused by the magneto-optical properties of the material in the bit or site. Thus, the Kerr effect, Faraday effect, or a combination of these two, is used to effect the change in the plane of light polarization. The plane of polarization of the transmitted or reflected light beam is rotated through the characteristic rotation angle θ . For upward bit magnetization, it rotates θ degrees and for downward magnetization $-\theta$ degrees. The recorded data, usually in digital form represented by logic values of 1 or 0 depending on the direction of bit magnetization, are detected by

reading the change in the intensity of light passing through or reflected from the individual bits, the intensity being responsive to the quantity of light which is rotated and the rotation angle.

Erasure can be accomplished by simply writing new information over old portions of the medium or by simply exposing any given bit with a laser beam of sufficient intensity and then cooling that bit in the presence of a magnetic field in the direction of the initially applied magnetic field. The entire storage medium can be erased by providing a large magnetic bias field in the original saturation direction which does not require a laser beam. Generally, in the recording process, the external biasing magnetic field is applied by a magnet set above or behind the magneto optic medium, and in the erasing process, the magnet is reversed in direction.

The signal-to-noise ratio (SNR) or carrier-to-noise ratio (CNR) of an erasable magneto optic medium is proportional to θ^2/R , where R equals power reflectivity of the medium and θ is the angle of rotation. Forty-five decibels in a 30 kHz band width is generally considered the minimum CNR acceptable for direct read after write (DRAW) media. The speed at which the bits can be interrogated and the reliability with which the data can be read depends upon the magnitude of the magneto-optical properties, such as the angle of rotation, of the thin film and upon the ability of the interrogation system to detect these properties. An increase in the angle of rotation θ results in an increase in CNR.

For purposes of this discussion, the noise floor or noise level is measured at the average noise level.

The main parameters that characterize a magneto optic material are the angle of rotation, the coercive force (H_c), the Curie temperature and the compensation point temperature. The medium is generally comprised of a single element or multicomponent system where at least one of the components is an amorphous metal composition. Binary and ternary compositions are particularly suitable for these amorphous metal alloys. Suitable examples would be rare earth transition metal (RE-TM) compositions such as: Gadolinium-cobalt (Gd-Co), Gadolinium-iron (Gd-Fe), Terbium-iron (Tb-Fe), Dysprosium-iron (Dy-Fe), Gd-Tb-Fe, Tb-Dy-Fe, Tb-Fe-Co, Terbium-iron-chromium (Tb-Fe-Cr), Gd-Fe-Bi (Bismuth), Gd-Fe-Sn (Tin), Gd-Fe-Co, Gd-Co-Bi, and Gd-Dy-Fe.

Japanese patent publication number 56/143547 discloses a magneto optic medium of the type just discussed. It comprises a thin film of gadolinium-terbium-iron alloy in a ratio of 0.24/0.18/1 which film is more than 1000 angstroms thick when using the Kerr effect and 500 to 800 angstroms thick when using the Faraday effect. The film of this patent also has 540 nm a (5400 angstrom) thick glass (silicon dioxide) film on top of the Gd:Tb:Fe film.

The magneto optic amorphous thin films can be fabricated by known thin film deposition techniques, such as sputtering, evaporation and sput cooling. In sput cooling a hot liquid of the film constituents is incident on a cool surface where they are quenched and solidified rapidly to form an amorphous bulk film. Generally, no matter what deposition rate is used, the substrate temperature must be less than that at which crystallization occurs in order to provide amorphous magnetic materials.

The preferred process for thin film deposition is sputtering. Typical known sputtering conditions for amorphous thin films are: initial vacuum less than 1.33×10^{-3} Pa (1×10^{-5} Torr); sputtering pressure of from 4×10^{-4} to 2.67 Pa (3×10^{-2} to 2×10^{-2} Torr); pre-sputtering of a sputtering source of material to clear the surface thereof; substrate temperature of 30° to 100°C; and an argon partial pressure.

In the cathodic sputtering process, argon gas ions bombard the solid alloy target cathode in the sputtering chamber dislodging metal atoms by transferring the momentum of the accelerated ions to the metal atoms near the surface of the target. The cathode is said to glow, and the mass of ionized gas between the cathode and the anode is a plasma. The substrate is placed at the anode, and the metal alloy atoms traverse the space between the anode and cathode to deposit or condense on the substrate.

The object of this invention is to enable the manufacture of a magneto optic medium which has a carrier-to-noise ratio of at least 45 decibels and has an excellent quality of interaction between the medium and the optical system to take advantage of the inherent quality of the medium. This involves not only maximizing theta, but also decreasing the intensity of the inherent noise level in the medium.

50 Disclosure of invention

According to the present invention, there is provided a magneto-optical recording medium comprising a substrate bearing a magnetizable amorphous film, the film containing an element with an unpaired electron and having a magnetic anisotropy perpendicular to the film surface, characterized in that the film has an oxygen concentration of less than one atom percent and the composition of the magnetizable amorphous film is such that the rotation angle for polarized light reflected from the medium is at least 0.4° measured with a laser diode at a wavelength of 780 to 850 nanometres (7800 to 8500 Ångstroms).

Many film substrates can be used. They may be formed of any material which is dimensionally stable, minimizing radial displacement variations during recording and playback. Semiconductors, insulators, or metals can be used. Suitable substrates include glass, spinel, quartz, sapphire, aluminum oxide, metals such as aluminum and copper, and polymers such as polymethyl-methacrylate and polyester. The substrate is typically in the form of a disc.

This medium can be incorporated into a multilayer construction, wherein it is sandwiched between optical interference layers. The resulting observed effective magneto optic rotations of polarized light with the sandwich construction (in the range of 1 to 10°) are relatively large and represent an improvement over values of theta reported for rare earth transition metal (RE-TM) multi-layer constructions in the literature.

The above-described erasable optical recording medium also has more precise bits (i.e. less average bit roughness) than known media, due to the smaller size of the domains (usually about 10 nm (100 angstroms)). Bits are typically 1 to 5×10^{-6} m (1 to 5 microns) in longest dimension.

Although a Kaufman source or duoplasmatron could be used, the triode sputtering process is preferred for depositing the amorphous thin films. Under ordinary, higher pressure cathodic sputtering conditions, the sputtered atoms lose kinetic energy through collision with gas molecules. The deposition rate is inversely proportional to sputtering pressure and the distance between the receiving surface and the cathode. Triode sputtering, in addition to the main anode and cathode, has a thermionic cathode (emitter) and anode which has the advantage that a plasma can be maintained at much lower pressures than a direct current glow discharge (even in a magnetic field or magnetron). The ability of a triode sputtering apparatus to maintain an argon plasma at very low vacuums permits the deposition of these thin films at vacuums in the range of 0.53 to 8×10^{-2} Pa (4×10^{-3} to 6×10^{-4} Torr). The metal atoms which diffuse across the space between the sputtering cathode and anode are able to strike the substrate at a higher energy than they would at a lower vacuum since there are fewer argon ions in the space to interfere with the motion of the metal atoms, giving a greater mean-free path.

With triode sputtering, there are also more nucleation sites on the substrate because of the statistically higher rate of bombardment by energetic film constituent (metal alloy) atoms. This is believed to lead to a magneto optic film having a smoother surface than otherwise would occur. This in turn, leads to a magneto optical recording medium in which the surface of the film yields a background noise level that is at least 50 decibels below the carrier level when a 2 milliwatt peak-to-peak laser beam modulated at about 5.0 megahertz is reflected from the unwritten medium moving at a linear velocity of about ten meters per second. For the media of this invention, background noise is usually at least 65 decibels below the carrier level under the conditions stated above.

Although the media of this invention are erasable, they may be used in the same application as write-once or non-erasable media.

Brief description of the figures

Figure No. 1 is a transmission electron microscope photomicrograph at $200,000 \times$ of an amorphous metal alloy thin film magneto optical medium of this invention.

Figure No. 2 is an electron beam diffraction pattern of an amorphous metal alloy magneto optical thin film medium of the invention.

Figure No. 3 is a profile of the electron beam diffraction pattern for the inventive magneto optic medium in Figure 2.

Figure No. 4 is a set of magnetic hysteresis loops for magneto optic films of this invention.

Figure No. 5 is a set of optical hysteresis loops for magneto optic films of this invention.

Detailed description of the invention

The good performance characteristics of these media (high θ and CNR) are thought to be attributable to physically identifiable features in the media. The two features believed to be most important are the existence of small domains and the optical constants of the recording medium (high refractive index and low extinction coefficient). Index of refraction (n) and extinction coefficient (k) for a gadolinium-terbium-iron alloy film of this invention have been determined to be 4.5 and 1.8 respectively. Domain size is preferably less than 20 nm (200 angstroms) in largest dimension. Thus, a one micrometer bit can be made up of many magnetized domains. Figure 1 indicates domain boundary walls of 20 nm (200 angstroms) or less in largest dimension.

Domain formation in magnetic materials is well known. However, the teachings of the prior art lead to the conclusion that as domain size decreases into the extremely small range of this invention, the domains would be unstable. A bit comprised of unstable domains will generally undergo observable changes within about two minutes after it has been recorded, such as changes in location on the medium, CNR and bit size. A loss in CNR can indicate increased bit edge roughness. Stable bits are needed in order to maintain the integrity of recorded data for long periods.

A 5 1/4 inch (133 mm) diameter disc medium having a Gd-Tb-Fe amorphous alloy film of this invention coated thereon was tested for stability by recording a series of bits at 9 milliwatts laser power using a bias magnetic field of about 1.99×10^4 A/m (250 Oersteds). The recorded bits were read at 3.0 milliwatts laser power immediately after recording and about 14 days later. Within the limits of experimental error there were no changes in CNR, bit size or read signal amplitude between the two readings, indicating good bit and domain stability. Recorded bits on the inventive media have been stable for months.

The magnetizable amorphous film of the media herein described contains an element having an unpaired electron. One amorphous alloy composition particularly well-suited to this invention is gadolinium-terbium-iron ternary alloy. The composition range preferred is 6—15 atom percent gadolinium, 10—20 percent terbium and 65—84 percent iron. One composition made in the course of this invention was about 14% Gd, 17% Tb and 69% Fe. The Curie point temperature of this medium is about 120°C . The thin films made of this composition are generally greater than 50 angstroms thick and have a coercivity sufficient to create a stable memory. At a minimum, this should be about $3.98 \cdot 10^4$ A/m (500 Oe), but a range of 1.6×10^5 to 2.4×10^5 A/m (2000 to 3000 Oe) is generally used.

As shown by Figure 2, which is an electron beam diffraction pattern of such a ternary alloy made on a 200 keV apparatus, these materials show a diffraction pattern with broad halos that are not easily assigned a crystalline structure. In diffraction patterns, amorphous character is indicated by line broadening to the point where individual lines overlap. A broadened ring or fuzzy area which is divided by a concentric line is known as a split ring and indicates some short range ordering in the amorphous character of the film.

The information from the photographic image of the diffraction pattern can be translated to a profile plot of the diffracted intensity versus distance from the center of the diffraction pattern to give a more precise indication of amorphous character. The profiles of amorphous materials lack distinct peaks; whereas, those of crystalline materials have a number of quite distinct peaks indicating the lattice spacing or spacing between the atomic orbitals within the lattice.

As explained before, a triode sputtering process is suitable for depositing the magneto optic films of this invention. In the experiments by which this process was reduced to practice, the argon used for the sputtering was ultrahigh purity, (99.999 percent minimum purity). Argon flow rate into the triode sputtering apparatus was about 50 standard cubic centimeters per minute (scc/min), at a pressure of about 1.73×10^{-1} Pa (1.3 milli-Torr) (which implies about 3 parts per million of gas present in the system). This represents a decrease in the presence of oxygen present in and flushed through the system by a multiple of at least 20 to 100 times less than ordinary direct current or radio frequency cathode sputtering.

The triode sputtering apparatus comprises a vacuum chamber containing a sputtering cathode target where the metal alloy is placed. The alloy sputters to provide an accumulation on the substrate which is placed on the anode substrate holder. The anode is held at a low negative bias voltage with respect to the chamber wall. The cathode target is water cooled, and the substrate can be made to rotate through an external drive means. A shutter is usually provided between the target and the anode to allow sputter cleaning of the substrate. Magnetically assisted triode sputtering is preferred, in which a magnetic field is imposed in line with the thermionic cathode and anode to confine the electrons to the plasma of ionizing gas and keep them away from the substrate where electron bombardment would cause heating. The sputtering chamber itself is made of stainless steel.

The optical properties of an amorphous thin film are a function of both the composition and the process by which the composition is formed or deposited. It is known that rare earth metals oxidize readily, and the control over this oxidation is an important part of the process of this invention to lead to a product of higher purity. If the anode is given a negative potential, with respect to the plasma, the resulting technique is referred to as bias sputtering. This bias is believed to cause a preferential removal of impurities such as oxygen from the main film by resputtering.

Radio frequency (RF) sputtering (rather than direct current) can be used to effect cleaning and to deposit insulators, such as transparent dielectric films. In this technique, a radio frequency alternating voltage is applied to the sputtering chamber by means of RF electrodes.

In operation, the sputtering chamber is typically pumped down to some initial background pressure (e.g. 5.33×10^{-5} Pa (4.0×10^{-7} Torr)) after which the sputter gas (argon) is introduced. Typically, the substrate is cleaned by pre-sputtering or sputter etching for about 60 seconds at a bias voltage of about 300 volts. The substrate is exposed to the flux of atoms from the target after the predetermined sputtering conditions have been reached. The deposition rate of the magneto optic film is generally 0.05 to 0.4 nm (0.5 to 4.0 angstroms) per second in the case of the gadolinium terbium iron ternary alloy. A thin film thermocouple is located near the anode substrate holder to measure the approximate substrate and equilibrium plasma temperature.

The higher vacuum of the triode apparatus appears to result in thin films of higher density and higher index of refraction than known magneto optic films such as those of U.S. Patent No. 3,965,463.

It has been observed that the character of the magneto optic film at its surface can be different from the bulk properties of the film. This has been particularly evident in comparing coercivity measurements for the surface and the bulk of an unpassivated film. H_c (coercivity) has been found to vary by an order of magnitude in extreme cases. These changes are especially important in an optical memory system, since the interaction of the read optical beam and the RE-TM storage materials occurs in the first 15 to 20 nm (150 to 200 angstroms) of the film. Oxidation of the rare earth is suspected of being the main cause of changes in the characteristics of thin film at the surface.

Passivation is the change of a chemically active metal surface to a much less reactive state. By coating the RE-TM films with a passivation layer, typically consisting of less than 30 nm (300 angstroms) thick of SiO_x (x less than 2) the change in characteristics with time has been nearly eliminated, and higher magneto optic rotations have been measured than were previously obtained for RE-TM films without such a layer. This represents a significant increase in the stability of rare earth-transition metal magneto optical memory materials. Other materials useful for the passivating layer are: titanium dioxide, SiO_2 , cerium oxide, aluminum oxide, and aluminum nitride.

A depth profile of elements in a sample of the inventive media having a Gd-Tb-Fe alloy film passivated by a covering of SiO_x glass was made by Auger Electron Spectroscopy (AER) and by secondary ion mass spectroscopy (SIMS). The results indicated oxygen level in the Gd-Tb-Fe film of less than one atom percent. Electron Spectroscopy for Chemical Analysis (ESCA) has shown the SiO_x films deposited over the Gd-Tb-Fe films to have x of 1.2—1.6 or an oxygen content of 55—62 atom percent. Depth profile analysis shows

EP 0 125 881 B1

oxygen level within the Gd-Tb-Fe films to be about 200 times less than it is in the SiO_x , or by implication about 0.3 atom percent.

This invention will be further clarified by considering the examples which will follow in this description. They are intended to be purely exemplary.

Example I

A magneto optic film of a specified thickness was deposited on a reflector. This bi-layer was then overcoated with a third layer of SiO_x dielectric. The choice of the reflector generally relates to its efficiency of reflectivity at the wavelength of interest. The thickness of the magneto optic film will be dependent upon its optical properties as observed at the wavelength of the light of interest. The magneto optic material must be semi-transmissive in order to obtain increases in rotation from both the Faraday and Kerr effects. Films of Gd (11 atom percent) Tb (11 atom percent) with the balance being Fe (as determined by x-ray fluorescence) were deposited on copper coated (reflective layer) and uncoated plain glass slides. The angle of rotation, theta, was measured both with a helium neon (HeNe) laser, wavelength 632.8 nm (6328 angstroms)) and a laser diode (L.D. wavelength 830 nm (8300 angstroms)). The results are given in Table 1 below.

TABLE 1

	Sample number	Substrate		Magneto-optic nm (Å) film thickness	SiO_x nm () thickness	Rotation Angle	
		Cu Coated glass	Uncoated glass			HeNe	L.D.
25	132	X		38.5 (385Å)	27 (270)	0.27	0.47
	139	X		" (385Å)	95 (950)	1.12	1.10
	138	X		" (385Å)	102.5 (1025)	1.32	1.37
30	140	X		" (385Å)	106.5 (1065)	1.27	1.55
	145 on 144	X		" (385Å)	110 (1100)	.45	1.71
35	141	X		" (385Å)	120 (1200)	1.21	1.69
	142	X		" (385Å)	124 (1240)	0.87	1.96
	143	X		" (385Å)	130 (1300)	0.45	1.73
40	130	X		30.0 (300Å)	30 (300)	0.36	0.47
	129	X		" (300Å)	43.5 (435)	0.35	0.44
45	128	X		" (300Å)	61 (610)		0.70
	126	X		" (300Å)	74 (740)		0.85
	133	X		" (300Å)	87.8 (878)	1.75	1.21
50	137	X		" (300Å)	95 (950)	1.30	1.43
	134	X		" (300Å)	101 (1010)	0.86	1.68
55	136	X		" (300Å)	105 (1050)	0.99	1.55
	135	X		" (300Å)	119.5 (1195)	0.68	1.48
	132		X	38.5 (385Å)	27 (270)	0.08	0.17
60	139		X	" (385Å)	95 (950)	0.18	0.23
	138		X	" (385Å)	102.5 (1025)	0.41	0.29
65	140		X	" (385Å)	106.5 (1065)	0.36	0.25

TABLE 1 (cont.)

5	Sample number	Substrate		Magneto-optic nm (Å) film thickness	SiO _x nm () thickness	Rotation Angle	
		Cu Coated glass	Uncoated glass			HeNe	L.D.
	141		X	" (385Å)	120 (1200)	0.24	0.18
10	142		X	" (385Å)	124 (1240)	0.58	0.26
	143		X	" (385Å)	130 (1300)	0.47	0.54
	130		X	30.0 (300Å)	30 (300)	0.04	0.11
15	129		X	" (300Å)	43.5 (435)	0.06	0.17
	128		X	" (300Å)	61 (610)		
20	126		X	" (300Å)	74 (740)	0.01	0.11
	133		X	" (300Å)	87.8 (878)	0.03	0.12
	137		X	" (300Å)	95 (950)	0.31	0.12
25	134		X	" (300Å)	101 (1010)	0.67	0.15
	136		X	" (300Å)	105 (1050)	0.19	0.16
30	135		X	" (300Å)	119.5 (1195)	0.73	0.14
	144	X		38.5 (385Å)	— (—0—)	0.23	0.40
	147	X		97.0 (970Å)	95 (950)	0.70	0.76
35	147		X	" (970Å)	95 (950)	0.68	0.75

The thicknesses of the magneto optic film and the silicon suboxide film were measured by a double beam interferometer. These results indicate the dependence of rotation angle on both the thickness of the magneto optic film and that of the interference film. They also indicate the clear advantage of using a magneto optic film deposited over a reflector.

Various apparatus and methods are available and known to the art for reading data stored in magneto optic media, as is illustrated in U.S. patent 3,651,281 Fig. 3 and column 6 and 7. The same sort of arrangement may be used to test magneto optic media with some modifications. The basic testing apparatus comprises a laser diode emitting a beam which is directed by means of various dielectric mirrors, plano mirrors, polarizers, lenses and prisms to the magneto optic medium, and from there to a set of detectors which translate the intensity of the rotated light beam into an electronic signal. The laser diode emits a diverging beam at a wavelength about 830 nm (8300 angstroms), which is polarized, modulated, collected and collimated by a lens and made circular by a prism. This circular beam is directed by mirrors through a focusing head onto the medium. By virtue of the combined Kerr and Faraday rotations, the plane of polarization of the light is rotated through angle theta. Upon reflection, all of the rotated light, as well as part of the non-rotated light, is directed onto a read path through polarizing beam splitters and toward photodiode detectors. Focusing of the read beam onto the medium can be done by imaging optics means (e.g., a TAOHS type .6 NA lens head from Olympus Co.).

A biasing magnet is located near the medium at the point where the beam strikes it. The bias field used in recording can influence carrier-to-noise ratio. However, as long as the bias field is more than about 2.4×10^4 A/m (300 Oersteds), CNR is relatively independent of bias field strength.

The triode sputtering process can be used to control several parameters of the final magneto optic film.

The magnetic and optical hysteresis curves depicted in Figures 5 and 6 represent the characteristics of three gadolinium, terbium, iron alloy films produced by triode sputtering under 3 different conditions. The films were all of the same composition (13.5 percent gadolinium, 16 percent terbium and 70 percent iron), and they were all about 200 nm (2000 angstroms) thick. Film DC1 was sputtered on at 130°C.; DC2 at 200°C; and DC11 at 270°C. It is the more rectangular hysteresis loops of Sample DC11 which are desired.

An additional series of experiments showed that a decreasing rare earth concentration results in an

increased tendency to form a longitudinal component in the magneto optic film. An applied magnetic field around the target in the sputtering process also results in the formation of a longitudinally oriented medium. On the other hand, an increase in the deposition rate results in the suppression of the longitudinal component of the ternary alloy to some extent.

The different amorphous phases, which are necessary to the existence of domains adjacent to each other, appear to be dependent upon deposition rate, temperature, and film thickness.

Also, the anode or substrate bias has been found to be a useful control in the triode sputtering process. In one series of experiments, keeping all conditions the same except for substrate bias, which was varied from 0 volts to 623 volts, it was found that the rectilinearity of the magnetic hysteresis curve was increased substantially with increasing anode bias.

When a magnetizable amorphous film is deposited on a reflector, it is known that the magneto optic rotation is increased because the Faraday effect is added to the Kerr effect. The former effect rotates the plane of polarization of the light as it passes back and forth through the magneto-optic layer while the Kerr effect rotates it at the surface of the layer. Therefore, it is beneficial to deposit the magnetizable amorphous films on a substrate which has been reflectorized. Typical reflecting layers are copper, aluminum or gold.

The performance of these media may also be improved by interference enhancement. The read beam reflected from a magneto optic medium has a regular component I_x and a magneto optically induced component I_y . The magnitude of the light rotation effect I_y is determined both by the inherent properties of the medium and the ability to transmit the rotated radiation from the medium to some outside detecting means. This latter aspect is affected by optical interference layers. In addition to optical effects, an overlayer of transparent dielectric, such as glass, can reduce the effect of oxidation on the amorphous metal alloy. Such overlayers also reduce the effect of dust and impurities on the transmission of the read beam. These media are generally known as interference enhanced media. The recording sensitivity of the magnetic thin layer varies in response to the thickness of the dielectric interference layer covering it and also with the magneto optic amorphous alloy composition and the wave length of the incident light.

The dielectric anti-reflection coating on top produces some gain; however, further increases in the efficiency of conversion can be brought about by a tri-layer film in which the magneto optic film is deposited on a transparent dielectric film which itself rests on an opaque reflector. This intermediate dielectric layer ideally has a thickness of some integer multiple of $\lambda/4$, where λ is the wavelength of the read beam light. When this condition is met, the rotated component (I_y) of the magneto optically induced light, which is emitted both forwards and backwards from the magneto optic thin film, is maximized by in phase addition of the exiting rays. An overlayer of a transparent anti-reflective dielectric film can also be used in conjunction with the intermediate layer. In this case, the structure is known as a quadrilayer structure.

Example II

A polymerically subbed polished aluminum disc, having a diameter of 30 centimeters was provided. This disc had been made by coating a polished aluminum disc, which had been previously cleaned, with a polymer (e.g. styrene-butadiene polymer). A solution of the polymer (e.g. about 4% solids in a solvent with a boiling point greater than about 140°C), had been applied to the disc (while it was spinning). The solvent was evaporated, leaving a thin polymeric subbing layer. The function of the subbing layer is to provide a very smooth surface for recording. The polymer should wet and adhere to the aluminum surface.

The subbed disc was coated with a priming layer of chromium oxide (to promote adhesion of the reflecting layer to the substrate) by magnetron sputtering using a chromium target in an atmosphere of argon, water vapor and air. The chromium oxide sputtering was continued for about one to two minutes at a target current of about 500 mA and a background operating pressure of about 2.7×10^{-3} Pa (2×10^{-5} Torr), thereby obtaining a nucleation, adhesion-promoting layer of about 4.0 nm (40 angstroms) thick. Other suitable priming materials would be the oxides of titanium, tantalum and aluminum.

Over this, a reflecting copper layer about 100 nm (1000 angstroms) thick was applied by vacuum, resistance evaporation at a background pressure of about 2.7×10^{-4} Pa (2×10^{-6} Torr). The substrate thus prepared was cleaned by sputter etching for about 60 seconds at a bias voltage of about 300 volts in the presence of argon. An intermediate glass film of silicon suboxide (SiO_x) was deposited from a silicon monoxide smoke source (obtained from RD Mathis Company in Long Beach, California) to a thickness of about 25 nm (250 angstroms) by sputtering.

The triode sputtering method was then used to coat the prepared substrate with gadolinium, terbium, iron alloy. High-purity argon gas was leaked into the triode sputtering apparatus creating a background pressure of about 1.6×10^{-1} Pa (1.2×10^{-3} Torr), and the deposition of the ternary alloy film was carried out under a substrate bias of about 300 volts and a target bias of about 300 volts. The deposition rate was in the range of 0.25 to 0.3 nm (2.5 to 3 angstroms) per second with a final film thickness of about 28.5 nm (285 angstroms). At a vacuum of less than about 1.2×10^{-4} Pa (9.0×10^{-7} Torr), a glass overcoat of about 136 nm (1360 angstroms) thick was deposited from an SiO_x smoke source.

The alloy target used to create this magneto optic film was a mosaic of the desired constituents. Final composition of the deposited films was determined by energy dispersive x-ray fluorescence spectroscopy. The composition of the produced sample number 34-195 was determined to be 6.5 atom percent gadolinium, 10.0 percent terbium and 83.5 percent iron.

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EP 0 125 881 B1

Table 2 indicates various magneto optic properties of Sample 34-195 and compares them to certain published values of known magneto optic media. All the data for sample 34-195 was recorded and read at a 115 mm radius on the disc.

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Sample

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Samples Pub 1—4 are taken from Imamura, Nobutake, "The Development of Magneto-Optical Disc Memory With Semi-conductor Lasers", KDD Research and Development Laboratory, Tokyo, Japan, and the data for sample Pub-5 is taken from Bell, Alan E., "Optical Data Storage" *Laser Focus*, January, 1983.

Figure 1 is a transmission electron microscope photomicrograph of the medium of sample 34-195 at 200,000 $\times$. The very small domain size is suggested by this photograph. The space between the hash marks A denotes a distance of 200 angstroms, and the small identifiable spots, believed to represent domains, appear smaller than distance A in largest dimension.

Figures 2 and 3 are the electron beam diffraction pattern and profile respectively for the medium of sample 34-195, showing its amorphous character.

Except for the carrier to noise ratio at the lowest write laser power of 6 milliwatts, the carrier-to-noise ratio of the inventive sample is significantly greater than that of the published media. It is felt that a CNR of at least 60 can be obtained using the techniques and materials described above.

Example III

A sputtering target was made by placing terbium chips onto an iron target having an approximate area of 7742 mm². The chips were about 10 mm $\times$ 25 mm in size, and the areal ratio used was 25.8% Tb to 74.2% Fe.

5 1/4 inch (133 mm) diameter polymethyl methacrylate (PMMA) discs were used as substrates. The discs were grooved and had a subbing layer made of 100% solids photopolymer cured with ultraviolet light. One substrate plus four slides (two PMMA and two glass) were loaded into the sputtering chamber, the disc being mounted on a rotating platen.

After pumping down the pressure to about 5.6×10^{-5} Pa (5.6×10^{-7} mbar), SiO_x was evaporated by resistance heating from a baffled source filled with silicon monoxide granules. It was deposited on the substrate at an average rate of about 0.55 nm/sec (5.5 Å/sec), to a thickness of about (400 Å). Pressure during SiO_x evaporation was about 6.2×10^{-5} Pa (6.2×10^{-7} mbar), and after evaporation it was about 7.3×10^{-5} Pa (7.3×10^{-7} mbar).

The next step was to radio frequency sputter etch the SiO_x just deposited. This was done in argon using 80 v for 30 seconds.

The triode sputtering apparatus was made ready for Tb-Fe sputtering. The argon flow was set at 28.6 sccm (standard cubic centimeters per second) while the triode emitter was warming up. The triode was stable with argon pressure at 1.3×10^{-1} Pa (1.3×10^{-3} mbar). The direct current (d.c.) bias power supply was turned on and warmed up to a constant voltage of 300 v and a current of 0.69 amps. The target was shuttered during these operations to prevent premature deposition. The triode operated in this warmed up state for about 30 seconds. The radio frequency substrate bias was turned on and adjusted to 80 v with 30 seconds duration.

At this point, the shutter covering the Tb-Fe target was opened and the radio frequency substrate bias adjusted to 200 v. The triode plasma supply operated at 5 amps and 49 v; target bias at a constant 0.69 amps at 300 v. d.c. The sputtering chamber pressure during sputtering was 1.3×10^{-1} Pa (1.3×10^{-3} mbar). Average deposition rate was 0.15—0.2 nm/sec (1.5—2.0 Å/sec), and deposition of the Tb-Fe was terminated when the Tb-Fe film thickness was about 27.5 nm (275 Å). Chamber pressure after this termination (gas flow off) was 5.2×10^{-5} Pa (5.2×10^{-7} mbar).

SiO_x was then coated over the Tb-Fe layer by evaporation, as described previously, to a thickness of about 29 nm (290 Å) at a pressure of 4.6×10^{-5} Pa (4.6×10^{-7} mbar). After a cool down time of about 30 minutes, the system was vented to dry nitrogen, opened up and the samples removed.

The disc and two of the slides (one plastic, one glass) were mounted onto a rotating substrate holder and placed in another vacuum chamber. After pumping down to a background pressure of 9.8×10^{-6} Pa (7.4×10^{-7} Torr), CrO_x primer was deposited over the second SiO_x layer. Oxygen at a flow of 0.5 sccm and argon at 56 sccm were left into the vacuum chamber. The argon and oxygen pressure with the throttle valve closed was 3.3×10^{-3} . Deposition of CrO_x by magnetically assisted diode sputtering from a chromium target proceeded for four seconds, giving a primer film thickness of about 10 nm (100 Å).

Next a copper layer was deposited by resistance heating copper in a molybdenum boat. Background pressure was 1.1×10^{-4} Pa (8×10^{-7} Torr). Copper was evaporated and deposited on the CrO_x primer at an average rate of 4 nm/sec (40 Å/sec), up to a film thickness of about 100 nm (1000 Å). Background pressure after copper deposition was 1.33×10^{-4} Pa (10^{-6} Torr).

A final SiO_x layer was deposited over the copper layer by electron beam evaporation of silica granules. Background pressure was 1.1×10^{-4} Pa (8×10^{-7} Torr). The SiO_x was evaporated with the electron gun at 8 Kv and was deposited at a rate of about 1.5 nm/sec (15 Å/sec), to a total thickness of about 120 nm (1200 Å).

The disk and slides were removed from the vacuum chamber, and analysis showed the magneto optic layer composition to be about 25 atom % Tb and 75% Fe. The following data were measured on the disc:

17

specular reflectance at 820 nm wavelength (using a spectroradiometer) 20.4%

Hc at room temperature

2.3×10^5 A/m (2900 Oe)

5 Dynamic tests

CNR at write laser power of 9 mW

52

background noise level

70 dB below carrier level

10 Example IV

The sputtering target as used in Example III was modified by placing eight cobalt chips, each being approximately 50 mm² in area, on the iron target surface between the previously described Tb chips. The areal ratios were 25.8% Tb, 67.2% Fe and 7% Co. The process was performed in a similar manner to Example III with the following exceptions:

15 In depositing the first SiO_x film the sputtering apparatus was pumped down to 2.6×10^{-4} Pa (2.6×10^{-6} mbar), and the SiO_x film was deposited at about 0.54 nm/sec (5.4 Å/sec) to a thickness of about 80 nm (800 Å). Pressure during evaporation was about 2.2×10^{-4} Pa (2.2×10^{-6} mbar) and 2.4×10^{-4} Pa (2.4×10^{-6} mbar) after evaporation.

20 In sputtering the Tb-Fe-Co layer: the d.c. target bias was warmed up to a constant current of 0.63 amps, triode plasma supply ran at 47 v; target bias was at 0.63 amps; and chamber pressure after termination of the Tb-Fe-Co film deposition was 2.1×10^{-4} Pa (2.1×10^{-6} mbar).

The second SiO_x coating step was at a pressure of 2.0×10^{-4} Pa (2.0×10^{-6} mbar) and deposited SiO_x at 0.51 nm/sec (5.1 Å/sec).

25 The vacuum chamber was pumped down to a background pressure of 1.2×10^{-4} Pa (9×10^{-7} Torr) prior to CrO_x deposition.

For the copper coating step, background pressure was 1.2×10^{-4} Pa (9×10^{-7} Torr), and chamber pressure after deposition was 1.65×10^{-4} Pa (1.24×10^{-6} Torr).

Background pressure for the deposition of the final SiO_x layer was 1.2×10^{-4} Pa (9×10^{-7} Torr).

Analysis showed the magneto-optic layer to have the following composition: 23% Tb, 66% Fe and 11%

30 Co.

The following data were measured on the disc:

specular reflectance at 820 nm wavelength

14.1%

35

room temperature Hc

2.3×10^5 A/m (2600 Oe)

Dynamic tests

CNR at write laser power of 12 mW

about 53

40

background noise level

67.4 dB below carrier level.

Claims

45 1. A magneto-optical recording medium comprising a substrate bearing a magnetizable amorphous film, the film containing an element with an unpaired electron and having a magnetic anisotropy perpendicular to the film surface, characterized in that the film has an oxygen concentration of less than one atom percent and the composition of the magnetizable amorphous film is such that the rotation angle for polarized light reflected from the medium is at least 0.4° measured with a laser diode at a wavelength of 780 to 850 nanometres (7800 to 8500 Ångstroms).

50 2. A recording medium according to claim 1, the film having magnetic domains of a domain size less than 50 nanometres (500 Ångstroms) in largest dimension, measured in the plane of the film.

3. A recording medium according to claim 1 or 2 further including a transparent passivating layer coated on top of the magnetizable amorphous film.

55 4. A recording medium according to claim 1, 2, or 3 further including a reflecting layer on which the magnetizable amorphous film has been deposited.

5. A recording medium according to any preceding claim wherein the amorphous film comprises an alloy of at least one rare earth element and at least one transition metal.

6. A recording medium according to claim 5 wherein said alloy is selected from the group consisting of gadolinium-terbium-iron, terbium-iron and terbium-iron-cobalt alloys.

60 7. A recording medium according to any preceding claim wherein the said oxygen concentration is about 0.3 atom percent.

Patentansprüche

65 1. Magnetooptischer Aufzeichnungsträger mit einem Substrat, das eine magnetisierbare amorphe Schicht trägt, die ein Element enthält, das ein ungepaartes Elektron besitzt und das eine zu der Oberfläche

specular reflectance at 820 nm wavelength (using a spectroradiometer) 20.4%

Hc at room temperature

2.3×10^5 A/m (2900 Oe)

5 Dynamic tests

CNR at write laser power of 9 mW

52

background noise level

70 dB below carrier level

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The sputtering target as used in Example III was modified by placing eight cobalt chips, each being approximately 50 mm² in area, on the iron target surface between the previously described Tb chips. The areal ratios were 25.8% Tb, 67.2% Fe and 7% Co. The process was performed in a similar manner to Example III with the following exceptions:

15 In depositing the first SiO_x film the sputtering apparatus was pumped down to 2.6×10^{-4} Pa (2.6×10^{-6} mbar), and the SiO_x film was deposited at about 0.54 nm/sec (5.4 Å/sec) to a thickness of about 80 nm (800 Å). Pressure during evaporation was about 2.2×10^{-4} Pa (2.2×10^{-6} mbar) and 2.4×10^{-4} Pa (2.4×10^{-6} mbar) after evaporation.

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The second SiO_x coating step was at a pressure of 2.0×10^{-4} Pa (2.0×10^{-6} mbar) and deposited SiO_x at 0.51 nm/sec (5.1 Å/sec).

25 The vacuum chamber was pumped down to a background pressure of 1.2×10^{-4} Pa (9×10^{-7} Torr) prior to CrO_x deposition.

For the copper coating step, background pressure was 1.2×10^{-4} Pa (9×10^{-7} Torr), and chamber pressure after deposition was 1.65×10^{-4} Pa (1.24×10^{-6} Torr).

Background pressure for the deposition of the final SiO_x layer was 1.2×10^{-4} Pa (9×10^{-7} Torr).

30 Co. Analysis showed the magneto-optic layer to have the following composition: 23% Tb, 66% Fe and 11% Co.

The following data were measured on the disc:

specular reflectance at 820 nm wavelength

14.1%

35 room temperature Hc

2.3×10^5 A/m (2600 Oe)

Dynamic tests

CNR at write laser power of 12 mW

about 53

40 background noise level

67.4 dB blow carrier level.

Claims

45 1. A magneto-optical recording medium comprising a substrate bearing a magnetizable amorphous film, the film containing an element with an unpaired electron and having a magnetic anisotropy perpendicular to the film surface, characterized in that the film has an oxygen concentration of less than one atom percent and the composition of the magnetizable amorphous film is such that the rotation angle for polarized light reflected from the medium is at least 0.4° measured with a laser diode at a wavelength of 780 to 850 nanometres (7800 to 8500 Ångstroms).

50 2. A recording medium according to claim 1, the film having magnetic domains of a domain size less than 50 nanometres (500 Ångstroms) in largest dimension, measured in the plane of the film.

3. A recording medium according to claim 1 or 2 further including a transparent passivating layer coated on top of the magnetizable amorphous film.

55 4. A recording medium according to claim 1, 2, or 3 further including a reflecting layer on which the magnetizable amorphous film has been deposited.

5. A recording medium according to any preceding claim wherein the amorphous film comprises an alloy of at least one rare earth element and at least one transition metal.

6. A recording medium according to claim 5 wherein said alloy is selected from the group consisting of gadolinium-terbium-iron, terbium-iron and terbium-iron-cobalt alloys.

60 7. A recording medium according to any preceding claim wherein the said oxygen concentration is about 0.3 atom percent.

Patentansprüche

65 1. Magnetooptischer Aufzeichnungsträger mit einem Substrat, das eine magnetisierbare omorphen Schicht trägt, die ein Element enthält, das ein ungepaartes Elektron besitzt und das eine zu der Oberfläche



der Schicht recht rechteckige magnetische Anisotropie besitzt, dadurch gekennzeichnet, daß die Schicht eine Sauerstoffkonzentration von weniger als einem Atomprozent besitzt und daß die magnetisierbare amorphe Schicht eine solche Zusammensetzung hat, daß der Drehwinkel des von dem Träger reflektierten polarisierten Lichts bei Messung mit einer Laserdiode mit einer Wellenlänge von 780 bis 850 nm mindestens 0,4° beträgt.

2. Aufzeichnungsträger nach Anspruch 1, in dem die Schicht magnetische Domänen mit einer Domänengröße von weniger als 50 nm in der größten Abmessung besitzt, in der Ebene der Schicht gemessen.

3. Aufzeichnungsträger nach Anspruch 1 oder 2, mit einer oben auf die magnetisierbare amorphe Schicht aufgetragenen, durchsichtigen Passivierungsschicht.

4. Aufzeichnungsträger nach Anspruch 1, 2 oder 3, mit einer reflektierenden Schicht, auf die die magnetisierbare amorphe Schicht aufgetragen ist.

5. Aufzeichnungsträger nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die amorphe Schicht mindestens teilweise aus einer Legierung aus mindestens einem Seltenerdelement und mindestens einem Übergangsmetall besteht.

6. Aufzeichnungsträger nach Anspruch 5, dadurch gekennzeichnet, daß die Legierung aus der Gruppe ausgewählt ist, die aus den Legierungen Gadolinium-Terbium-Eisen, Terbium-Eisen und Terbium-Eisen-Kobalt besteht.

7. Aufzeichnungsträger nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die genannte Sauerstoffkonzentration etwa 0,3 Atomprozent beträgt.

Revendications

1. Support d'enregistrement magnéto-optique comprenant un substrat portant une pellicule amorphe magnétisable, cette pellicule contenant un élément comportant un électron non apparié et présentant une anisotropie magnétique perpendiculaire à la surface de la pellicule, caractérisé en ce que la pellicule a une concentration en oxygène de moins de 1 atome %, et la composition de la pellicule amorphe magnétisable est telle que l'angle de rotation de la lumière polarisée réfléchiée depuis le support est d'au moins 0,4 degré mesuré avec une diode laser à une longueur d'onde de 780 à 850 nanomètres (7800 à 8500 Angstroms).

2. Support d'enregistrement suivant la revendication 1, caractérisé en ce que la pellicule comporte des domaines magnétiques d'une taille de domaines de moins de 50 nanomètres (500 Angstroms) dans la dimension la plus grande, la mesure étant prise dans le plan de la pellicule.

3. Support d'enregistrement suivant la revendication 1 ou 2, caractérisé en ce qu'il comprend en outre une couche de passivation transparente appliquée sur la pellicule amorphe magnétisable.

4. Support d'enregistrement suivant la revendication 1, 2 ou 3, caractérisé en ce qu'il comprend en outre une couche réfléchissante sur laquelle la pellicule amorphe magnétisable a été déposée.

5. Support d'enregistrement suivant l'une quelconque des revendications précédentes, caractérisé en ce que la pellicule amorphe comprend un alliage d'au moins un élément de terre rare et d'au moins un métal de transition.

6. Support d'enregistrement suivant la revendication 5, caractérisé en ce que l'alliage susdit est choisi dans le groupe comprenant les alliages de gadolinium-terbium-fer, de terbium-fer et de terbium-fer-cobalt.

7. Support d'enregistrement suivant l'une quelconque des revendications précédentes, caractérisé en ce que la concentration en oxygène est d'environ 0,3 atome %.

