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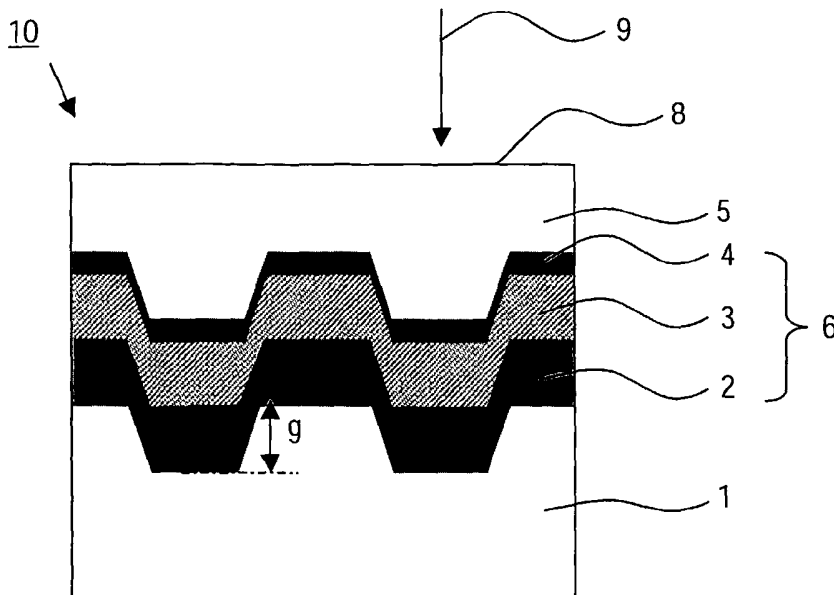
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[Continued on next page]

(54) Title: OPTICAL DATA STORAGE MEDIUM FOR WRITE ONCE RECORDING



(57) Abstract: An optical data storage medium (10) for write-once recording using a focused radiation beam (9) is described. The beam, having a wavelength λ , enters the medium at an entrance face (8) and further propagates through a transparent protection layer (5). Present on a side thereof are a recording stack (6), comprising a metallic layer (4) having a complex refractive index $\tilde{n}_m = n_m - i.k_m$ at λ and having a thickness d_m , a reflective layer (2), a transparent interference layer (3) sandwiched between the first and reflective layer. Said metallic layer is present at a position closer to the entrance face (8) than the reflective layer (2). The metallic layer (4) has a $k_m > 3.5$, preferably $k_m > 6$ by which it is achieved that the recording stack has improved sensitivity combined with an acceptably high reflection times modulation product.



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Optical data storage medium for write once recording

The invention relates to an optical data storage medium for write-once recording using a focused radiation beam, having a wavelength λ , and entering the medium at an entrance face and further propagating through a transparent protection layer with present on a side thereof: a recording stack, comprising a metallic layer having a complex refractive index $\tilde{n}_m = n_m - i.k_m$ at λ and having a thickness d_m , a reflective layer, a transparent interference layer sandwiched between the metallic layer and the reflective layer, said metallic layer being present at a position closer to the entrance face than the reflective layer.

10 An embodiment of an optical data storage medium as described in the opening paragraph is known from Japanese Patent Application JP-2001-101709.

Dyes are widely used as the data-storage recording layer in write-once optical data storage media such as CD-R and DVD+R. An advantage of dye-based optical data storage media or optical record carriers is the high reflection of the media, which provides backwards compatibility of the recorded media in read only (ROM) players. The high reflection is made possible because of the intrinsic transparency of the dye material at the wavelength of the laser used for recording and reading the data. By adding a reflector layer behind the dye layer, a medium having a relatively high reflection is obtained.

Currently, several shortcomings of dye-based media are faced. For example, high-speed Digital Versatile Disk recording (DVD+R) in dye-based media shows progressively worse margins. Another example is the severe cross-write in so-called inverted stacks for the L1 layer, i.e. the layer farthest from the laser beam, in dual-layer DVD+R media based on dye materials. The term inverted stack refers to the order of layer deposition in the fabrication process being opposite from that of conventional optical record carriers such as CD-R and DVD+R. In an inverted stack the reflector layer is deposited directly on the substrate whereafter the recording layer is deposited on top of the reflector layer. Optionally, a protective layer and/or spacer-layer is deposited. The radiation beam does not propagate through the substrate but through said protective layer and/or spacer-layer. The mentioned problems can be solved by using write-once media based on inorganic materials. However, a

disadvantage of most inorganic media is their low reflectivity. JP2001-101709 discloses a write-once stack structure of the "MIM" type consisting of a first metal layer (M), a dielectric layer (I), and a second metal reflective layer (M) respectively. Recording of a pit or mark occurs by melting the first metal layer, which results in a (permanent) hole in the thin metal layer. Due to the presence of the relatively thick second metal layer a high reflection is possible. In JP2001-101709 it is further argued that the product of refractive index and thickness ($n_m \cdot d_m$) of the first thin metal layer should be 1/50 of the recording and reading wavelength or less. Therefore, it is mentioned that it is advantageous to use a metal-alloy having a low refractive index for which Au-alloys and Ag-alloys are proposed. This solution can be used both for transparent and non-transparent recording stacks, i.e. a thin respectively a thick second metal layer.

The solution proposed in JP2001-101709 requires first metal layers that are still relatively thick; the embodiments mention AuSi (96:4) of 22 – 24 nm thick. The reason is that thinner AuSi layers result in lower modulation M, defined below, of the recorded signals which implies less reliable read-back. The requirement of relatively thick 'thin-metal' layers results in poor sensitivity of the recording stack because of the high cooling power of the first metal film (proportional to the thickness). Further, when using Au-alloys or Ag-alloys as the thin metal-layer, the reflection R is not optimum when the modulation M of the stack is high, i.e. the $R \cdot M$ product is low. The reflection R is defined as the fraction of the incident radiation intensity that is returned from the recording stack and the modulation M is defined as $(R - R_m)/R$ wherein R_m is the reflection when a pit or mark is present. Modulation M defined here should not be confused with the M in the "MIM" recording stack as described above where M refers to a metal layer. The context will make clear which of the two is meant.

It is an object of the invention to provide an optical data storage medium of the type mentioned in the opening paragraph which has improved sensitivity of the recording stack combined with an acceptably high $R \cdot M$ product.

This object is achieved by an optical data storage medium according to the invention which is characterized in that the metallic layer has a $k_m > 3.5$, preferably $k_m > 6$. Applicants have found that a relatively thin and therefore relatively sensitive metallic layer of the recording stack structure is possible when k_m of the metallic layer is larger than 3.5. At this relatively low thickness still an acceptably high $R \cdot M$ value is achieved. The mentioned

materials of the metallic layer in JP2001-101709 have k_m values below 3.5.

In a preferred embodiment $0.02*\lambda < k_m*d_m < 0.20*\lambda$. Applicants have further found that for $0.02*\lambda < k_m*d_m < 0.20*\lambda$ good modulation (M) values are achieved (see Fig. 6). An even more preferred thickness range is $0.04*\lambda < k_m*d_m < 0.10*\lambda$ for more optimal M values. A relatively thin first metal layer and therefore relatively sensitive MIM recording stack structure having good R*M value is possible when k_m of the first metal layer is larger than 3.5. Even higher values of k_m (e.g. $k_m > 6$) are more preferred because of the possibility to even further reduce d_m .

It is preferred that $n_m < 3$ because for a given k_m and d_m the reflection of the MIM stack drops below acceptable values when n_m increases above this range. More preferably $n_m < 2$ for even higher reflection values.

In the preferred embodiment the interference layer has a complex refractive index $\tilde{n}_l = n_l - i.k_l$ at λ and a thickness d_l while the following relation is fulfilled $0.07*\lambda < n_l*d_l < 0.34*\lambda$. A relatively high R*M value is achieved in this range. Suitable materials as interference layer include dielectrics such as e.g. SiO_x , $ZnS-SiO_2$, MgO , ZnS , MgF_2 , Ta_2O_5 , Al_2O_3 , et cetera. Preferably, the interference layer is resistant against influences of the radiation beam.

Preferably, the recording stack is formed adjacent a guide groove, also called pre-groove or tracking groove, having a depth $g < \lambda/(4*n_p)$ where n_p is the refractive index of the transparent protection layer. Such a guide groove is generally used to guide the radiation beam spot by means of an opto-mechanical servo system. The groove depth should not exceed the preferred range in order to avoid deterioration of the optical servo signal and/or the read out signal of written pits or marks. For a DVD optical data storage medium λ is approximately 655 nm. In a more preferred embodiment the guide groove adjacent the MIM recording stack structure has a depth $g < \lambda/(10*n_p)$.

In an embodiment the metallic layer comprises Al. Al is a metal that is relatively easy to deposit, cheap and frequently used. The relatively thin layer thickness achieves a relatively high temperature increase in this layer during recording. This is advantageous for a relatively high sensitivity of the medium. In order to further increase the sensitivity the metallic layer preferably comprises an alloy of Al and least one other element, which alloy has a melting point below 500° C, e.g. AlGe, AlMg or AlSi.

In another embodiment a further recording stack, comprising a further write once recording layer, and a further transparent protection layer are present between the transparent protection layer and the entrance face. Because of the relatively high R*M- and

sensitivity value the recording stack according to the invention may successfully be used as the deepest recording stack in a dual or multi stack optical data storage medium. In case of a dual stack medium this deepest stack sometimes is also called L1. Deepest refers to the stack farthest from the entrance face. In a further embodiment the further recording stack is of the same type as the recording stack according to the invention. The reflective layer may be made relatively thin and semi-transparent to the radiation beam in order to allow the radiation beam to pass to deeper recording stacks. Using the same type of recording stack design is advantageous in manufacture of the medium because the same production equipment may be used for each recording stack. In a more preferred embodiment the further write-once recording stack, i.e. L0 stack, comprises a write-once recording layer being a suitable organic dye layer, e.g. an azo dye. This stack has the advantage of a higher transmission value.

The reflective layer usually comprises a metal, but any highly reflective material may be used. The reflective layer of the deepest stack may comprise any metal with suitable reflection including Al. In case of multi recording stacks the reflective layer of stacks between the entrance face and the deepest stack preferably comprises a metal suitable as a semi transparent reflective layer e.g. Au, Cu and Ag. These materials have a relatively high transmission value at a suitable layer thickness.

The invention will be elucidated in greater detail with reference to the accompanying drawings, in which:

Fig. 1a shows a schematic cross section layout of an embodiment of the optical data storage medium including a MIM recording stack according to the invention;

Fig. 1b shows a schematic cross section layout of another embodiment of the optical data storage medium including two MIM recording stacks according to the invention;

Fig. 2 shows a normalized calculated maximum temperature profile of a stack (T_{norm} as a function of the depth d_s in the stack) according to the invention (21) and a stack according to prior art (22);

Fig. 3a and 3b respectively show the calculated reflection R and modulation M for a stack of Al / SiO₂ / X as a function of the SiO₂ thickness d_1 for the case when X=Al (7nm) according to the invention and X= AuSi (20nm) according to prior art;

Fig. 4 shows the calculated $R*M$ for different metallic layers as a function of the SiO₂ thickness d_1 in a stack: Al / SiO₂ / metallic layer,

Fig. 5 shows the calculated modulation M as a function of the reflection for different metallic layers in a stack: Al / SiO₂ / metallic layer;

Fig. 6 shows the calculated modulation M as a function of $k_m \cdot d_m / \lambda$ for different values of k_m of the metallic layer for a stack: 100 nm Al(reflective layer)/70 nm SiO₂/metallic layer.

Fig. 7 shows the experimentally measured modulation M of an IIT mark as a function of the write power P_w for 3 different stacks according to the invention at a recording speed of 9.22 m/s.

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In Fig. 1a an optical data storage medium 10 for write-once recording using a focused laser light beam 9, having a wavelength $\lambda = 655$ nm and numerical aperture (NA) = 0.65 is shown. The beam 9 enters the medium 10 at an entrance face 8. The beam 9 further propagates through a transparent protection layer 5. Present on a side thereof is a recording stack 6, comprising a metallic layer 4 made of Al having a complex refractive index $\tilde{n}_m = n_m - i.k_m = 1.4 - i.7.0$ at $\lambda = 655$ nm and having a thickness $d_m = 7$ nm, a reflective layer 2 made of 100 nm Al, and a transparent interference layer 3 made of (ZnS)₈₀(SiO₂)₂₀ sandwiched between the metallic layer 4 and the reflective layer 2. The metallic layer 4 is present at a position closer to the entrance face 8 than the reflective layer 2. The layers of the recording stack 6 were deposited by sputtering. The transparent protection layer 5 was deposited by spin coating a UV-curable resin. Both deposition techniques are well known in the art. At a side opposite of the side of the transparent protection layer 5 a further substrate 1, made of polycarbonate (PC), is present adjacent the recording stack 6. The interference layer 3 has a complex refractive index $\tilde{n}_i = n_i - i.k_i = 2.15 - i.0$ at $\lambda = 655$ nm and a thickness $d_i = 50$ nm. This thickness fulfils $0.07 \cdot \lambda < n_i \cdot d_i < 0.34 \cdot \lambda$. The recording stack is formed adjacent a guide groove having a depth $g = 35$ nm $< \lambda / (4 \cdot n_p)$ where n_p is the refractive index of the transparent protection layer being 1.58.

The metallic layer may also comprise an alloy of Al and least one other element, which alloy has a melting point below 500° C e.g. AlGe, AlMg or AlSi. Using such an alloy will enhance the sensitivity of the recording stack. The reflective layer comprises Al and has a thickness of 100 nm. Alternative materials for the reflective layer are e.g. Ag, Au, Cu or metal alloys.

In Fig. 1b another embodiment of an optical data storage medium according to the invention is shown. Reference numerals 1-6, 8 and 9 correspond to the description of

Fig. 1a. A further recording stack 6', comprising a further write once recording layer 4', and a further transparent protection layer 5' are present between the transparent protection layer 5 and the entrance face 8. The further recording stack 6' is of the same type as the recording stack 6 and layer 2', 3' and 4' are made of the same material as layers 2, 3 and 4. Layers 3' and 4' have nearly the same thickness as layers 3 and 4 but the thickness of the reflective layer 2' is 10 nm or less, which is relatively thin in order to allow the laser light 9 to pass to stack 6. In this embodiment the reflective layer 2' is preferably made of Ag, Au, Cu or alloys thereof. Al has a relatively low transmission value and is preferably not used as reflective layer 2' in such a dual stack medium. Alternatively, the further recording stack 6' may also comprise an organic dye-type write once recording layer, e.g. an azo dye, instead of the metallic layer 4' in which case the interference layer 3' may be omitted. Only one metallic layer may be required, e.g. reflective layer 2' serving as semi-transparent reflector. It is even feasible that interference layer 3' serves as semi-transparent reflective layer in which case metallic layer 2' may be omitted. The thickness of the interference layer and its refractive index should be chosen such to achieve optimal R and M. The further recording stack is formed adjacent a guide groove having a depth $g' = 35 \text{ nm} < \lambda/(4 \cdot n_p)$ where n_p is the refractive index of the transparent protection layer 5' and may be made of the same material as the transparent layer 5.

In Fig. 2 results of thermal calculations are shown by way of a normalized calculated maximum temperature profile of different stacks (T_{norm} as a function of the depth d_s in the stack). The different stacks are Al/SiO₂/Al and Al/SiO₂/AuSi. The SiO₂ thickness was taken in both cases such that the effective reflection of the stacks was about the same, i.e. the same amount of optical power is absorbed.

Graph 21: 100 nm Al/70 nm SiO₂/5 nm Al/polycarbonate.

Graph 22: 100 nm Al/85 nm SiO₂/25 nm AuSi/polycarbonate.

The calculation clearly shows that, for the same stack-absorption and same recording power, the thin Al-stack reaches much higher temperatures and is thus much more sensitive (temperature profile after 10 ns write pulse).

In Fig. 3a and 3b results of optical calculations of reflection R and modulation M for in-groove recording that have been performed for stacks with AuSi and Al thin metallic layers as a function of SiO₂ thickness (Al/SiO₂/thin metal stacks) are shown. In-groove means that the direction of the guide groove at which the laser is focused is directed away from the entrance face. The calculations for M are based on the assumption that a permanent hole is formed in the metallic layer during recording. On-groove recording,

meaning that the direction of the guide groove at which the laser is focused is directed towards the entrance face, gives lower (worse) M values. The groove depth $g = 35$ nm, track pitch = 740 nm, groove duty cycle = 50%, $\lambda = 655$ nm and $NA = 0.65$. These results show that for a specific thickness of dielectric layer, the AuSi stack sometimes has higher

5 modulation or higher reflection, although never simultaneously.

In Fig. 4 the calculated $R \cdot M$ value for different metallic layers as a function of the SiO_2 layer thickness d_1 in a stack: Al / SiO_2 / metallic layer is shown. The advantage of the Al thin metallic layer compared to the AuSi thin metallic layer becomes more clear when comparing the reflection*modulation ($R \cdot M$) product: stacks with thin Al-layer obtain a high

10 $R \cdot M$ product even at a relatively thin metallic layer thickness.

In Fig. 5 the modulation M as a function of reflection R is shown for different metallic layers. The advantage becomes clear: using the relatively thin Al-layer, a high modulation M can be obtained at higher reflection values than in the case of the thin AuSi layer. Moreover, similar (or somewhat higher) R and M values are obtained for metallic

15 layers 4 that are about 3 to 4 times thinner in case of Al compared to the case of AuSi. This is beneficial for the sensitivity of the recording stack.

In Fig. 6 the calculated modulation M for different k_m values of the metallic layer 4 as a function of $k_m \cdot d_m / \lambda$ is shown. The recording stack structure is: 100 nm Al(reflective layer)/70 nm SiO_2 (interference layer)/metallic layer. When the thickness range

20 is $0.04 \cdot \lambda < k_m \cdot d_m < 0.10 \cdot \lambda$ M values of higher than 0.6 are achieved at $k_m = 7$.

In Fig. 7 (in-groove) recording results are shown for signal modulation M at a recording velocity 9.22 m/s. The modulation M was measured by writing an 11T mark as a function of the write power P_w (in mW) for 3 different stacks according to the invention at a recording speed of 9.22 m/s. Modulation values of more than 0.6 are achieved. The recording

25 velocity of 9.22 m/s is relatively high compared to the recording velocity in JP-2001-101709 where, at 3.49 m/s, 10–12 mW of recording power is needed. Because recording power is about proportional to the recording velocity a comparable result is achieved. However JP2002-101709 uses an AuSi alloy with a melting point $< 400^\circ\text{C}$ while in the experiment of Fig. 7 Al (m.p. = 660°C) is used. Furthermore the present experiment uses $(\text{ZnS})_{80}(\text{SiO}_2)_{20}$ as

30 interference layer. When SiO_2 is used as interference layer the sensitivity will increase further because such a layer may be made thicker giving rise to less heat conduction from the first to the reflective layer. Also, by using a metallic layer which comprises an alloy of Al and at least one other element which alloy has a melting point below 500°C , e.g. AlGe, AlMg or AlSi the sensitivity is further enhanced.

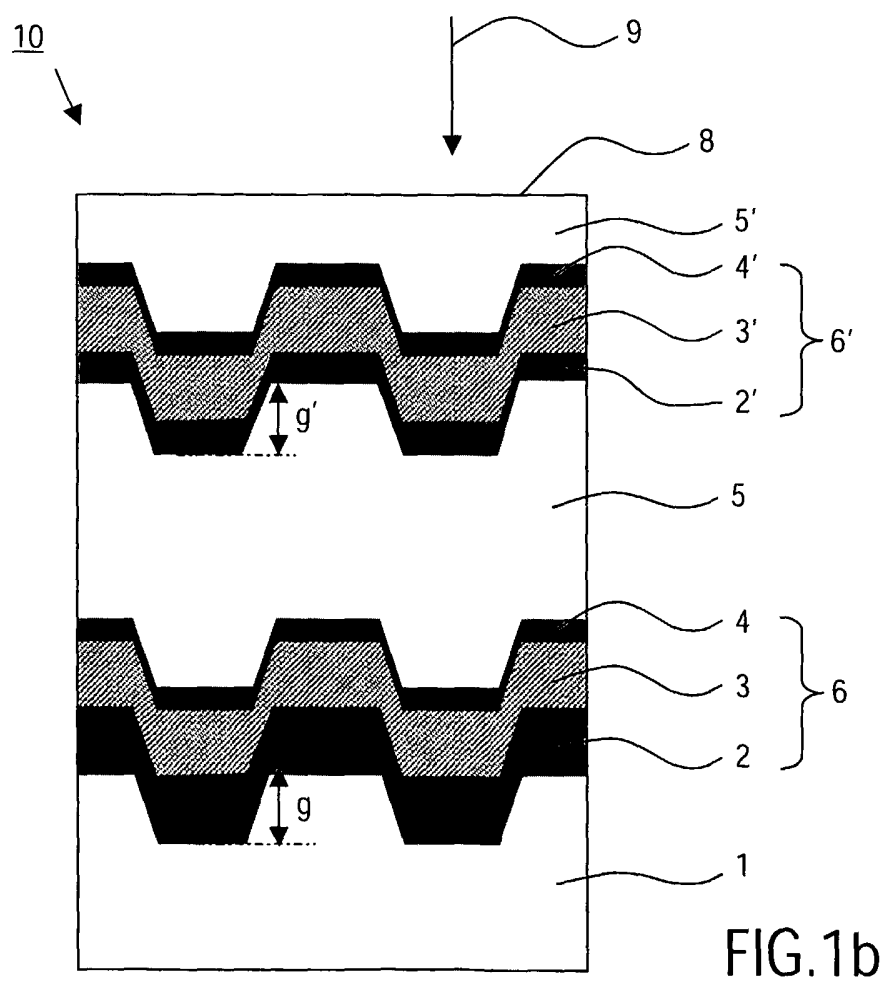
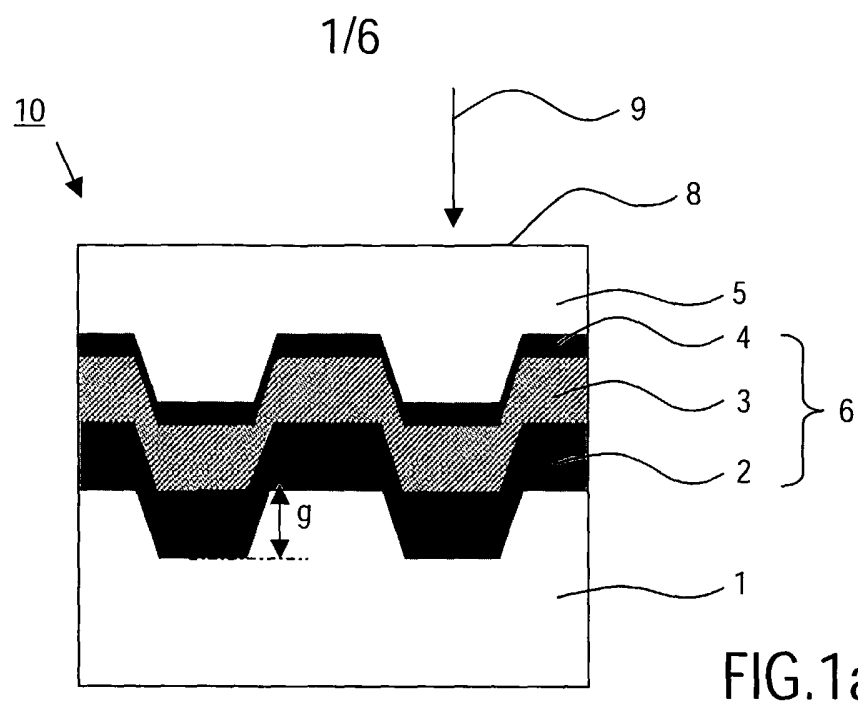
It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The

5 word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS:

1. An optical data storage medium (10) for write-once recording using a focused radiation beam (9), having a wavelength λ , and entering the medium at an entrance face (8) and further propagating through a transparent protection layer (5) with present on a side thereof:
 - 5 a recording stack (6), comprising
 - a metallic layer (4) having a complex refractive index $\tilde{n}_m = n_m - i.k_m$ at λ and having a thickness d_m ,
 - a reflective layer (2),
 - a transparent interference layer (3) sandwiched between the metallic layer
 - 10 and the reflective layer,
 - said metallic layer being present at a position closer to the entrance face than the reflective layer, characterized in that the metallic layer (4) has a $k_m > 3.5$, preferably $k_m > 6$.
- 15 2. An optical data storage medium as claimed in claim 1, wherein $0.02*\lambda < k_m*d_m < 0.20*\lambda$.
3. An optical data storage medium as claimed in any one of claims 1 or 2, wherein $0.04*\lambda < k_m*d_m < 0.10*\lambda$.
- 20 4. An optical data storage medium as claimed in any one of claims 1 -3, wherein $n_m < 3$.
5. An optical data storage medium as claimed in any one of claims 1 - 4, wherein
 - 25 the interference layer (3) has a complex refractive index $\tilde{n}_i = n_i - i.k_i$ at λ and a thickness d_i while the following relation is fulfilled $0.07*\lambda < n_i*d_i < 0.34*\lambda$.

6. An optical data storage medium as claimed in any one of claims 1 - 5, wherein the recording stack (6) is formed adjacent a guide groove having a depth $g < \lambda/(4 \cdot n_p)$ where n_p is the refractive index of the transparent protection layer (5).
- 5 7. An optical data storage medium as claimed in claim 6, wherein the recording stack (6) is formed adjacent a guide groove having a depth $g < \lambda/(10 \cdot n_p)$ where n_p is the refractive index of the transparent protection layer (5).
8. An optical data storage medium as claimed in any one of claims 1 - 7, wherein
10 λ is approximately 655 nm.
9. An optical data storage medium as claimed in any one of claims 1 - 8, wherein the metallic layer (4) comprises Al.
- 15 10. An optical data storage medium as claimed in claim 9, wherein the metallic layer comprises an alloy of Al and at least one other element which alloy has a melting point below 500° C.
11. An optical data storage medium as claimed in claim 10, wherein the metallic
20 layer comprises an alloy selected from the group of AlGe, AlMg and AlSi.
12. An optical data storage medium as claimed in any one of the preceding claims, wherein a further recording stack (6'), comprising a further write once recording layer (4'), and a further transparent protection layer (5') are present between the transparent protection
25 layer (5) and the entrance face (8).
13. An optical data storage medium as claimed in claim 12, wherein the further recording stack is of the same type as the recording stack as claimed in claim 1.



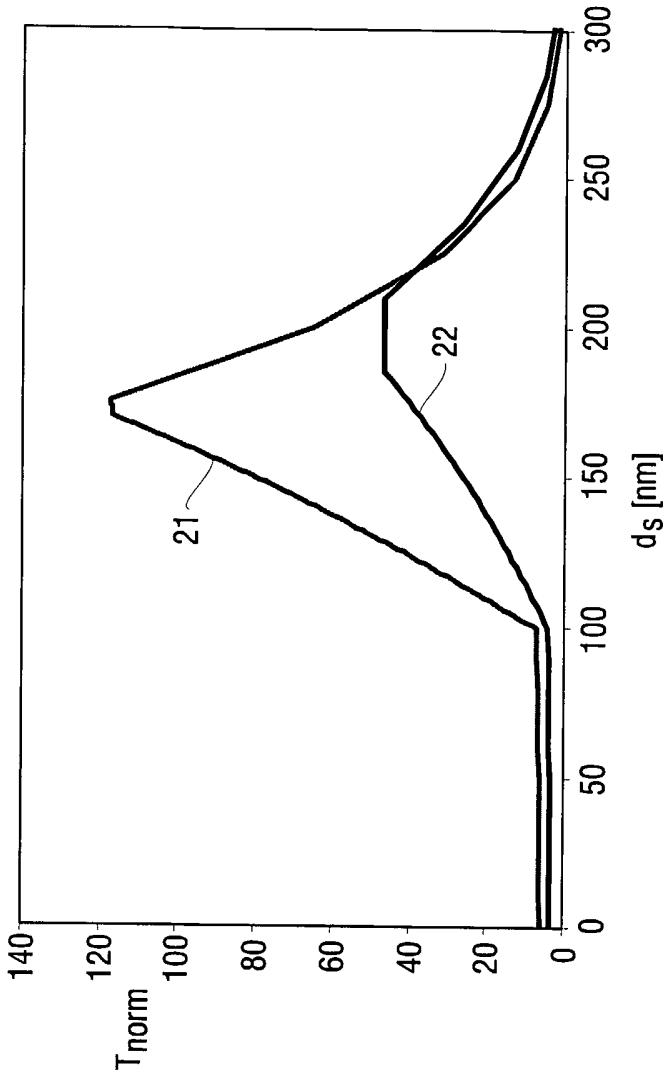


FIG.2

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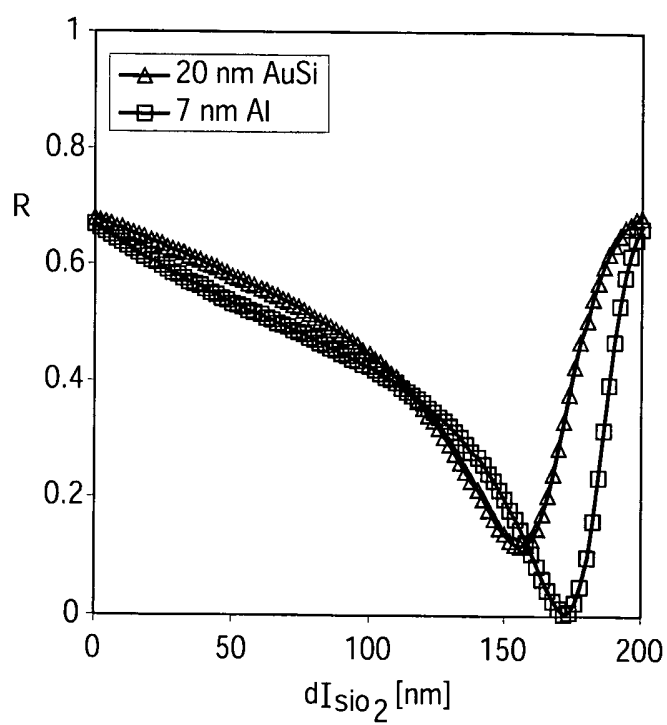


FIG.3a

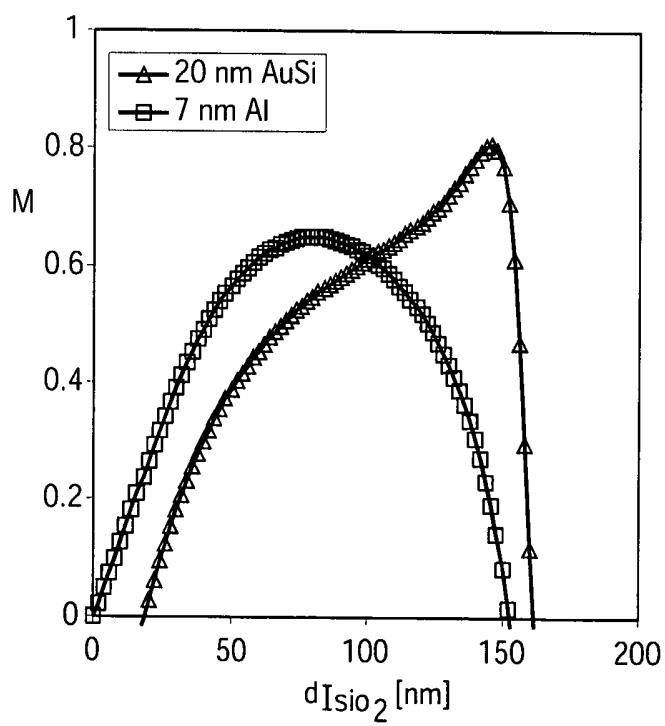


FIG.3b

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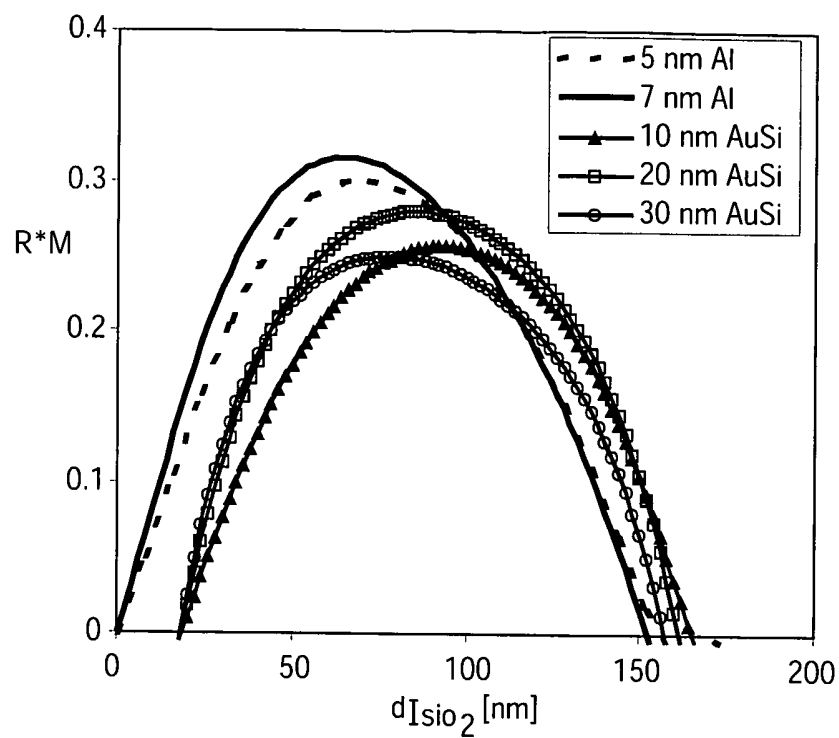


FIG. 4

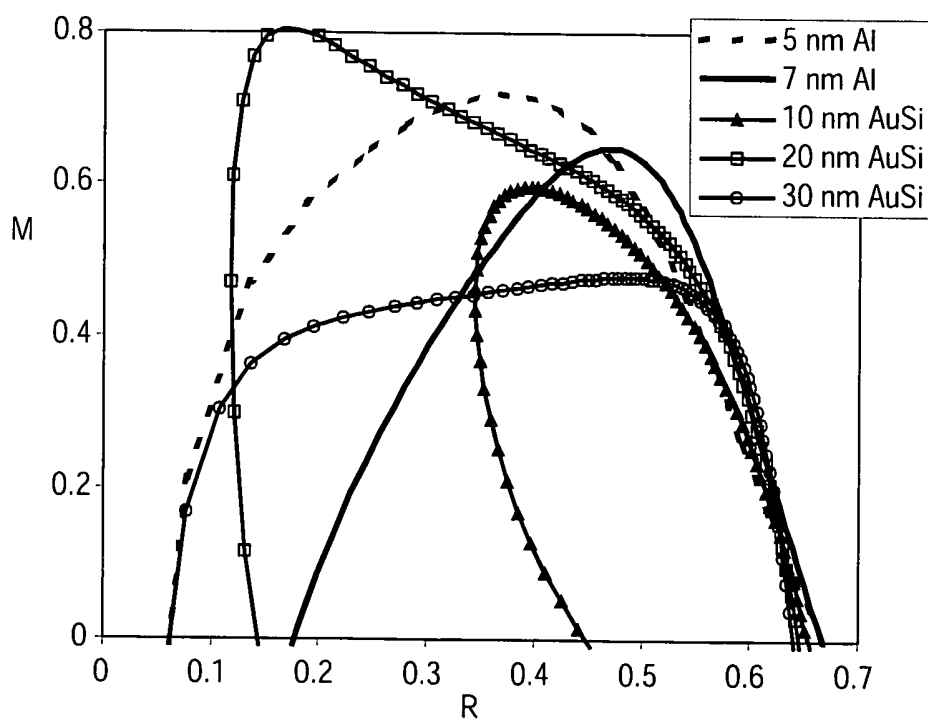


FIG. 5

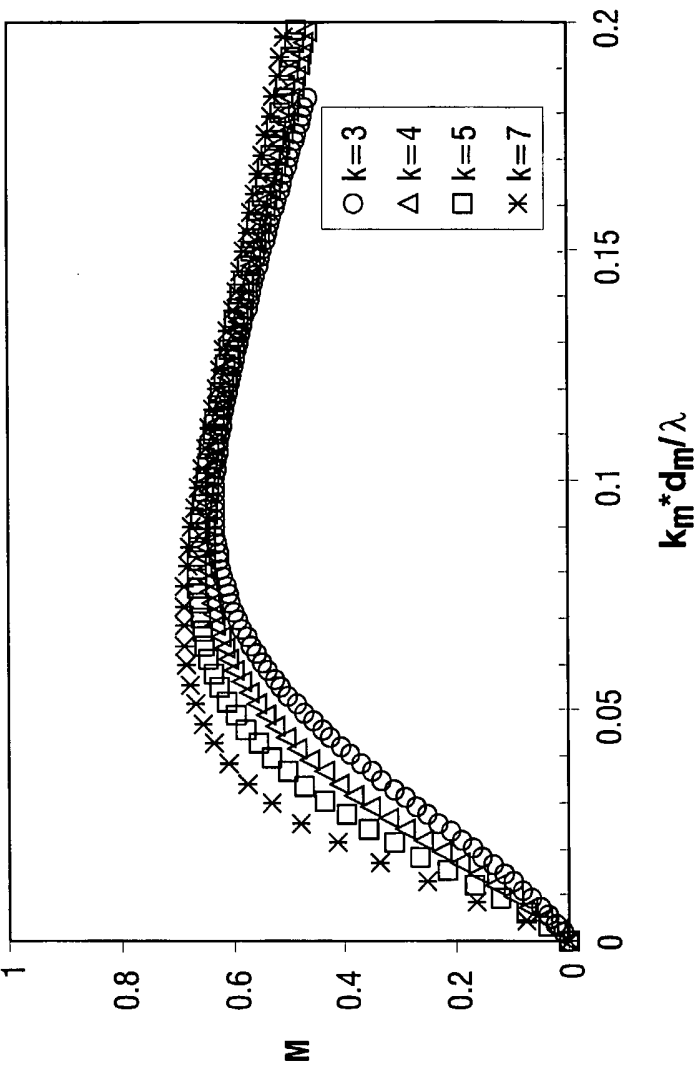


FIG.6

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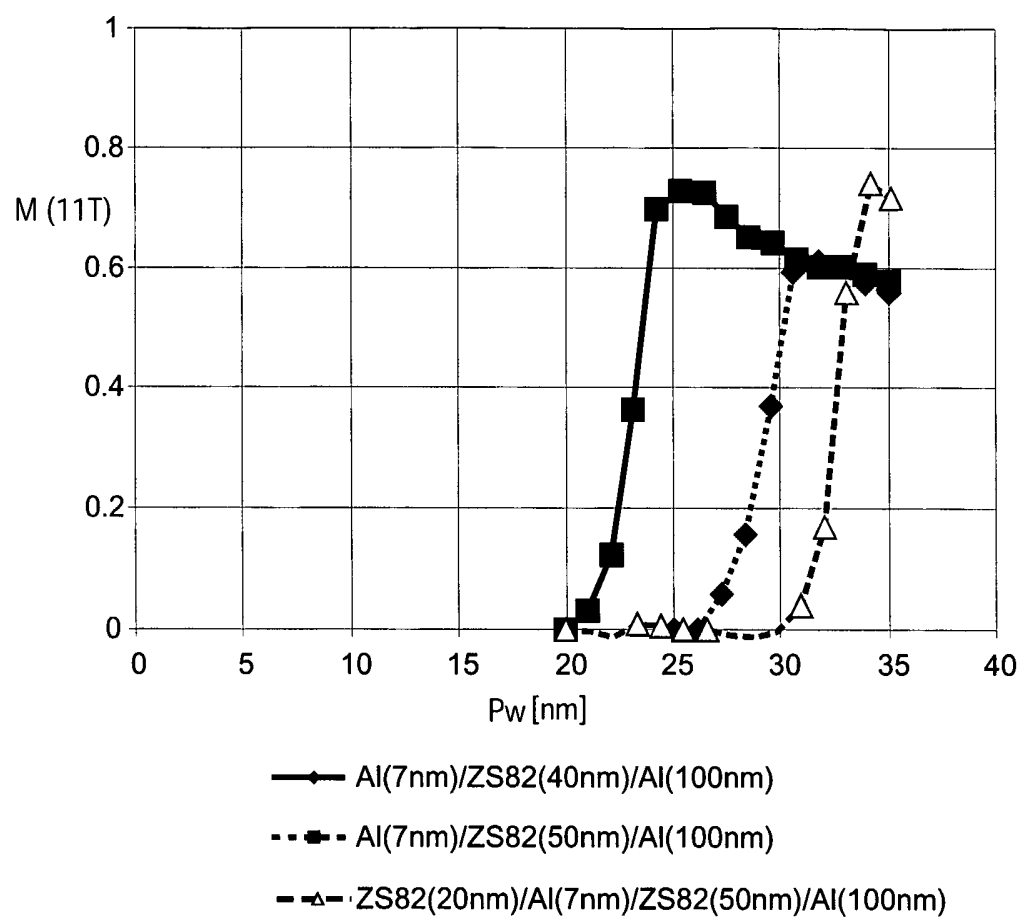


FIG.7