Problems to be solved and Technological Evolution of Magnetic Recording Media

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Abstract

Magnetic recording medium using metal thin film has been developed by both wet and dry plating deposition. In this paper, dry deposition, especially, physical vapor deposition is focused. Preliminary sputtered disk for longitudinal magnetic recording was developed in the 1970s. In the five patents spanning the evolution of longitudinal recording media from its early stages to the end of its development, the transforming of a single magnetic layer into a multilayer was proposed to reduce media noise and thermal fluctuation. This was a trend that included at least three inventive principles such as “Segmentation of the recording layer and underlayer,” “Move to a new dimension,” and “Composite materials.”

1. Introduction

Transition metal, Cobalt (Co) has a large magnetic saturation flux density, and a relatively higher magnetic anisotropy as one of industrial materials. It has been focused as a magnetic recording material. A preliminary investigation of Co thin film deposited on a Chromium (Cr) underlayer was performed using vacuum evaporation [1, 2]. RF-sputtered hard magnetic thin film of multi-layered Co and tungsten (W) [3] and Co film deposited on Cr underlayer as a preliminary sputtered longitudinal recording media [4, 5] were investigated. The general result of alloying experiments was that good recording films show poor corrosion resistance, while good corrosion-resistance films show poor recording properties. That is, a technical contradiction between corrosion resistance and recording performance was pointed out [6]. In order to solve this contradiction, alloying of magnetic layer containing Co as a main component was investigated.

Sputtered disks for longitudinal magnetic recording have been focused as an example of technological evolution in hard disk drives. Five patents spanning the evolution of longitudinal recording media and introduced between 1986 and 2005 were selected for discussion in this paper. Cross-sectional media structures proposed in these patents are shown in Table 1. Problems to be solved of these magnetic recording media and related solution are discussed and related to their technological evolution and relevant inventive principles.

2. Longitudinal recording media

2.1 JP 3,033,577

When pure Co was applied as a recording layer, improvement of corrosion-resistance was expected. Co-X binary alloy systems were also studied. For example, Pt [7], Ni [8], and Cr [9] were investigated as additives X. Based on these fundamental trials, Co-Cr-X ternary alloy systems were introduced, which could simultaneously meet the demands both good magnetic properties and good corrosion-resistance, as shown under JP 3,033,577 (media A). Here, a Co-Cr-X ternary alloy film was deposited on a Cr underlayer.

Problems to be solved in JP 3,033,577 are as follows.

Table 1. Layer structure of the media proposed in the patents (arrows indicate the direction of magnetization)

JP 3,033,577	US 5,587,235 JP 3,390,957	US 6,773,834	US 7,273,667 JP Laid Open 2004-355716	US 2006/0292401A1 JP Laid Open 2007-4907
C CoCrX alloy X = Zr, V, Ti, Ru, Ni, Rh, Ta, Pd, W, Pt, Nb, Mo, more than 6 wt.% Cr Substrate	C → CoCrPt(15-8) paramagnetic CoCr → CoCrPt(15-8) Cr−(Ti, Si, W) Substrate	C → CoCrPtB(14-12-11) Ru → CoCrPtB(14-12-11) Ru ← CoCr11 CrTi10 – RuAl CrTi Substrate	C → Co Alloy Ru → Co Alloy Ru ← CoCrPt(14−6) CrTiB(15−5) Heating, Surface Conditioning Ta NiTa35 Substrate	C → CoCrPtB(12-13-10) Ru → CoCrPtB(12-13-12) → CoCrPtBTa(23-13-5-2) Ru ← CoCrPt(16−9) CrTiB(10−3) Heating, Surface Conditioning WCo30 TiCoNi(40−10) Substrate
Media A	Media B	Media C	Media D	Media E

The demand for both higher recording density and higher reliability has been increased. Especially in the case of the metal magnetic thin film, corrosion-resistant improvement is the biggest technical problem, and in order to improve corrosion resistance, the proposal which adds the 3rd element, such as Cr and Nb, to a magnetic metal is made as shown in JP Laid open 57-15406 and 57-196508. However, most inventions of these relate to the magnetic tape application, and did not meet the demand of specification for higher reliability like the hard disk for computers. The purpose of this invention is offering a longitudinal magnetic recording medium for magnetic disk apparatus comprising the Co-Cr system magnetic thin film which has the improved corrosion resistance, maintaining substantially the excellent magnetic properties.

For the problems to be solved, one of the followings is registered [10]. Magnetic recording medium comprising a substrate, an underlayer provided on the substrate, a magnetic layer provided on the underlayer, a non-magnetic coating film provided on the magnetic layer, and a surface lubricant layer provided on the non-magnetic coating film, said magnetic layer comprising mainly Co and Cr, not less than 6 wt. % of at least one metal element selected from the group consisting of Zr, V, Ti, Ru, Ni, Rh, Ta, Pd, W, Pt, Nb, and Mo, and Cr being not less than 1 at. % but not more than 22 at. % of Co-Cr binary alloy.

2.2 US 5,587,235, JP 3,390,957

For a higher areal recording density compared with media A shown in Table 1, lower media noise is required. To reduce media noise, it is effective to reduce magnetic interaction along the depth direction. However, there are some problems to be solved for the multilayers stacked interlayer such as W and Cr with body centered cubic structure and recording layer such as Co with hexagonal closed packing structure, as follows. For layered films of Co and W, the reduction of stacking numbers and lower deposition temperature setting were bottleneck. For layered films of Co and Cr, the thinner the Cr interlayer, the lower the coercive force, Hc.

To solve these problems, media B shown in Table 1 using an intermediate region with the same crystallographic structure as the recording layer and being not ferromagnetic were proposed [12, 13]. This is based on the reduction of magnetic interaction along the depth direction of recording layer and simultaneous improvement of crystallographic orientation.

That is, "in conventional magnetic recording media, it is required to form a non-magnetic intermediate layer. Therefore, after forming a non-magnetic underlying layer and a magnetic layer on it, at least one Cr alloy non-magnetic metal layer is formed and then a magnetic layer is formed on it. However, this structure has difficulty in reducing medium noise in high density recording. As a result, a magnetic recording apparatus using this type of recording medium also has difficulty in increasing recording density per unit volume," [12].

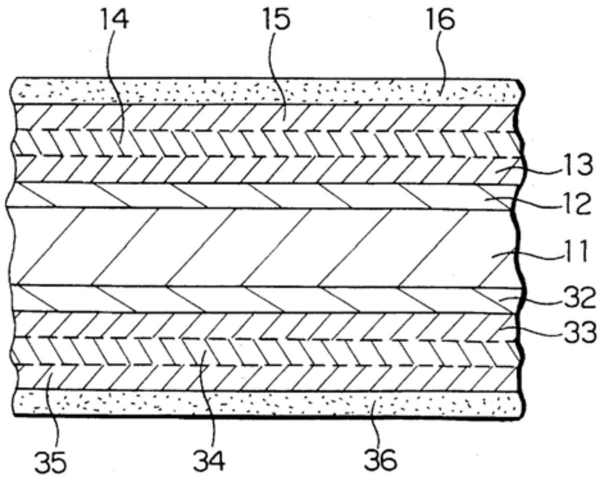

Fig. 1. One of the embodiments of media B [12].

One of claims, "a magnetic recording medium comprising: a substrate 11; a non-magnetic underlying layer 12 formed on the substrate; a plurality of stacked ferromagnetic alloy thin film layers 13-15 each containing Co and at least one additional element selected from the group consisting of Cr and Ni, wherein a first one of the ferromagnetic alloy thin film layers is disposed on said non-magnetic underlying layer and another one of said plurality of ferromagnetic alloy thin film layers is disposed over said first ferromagnetic alloy thin film layer; and a mainly paramagnetic intermediate region 14 laminated on said first one of the ferromagnetic alloy thin film layers, which intermediate region reduces magnetic interaction occurring in the stacked ferromagnetic alloy thin film layers, said intermediate region being made to contain the same crystal structure as those of the ferromagnetic alloy thin film layers and to contain both a Co content lower than that of said first ferromagnetic thin film alloy layer and said additional element in a content larger than that of the ferromagnetic alloy layer" was registered [12].

2.3 US 6,773,834

To reduce thermal decay of media B, media C with a bottom magnetic layer was proposed in US 6,773,834 [14]. Although parallel while writing, magnetizations in the bottom CoCr11 layer couple anti-ferromagnetically (AF) with those in the top and bottom CoCrPtB layer during play-back, as shown in media C of Table 1 [15, 16].

AF coupling improves thermal stability by adding the recorded magnetization of bottom recording layer which does not contribute to play back signal [17].

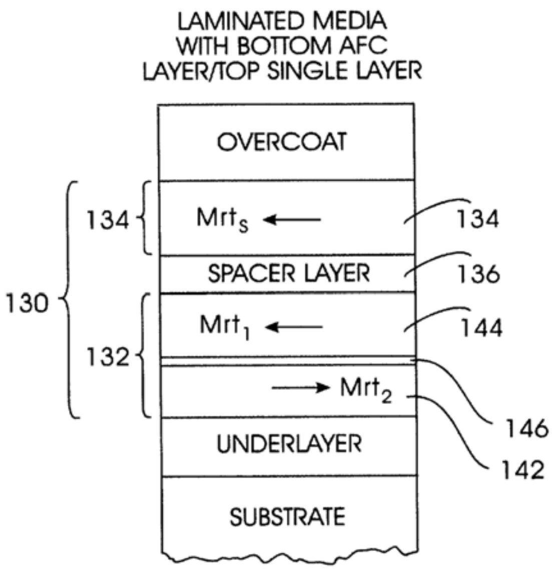

Fig. 2. One of the embodiments of media C [14].

As one of claims, "a magnetic recording medium comprising: a substrate; a magnetic recording layer on the substrate and comprising an antiferromagnetically-coupled (AFC) layer 132, a ferromagnetic layer 134 and a nonferromagnetic spacer layer 136 separating the AFC layer and the ferromagnetic layer, the AFC layer comprising a first ferromagnetic film 142, a second ferromagnetic film 144 and an antiferromagnetically coupling film 146 located between the first and second ferromagnetic films and having a thickness and composition to provide antiferromagnetic exchange coupling of the first and second ferromagnetic films, the nonferromagnetic spacer layer 136 being located between the second ferromagnetic film of the AFC layer and the ferromagnetic layer and having a thickness and composition wherein the ferromagnetic layer and the second ferromagnetic film of the AFC layer are not exchange coupled," was registered [14].

2.4 US 7,273,667 JP Laid Open 2004-355716

To simultaneously improve the S/N ratio, overwrite, and thermal decay, US 7,273,667 [18] and Japanese Patent Laid Open 2004-355716 [19] were proposed, as shown in Table 1 as media D.

The problem to be solved by the present invention is as follows. "The techniques described in prior arts, even when combined, are still insufficient to attain an areal recording density of 100 Mbit or more per 1 mm^2 and it is necessary to further improve the reading output and improve the medium S/N.

It is an object of the present invention to provide a longitudinal magnetic recording medium having a high medium S/N, excellent overwriting characteristics and stability sufficient for thermal fluctuation."

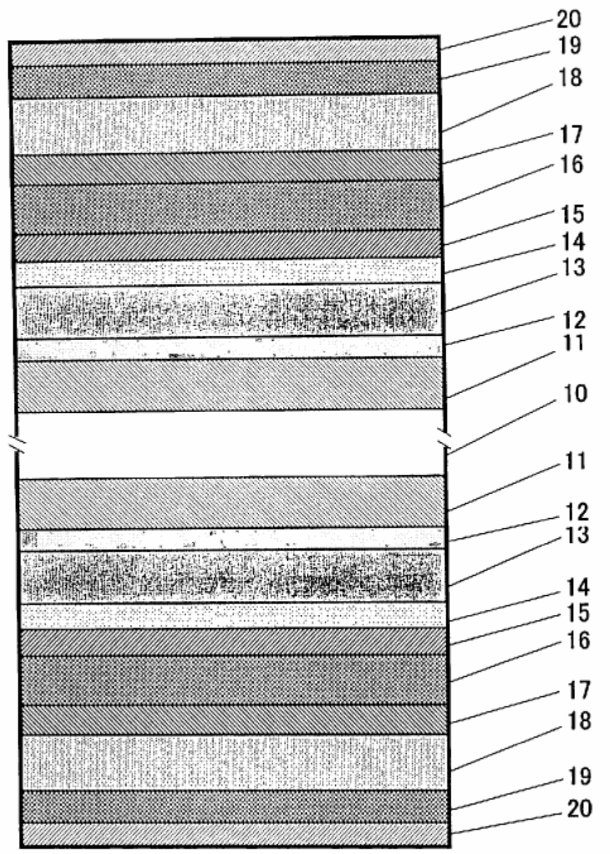

Fig. 3. One of the embodiments of media D [18].

For this problem, one of claims, "a magnetic recording medium, comprising: an underlayer 11-13, a first magnetic layer 14, a first intermediate layer 15, a second magnetic layer 16, a second intermediate layer 17, a third magnetic layer 18, a protection layer 19 and a lubrication layer 20, which are formed above a substrate; and each of the third magnetic layer 18 and the second magnetic layer 16 comprises a cobalt-based alloy containing at least platinum and chromium, a concentration of platinum contained in the second magnetic layer 16 is not more than that in the third magnetic layer 18, platinum contained in the third magnetic layer is 15 at % or less, a concentration of chromium contained in the third magnetic layer is 15 at % or more and 18 at % or less, and a concentration of boron contained in the third magnetic layer is 7 at % or more and 10 at % or less" was registered [18].

2.5 US 2006/0292401A1

To improve the bit error rate and thermal decay, division of the middle magnetic layer were proposed in Japanese Patent Laid Open 2007-4907 [20] and US 2006/ 0292401A1 [21] as shown in Table 1 as media E. By reducing the lower middle magnetic moment, which is far from the writing head, writability was enhanced.

As shown in Fig. 4, "a magnetic recording medium comprising: a substrate 10; an underlayer film 11-13 formed above the substrate; a magnetic film comprising a

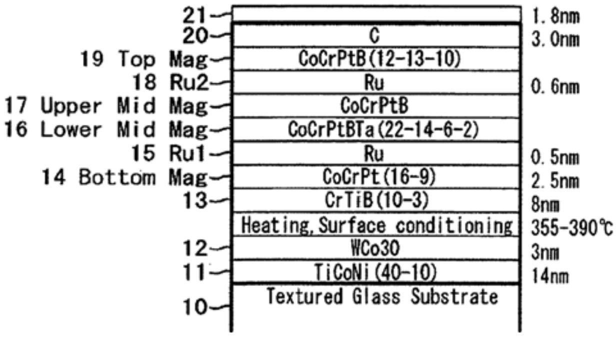

Fig. 4. One of the embodiments of media D [21].

first magnetic layer 14, a first non-magnetic intermediate layer 15, a second magnetic layer 16, a third magnetic layer 17, a second non-magnetic intermediate layer 18 and a fourth magnetic layer 19 stacked above the underlayer film; and a protective layer 20 formed above the magnetic film; wherein: a product (Brt2) of residual magnetic flux density and film thickness of the second magnetic layer is smaller than a product (Brt3) of residual magnetic flux density and film thickness of the third magnetic layer; the second magnetic layer has a thickness larger than a thickness of the third magnetic layer; the second magnetic layer is coupled antiferromagnetically with the first magnetic layer by way of the first non-magnetic intermediate layer; the fourth magnetic layer is formed by way of the second non-magnetic intermediate layer above the third magnetic layer; and a product (Brt4) of residual magnetic flux density and film thickness of the fourth magnetic layer is from about 47% to 52% of a product (Brt_total) of residual magnetic flux density and film thickness of entire magnetic layers in a state of residual magnetization with an external magnetic field removed," was proposed [21].

During play-back, the direction of remanent magnetization of the second 16, third 17, and fourth 19 magnetic layer is anti-parallel to the first 14, as shown by arrows in Media E of Table 1. By setting the smaller Brt2 compared with Brt3, it is easy for the far recording layer to write. Here a recording layer 17 having a larger magnetic moment is relatively closer to the writing head compared with a recording layer 16 having a smaller magnetic moment.

3. Trends of Evolution & Inventive Principles

3.1 Recording Layer

At the early stage of the development, magnetic properties were optimized by introducing underlayers or intermediate layers, which derive magnetic crystalline anisotropy of Co alloy recording layer, and by reducing magnetic interaction along the depth direction of recording layer. These improvements correspond to the introduction of "Another Dimension," which means "Use a stacking arrangement of objects instead of a single level arrangement," Inventive Principle 17 (abbreviated as #17 hereafter) [22].

In order to put into practical use of magnetic recording media using metallic thin film, alloying of recording layer having good magnetic properties and a good corrosion resistance was investigated, such as Media A. Later multilayered media such as Media B to E were introduced using "Composite Materials #40."

AF coupling [17, 23] used for Media C to E might be embodiments of "Dynamization #15," "Preliminary Action #10," "Beforehand Cushioning #11," "Apply Counter-Balance #46," and "Postponed Action #58," assuming "Separation in Time" as a Physical Contradiction Solution Route [22, 24]. This trend of evolution might correspond to "Increasing Asymmetry."

A reduction of magnetic moment of recording layer which is set far from writing head shown in Media E is an embodiment of "Modify or Substitute the System #68," and "Localize and/or Locally Weaken a Harmful Effect #71" [22].

3.2 Underlayer

The underlayer of Media A is pure Cr. On the other hand, Cr based alloy [25, 26] is proposed in Media B. Improvement of lattice matching in hetero-epitaxial growth by alloying corresponds to "Equipotentiality #12."

Single underlayer is proposed for Media A and B. Multi-underlayer is introduced to Media C to E. Here each underlayer's function is divided such as adhesion, and crystallographic orientation control etc. These divisions correspond to the usage of "Composite Materials #40." Reduction of grain size by adding Boron into Cr-Ti alloy underlayer are proposed as shown in Media D and E [27, 28]. This idea relates to "Transform an Object Micro-Structure #63."

The Trends of Evolution of these recording layer and underlayer are "Mono-Bi-Poly," and Increase of "Degrees of Freedom" [24].

4. Conclusion

Comparison of the patents in Table 1 indicates "Mono-Bi-Poly," and Increase of "Degrees of Freedom" as Trends of Evolution of sputtered disk for longitudinal recording. These relate to the following Inventive Principles.

(1) "Segmentation #1" of recording layer and underlayer.
(2) "Another Dimension #17" by multilayered device.
(3) "Composite Materials #40" by stacking alloys.

Moreover, there are some related Principles in "37 Most Important Combined and Special Principles" such as "Transform an Object Micro-Structure #63," "Modify or

Substitute the System #68," and "Localize and/or Locally Weaken a Harmful Effect #71," [22].

Perpendicular magnetic recording media follow a similar trend in its technological evolution. In future work, segmentation of the recording layer and underlayer is likely to continue.

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