The Development on Areal Density of Magnetic Recording

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Abstract: With the development in magnetic recording, people will seek for higher areal density. To raise the areal density without damaging signal to noise ratio (SNR) and thermal stability, several methods have been proposed after many years of research. This passage will introduce two major approaches, heat assisted magnetic recording (HAMR) and composite media. Besides, the evaluation for two methods will also be discussed in the passage. Apart from these two methods, a new method trapping electron assisted magnetic recording (TEAMR) will also be mentioned in the final of the passage. In conclusion, HAMR is faced with many problems in fabrication, composite media has many improvements to take full advantage of it and TEAMR is promising but costs much nowadays.

Keywords: Magnetic Recording, HAMR, Composite Media, TEAMR.

1. Introduction

The proliferation of magnetic recording has been pushed by many factors. Specifically, people often pursue higher magnetic areal density and lower expense per gigabyte. Areal density, in fact, is one of the most significant advantages of data storage technologies. With the rise in areal density, however, the magnetic media grains have to experience a decrease in dimensions to maintain signal-to-noise ratio (SNR). Subsequently, the diminish of magnetic energy barrier is caused by the decrease of grain dimensions. Consequently, the information stored will lose thermal activation. So the magnetic anisotropy of grains should be elevated in order to improve the thermal stability. Nonetheless, the higheset value of anisotropy depends on fields of write head. Therefore, the problem mentioned above leads to the physical limitation that magnetic recording confronts [1].

Generally speaking, there are three aspects to consider when developing magnetic recording. The first one is SNR, the second one is thermal stability and the last one is write ability. For the SNR problem, bit patterned media tend to use one magnetic island to record one bit so that this problem can be solved. And for the thermal stability, some material can be used which has high magnetic anisotropy so that the recorded data will only occupy small volume without destroying thermal stability. Therefore, the remaining problem is how to improve the write ability [2].

Nowadays, with the effort to reach 10 Tb/in^2, some methods have been proposed. In the following of this article, two common methods will be introduced and evaluated and a new method will also be mentioned.

2. Two Common Methods

2.1 Heat assisted Magnetic Recording (HAMR)

In HAMR process, a small proportion of media, which has high coercivity at room temperature, will be heated to very high temperature. As a result, the coervicity of heated region will be reduced dramatically and the magnetization of can be altered by a small writing field from the head pole. Then the region with switched magnetization will be frozen to form a switch bit. Under the mixed effect of thermal and magnetic field footprint, the write bubble emerges.

When using HAMR, the recording medium is thought as a granular ensemble where each two grains are isolated magnetically. Those closely stacked particles have same average volume, which is V, which all have high enough uniaxial magnetocrystalline anisotropy K_u, guaranteeing the ambient temperature stability according to $K_u V / K_B T \geq 70$. Take notice that the value 70 in the right side is not rigorously accurate. Nonetheless it permits the smallest grains to maintain stable for about 10 years if they are in a typical size distribution. During the process, the heating and cooling are conducted on the same time scale. In HAMR, a big effective writing field gradient is able to be realized without the contribution from magnet of the writing head. The relation can be expressed as $\frac{dH_{write}}{dx} \sim \frac{dH_k}{dT} \cdot \frac{dT}{dx}$. In the formula, the first item on the right side is the medium's anisotropy field H_k which depends on temperature. The temperature, in normal condition, is just below the Curie temperature T_C (Curie temperature is where both H_k and medium magnetism disappear). The second one means the gradient of thermal profile at freezing temperature, which serves as media. By using the values estimated on the right side of the formula, a writing gradient that is effective can be yielded, which can be 3 times to 20 times larger than a direct writing field. In HAMR process, Arrhenius–Neel–Brown (ANB) theory is usually used in uniaxial anisotropy particles where an increased temperature is applied to recorded information. For example, by analyzing the thermal erasure, which passes on adjacent tracks, people can apply ANB theory to estimate the cumulative degradation of recorded information [3]. The mechanism of HAMR is shown in Figure 1.

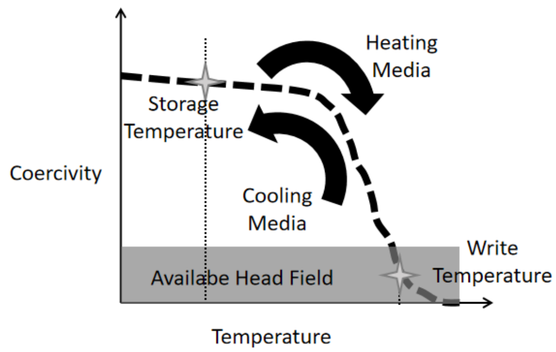

Figure 1. HAMR Process

2.2 Composite Media

It is obvious that the barrier in magnetic recording lies in the existence of thermal fluctuations. Under the mixed influence of thermal fluctuations and charged domain walls, grains may stretch into unexpected directions. To tackle this problem, there are two ways. One is to increase the media coercivity, the other is to increase the media thickness. However, the first method will be limited by fringing fields and the second will result in higher demagnetizing fields, both of which will prevent the development in magnetic recording. Therefore, perpendicular recording is raised. Generally speaking, it has advantages mainly in three aspects. Firstly, it doubles the recording field. Secondly it guarantees the stability of recording with high density. Thirdly, it amplifies the magnetostatic effect [4].

Despite the advantages of perpendicular recording, it also has many problems, resulting from its recording field and the over close arrangement of uniaxial anisotropy axis. Consequently, this method sacrifices the write ability. Therefore, composite media is raised by Victora and Shen as an alternative method. It consists of two layers. One is hard layer, possessing anisotropy that is high, while the other is a soft one, possessing opposite anisotropy. In this way, switching field can be much lower than what a single layer structure has. Assume that K_1 is anisotropy of hard layer and K_2 is anisotropy of the soft one. Since the ratio K_1/K_2 can greatly affect ξ, which means the ratio of the barrier in stabilizing energy ΔE to the switching filed. If K_1/K_2 equals to 1, the maximum of ξ is 1.2. However, if K_1/K_2 can be infinity, ξ can be close to 2. This explains why people use one hard magnet region and a soft one instead of two same hard or same soft regions. In order to optimize the structure, the angles between saturation magnetization of both layers and the applied field should also be taken into consideration. With proper moderation and calculation, the smallest normalized switching field h_s is 0.3 and the highest ξ is 1.67. In composite media process, the magnetization of soft region will rotate because of applied field, then the angle of exchange field, which is applied to hard region, will also be changed. Notice that people often use M_1 and M_2 to express the saturation magnetization. In order to further improve the ξ, different magnetization and volume ratio will be used [5]. The structure of composite media is shown in Figure 2.

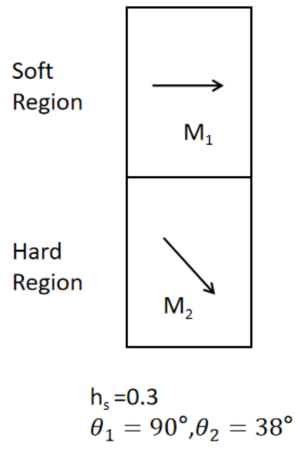

Figure 2. Composite Media Structure

3. Evaluation

3.1 HAMR

3.1.1 Temperature Problem

Temperature, which is dependent on magnetic properties, is of great significance in HAMR process, especially around Curie temperature. As the temperature surpass or drop below Curie temperature, both reformation and disappearance of memory layer will exert great influence on the recording quality and rate in HAMR process will also be influenced. A common problem appears that saturated magnetization remnant is pone to fail to be achieved during rapid cooling process. Consequently, not all the grains are frozen into expected magnetic polarity, which means that some grains are not align with head field. Unfortunately. This problem still stands at the frontier of condensed matter physics and requires cutting-edge technology to research it. Therefore, people are not able to solve it properly nowadays.

3.1.2 Light delivery system

In HAMR, the diffraction limit is a great obstacle. According to the scalar diffraction theory, the diffraction limit for the condition that the value of full width at half-maximum (FWHM) of optical spot size is d can be described as $d = \frac{0.51\lambda}{NA}$, in which NA is the value of numerical aperture of focusing lens and λ is the wavelength. In order to get smallest focused spot, light should be focused through a medium whose index is as high as possible. Specifically, light can be focused at the bottom of a lens if placed in solid immersion lens (SIL). Besides, a variation for the methods mentioned above can be solid immersion mirror (SIM). Both these methods can be modified to satisfy the planar waveguide geometry so that they can be applied into producing the recording head of hard disk drive. Nonetheless, neither SIL nor SIM reaches the standard that HAMR process requires. Precisely, the spot size of SIL is 115nm and that of SIM is 90nm.In HAMR, however, spot size needed is 25nm. Apparently, it is much smaller than that of SIL and SIM. Therefore, the standard for HAMR is far beyond what people are able to reach now.

3.1.3 Media Challenges

HAMR media has rigorous requirement in magnet properties, which is difficult to satisfy now. Generally speaking, the grains in the media should be small and fully isolated. It should also have high anisotropy and can moderate Curie temperature. It is challenging to find a material to satisfy all these needs. L_{10}-FePt serves as the most promising candidate. Although it has high anisotropy and it cannot be eroded easily, it fails to satisfy the requirement that grain size should be small enough. In HAMR media, the size of grains should be smaller than 5 nm, while the size of this kind of material is 7.5nm. Actually, this kind of material is often utilized by combining films with carbon which will be deposited on MgO interlayers. Multilayers can guarantee the high anisotropy and can reduce the switching temperature. The size, however, remains a problem that hinders the development [6].

3.1.4 Summary

Although HAMR is considered as a promising method for developing magnetic recording in the future, it still has many potential problems. The most serious one exists in the difficulty in fabrication. Such difficulty has many aspects, among which temperature problem, light delivery system and media challenges are most obvious.

3.2 Composite Media

3.2.1 Domain Wall Assisted Magnetic Recording (DWAMR)

In order to optimize the composite media, people attempt to reduce the switching field. Then the concept is proposed, which is exchanging spring media. This kind of media mainly uses noncoherent magnetization rotation between hard and soft layers. When the interfacial domain wall fits in hard and soft layer, composite media can perform much better than ordinary condition, even realizes its full potential. The position of domain wall depends on the value of anisotropy field. At the anisotropy field of 6 KOe, the domain wall is mainly in the soft layer, while the field increases to near 20 KOe, the domain wall will pass into the hard layer. The interlayer switching field can also be optimized if the ratio $M_{soft}t_{soft}/M_{hard}t_{hard}$ (M is saturation magnetization and t is thickness) is moderated properly. And if the product of stiffness and saturation magnetization is the same for soft and hard layer, the switching field can be reduced in soft layer. In theory, DWAMR can yield a 25% lower maximum gain value [7].

3.2.2 Microwave Assisted Reversal

In microwave assisted reversal, energy can be transferred through microwave fields in a resonant way. Therefore, high amplitude dynamics can be induced. For the spin system, it can overcome the minimum of metastable energy if given this condition.

According to the experiment conducted on $Ni_{80}Fe_{20}$, in magnetic tunnel junction (MTJ) structure, coercivity is dramatically reduced with the application of microwave assisted reversal. If given different frequencies and different input powers, the extent of reduction will vary from each other [8].

3.2.3 Combination of two methods

Actually, two methods mentioned above can also be used together. With the application of both methods, the field needed to switch the hard layer can be reduced by 86%. The switching field will have a further 40% reduction if a certain field is added, which is spatially uniform, oscillating and has the frequency matching the lowest frequency magnon node [9].

3.2.4 Summary

Composite media is also a very promising method to develop magnet recording in the future. However, this method is far from perfect now. Fortunately, unlike HAMR that has many problems remaining difficult to solve, many improvements in composite media have been proposed. Generally speaking, there are two major methods to make the most of composite media, they are domain wall assisted magnetic recording (DWAMR) and microwave assisted reversal. With the combination of these two methods, composite media can be taken full advantage of.

4. Future Development-Trapping Electron Assisted Magnetic Recording (TEAMR)

Besides two methods mentioned in the previous paragraph, people have never stopped searching for new methods. For the magnetic recording of next generation, people will pursue the density of 10 Tb/in^2, which may be impossible to realize for existing methods. New alternative method has been proposed. That is trapping electron assisted magnetic recording. The method is quite innovative since it changes the traditional writer which is perpendicular. When the magnetic medium is connected to the ground, the new writer pole will be biased by a static electrical potential. In the nanometer head media, a strong electric field will be yielded, which locates between the disk media and the writer pole. At the surfaces of material interface, static electric charges will be accumulated by the dielectric material of the grain boundary and disk media overcoat. With the material permittivity gets higher, the charge density will be bigger there. The atoms of magnetic grains at the surface will trap the free electrons and confine them in the unfilled electronic shell of the magnetic material under the strong electric field that mentioned above. This reduces both the switching field of grains and the magnetic anisotropy of atoms at the surface. This novel writing technology is called trapping electron assisted magnetic recording. It seems that this method is feasible in theory. The cost, however, can be a great problem because it is not cheap to use new systems to replace the traditional devices. Anyway, as a new proposed method, it is quite worth further research and development [10].

5. Conclusions

During the process of developing magnetic recording, many methods aimed at increasing areal density has been proposed. Among them, HAMR and composite are two promising approaches. However, they are both far from perfect. By comparison, HAMR is faced with more problems because the difficulty of fabrication in its process is hard to solve now. While several improvements in composite media have been raised. For the future development, scientists have managed to find a new method called TEAMR. It is innovative and feasible in theory. However, the cost in its application remains a problem.

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