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Current Perspectives

# Recording media research for future hard disk drives

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ABSTRACT

Perpendicular magnetic recording (PMR) technology has recently been introduced in hard disk drives (HDDs) by almost all the HDD manufacturers. It is expected that because of PMR technology, the superparamagnetic limit can be circumvented until around 2012. At this stage, it is necessary to seek out alternatives to extend the current PMR technology, or to invent new alternatives to move beyond the PMR technology. There are several research opportunities becoming available, as we try to extend the competitive advantage of magnetic recording. This article is an attempt to provide a brief review of the research that has been carried out, interspersed with an analysis of possible new directions.



## 1. Introduction

For more than five decades, the primary storage device for computers has been the hard disk drive (HDD). There was tremendous growth in the areal density of HDDs in the late 1990s, at times reaching 100% per year. Between 2000 and 2003, the areal density increased by eight times, and the price per bit dropped by eight times. Because of such an areal density increase, it was possible to make smaller HDDs with larger capacities and at cheaper prices. As a result, HDDs could find new applications in consumer electronics (CE) devices. MP3 players, video recorders, video cameras, game consoles and many other devices are using HDDs to store information. Although the market for MP3 applications has almost been taken over by the flash memory drives, the use of HDDs in video camcorders and video recorders is still growing because of the need for huge storage requirements. Such a demand is good for the HDD industry because, while the markets for HDD in computer applications may have saturated, the market in CE is a growth area. This article will try to review the status of longitudinal and perpendicular recording media in brief, and focus on the possibilities of the future. In Section 2, a brief discussion is made on magnetic recording in the longitudinal recording mode, and on the challenges faced by longitudinal recording media. Section 3 describes the status of current perpendicular recording media and the recent advances in perpendicular magnetic recording (PMR) technology. Section 4 describes the potential research areas in oxide-based perpendicular recording media. Section 5 describes the status and possible research directions in recording media of the future. Finally, a discussion on characterization and analysis techniques that help in advancing the science of the perpendicular recording technology and on possible new magnetization reversal schemes is made.

## 2. Overview of longitudinal magnetic recording

There are several review papers that discuss the longitudinal magnetic recording technology in great detail [1,2]. However, in order to be self-contained, the fundamentals of LMR are provided in brief. Thin film media, which are usually deposited by dc magnetron sputtering, are used in current HDDs. The magnetic layer and several other layers in hard disk media are in a polycrystalline state. Therefore, the grains of the recording medium would have random orientations with respect to the film-plane and with respect to the track direction. Because of such randomness in the nature of the grains used for storing the information, a group of grains are used. As the signal-to-noise ratio (SNR) from such a medium depends on the number of grains in a bit, reduction in grain size and grain size distribution are achieved by the use of seedlayers or underlayers with small grain sizes or from the magnetic layer itself [3–6]. In order to minimize the noise from the randomness, underlayers such as Cr and the concepts such as orientation ratio (OR) were used. The latter is the ratio of $H_c$ in the circumferential to that in the radial direction, and was brought about by a mechanical texturing process. Experimental studies on oriented media are yet to clarify as to what causes the OR [7–10]. It may be worthwhile to carry out film growth simulations of Cr underlayer and a Co-alloy recording layer (RL) on textured and non-textured substrates, to understand the real cause of preferred orientation along the track direction. However, there has been no such simulation study so far, although there have been certain efforts to understand the origin of OR [11].

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In magnetic recording, the energy barrier that prevents the magnetization of a particle from changing direction is proportional to anisotropy energy $K_uV$, where $K_u$ is the anisotropy constant of the material and $V$ is the volume of the grain. As the areal density growth progresses, the grain volume gets reduced. If $K_u$ were kept fixed, this leads to a reduction in the anisotropy energy $K_uV$. When this happens, the thermal energy $k_BT$ starts competing with the anisotropy energy and causes the magnetization to be thermally excited and reversed. Such a phenomenon, wherein the magnetic particles could reverse their magnetization without any external field, is called superparamagnetism. Since a recording medium is composed of grains of different sizes, some of the smaller grains would be more susceptible to thermal switching. The thermal stability issue could be solved by increasing the anisotropy constant ($K_u$) of the material used. However, that leads to the problem of writability, as there is a limit to the writing field that can be produced based on the availability of write-head materials. Therefore, SNR, writability and thermal stability are intertwined in such a way that the improvement of one may lead to deterioration of the other. This aspect is popularly called media-trilemma. Longitudinal recording technology is very close to its superparamagnetic limit now. Therefore, perpendicular recording technology was introduced in order to extend the life of HDDs. At this point of time, all companies have introduced perpendicular recording in their HDD products. It is expected that LMR technology will be phased out by 2008.

## 3. Status of current perpendicular recording media

Iwasaki et al. introduced almost all the fundamentals of PMR in the 1970s, in order to overcome the problem of large demagnetizing fields exhibited by the transitions in longitudinal recording [12–14]. Media based on CoCr alloy with perpendicular anisotropy, double-layered perpendicular recording media with CoCr RL and NiFe as the soft underlayer (SUL) were invented. Several types of head designs, including a single pole head for perpendicular recording were developed. Together, these inventions indicated the potentially superior performance of perpendicular recording compared to longitudinal recording. However, perpendicular recording took about three decades before securing its place in the HDD. This section will review the status of current perpendicular recording media

Fig. 1 illustrates various functional layers such as SUL, RL, etc. of a typical double-layered perpendicular recording medium, and the writing process. In practical designs, there is usually more than one layer involved for every function. However, only a simple design is shown here, and for the sake of simplicity, only one layer is shown to illustrate the function of each layer. The recording media may be coated on an AlMg alloy or glass substrate of a dimension suitable for its particular application. Most of the layers in hard disk media are deposited by the sputtering process. The first layer to be coated on the substrates is an adhesion or interface layer made of Ta, Ti, or an alloy of these materials. This layer helps in improving the adhesion of the SUL and all the other layers with the substrate. The next layer deposited on the adhesion layer is the soft magnetic underlayer. The soft magnetic underlayer helps in the writing process by conducting the flux from the writing pole of the head to the trailing pole. It is usually said that the SUL acts as a magnetic mirror. Therefore, if the writing head has a north pole in its tip, a south pole (image) is formed on the top surface of the SUL. Formation of this polarity helps to keep the media between the pole gaps (one real pole and one imaged pole). Therefore, with the help of the SUL, the media is placed in the head gap, which produces more field than the fringing field used in the longitudinal recording. This is one main reason for the superiority of perpendicular recording over longitudinal recording.

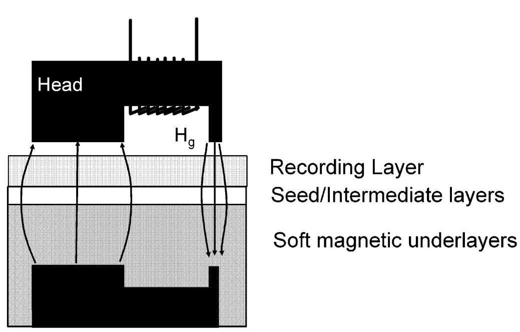


**Fig. 1.** Schematic illustration of various layers of perpendicular recording media and the writing process.

It was reported way back in the 1980s, that the SUL may generate significant noise [15]. Until 2000, the issue of noise from the SUL was not resolved. Only during the past 5 years, several SUL designs were studied and ways of counteracting the noise from SUL were devised. One way to minimize the noise of the SUL is to pin its magnetization along the radial direction. The pinning can be carried out with a hard magnetic layer, or with the help of an antiferromagnetic pinning layer (such as IrMn), or with the help of an in-plane applied magnetic field during the deposition of the SUL [16,17]. In certain cases, all these techniques may be employed to minimize the noise. Another scheme that has commonly been used to minimize the noise is anti-parallel coupled soft underlayers (APC-SUL) [18].

On top of the SUL, some intermediate layers may be deposited with or without seedlayers. The intermediate layers have at least two functions in perpendicular recording. Exchange decoupling the SUL and the RL is one of them. Providing epitaxial growth conditions for the RL is another function. For perpendicular media with Co-based RLs, it is essential to obtain grains with a Co(0 0 0 2) orientation perpendicular to the film-plane. Therefore, the intermediate layer should have the fcc(1 1 1) or hcp(0 0 0 2) texture. At present, Ru is the most commonly used element as the intermediate layer. In addition, a seedlayer may be deposited below the intermediate layer to enhance the preferred growth. It has been noticed that the choice of a suitable seedlayer material is crucial to enhance the growth of the intermediate layer [19,20]. Very recently, intermediate layers have also provided the additional functions of inducing exchange decoupling, and grain size reduction in the RL. For these purposes, an additional Ru or Ru alloy layer is deposited at high pressures and perhaps in the presence of a reactive gas such as oxygen.

The RL is a Co-based hcp alloy for most of the designs carried out so far. The function of the RL is to store the information for long periods of time (about 10 years) and to produce the signal when reading the information back. CoCrPt along with some form of oxide is the most commonly used material. The oxide material in the sputtering target may be an oxide of Si, Ti or Ta, or the target may be sputtered in the presence of oxygen to form oxides of Cr. A mixture of oxides may be formed at the grain boundary, which helps to decouple the grains and reduce the noise [21]. Pt in the target helps to improve the anisotropy constant of the grain. Grain size can be controlled by increasing the concentration of oxides [22]. Thermal stability may be improved by forming two or more layers of the RL, by providing each layer with different functions. The bottom-most layers may be designed to obtain fine grains, and the top-most layers are designed to achieve high thermal stability [23]. In addition to all the layers discussed above, the disk will also be coated with