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Current Perspectives

CPP-GMR technology for magnetic read heads of future high-density recording systems

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ABSTRACT

This paper introduces CPP-GMR technology, its features, routes to output enhancement, problems to be solved and possibilities as a recording head. For instance, use of high spin-dependent bulk scattering, high resistivity, or half-metallic magnetic materials for free and reference magnetic layers were shown as ways to improve the output of CPP-GMR. A current state of CPP-GMR head development was also mentioned in view points of sensor downsizing, magnetic head noise and high-density recording demonstration. CPP-GMR still has some points to be improved, however it is believed that the CPP-GMR will actualize a next high-performance magnetic read head in no distant future.

1. Introduction

One of the present key-technologies for keeping a high growth-rate of magnetic recording density in hard disk drive (HDD) systems is a development of magnetic read heads using a tunneling magnetoresistance (TMR) sensor. The TMR sensor consists of a magnetoresistive film with a thin barrier-layer in a current-perpendicular-to-plane (CPP) structure. However, its high resistance is a critical obstacle to downsizing the sensors for future high-density recording, although the TMR head produces quite a high output signal. Fig. 1 shows the trends of data-transfer rate for high-end HDD systems and allowed resistance-area product (*RA*) of read head sensors with a CPP structure versus areal density. A cut-off frequency of an electrical circuit, which limits the data-transfer rate of a drive system, is inversely proportional to the resistance of the magnetic head. Keeping or reducing this head resistance (*R*) is much important for high areal density. Moreover, the magnetic sensor size (*A*) should be reduced with increasing the areal density. Consequently, *RA* of the CPP-type sensor must be reduced as shown in Fig. 1. These trends indicate that the TMR head, whose minimum achievable *RA* value is thought to be about 1 $\Omega\,\mu m^2$, will face the *RA* limit at about 300–400 Gbit/in^2.

On the other hand, in terms of sensor resistance, a CPP-GMR (giant magnetoresistance) sensor, which also has a CPP structure, can be applied to much higher areal densities because it uses a metallic spin-valve film and therefore has quite a low *RA* of around 0.1 $\Omega\,\mu m^2$. The CPP-GMR film can be applied to a sensor that is several 10 s of nanometers long. Moreover, the CPP structure has advantages such as a short read gap and good thermal contact with the electrodes. Therefore, the CPP-GMR head is expected to replace the TMR head and enables densities exceeding 300 Gbit/in^2 [1–4].

In this paper, I take a general view of several methods for enhancing the CPP-GMR. I also point out the recent state of development and problem of magnetic read heads with the CPP-GMR sensors and give my opinion on the possibility of future high-density magnetic recording.

2. Output (ΔRA) of CPP-GMR sensors

2.1. ΔRA requirement

Although CPP-GMR has the advantage of low *RA*, the performance of CPP-GMR sensors that use spin-valves made of conventional materials is limited by their small specific magnetoresistance change (ΔRA: resistance-change and area product) less than 1 m$\Omega\,\mu m^2$ (Fig. 2). This is too small to achieve a sufficiently high signal-to-noise ratio (SNR) due to the small change in film resistance that occurs when the relative angle between magnetizations of two magnetic layers is changed. Fig. 2 shows the required ΔRA of the CPP-GMR for recording densities as estimated using the following assumed conditions: output signal voltage for sufficient SNR = 1.5 mV, head efficiency = 30%, sense current density = 100 MA/cm^2, power consumption of sensor element = 0.6 mW [5].

One of the special features of the CPP-GMR is that an absolute ΔR value increases as the sensor is downsized. Because of this feature, the required ΔRA becomes smaller as the recording density approaches 300–400 Gbit/in^2, where the power consumption of the sensor causing temperature rise by Joule heating is a dominant factor in limiting the sense current. On the other hand,

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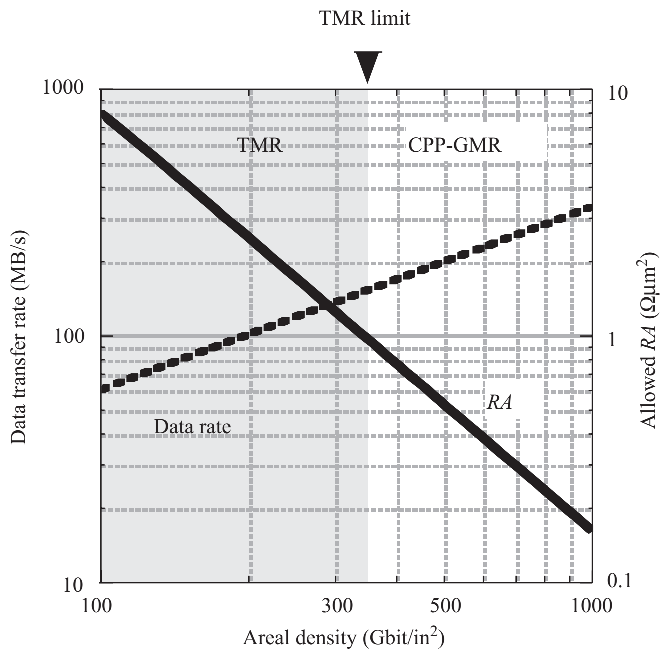

Fig. 1. Trends of data-transfer rate for high-end HDD systems and allowed resistance-area product (*RA*) of read head sensors with current-perpendicular-to-plane (CPP) structure versus areal density.

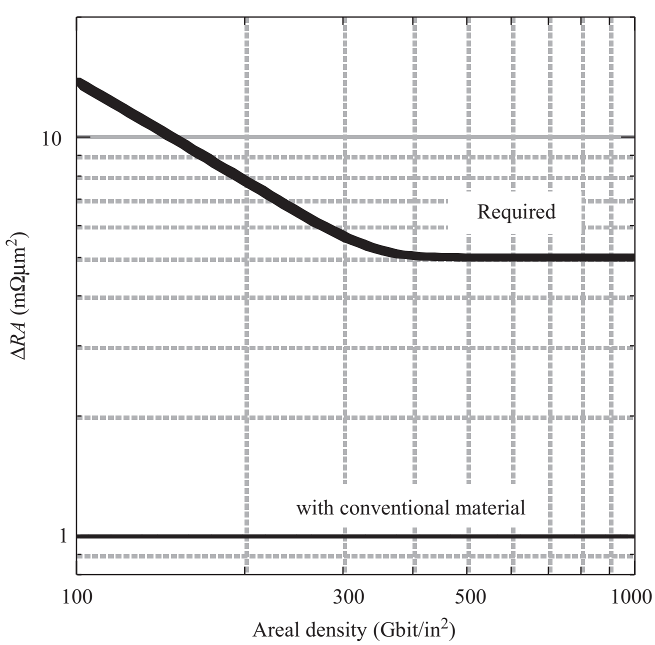

Fig. 2. Estimated required Δ*RA* of CPP-GMR for higher recording densities for output signal voltage = 1.5 mV, head efficiency = 30%, sense current density = 100 MA/cm^2, and power consumption of sensor element = 0.6 mW.

the current density limit due to an electrical migration or rotational magnetic field becomes dominant over 300–400 Gbit/in^2, which makes the required Δ*RA* constant, and it is found from this estimation that a Δ*RA* of at least 5 mΩ μm^2 is needed.

2.2. How to enhance ΔRA

By assuming that the spin-diffusion length is much longer than the layer thickness, *RA* and Δ*RA* of the CPP structure can be described by a simple two-current model [6–7] derived from Boltzmann's equation. The Δ*RA* of the CPP configuration, which has a synthetic ferri-coupled magnetic pinned-layer structure for obtaining a strong pinning field and a laminated free-layer structure (Fig. 3, the free-layer structure is single.), can be expressed as follows:

$$\Delta RA = \frac{4(\beta_F \rho_F^* t_F + 2\gamma R_{F/N}^* A n)(\beta_R \rho_R^* t_R - \beta_P \rho_P^* t_P + \gamma R_{F/N}^* A)}{\beta_F^* t_F + \rho_R^* t_R + \rho_P^* t_P + (2n+1) R_{F/N}^* A + (n-1)\rho_{in} t_{in} + R_{para}}. \quad (1)$$

Here, β and γ are, respectively, the bulk and interface spin-asymmetry coefficients; t the thickness of each magnetic layer; $\rho^* = \rho/(1-\beta^2)$; and ρ the resistivity of the magnetic layer. The suffixes *F*, *R*, and *P* indicate, respectively, the free, reference, and pinned layers. $R^*A = RA/(1-\gamma^2)$ and *RA* is the resistance-area product at the interface between the magnetic and non-magnetic layers. n is the number of the free layer, i.e., $n-1$ spacers are inserted in the free-layer structure. R_{Para} is a parasitic resistance in the CPP structure and includes the resistances of terminals, contacts, anti-ferromagnetic pinning layer, and other elements and also crowding resistance. The effect of Ru, which is a typical material, in the synthetic-ferri pinned-layer structure was ignored for simplicity.

Eq. (1) shows there are several methods of enhancing the Δ*RA*; for example, we could use a material with a high $\beta\rho^*$ and γR^*A, thicken the free and reference layers (although this is not practicable because it reduces the free-layer sensitivity and effective strength of the pinning field), or decreases the parasitic resistance. It is also quite effective to use a small or negative β material for the pinned layer. A magnetic/non-magnetic laminated structure of the free (and pinned) layer can be applied, too. It is, however, difficult to use all of these methods in combination because, for example, a high-resistivity material shows little or no spin-dependent scattering. Therefore, realization of a combination in some of these must be a key approach for improving the CPP-GMR.

2.3. Magnetic material development

In relation to the above guides to enhance the Δ*RA*, a great deal of effort has therefore been made to improve the Δ*RA* value of CPP

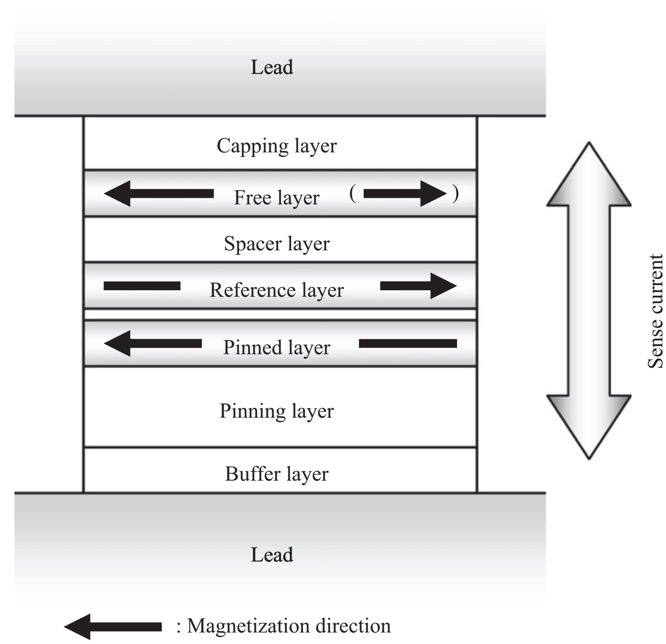

Fig. 3. CPP-GMR structure used for calculating Δ*RA*. Spin-valve film is a bottom-type structure with a synthetic ferrimagnet pinned layer.