Fabrication and Analysis of PM-biased Spin-valve Sensors

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Abstract: GMR spin-valve sensors are fabricated and analyzed, where a pair of CoPt permanent magnets (PM) are attached to two ends of the sensor elements to suppress the hysteresis. The size dependence of the spin-valve sensors is investigated by measuring GMR spin-valve sensing elements patterned with different lengths and widths. The results show that the GMR ratio reduces and the saturation field increases respectively with decreased length of the spin-valve sensor. And the saturation field also decreases with increasing width due to a stronger demagnetization effect. The experimental results are in good agreement with the theoretical prediction.

Keywords: Unshielded spin valve; Transfer curve; Linearity; GMR ratio

1. Introduction
Since the pioneering work by Dieny et al. in 1991 [1], Spin valve has proved to be one of the best materials applied in a variety of magnetic devices, e.g. read heads [2] due to higher sensitivity and better linearity compared to conventional Hall-effect sensing elements and anisotropic magnetoresistive (AMR) sensing materials [3-5]. For read head applications, obtaining much higher-sensitive sensors is always one of the key objections to meet the requirement of continuously-increased areal storage densities. In order to achieve higher resolution reading, it is common to place the spin-valve sensing elements through insulator gaps between two magnetic shields, which can eliminate the external field influence on the read signal [6]. However, the spin-valve sensing elements also can be used in many other areas, such as magnetic media readers (e.g. credit card readers), and field sensors etc.. Theoretically, the spin-valve materials are intrinsically linear if the hysteresis is suppressed. How to decrease or eliminate the hysteresis of spin-valve sensor is vital to making excellent linear devices. In this work, we will describe the fabrication and analysis of a GMR spin-valve sensor, of which the hysteresis is suppressed by placing a pair of permanent magnets (PM) on both ends of the sensor, as shown in Figure 1.
The patterned spin-valve sensing elements exhibit different characteristics as compared with the sheet film due to size effect. Herein we will briefly describe the main fabrication process for the GMR spin-valve sensor firstly. Then, we will investigate the dimension dependence of the sensor performance by measuring spin-valve sensing elements patterned with different lengths and widths.

2. Experimental

2.1 Fabrication

The fabrication of the unshielded GMR spin-valve sensor employs the modern manufacture technology, similar to that of spin-valve read head of hard disk drivers, but much simpler. The main process steps, as shown in Figure 2, are explained as below: a) Deposit GMR spin-valve materials on silicon substrate after depositing a SiO₂ insulating layer, and then deposite MRS protect layer; b) Spin-coat photoresist 1; To make the resist lift-off feasible, an undercut resist structure is used for the following PM deposition [7]; c) Pattern spin-valve layer and protect layer by photo and IBE techniques; d) Deposit PM (CoPt used in this case); e) Lift off photoresist 1 and chemical-mechanical polishing (CMP) the surface; f) Spin-coat photoresist 2 and deposite conductor layer; g) Lift off to form touch conductor on the top of the PM.

2.2 Analysis
The experimental GMR transfer curves for the spin-valve sheet films and the patterned spin-valve sensing elements are measured with a magnetic tester, and the experimental curves are compared with the theoretically simulated transfer curves.

3. Results and Discussion

The materials used in the GMR spin-valve sensors in this work (as shown in Figure 1b) has a configuration of $\text{NiFeCr}(45\AA)\text{-NiFe}(55\AA)\text{-CoFe}(15\AA)\text{-Cu}(21\AA)\text{-CoFe}(24\AA)\text{-Ru}(10\AA)\text{-CoFe}(22\AA)\text{-PtMn}(250\AA)\text{-NiFeCr}(70\AA)$. Figure 3 gives the transfer curve of the sheet GMR spin-valve materials, showing excellent performance with a high GMR of about 9.9%.

![Figure 3 GMR properties of the sheet spin-valve.](image)

Shown in Table 1 are fabricated spin valve sensing resistors with different dimensions.

| Table 1 Length and width of tested GMR spin-valve devices |
|-------------------------------|-------------------------------|
| Device 1 | Device 2 |
| Length  | Width  | Length  | Width  |
| 14.0     | 2.5    | 2.9     | 1.8    |

Figure 4 shows respectively the experimental GMR transfer curves and the theoretic simulation for the Device 1. The tested sensor (Device 1) has a dimension of 14 um length and 2.5 um width, and is biased with a pair of 400 Å CoPt permanents (PM). A comparison indicates that the experimental transfer curve (Figure 4a) is roughly in agreement with the normalized simulation result (Figure 4b). It should be noted that, with biased by CoPt permanent magnets, the GMR spin-valve sensors theoretically should have no hysteresis, since the biased field generated by the patterned CoPt permanent magnets could induce a single domain structure in free layer and thus suppress the hysteresis of GMR spin-valve sensing elements. However, as can be seen from Figure 4a, the experimental transfer curve still has little hysteresis, indicating the unperfect bias in Device 1.
Figure 4 GMR spin-valve transfer curves for D1: a) experimental result, b) normalized simulation result.

Figure 5 shows the GMR transfer curves for Device 2. Although biased with a pair of 400Å CoPt permanents (PM) in the same way, the transducer Device 2 has a smaller dimension than Device 1: the length is decreased to 2.9 um in Device 2 from 14 um in Device 1, the width is reduced to 1.8 um in Device 2 from 2.5 um in Device 1. Again, the experimental and simulated transfer curves are in a very good agreement. Device 2 exhibits an excellent performance showing no hysteresis.

Figure 5 GMR spin-valve transfer curves for D2: a) experimental result, b) normalized simulation result.

From the experimental results, we found that after the device patterning, the GMR is drastically reduced as compared to the initial sheet film level. The GMR spin-valve sensor Device 1 exhibits a reduced GMR of 8.16% from nearly 10% at the initial sheet film level, while sensor Device 2 shows much smaller GMR of 6.34%. The reasons behind this GMR reduction are probably due to two factors: 1) device size effect and 2) series resistance added by sensor/PM junction.

Otherwise, by comparing Figure 4 and Figure 5, it is easy to draw a conclusion that the saturation field of the GMR sensor increases with decreasing the sensor length and width. This can be explained from two aspects: 1) the effective biasing field on the sensing element generated by the permanent magnets increases with decreasing the sensor length; 2) the demagnetization field becomes larger when reducing the sensor width.

4. Conclusion

GMR spin-valve sensors have been fabricated, where the hysteresis is suppressed by placing a pair of CoPt permanent magnets at both ends of the sensing elements. It is found that the size of the spin-valve sensing element has great influence on the device performance. With
reduced length and width of the spin valve sensing element, the GMR ratio decreases slightly and the saturation field increases respectively. The fabricated spin-valve sensors exhibited high GMR ratio and good linearity, showing promising applications in linear devices.

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