The Linewidth Dependence of GMR Properties in Patterned Spin Valve Resistors

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Abstract. The spin-valve structures with the configuration of NiFeCo(42.5Å)/CoFe(15Å)/Cu(25Å)/CoFe(42.5Å)/CrPtMn(300Å) were fabricated by RF diode sputtering. After a annealing process, the sheet spin-valve thin films were photolithographically patterned into serpentine resistors with different linewidths. The effect of linewidths on the magnetic properties and GMR ratio of patterned spin-valve resistors were studied. It was found GMR decrease with decreasing linewidths due to size effect and the effective anisotropy field \(H_k\) and the bias field field \(H_b\) are both inversely proportional to linewidths.

1. Introduction
Spin-Valve sensing resistors [1] have attracted much attention and are widely used in hard disks and in a variety of other applications [2-6]. Due to the size effect, patterned Spin-Valve sensing resistors show quite different GMR properties as compared to the sheet Spin-Valve thin films. Exploring the relationship between patterned Spin-Valve sensing resistors’ dimension and their GMR properties is very important for optimizing the performance of Spin-Valve based devices. In this work, GMR spin-valves have been patterned into serpentine sensing resistors with different linewidths, the size effect of GMR properties has been investigated with respect to GMR ratio and the effective anisotropy field \(H_k\), a mixed effect of shape and uniaxial anisotropies, the offset field \(H_b\).

2. Experiment Procedure
Spin-valve multilayers used in this work were deposited on Si/Si₃N₄(2KÅ) substrates by a RF diode sputtering system. The free and pinned magnetic layers were deposited with a 200e field in the same direction. Subsequent to the deposition, the spin-valve multilayers were annealed at 240°C for 2 hours in forming gas with a field of 4000Oe parallel to the easy axes of the magnetic layers in order to lower the free layer dispersion and maximize the pinning strength induced by the pinning layer to the pinned layer. The annealed spin valves show excellent properties, with a pinning field larger than 250Oe.
properties of the annealed sheet film is summarized in Table 1. Here, $H_c$ represents the coercivity of the free layer, $H_{coup}$ represents the interlayer (‘orange peel’) coupling between the free and pinned layers.

Table 1  Summary of Magnetic Properties of Sheet Spin-Valves

| $H_c$ (Oe) | $H_{coup}$ (Oe) | GMR% | Spin-Valve Configuration       |
|-----------|---------------|------|--------------------------------|
| 3.47      | 11.5          | 8.62 | NiFeCo(42.5Å)/CoFe(15Å)/Cu(25Å)/CoFe(42.5Å)/CrPtMn(300Å) |

The sheet spin-valve multilayers were then photolithographically patterned into serpentine resistors with different linewidths.

The easy axis of free layer and the pinning direction were patterned along the lengths of patterned spin valves. The pinned layers were then reoriented into the transverse direction by annealing at 240°C for 2 hours in forming gas with a field of 4000Oe applied in the direction perpendicular to the length of patterned spin-valves.

The performance of the spin-valve resistors was measured with a test station, where the magnetic field can be varied from –500 Oe to 500 Oe. During measurement, the field was applied parallel to the sensing axis, which is in the transverse direction of patterned spin-valve sensing resistors. The MR transfer curve was acquired by sweeping the applied magnetic signal field.

3. Results and discussions

3.1. Effect of Patterned Linewidths on the Effective Anisotropy

The effective anisotropy $H_k$ comes from the mixed effect of the shape anisotropy and the uniaxial anisotropy of the free layer. It plays an important role in the determination of sensitivity of patterned spin-valve, and can be expressed as Sensitivity = GMR%/ (2* $H_k$). In principle, three factors can be used to adjust the $H_k$. The first one is the orientation of the easy axis of the free FM layer anisotropy. The second one is the patterned spin-valve linewidth. The third one is the thickness of the free FM layer. Figure 1 shows the effect of the patterned spin-valve linewidths on the $H_k$.

![Figure 1. Dependences of $H_k$ on the patterned spin-valve linewidths](image-url)
It shows that the $H_k$ is inversely proportional to the inverse linewidth of patterned spin-valve resistors, and be expressed by

$$H_k = C_1 + C_2/W \quad (3.1)$$

Here, The first term $C_1$ is contributed by the uniaxial anisotropy of the free layer, and the second term $C_2/W$ is contributed by the shape anisotropy of the free layer, where $C_2$ is constant and $W$ is patterned linewidth. By curve fitting, $C_1$ and $C_2$ are determined respectively to be 13.84 Oe and 73.4 Oe$\mu$m for the Wafer 1. $C_1$ is related to the uniaxial anisotropy field of the free layer. For NiFeCo layer the uniaxial anisotropy is 21Oe. The discrepancy of the experimental value with the predicted value indicates that the easy axis of the free layer is no longer aligned along the lengths of the patterned spin-valve resistors, it is either randomized or altered away by the annealing process. $C_2$ is related to both the free layer magnetization $M_f$ and the free FM layer thickness $t_f$, and can be expressed by a formula of $4\pi M_f t_f$. By calculation, $C_2$ are 72.2 Oe$\mu$m, and that is very close to the experimental data acquired from the curve fitting.

3.2 Effect of Patterned Linewidths on the Offset Field $H_b$

The patterned linewidth not only exhibits a strong effect on the effective $H_k$ but also shows a strong effect on the offset field $H_b$. The origin of the offset is mainly caused by the interlayer ‘orange peel’ coupling, which is arising from the roughness of the spin-valve multilayer [7]. Note the RKKY related coupling is so small and ignored in this case. The interaction between the free and pinned layer, which is arising from the uncompensated poles at the end of the free and pinned layers, also has an effect on $H_b$. The third one is the effect of the sensor current, which, in this study, is eliminated by averaging the data taken by passing the current both ways through the patterned spin-valve resistors. Figure 2 shows the dependence of the offset field $H_b$ on the spin-valve linewidth

![Figure 2](https://via.placeholder.com/150)

**Figure 2.** Dependences of $H_b$ on the patterned spin-valve linewidths

The offset field $H_b$ appears to be roughly inversely proportional to the linewidth of the spin-valve resistor, and can be expressed by

$$H_b = C_3 - C_4/W \quad (3.2)$$
Where, the first term $C_3$ is actually the “orange peel” coupling, and can be determined experimentally by the intercept of the straight line with the offset field axis. The second term $-C_4/W$ is a result of magnetostatic interaction between the free and pinned layers, where $C_4$ can be determined by the slope of the straight line.

Table 2 summarizes the data from the curve fittings from Fig. 2.

| $C_3$ (Oe) | $C_4$ (Oe$\cdot$μm) |
|------------|---------------------|
| 8.6        | 60.2                |

In Table 2, it shows that the “orange peel” coupling $C_3$ determined by the intercept of the straight line with the offset field axis is consistent with the result from the sheet film measurement. The slope $C_4$ is a measure of the strength of the effect on the free layer generated by uncompensated poles at the edges of the pinned layer, and can be expressed as $C_4 = 4\pi M_p t_p$, where the $M_p$ and $t_p$ are the magnetization and thickness of the pinned layer respectively.

### 3.3. Effects of Patterned Linewidths on GMR ratio

![Figure 3. Dependence of GMR ratio on the patterned spin-valve linewidth](image)

As shown in Fig. 3, the GMR decreases with decreasing resistor linewidth. The GMR drops from 6.7% with a linewidth of 2 μm to 6.2% with a linewidth of 1μm, and drops further with decreasing linewidth. The effect of the patterned linewidth on the GMR is mainly contributed by two factors, 1) higher probability of electron scattering at edges with narrower linewidth, 2) deterioration of pinning alignment in the transverse direction by stronger demagnetization effect with narrower linewidth.

### 4. Conclusions

The dependences of magnetic properties on linewidths in patterned spin-valve sensing resistors have been investigated. The GMR ratio is found to decrease with decreasing the linewidths of the patterned spin-valve resistors. Both the effective anisotropy field $H_k$ and the offset field $H_b$ are also size-dependent, and are inversely proportional to the linewidth of patterned spin valve.
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