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Magnetoresistance and Strain in Permalloy Films

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We measured the magnetoresistance (MR) of sputtered Permalloy ($Ni_{83}Fe_{17}$) films with external strains produced by piezoelectric transducer actuators. We observe that the MR ratio was increased by 2.3 times by a compressive strain of 3.5×10^{-4} compared to that of the as-deposited film. Tensile strains and compressive strains reduced the MR ratio. These observations suggest that it is possible to tune the MR properties through the use of the external strains. We expect to apply the results for the multi-head magnetic recorders with selectively activated recording heads.

1. Introduction

As magnetoresistance (MR) in transition metal is mainly caused by spin scattering and magnetoelasticity results from orbit-spin coupling (L-S), these two phenomena are interrelated [1]. Strains produce magnetoelastic (ME) energy, and ME energy affects the spin configurations through L-S coupling. Therefore, strains lead to MR variations [2, 3].

Although we believe that the strains affect the MR properties of magnetic films, the quantitative relationship between MR and strain has not been well reported. In this study, we investigated MR properties in $Ni_{83}Fe_{17}$ Permalloy films with uniformly imposed strains produced by a piezoelectric transducer (PZT). We selected a composition of $Ni_{83}Fe_{17}$ Permalloy for a negative magnetostriction coefficient (that is, negative L-S coupling) of -4×10^{-6} [4].

2. Experimental Procedures

Our experimental setup is shown in Fig. 1. Permalloy films were deposited using rf magnetron sputtering from a $Ni_{83}Fe_{17}$ alloy target. A 2 × 20 mm film was prepared using a metal mask on a PZT substrate. The thickness of the film was 200nm. The deposition rate was 0.22 nm/sec and the sputtering Ar pressure was 20 mTorr. The PZT was covered with a 500 μm-thick epoxy insulator and our Permalloy films were deposited on top of the epoxy insulator. We kept the PZT substrate at room temperature during whole deposition procedure in order to prevent any deterioration of the PZT.

The PZT (AE1010D16, from Token LTD) could elongate or contract linearly up to strains of $\pm 8.3 \times 10^{-4}$ with applied voltages of ± 100 V, respectively.

A four-point probe MR measurement system was used with a current of 0.7 mA after the film had been deposited. External magnetic fields up to ± 7960 A/m (= ± 100 Oe) were applied during MR measurements. Therefore, we obtained MR ratio as a function of both magnetic field and imposed strains.

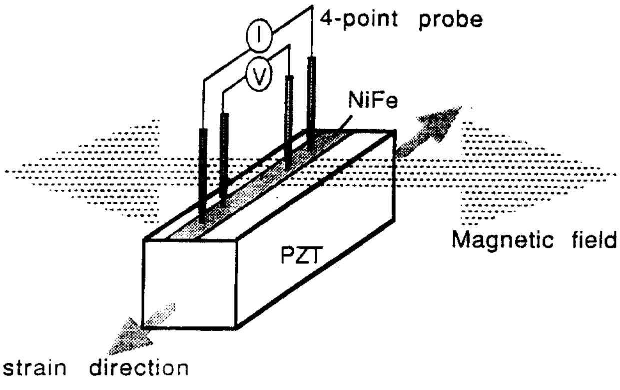

Fig. 1. Experimental setup.

3. Experimental Results and Discussion

The most important parameters for describing MR properties are the MR ratio, saturation magnetic field (Hsat), and MR sensitivity. We defined the MR ratio (ΔR) as Eq. (1).

$$\Delta R = (Rmax - Rmin)/Rmin \qquad (1)$$

Rmax is the maximum resistance during MR measurements around H = 0, and Rmin is the minimum resistance with a saturation external magnetic fields of ± 7960 A/m, respectively.

Experimental results are given in Fig. 2 which shows ΔR as a function of various strains. It can be seen that ΔR at a compressive strain of 3.5×10^{-4} becomes up to 2.3 times as large as the ratio with no imposed strain. Tensile strains reduced the ΔR by up to 50 % of the ratio with no imposed strain. We observed an abrupt change in ΔR around -3.5×10^{-4}. Figure 2 reveals ΔR is very sensitive to even a small amount of the strain.

As the hysteresis in an MR versus H curve appears, we define H_{50} as the magnetic field difference at the ΔR/2 points in the ΔR –H curve. The lower ΔH_{50} implies that we need less saturation magnetic fields to operate MR devices. We show the ΔH_{50} results in Fig. 3 which is a plot of ΔH_{50} versus imposed strains. ΔH_{50} becomes smaller with compressive strains and reaches its minimum ratio when ΔR reaches its maximum in Fig. 2. ΔH_{50} becomes larger with increasing tensile strain.

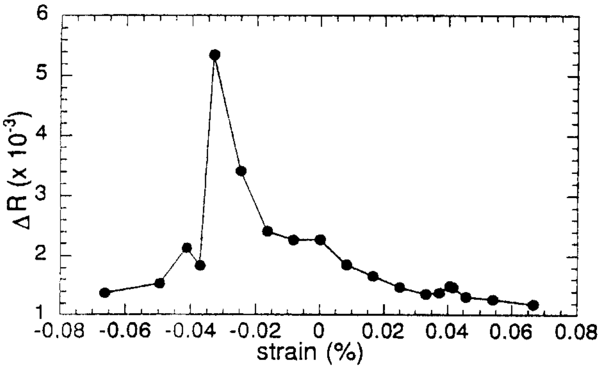

Fig. 2. Plot of ΔR versus imposed strains.

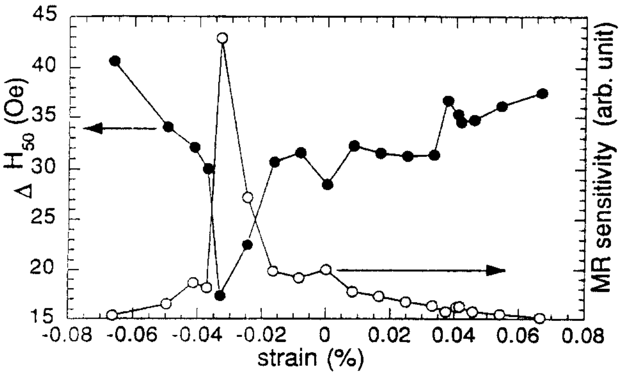

Fig. 3. Plots of H_{50} and MR sensitivity versus imposed strains.

MR sensitivity, which can be defined as the rate of change of ΔR with respect to the magnetic fileds, is very important in a practical sense. In this study, we defined the MR sensitivity as $\Delta R/\Delta H_{50}$. We obtain an optimum MR sensitivity at a compressive strain of 3.5×10^{-4} as shown in Fig. 3. This implies that the MR sensitivity is strongly related to the strains in a practical sense.

We observed that the MR properties depend on the imposed strain (e). Even a small amount of the imposed strain may result in large differences in MR properties. We explain the MR behavior as follows:

If no strain (e = 0) is imposed as shown in Fig. 4(a), the magnetic spins, expressed as arrows align randomly at H = 0 as shown in the center of the figure. The spins align at the maximum external magnetic field at H = +Hmax (= +7960 A/m) as shown on both sides in Fig. 4(a). If we measure the resistance between H = 0 and H = Hmax by flowing the current indicated as '*i*', then we obtain ΔRo.

If we imposed tensile stress (e > 0) on the film, the strain tries to align the spins by L-S coupling as shown in the center of Fig. 4(b). Only a small spin scattering difference between H = 0 and H = Hmax is produced as a result of the negative L-S coupling. Therefore, ΔRtensile in Fig. 4(b) becomes smaller compared with that of no imposed strain, ΔRo, in Fig. 4(a).

With compressive strains (e < 0), spins align parallel to the strain direction even at H = 0 as shown in the center of Fig. 4 (c). With a maximum magnetic field (Hmax), the spins align perpendicular to the strain direction. Finally, ΔRcompressive between H = 0 and H = Hmax in Fig. 4 (c) becomes larger than that of Fig. 4(a) and (b).

If the imposed strain is large enough ($e << -3.5 \times 10^{-4}$) as shown in Fig. 4(d), L-S coupling from the strain tries to maintain the spin configurations even at a saturation magnetic field (Hsat), which reduces ΔR.

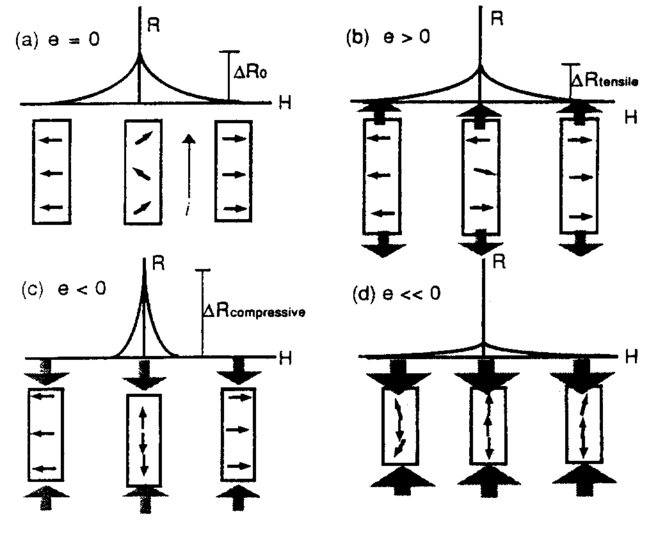

Fig. 4. Illustration of ΔR with magnetic spin and strain configurations : (a) without imposed strain (b) with tensile strain (c) with compressive strain (d) with very large compressive strain.

We may apply the above results to tune the sensitivity of the multi-head devices. We may activate only the selected head among the several multi-heads, or deactivate specific track heads to lessen noise. PZT seems to be a appropriate actuator to tune the magnetic property by strain. Uniform imposed strain was possible with the PZT which is small enough for the micro-electronics devices.

4. Summary

We measured the MR properties of $Ni_{83}Fe_{17}$ films with uniformly imposed strains from PZT. MR increased in an appropriate compressive strain range and decreased with tensile strains. The MR ratio was enhanced by 230 % with a compressive strain of 3.5×10^{-4} compared with the ratio with no external strain. Tensile strains and compressive strains above 3.5×10^{-4} reduced the MR ratio. The ME energy enabled us to tune the MR properties even with a small amount of imposed strain. We expect to apply the results for the multi-head magnetic recorder by activating the selected heads.

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