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Spin diffusion length and giant magnetoresistance in spin-valve tri-layers

Yoshiaki Hashimoto, Shingo Katsumoto*[,1], Chizuko Murayama, Yasuhiro Iye[1]

Institute for Solid State Physics, University of Tokyo, 7-22-1 Roppongi, Tokyo 106-8666, Japan

Abstract

We applied giant magnetoresistance (GMR) effect to measure spin diffusion length in a non-magnetic metal. The temperature dependence of the magnetoresistance observed in Fe/Cu/Ni tri-layer samples was strongly dependent on the thickness of the middle Cu layers, apparently reflecting the spin diffusion length. Assuming the error-function dependence on the thickness, we derived the values of the spin diffusion length.

Keywords: Giant magnetoresistance; Spin diffusion length; Spin valve

Spin diffusion length l_s in non-magnetic material is one of the key parameters in quantum transport such as weak localization effect. An electron can no longer interfere with itself after it experiences a spin-flip scattering, thus saturation of the phase coherence length at low temperatures is often attributed to the limitation by l_s. Weak localization magnetoresistance can provide such lengths [1,2], though it is difficult to determine l_s independently.

The finding of giant magnetoresistance (GMR) in ferromagnetic-normal metal superlattice triggered extensive studies of spin-related electronic transport. It is usually assumed that l_s is much longer than the period of the superlattice. It is apparent then, that the amplitude of GMR should be largely diminished if this assumption is broken and the decrease of GMR amplitude works as a direct measure of l_s.

Here we report measurements of GMR in so called spin-valve structures in which the non-magnetic layers are significantly thicker than those investigated so far.

We adopted a Fe/Cu/Ni tri-layer structure to realize the spin valve. The substrates were non-doped Si wafers covered with SiO_2. The samples were prepared in two different ways. In the first set, the films were deposited by vacuum evaporation of the metal sources, which were heated by an electron gun. The substrates were significantly heated by the sources. With increasing the Cu thickness d_{Cu}, the resistivity decreased rather abruptly around 200 A. The cause for this is not clear but might be re-crystallization.

In the second set, the films were deposited by ion-beam sputtering. The quality of the Cu was kept constant because of the low heat excitation, and the resistivity is almost constant against d_{Cu} (i.e., the resistance is proportional to d_{Cu}^{-1}).

Fig. 1 shows magnetoresistance of a sample at 300 K and 18 K. The strong temperature dependence indicates that the GMR reflects that of l_s in Cu. However the increase in the cohesive force indicates that magnetic properties such as domain structures are also temperature dependent.

In order to extract l_s, we adopted the following procedure. First, the amplitudes of the magneto-conductance ΔG are normalized by the value at 18 K, where ΔG shows saturation. This process normalizes the quality of Cu layers and $\Delta G/\Delta G_{18\,K}$ align in order of d_{Cu} though ΔG randomly distributes for d_{Cu} in the first set.

We assume that (1) the "spin conserved" electrons emitted from a ferromagnetic layer distribute in Cu layers as a Gaussian with the dispersion l_s^2; (2) the

* Corresponding author.

E-mail address: kats@issp.u-tokyo.ac.jp (S. Katsumoto)

[1] Also at Japan Science and Technology Corporation, Mejiro, Japan.

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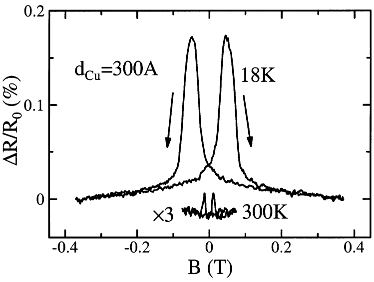

Fig. 1. Magnetoresistance of a spin-valve sample with d_{Cu} = 300 A. The data are offset for clarity.

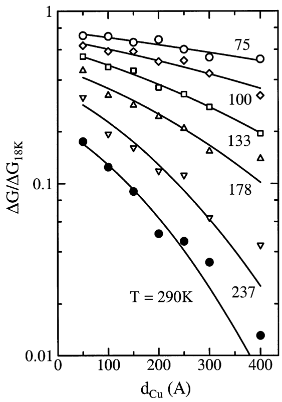

Fig. 2. Normalized magneto-conductance as a function of Cu thickness. Solid curves show the fitted error-functions.

electrons that distribute over d_{Cu} contribute to the GMR. Then ΔG should be proportional to $\mathrm{Erfc}(d_{\mathrm{Cu}}/l_s)$. The solid curves in Fig. 2 show the result of fitting, from which we obtain l_s. Note that the magnetic properties are normalized with this procedure.

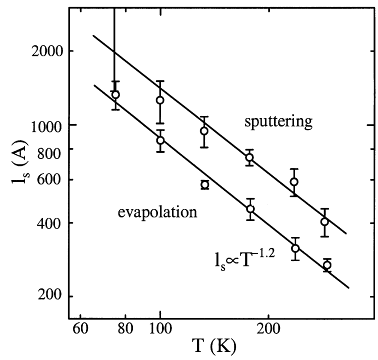

Fig. 3. Spin diffusion length as a function of temperature.

Fig. 3 shows the temperature dependence of thus obtained l_s for the two series of samples. They show very similar temperature dependence in spite of big difference in the quality of deposited films. This result supports the legitimacy of the present analysis and indicates that l_s is rather insensitive to the quality of Cu layer. From 300 K to 75 K, the obtained l_s is proportional to $T^{-1.2}$. We could not assign a specific mechanism for the spin-flip scattering to this result but expect this would be a clue to clarify the origin of scattering.

References

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