Dissimilar hysteresis of Ni films and its combined effect in Ni/Si/Ni/GaAs (001)

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Abstract

At 4.2 K, the coercive field of Ni film on GaAs (001) was five times larger than that of Ni/Si(001). Because of these findings, a multilayer, Ni/Si/Ni/GaAs was prepared and its magnetization process was studied in a temperature range from 1.8 to 360 K. At temperatures below 250 K, an antiparallel spin state was observed, the degree of which was highest at 1.8 K. The bottom Ni layer was observed to be totally influenced by the underneath GaAs but not by the Si.

Key words: Magnetization process; Ferromagnet-semiconductor multilayer; Antiparallel spin sate; Low temperature

Research on magnetism has undergone renaissance over the last decade. The recognition of the spin in the conventional electronics is the key, which promises to unlock [1,2] a whole new generation of spintronics devices. Among the versatile new functionalities most of the big challenges are still in laboratory. Research on ferromagnet-semiconductor layered structure is in the center of this emerging field.

A multilayer was prepared by depositing 50 nm Ni on GaAs (001) and a subsequent deposit of 25 nm Si and 20 nm Ni, which finally became Ni(20)/Si(25)/Ni(50)/GaAs. Thicknesses were monitored by a quartz crystal oscillator and also confirmed by an AFM. Magnetization was measured by a high resolution SQUID in a temperature range from 1.8 to 360 K.

The magnetization process of a Ni/GaAs (001) was found to be quite anomalous at low temperature [3]. This exhibited high coercivity (H_c=33.8 mT at 4.2 K) and high saturation field ($>$ 250 mT at 4.2 K). The squareness, M_r/M_s was found to be as low as 0.48. Unlike the Ni/GaAs, the corresponding properties (H_c=6.8 mT and M_r/M_s=0.89 at 4.2 K) of Ni/Si (001) were quite close to the typical bulk Ni. The degree of the anomaly in the Ni/GaAs gradually decreased with the increase of temperature, and the anomaly disappeared at temperatures close to 300 K.

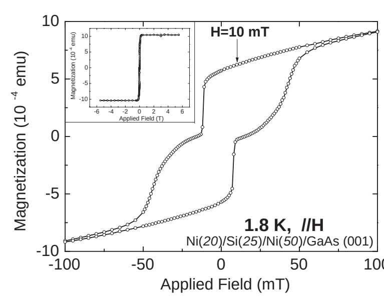

Fig. 1. Magnetization process of Ni/Si/Ni/GaAs (001) multilayer measured at 1.8 K.

Because of the dissimilarities in H_c of the Ni/GaAs and Ni/Si, they were brought together in a multilayer (Ni/Si/Ni/GaAs), in particular to achieve an antiparallel spin state in it. The field-dependent magnetization ($M-H$) of the multilayer (Fig. 1) was a resultant of the two dissimilar characteristics of the Ni films. At

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the positive remanent point (0 T) on the $M-H$ curve both Ni spins were unidirectional. A little further away towards the negative saturation, at –10 mT, the top Ni film on the Si reversed its magnetization. This was indicated by a sharp fall of the moment on the magnetization curve. The negative applied field at this point was still competing to alter the magnetization direction of the inner Ni layer on the GaAs. Until the magnetization reversal took place in the inner Ni layer, the multilayer had an antiparallel spin state in it.

The coercivity of the top Ni film on the Si layer was similar to that of the Ni/Si bilayer. The choice of the inner Ni layer thicknesses in the multilayer was rather restricted by its respective magnetization characteristic while deposited individually on the GaAs (001). It was observed [4] that the coercivities of the Ni films having thicknesses less than 32 nm were very low and were close to that of the Ni/Si. On the other hand, films having thicknesses greater than that threshold value exhibited high H_c. Therefore, to achieve the antiparallel spin state in this multilayer, the inner Ni thickness should be larger than 32 nm.

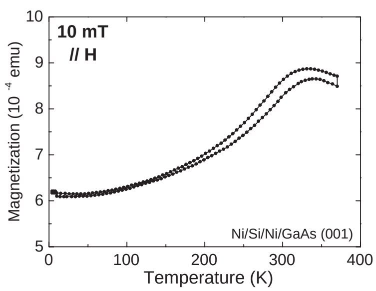

Fig. 2. Temperature dependency of magnetization of the multilayer at 10 mT parallel magnetic field. This filed corresponds to the point marked on Fig. 1.

The $M-H$ of the multilayer was also measured at various elevated temperatures, namely, 50, 100, 150, 200, 250 and 300 K. The antiparallel spin state was observed until 250 K but having a narrow antiparallel spin state. It completely disappeared at 300 K. It was worth to mention that the squareness of the multilayer was gradually increased with the increase of temperature. This could be better understood by measuring the temperature dependency of the magnetization ($M-T$). The magnetization was observed (Fig. 2) in a constant applied field of 10 mT that corresponded to the point indicated in Fig. 1. The maximum decrease of the moment at lowest temperature was 45.6%. A peak appeared at around 335 K. The moment on this peak was quite comparable to the $M-T$ of the saturation moment. Below this temperature the moment decreased because of the anomalous effect originating from the GaAs, and over this temperature the moment decreased because of the dominating typical spin fluctuation. Therefore, the ability of the GaAs to modulate the magnetic properties of Ni became stronger with the decrease of temperature.

It was understood that the GaAs substrate was affecting the magnetic properties of Ni films. In this multilayer, the bottom Ni film of the multilayer had contacts with GaAs as well as Si. Thus, the bottom Ni film might be under influence of both the semiconductors. The question of degree of the sharing of the influence could not be well answered from the magnetization curve of the multilayer although it appeared that the GaAs influenced much on it. However, from Fig. 1 it was not clearly understood that whether a small part of the Ni adjacent to the Si layer was following the magnetic properties of the Ni/Si. In order to make it clear, a trilayer of Si/Ni/GaAs (001) was prepared and measured in the same environment. The magnetization curve was just a duplication of one observed for the Ni/GaAs bilayer, confirming that the bottom Ni layer of the multilayer was fully influenced by the GaAs (001). It could be worth to study a trilayer by altering the deposition order, for instance, GaAs/Ni/Si instead of Si/Ni/GaAs. But, deposition of GaAs on Ni was quite uncertain.

In conclusion, magnetic properties of Ni film in a Ni/GaAs bilayer were greatly affected by the GaAs at low temperatures but not by the Si in Ni/Si bilayer. The multilayer, which was a combination of these two systems exhibited antiparallel spin state that gradually became weak with the increase of temperature and disappeared at 300 K. It was GaAs but not Si, which fully influenced the inner Ni layer of the multilayer that had contacts with both semiconductors. Further study on the transport properties of the similar multilayer but having very thin Si spacer layer could be of worth. A thin Si layer may allow the two Ni layers to be magnetically coupled.

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