Effect Of Buffer And Spacer Layer Thicknesses On Magnetic Properties Of Co/Si/Co/GaAs Multilayer

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Abstract. Hysteresis loop changed from two phase to single phase with decreasing Si-spacer layer thickness in Co/Si/Co/GaAs. Addition of Au buffer layer changed the phase of hysteresis loop. Coercivity of 50 nm Co layer on Si decreased with increasing Si-spacer layer thickness. We propose that formation of cobalt silicides at the interface of Co and Si modulated magnetic properties of the multilayer without buffer layer. The multilayer ($d_{Si} \geq 25$ nm) showed two phase hysteresis loop without buffer layer at low temperature.

Keywords: Si-spacer layer, Co/Si/Co/GaAs multilayer, two phase hysteresis loop, buffer layer.
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INTRODUCTION

Spin degree of freedom of an electron is used in addition to its charge in spintronic devices for increased processing speed, better integration densities and reduced power consumption [1, 2]. Ferromagnetic/semiconductor (FS) structures are useful as non-volatile magnetic memories, and in the field of spintronics [3-7]. However, in the absence of buffer layer [8], chemical intermixing between transition metal and semiconductor substrate affect magnetization. Magnetic coupling between ferromagnetic layers depends on the thickness of amorphous Si-spacer [9]. Magnetic properties of Co/Ge/Co depend on temperature; in low magnetic field magnetization is practically zero up to a critical temperature (T_c), and increases sharply towards saturation above it [7]. In Ni/Si/Ni/GaAs, two phase spin reversal [10] and antiparallel spin state were reported below 250 K, and these effects became strongest at 1.8 K. Magnetic properties of FS multilayer can be modulated by tuning the transport properties by controlling carrier density of semiconductor spacer [4,6,11,12]. Here, we report the effect of Si-spacer layer thickness and of the use of a buffer layer on magnetic properties of the multilayer.

EXPERIMENTAL DETAILS

Substrates were chemically etched (Semico-23-clean) and rinsed with deionized water. The GaAs(001) substrate was Si-doped, with an electron carrier concentration of 1×10^{24} m^{-3}. Films were deposited by e-beam evaporation method at a base pressure of 1×10^{-6} Torr, with deposition rates for Co and Si being 1.5 Ås^{-1} and 0.3 Ås^{-1},

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respectively. The structure of the multilayer became Co(50 nm)/Si(d nm)/Co(125 nm)/GaAs, with 'd' as the thickness of Si-spacer layer, between 5 and 70 nm. Thicknesses of soft (top) and hard (bottom) layers were 50 and 125 nm, respectively [13]. For film thickness measurement, atomic force microscope (AFM) calibrated quartz crystal oscillator was used. In X-ray diffraction measurement, Co films grown on n-GaAs(001) substrate exhibited polycrystalline hcp structure. Magnetization was measured with a Quantum-Design MPMS after cooling the sample to the desired temperature. MR was measured in both current in plane (CIP) and current perpendicular to the plane (CPP) configurations with a Quantum-Design PPMS.

RESULTS AND DISCUSSION

Dissimilar coercivities were observed in Co/GaAs(001) and Co/Si(001) bilayers. Sandwiching Si layer between Co layers formed Co/Si/Co/GaAs multilayer with induced antiparallel spin state in it. Fig. 1(a) shows magnetization process of the multilayer with Si-pacer thicknesses (d_{Si}) of 5 and 25 nm, at 4.2 K. For 5 nm Si-spacer layer, two Co layers were coupled strongly to each other, and the resultant hysteresis loop was single phase within the temperature range 4.2-300 K. Coupling strength between Co layers decreased with increase in $d_{Si,}$ and antiparallel spin state was induced in multilayers with Si-spacer thickness of 25 nm and above within the same temperature range. However, without a buffer layer, a significant chemical intermixing occurs between ferromagnetic metal and semiconductor substrate, which influences the magnetization process. To investigate the effect of buffer layer on the magnetization process of the multilayer, 1 nm buffer layer of Au was deposited between Co and Si, and the magnetization process of the multilayer (d_{Si} = 50 nm) is shown in Fig. 1(b). Two phase hysteresis loop disappeared completely at 4.2 K, but reappeared at 300 K.

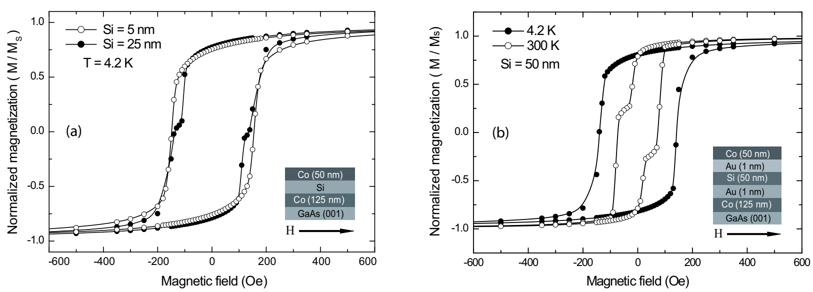

FIGURE 1. (a) Magnetization processes of Co/Si/Co/GaAs multilayer without and (b) with buffer layer. Magnetization loops are normalized by saturation magnetization (Ms = 1200 emu/cm^3) of Co films observed in the experiment.

To better quantify these results, Si-spacer thickness dependent coercivity and perpendicular resistance of the multilayer were measured at various temperatures (Fig. 2). With thinner Si-spacer, coercivities of top and bottom Co layers were comparable to each other at both 4.2 and 300 K. Thus, the multilayer showed single phase hysteresis for 5 nm Si-spacer layer. On the other hand, the difference in coercivity between top and bottom Co layers increased with increase in Si-spacer layer thickness for both temperatures. The multilayer having 25 nm Si-spacer showed two phase hysteresis loop in the temperature range 4.2-300 K. Perpendicular resistance increased with increasing Si-spacer thickness, and it appeared as two slopes.

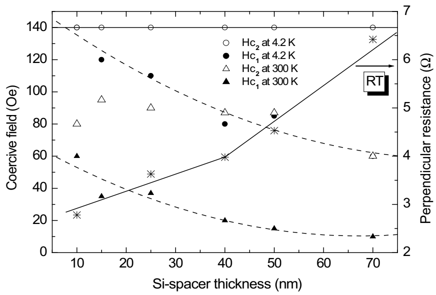

FIGURE 2. Si-spacer layer thickness dependent coercivities of Co layers and perpendicular resistance (stars) in the multilayer without buffer layer. The direction of the applied magnetic field was parallel, but current was perpendicular to the film plane.

Cobalt silicides, having much higher electrical conductivity than Si, forms at the interface of Co and Si [5,6] which explains the two slopes in the curve. The effective resistance of the multilayer was low with thinner Si-spacer (10-40 nm) as the width of cobalt silicides layer was comparable with Si-spacer. However, the interface width is limited to a certain extent in the Si layer. The effect of cobalt silicides on multilayer's total resistance was less dominant for thicker Si-spacer (40-70 nm).

We suggest that the two phase hysteresis loop in multilayer (d_{Si} = 25 nm) without buffer layer was due to cobalt silicides, which modulated magnetic properties of the multilayer, since two phase did not appear in the multilayer with buffer layer at 4.2 K. Two phase hysteresis loop observed in the multilayer (with $d_{Si} \geq$ 25 nm) can be used for magnetic random-access memory applications. The two phase hysteresis loop observed in the multilayer with buffer layer at 300 K might be due to spin fluctuation.

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