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Electric field control of induced magnetic moment in Pd on Co layer

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Abstract

By applying gate electric field, we achieved to control induced magnetic moment in Pd, which is usually a non-magnetic metal. In the Pd layer deposited on ferromagnetic Co layer, a ferromagnetically ordered magnetic moment is induced by the ferromagnetic proximity effect. In the experiment, a clear change in the induced magnetic moment was observed by applying electric field to the ferromagnetic surface of the Pd layer. The results indicate that magnetic moment extrinsically induced in non-magnetic metals by the proximity effect are electrically tunable.

1. Introduction

Applying an electric field using capacitor structure is a useful tool for controlling the magnetism of magnetic materials [1]. Recently, many studies for ferromagnetic metals have been reported. For example, ferromagnetic phase transition in a Co thin film was realized by using this method [2,3]. By applying electric field to ultra-thin ferromagnetic metals, it is considered that the carrier density at the surface of it is modulated, that is, the Fermi level shifts , resulting in the change in the magnetic properties. Then, we expect that the application of electric field may make non-magnetic metals ferromagnetic.

Pd is usually non-magnetic metal that nearly satisfy the Stoner criterion and the peak of the density of the states of bulk Pd is located at an energy near Fermi level [4]. Therefore, applying electric field may make magnetic property of Pd change. Also, it is known that a magnetic moment is induced in a Pd layer deposited on a Co layer by the ferromagnetic proximity effect [5]. We aimed to control the magnetic moment induced in Pd by the ferromagnetic proximity effect.

2. Results

We deposited Ta/Pt(4.1 nm) /Co(t_{Co})/Pd(1.7)/MgO layers (Pt/Co/Pd samples) from the substrate side on an intrinsic Si substrate by rf sputtering. To modulate the electron density in the Pd surface, an electric-double-layer (EDL) capacitor structure was used [3]. The structure consisted of an Au gate electrode, a polymer film containing an ionic liquid, and a Pt/Co/Pd sample (Fig. 1). The magnetic moment was confirmed to be induced in whole Pd layer at 10 K for the present Pd thickness. A gate voltage V_G was applied between the bottom Pd and the top nonmagnetic Au electrode through the ionic liquid. The magnetic moment under V_G was directly measured using superconducting quantum interference device (SQUID) magnetometer.

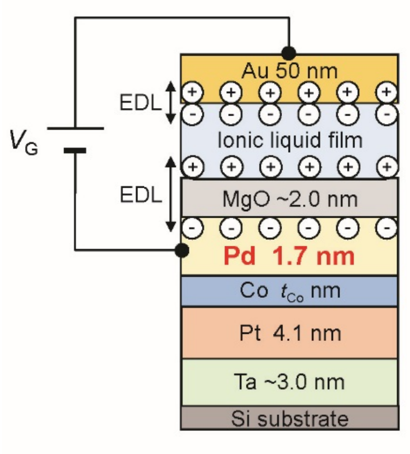

Fig.1 Schematic croee section of the device.

Fig. 2 shows the temperature T dependence of the perpendicular component of the magnetic moment $m_\perp$ divided by total sample area S_{total} under $V_G = \pm 2.0$ V. Below Curie temperature T_C, the change in the magnetic moment by changing V_G was clearly observed for both samples: a positive (negative) V_G, i.e., larger (smaller) electron density at the Pd surface, resulted in a larger (smaller) $m_\perp/S_{total}$. The inset of Fig. 1 shows the hysteresis loop under the application of V_G measured using the anomalous Hall effect for sample A. It is considered that $m_\perp$ was nearly equal to saturation magnetic moment m_s because the squareness ratio $m_\perp/m_s$ of the hysteresis loops was ~1 under V_G = ±2.0 V at a temperature of at least 10 K. Since the electron density was expected to be changed only at the outermost atomic layer of the Pd layer due to the Thomas-Fermi screening effect, this results indicate that induced magnetic moment in Pd was modulated by the electric field.

On the other hand, T_C was not clearly dependent on V_G in the present Pt/Co/Pd samples although the change in T_C up to 100 K was reported for a Pt/Co sample with a similar device structure.

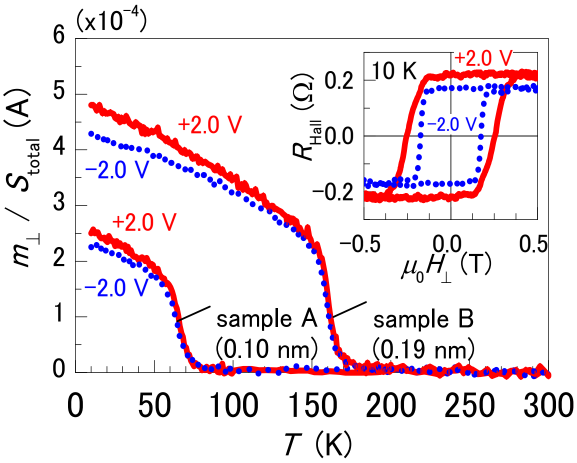

Fig. 2 Temperature T dependence of the perpendicular component of magnetic moment $m_\perp$ normalized by the total sample area S under the gate voltage V_G of ±2.0 V for samples with Co thickness t_{Co} = 0.10 nm (sample A) and 0.19 nm (sample B). The inset shows the hysteresis loops observed in the Hall resistance R_{Hall} at 10 K at V_G = ±2.0 V for sample A.

3. Conclusions

The induced magnetic moment in Pd by the proximity effect are electrically tunable. This suggests that the application of electric field may make non-magnetic metals ferromagnetic.

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