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Electric field control of ferromagnetism in transition metals

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Abstract

We show the recent experimental developments for electric-field control of magnetism in ultra-thin 3d transition metals. The application of an electric field changes the electron density at the surface of them, which results in modulation of its Curie temperature or other magnetic properties.

1. Introduction

Electric-field gating plays a significant role, particularly in semiconductor devices. Field-effect transistors are indispensable for information processing; furthermore, electric-field confinement of electrons in nano-scaled regions has opened up a new dimension in the research field of mesoscopic phenomena. Recently, the electric-field effect also offers new opportunities for manipulation of properties in magnetic materials [1-10]. Electrical switching of a magnetization direction is one of the most important processes for magnetic recording and information storage. The use of electric-field-induced magnetization switching is expected to dramatically reduce power consumption for storage devices. Field-effect devices consisting of a gate electrode, an insulator layer, and a ferromagnetic layer have been used to control the ferromagnetic properties through the modulation of the carrier density in the ferromagnetic layer by applying a gate voltage.

We show our recent achievement of electric-field control of ferromagnetism at room temperature [7-10]. We first discusses the electrical control of Curie temperature T_C and magnetization in field-effect devices with ultra-thin 3d transition metals. A very large change in T_C of ~100 K across room temperature is observed in the device with a Co ultra-thin-film [8]. We also discuss the electric-field effect on the domain-wall (DW) motion. Controlling the displacement of a magnetic domain wall (DW) is potentially useful for information processing in magnetic non-volatile memories and logic devices. We show that the application of an electric field can change the DW velocity in its creep regime by more than an order of magnitude [10]. This significant change is due to electrical modulation of the energy barrier for the DW motion.

2. Results

A capacitor structure consisting of a gate electrode, a solid-state dielectric insulator, and a bottom electrode made of a 3d transition metal is used to observe the effect. To obtain a larger change in the electron density, we also fabricated an electric double-layer capacitor structure using an ionic liquid. The device consisting of 0.4-0.5 nm-thick Co or Fe film covered by a HfO_2 dielectric layer (or a polymer film containing an ionic liquid) and a gate-electrode on top of that was fabricated. The anomalous Hall effect and a direct magnetization measurement were used to detect the magnetization direction and its magnitude under magnetic fields and gate voltages. We found that the ferromagnetic state of the Co film could be completely on and off isothermally and reversible way by applying electric field at around room temperature [7]. The change in the Curie temperature up to ~100 K was observed as shown in Fig. 1 in the ionic liquid device by applying gate voltage of ±2 V [8] (the positive gate voltage corresponds to direction of the electron accumulation at the cobalt layer surface). A change in magnetization was found in devices with Co and Fe [8,9]. The increase of the electron density at the surface of the ferromagnetic layer resulted in the increase of magnetization in both devices.

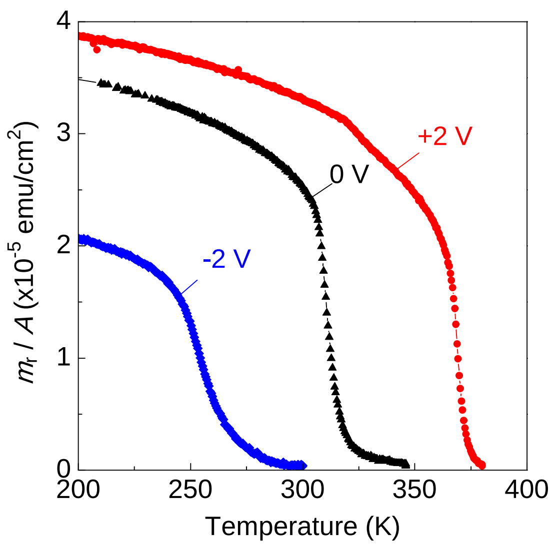

Fig. 1 Temperature dependence of remanent magnetization of Co ultra-thin film under applying gate voltage of +2 V, 0 V, and -2 V.

We also found that the applying an electric field was able to modulate significantly the velocity of a DW prepared in Co micro-wires [10]. The application of the electric fields in the range of ± 2-3 MV/cm changed the DW velocity in its creep regime (10^{-6}-10^{-3} m/s) by more than an order of magnitude, where the DW motion was induced by applying the external magnetic field. This significant change is due to electrical modulation of the energy barrier for the magnetic domain wall motion.

3. Summary

We have demonstrated an electric-field control of magnetism in ultra-thin 3d transition metal films. The results presented here are a significant development for future low-power magnetic devices at room temperature.

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