Spin reorientation transition in ultrathin Co film on InP(2×4) reconstructed surface

Yong-Sung Park, Jong-Ryul Jeong, and Sung-Chul Shin

Department of Physics and Center for Nanospinics of Spintronic Materials, Korea Advanced Institute of Science and Technology, 373-1, Yuseong-gu, Daejeon 305-701, Korea

(Presented on 8 November 2004; published online 11 May 2005)

We have investigated magnetic properties of monolayer (ML)-thickness Co film deposited on InP(2×4) reconstructed surface using in situ surface magneto-optical Kerr effects (SMOKE) measurement system. InP(2×4) reconstructed surface, obtained by several cycles of sputtering-and-annealing process, was confirmed by reflection high energy electron diffraction (RHEED) and scanning tunneling microscopy (STM) measurements. Co film grown on InP(2×4) reconstructed surface shows three distinguishable thickness regions which have different magnetic properties, depending on Co film thickness. In the Co film thickness region smaller than 7 ML, no SMOKE signal was detected. In the thickness region between 8 ML and 15 ML, both longitudinal and polar Kerr hysteresis loops were observed. In the film thickness larger than 16 ML, only longitudinal SMOKE signal without polar signal was detected. © 2005 American Institute of Physics. [DOI: 10.1063/1.1853873]

I. INTRODUCTION

Ferromagnet/semiconductor hybrid system has attracted great attention due to the possibility for applications to spintronic devices. In these devices, the magnetic and electronic properties of the ferromagnetic thin film, which plays a critical role for spin injection and spin transport, depend on the characteristics of the interface/surface between ferromagnet and semiconductor.1 Especially, atomically clean reconstructed surfaces of III-V semiconductor have the different stoichiometries and symmetries compared with the bulk one and are expected to affect the atomic-scale structure in the interface, initial film growth, leading to different magnetic and transport properties.

The present study is motivated to study ferromagnetic/semiconductor interface as well as to search for a new system applicable for spintronic devices. As a possible candidate, we have studied the Co/InP hybrid system. Among III-V semiconductors InP, which has a direct bandgap energy, is used in optoelectronic devices for realizing low rectifying contacts.2 On the other hand, Co plays an important role in many GMR devices due to the high spin polarization of the carriers at the Fermi level.3 In this paper, we have not only observed InP(2×4) reconstructed surface by sputtering-and-annealing using STM, but also investigated magnetic properties near the interface of Co/InP system using a SMOKE system.

II. EXPERIMENT

InP substrate of 0.35 mm×5 mm×10 mm was cut from an undoped n-InP(001) wafer (Wafer Technology Ltd.). The substrate was chemically etched in a solution of H3SO4:H2O2:H2O=4:1:1, and rinsed in ethanol using an ultrasonic cleaner. InP sample was mounted on a molybdenum plate and then, inserted into the ultrahigh vacuum (UHV) chamber. The base pressure of UHV chamber was 1×10−10 Torr. InP sample was sputtered with a 300 eV Ar+ ion beam and annealed up to 400 °C. The (2×4) reconstructed surface of InP was obtained by several cycles of sputtering-and-annealing process. RHEED was used for observing change of structure during each cycle of sputtering-and-annealing. InP(2×4) reconstructed surface was finally confirmed by using STM. Co was then deposited from a water-cooled e-beam evaporator at a rate of 0.4 ML/min. During the evaporation the pressure was maintained at a value less than 5×10−10 Torr. The in situ SMOKE measurements were then carried out at the same position in the growth chamber without any sample translation. All deposition and measurement were performed at room temperature.

III. RESULTS AND DISCUSSION

In Fig. 1(a), we demonstrate 30×30 nm2 STM image of InP (2×4) reconstructed surface obtained by the sputtering-and-annealing method. It is seen from Fig. 1(a) that the rows along [1 1 0] direction are uniformly arranged. Each row consists of unit features with round shape. The size of this unit feature is about 0.8 nm, which could be the aggregate of several atoms. This unit feature is separated by 0.85 nm along the [1 1 0] direction. This is twice the distance between two adjacent InP cations and represents 2-by periodicity of InP(2×4). The distance between two adjacent rows corresponds to about 1.7 nm which shows 4-by periodicity. The unit cell of InP(2×4) can thus be demonstrated by the black square depicted in Fig. 1(a). This InP(2×4) reconstructed surface is consistent with other group’s results obtained from treatment of InP in other conditions.4–7 Several groups have studied the atomic structure of InP(2×4) and several models such as trimer model,8 In-dimer model,9 P dimer model,10 and In-P mixed-dimer have been proposed.11 From
these studies, it is already known that In-rich \(\text{InP}(2 \times 4)\) structure favors the formation of mixed In-P dimers on top of an In-terminated surface.\(^{12}\)

Figure 1(b) represents a STM image of Co 0.1 ML on an \(\text{InP}(2 \times 4)\) reconstructed surface. As shown in Fig. 1(b) it is observed that Co clusters adsorb on the rows of \(\text{InP}(2 \times 4)\) reconstructed surface along the \([1\bar{1}0]\) direction of the \(\text{InP}(001)\) surface. Co clusters are typically 0.5 nm in diameter and 1.4 nm in height and form small 2D islands. When Co thickness is 1 ML, Co clusters cover the \(\text{InP}\) surface completely and \(\text{InP}(2 \times 4)\) surface is not observed any longer. At this coverage the Co islands become larger, but maintain a 2D growth.

After depositing Co films at the interval of monolayer, we also performed longitudinal and polar SMOKE measurements. During longitudinal measurements, the magnetic field is applied parallel to the \([1\bar{1}0]\) direction of the \(\text{InP}(001)\) substrate. Figure 2 shows some longitudinal and polar SMOKE results for different ML thickness of the Co film. As shown in Figs. 2(a) and 2(b), no magnetic signals appear until Co film thickness becomes several ML. This tendency remains up to Co thickness of 7 ML. This nonmagnetic signal could be attributed to the intermixing of Co with In or P due to diffusion near the interface, which results in the formation of a nonmagnetic alloy. As shown in Fig. 1(c), Co film shows 2D growth in initial growth stage. Therefore at the thickness of several monolayers the absence of a magnetic region might not be due to a growth of single or polycrystalline phase of Co but because of existence of alloy phase of Co–In or Co–P at the interface.

When the Co film thickness becomes 8 ML, ferromagnetic signals start to appear in both longitudinal and polar measurements. Note that both longitudinal and polar hysteresis loops are square, which implies a metastable phase with the coexisting in-plane and perpendicular anisotropies.\(^{13,14}\)

At this Co film thickness, longitudinal and polar loops have coercivity values of 6 Oe and 140 Oe, respectively: the polar loop has larger coercivity, compared with the longitudinal loop. This tendency remains until the Co film thickness becomes 15 ML. When the Co film thickness becomes 16 ML,
ferromagnetic signal is appeared only in the longitudinal measurement as seen from Fig. 2. Hence, a magnetic phase transition from a metastable coexistent phase to an in-plane anisotropy phase is believed to occur at this film thickness.

Interestingly, we witness three distinct regions in the dependence of the coercivity on the Co film thickness, as shown in Fig. 3. Here, the coercivity was measured from the longitudinal hysteresis loop. In Fig. 3 we see that there exist three regions with different coercivities: (I) zero coercivity in the thickness smaller than 7 ML, (II) low coercivity of about 10 Oe in the thickness of 8–15 ML, and (III) high coercivity of about 200 Oe in the thickness larger than 16 ML. It is known that when Co film is grown on GaAs, structural changes occur near the interface, and these changes affect magnetic properties of Co. Therefore, the existence of three distinguishable regions with respect to the film thickness seems to be caused by structural changes.

IV. CONCLUSIONS

Atomically flat InP(2×4) reconstructed surface was obtained by several cycles of sputtering-and-annealing process. We have observed growth morphology of Co/InP system in initial stage of growth. We have also investigated magnetic properties of monolayer-thickness Co film deposited on InP(2×4) reconstructed surface. Depending on the thickness of the Co film, we observed three distinguishable regions showing different magnetic properties. In Co film with thickness smaller than 7 ML, no SMOKE signal was detected. In the thickness regime between 8 ML and 15 ML, both longitudinal and polar Kerr hysteresis loops were observed. For film thicknesses larger than 16 ML, only longitudinal MOKE signal was detected. These results suggest that spin state of the Co film changes from metastable coexistence of in-plane and perpendicular anisotropy to in-plane anisotropy with increasing Co thickness.

ACKNOWLEDGMENTS

This work was supported by Ministry of Science and Technology through the Creative Research Initiatives Project and KAIST-Cavendish Cooperation Program.