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Abstract: *The magnetic dead layer for the ferromagnetic film on the semiconductor substrate is the concern issue for the magnetic device applications. In this study, we report the magnetic dead layer at the interfaces between Fe/graphene and Fe/HOPG surfaces. The Graphene was prepared at 1250 K on the SiC(0001) template. By using the magneto-optic Kerr effect, we found that at room temperature the ferromagnetic order appears at 3.3 ML and 5.5 ML for Fe/graphene and Fe/HOPG surface, respectively. From the thickness dependent magnetization measurements, we determined the magnetic dead layer for Fe/graphene and Fe/HOPG to be 2.5 ML and 5 ML, respectively.*

Keywords: Magnetic Measurement; Iron; Graphene; Magnetic Phenomena

1. INTRODUCTION

Because of the potential application of the magnetic storage device and spintronics, magnetic dead layer (MDL) have been widely studied [1–3]. As reported, the magnetic dead layer has not any magnetism in the interface/layer. To understand the thickness of MDL is the concern issue in the magnetic thin film used for magnetic storage device and spintronics device application [1,3].

A lot of research has been devoted to studying the interfacial magnetism of Fe films on Si substrates [3,4]. To our knowledge, the investigation of the interfacial MDL for ultrathin Fe film on graphene and highly oriented pyrolytic graphite (HOPG) is not reported. W. Q. Liu et al. and W. C. Lin et al. reported, interfacial magnetic dead layer for Fe/Graphene is 1 monolayer (ML) and 4.4 ML for Fe/HOPG surface [2,5].

In this study, the graphene and HOPG were used as templates for the determination of MDL. Magnetization curves at the interface of the Fe films on graphene and HOPG were measure by magneto-optic Kerr effect, and the interfacial MDL on the graphene and HOPG was evaluated.

2. EXPERIMENTAL

The experiments were conducted in a multi-chamber UHV system with a base pressure of 2×10^{-8} Pa, allowing in situ transfer between the chambers for low energy electron diffraction (LEED) and magneto-optic Kerr effect (MOKE) measurements. Graphene layers were synthesized on Silicon carbide- SiC(0001) that was annealed at 1250 K. The carbon-rich $6\sqrt{3}\times6\sqrt{3}$ phase was confirmed by LEED pattern [6,7]. The Fe deposition rate (~1 ML/min) and Fe coverage were monitored by a quartz crystal microbalance. Fe was evaporated from an electron beam evaporator. 1 ML of Fe is defined as 1.7×10^{15} atoms/cm^2, which corresponds to the surface atomic density of Fe(110), which is the energetically stable surface of bcc Fe [5]. The flat highly oriented pyrolytic Graphite (HOPG) substrate was cleaved in the air before insert into the vacuum chamber. GR and the HOPG substrate were fixed on a nonmagnetic sample holder inside of the vacuum chamber.

The magnetic properties were measured by *in-situ* MOKE with electromagnets applying up to 1000 O_e. A 635-nm laser diode was used as a light source, and the light incident angle was set at 45° on the sample.

3. RESULTS & DISCUSSIONS

Longitudinal MOKE used to investigate the interface magnetic properties of the ultrathin Fe films ($0<\theta_{Fe}<13.2$ ML) grown on the graphene and HOPG surfaces. The longitudinal geometry, i.e., the magnetic field applied within the plane of the films, was employed to measure magnetization hysteresis curves throughout the whole Fe thickness range. Typical magnetization loops with different Fe coverages at RT for graphene and HOPG surface are plotted in Fig. 1(a) and 1(b), respectively. There was no indication of a ferromagnetic (FM) order on the graphene and HOPG surfaces, below the Fe coverage of 3.3 ML. With increasing the Fe coverage, the FM order was starting to appear for Fe/graphene at θ_{Fe} = 3.3 ML, for Fe/HOPG at θ_{Fe} = 5.5 ML.

The measurement of Fe thickness dependent of Kerr rotation was done to identify the MDL on the graphene and HOPG surface. The Kerr rotation is approximately proportional to the total magnetization of the sample when the thickness of the sample is enough to thin compared with the light penetration depth [8]. Fig. 2 shows the Kerr rotations as a function of Fe coverages on the graphene and HOPG surfaces.

Thickness dependence of the Kerr rotations shows that the Fe film on graphene has larger Kerr rotations than the HOPG surface. The Kerr rotation of the Fe/graphene and Fe/HOPG surface was linearly increased while the Fe coverage increase. If the entire Fe film is ferromagnetic at the higher coverage, the intersection at zero Kerr rotation should correspond to zero Fe thickness [8,9]. However, in the case of the graphene and HOPG templates, the intersections show the magnetic dead layer. On graphene, the extrapolated Kerr rotation is zero at 2.5 ML, indicating that the magnetic dead layer (MDL) for graphene is 2.5 ML. In the same way, the Kerr rotation as a function of the Fe coverage indicates that the MDL is 5 ML for HOPG surface. These results indicate that the graphene template prevents further MDL formation than the HOPG surface.

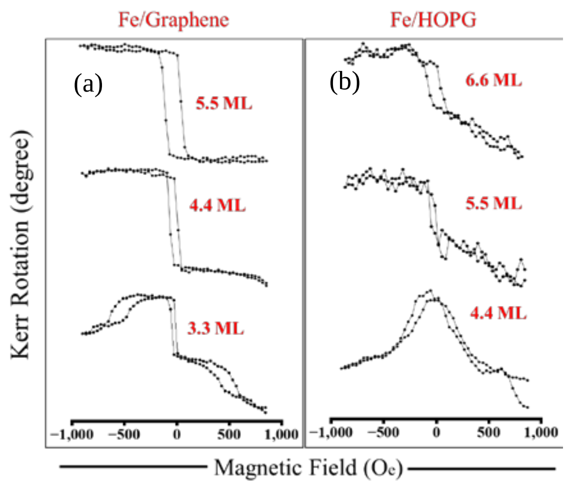

Fig. 1. Magnetization loops by the longitudinal MOKE as a function of Fe coverage on (a) Graphene and (b) HOPG surface. Fe coverages are indicated inside of the plots.

Within the all studied samples of graphene and HOPG, we were not able to obtain any ferromagnetic order at RT below 3.3 ML of Fe coverage. This is due to the intermixing of Fe and C, leading to the formation of thin non-ferromagnetic Fe-C interfacial phases. Similarly, our previous report showed that the intermixing of Fe and Si leading to the occurrence of MDL on iron silicide surfaces [3].

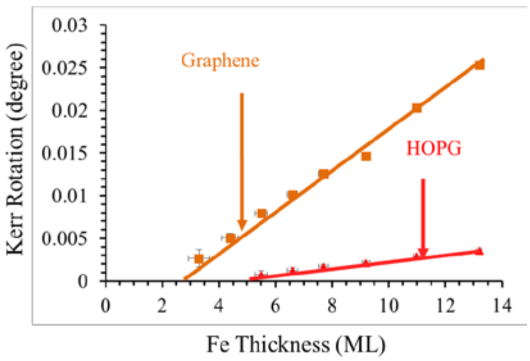

Fig. 2. Kerr rotation as a function of Fe coverage. Orange and red dots indicate Kerr rotation of Fe on Graphene and HOPG surface, respectively. The straight lines are the fits for the Kerr rotation (see text), and the intersections of the Fe coverages at the zero Kerr rotation indicates the Magnetic Dead layers.

On HOPG with Fe deposition at RT, the appearance of the ferromagnetic loop has been reported at 4.4 ML [5], which is thinner than our result. W.Q. Liu et al. reported, the magnetic moment of the epitaxial 1 ML of Fe on Graphene. This variation might come from the deposition conditions such as deposition rate, temperature. The deposition conditions affect the diffusion and morphology of the MDL [4]. The atomic concentration of the carbon atoms is dominating in the HOPG surface than the graphene. A. V. Krasheninnikov *et. al*. reported, transitional metal (TM) adsorption in the defected graphene, containing single and double vacancies, shows high magnetic moments [10]. We attributed that dominates the results towards lower MDL in graphene than the HOPG surface.

4. CONCLUSIONS

To summarize, we have investigated the interfacial magnetism and a magnetic dead layer of ultrathin Fe film/graphene and Fe film/HOPG interface at RT by MOKE. The MOKE result shows that 3.3 ML Fe/Graphene, 5.5 ML Fe/HOPG interface set in ferromagnetic order at RT, respectively. This different behavior of the Fe film on the graphene and HOPG surfaces is due to the interfacial intermixing between Fe and C atoms. The thickness dependent study of the Kerr rotations shows that the MDL for Fe/graphene is 2.5 ML and Fe/HOPG is 5 ML.

5. FUTURE PLAN

Future works will be done on the FM order and MDL of ultrathin Fe films on MoS_2, graphene oxide, (3×3) Si-face- Graphene, (√3×√3) Si-face- graphene by MOKE. X-ray Photoelectron Spectroscopy (XPS) will be used to investigate chemical states at the interfaces.

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