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Interfacial magnetic properties of Fe deposited on MoS_2 flakes

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Abstract: *Analysis of magnetic behavior of Fe deposited on MoS_2 flakes was carried out by magneto-optic Kerr effect (MOKE). Small hysteresis loop was observed after depositing 12.5 Å of Fe on transferred MoS_2 flakes on clean SiO_2 substrate. Using thickness dependent study of Kerr rotation, it was found that magnetic dead layer (MDL) existed at the interface of Fe and MoS_2 up to 7 Å of Fe deposition. The presence of magnetically dead layer was due to the existence of small interaction between Fe and MoS_2 which led to the generation of antiferromagnetic coupling between atoms at the interface. With the increase of Fe deposition, interactivity of Fe and MoS_2 was decreased and prompted magnetism through ferromagnetic coupling between deposited Fe atoms.*

Keywords: deposition; hysteresis; magnetism; MOKE; MoS_2.

1. INTRODUCTION

Two dimensional (2D) materials have drawn tremendous attention after the invention of 'graphene' because of exhibiting unique chemical and physical properties [1]–[3]. Due to having zero bandgap, application of graphene in upcoming electronic devices is limited [4]. Thereafter, 2D layered transition metal dichalcogenides (TMD) with a sizeable bandgap of 1-2 eV are developed as an alternative of graphene for different applications in future [5]. Among the group of TMD, molybdenum disulfide (MoS_2) is a layered semiconductor containing covalently bonded S-Mo-S trilayers that are bound together by van der Waal forces, which has been achieved numerous interests because of its extraordinary physical properties [3]. Naturally available MoS_2 shows semiconducting properties and exists in 2H phase which is diamagnetic in nature and therefore, it is difficult to utilize this nonmagnetic material in spintronic devices [6]. Whereas, 1T phase of MoS_2 is metallic and paramagnetic which has been achieved after reducing the thickness of bulk 2H-MoS_2 to single layer [6]. Many theoretical and experimental works have been carried out to introduce magnetic properties in MoS_2, such as, controlling thickness, applying external strain, creating defects and doping MoS_2 with transitional metals or nonmetals. Among them, inducing magnetism by transition metal doping is considered as an effective and facile way [7].
To investigate the magnetic, electronic and structural properties of MoS_2 with the change of doping concentration, Fan *et al.*, performed first principle calculations after doping monolayer MoS_2 with Cu, Co, Fe, Mn and V. They found that doped transition metals preferred to remain in nearest neighboring configurations and exhibited ferromagnetic coupling at low concentration [5]. Tongay *et al.*, reported that the existence of ferromagnetism in bulk MoS_2 due to the presence of zigzag edges at the grain boundaries [8]. Xia *et al.*, observed that doping MoS_2 nanosheets with Fe would generate ferromagnetism which could be adjusted by altering the Fe concentration [9]. In our study, we observed the magnetic behavior of deposited Fe on transferred MoS_2 flakes on SiO_2 substrate by MOKE measurements.

2. EXPERIMENT

MoS_2 flakes were transferred to clean SiO_2 substrate by mechanical and thermal methods. Nonmagnetic sample holder was utilized to hold the sample and placed it in ultrahigh vacuum (UHV) chamber. Experiments were performed in UHV condition with a base pressure of 2×10^{-7} Pa. Then, e-beam evaporator was used to deposit Fe on MoS_2 flakes with a deposition rate of 1 Å/min, which was estimated by using quartz crystal microbalance (QCM). MOKE measurements were conducted to analyze the magnetic behavior of Fe/MoS_2 by applying a magnetic field along the longitudinal direction at room temperature.

3. RESULTS AND DISCUSSION

The magnetic properties of Fe on transferred MoS_2 flakes on SiO_2 substrate was studied by MOKE measurements in room temperature with a magnetic field applying in the in-plane direction. The hysteresis loops obtained from MOKE measurements for Fe/MoS_2 is shown in Fig. 1. When the thickness of Fe was increased to 12.5 Å on MoS_2 flakes, a small hysteresis loop was observed.

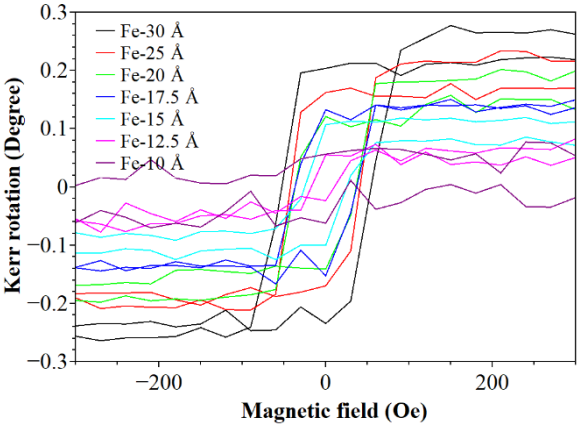

Fig. 1. MOKE hysteresis loops obtained after depositing various amount of Fe on transferred MoS_2 flakes on SiO_2 substrate at room temperature.

The absence of hysteresis loop after lower thickness of Fe deposition on MoS_2 flakes can be happened due to the low Curie temperature than room temperature or non-ferromagnetic behavior of material. As the Curie temperature of ferromagnetic material decreases with the decrease of its thickness, then there is a possibility of the absence of Kerr signal at room temperature due to the

deposited thickness of Fe was thinner than critical thickness [10]. Thus, a thickness-dependent study of Kerr rotation was carried out to determine the reason behind the non-ferromagnetic phase of the material at low coverage. Kerr rotation is related to the thickness of ferromagnetic material within the light penetration region. In this study, Kerr rotation would increase linearly with the Fe thickness up to around ~100 Å [10]. Fig. 2 shows the change of Kerr rotation for Fe/MoS_2 with Fe thickness. If the straight line extrapolation of these points intersects zero Kerr rotation at zero coverage of Fe, then there is no formation of magnetic dead layers at the interface of Fe/MoS_2 [11].

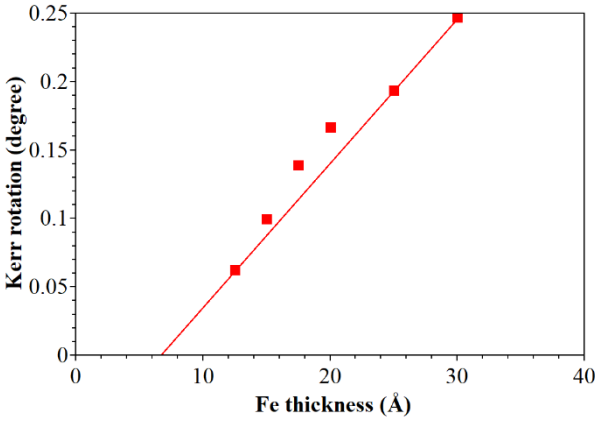

Fig. 2. Plot of Kerr rotation as a function of Fe thickness.

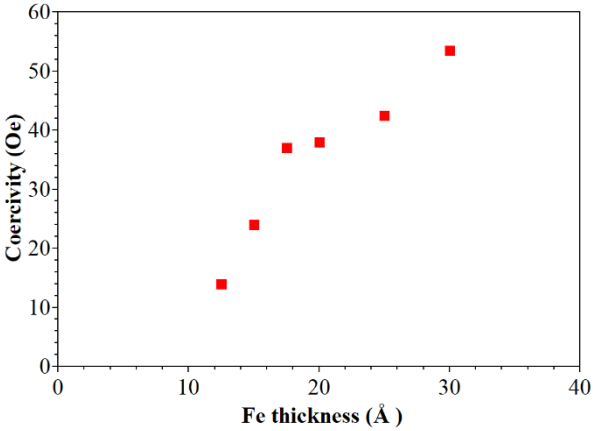

Fig. 3. Plot of coercivity as a function of Fe thickness.

In Fig. 2, it can be seen that straight line extrapolation intersects Fe thickness at 7 Å for Fe on MoS_2. Therefore, 7 Å of Fe was magnetically dead at the interface of Fe/MoS_2 instead of having low Curie temperature. Formation of magnetic dead layer (MDL) at the interface of Fe/MoS_2 might be due to the interaction between Fe and MoS_2 at lower thickness of Fe which could lead to the generation of antiferromagnetism because of the antiparallel spin alignment. Therefore, the formation of ferromagnetic phase after depositing more than 7 Å for Fe on MoS_2 flakes might be due to the absence of interaction between Fe and MoS_2, and the origination of ferromagnetic coupling between Fe atoms.

A plot of coercivity as a function of Fe thickness is shown in Fig. 3. It was found that coercivity was increased linearly with the increase of Fe thickness due to the pinning of domain wall and higher magnetic anisotropy.

4. CONCLUSIONS

We have analyzed the magnetic properties of MoS_2 flakes after depositing Fe on it by MOKE measurements. We found that hysteresis loop was appeared after 12.5 Å of Fe deposition as well as MDL was present at the interface up to 7 Å thickness of Fe. Deposited Fe interacted with MoS_2 flakes at lower thickness of Fe which might create antiparallel spin alignment between atoms and therefore, MDL was formed at the interface of Fe/MoS_2. Obtaining hysteresis loops at higher amount of Fe deposition might be due to the reduction of the interactivity of Fe and MoS_2 which could induce ferromagnetism.

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