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Magnetic Dead Layer on c(8×4), p(2×2) Iron Silicide and Si(111)-7×7 Surfaces

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Abstract
We report the magnetic dead layer (MDL) at the interface of the Fe/iron silicides (c(8×4), p(2×2)) and Fe/Si(111)-7×7 surface by magneto-optical Kerr effect (MOKE). We found that at room temperature the ferromagnetic order appears at 5.5 ML, 8.2 ML and 10.9 ML for Fe/c(8×4) silicide, p(2×2) silicide, and Si(111)-7×7 surface, respectively. From the thickness dependent magnetization measurement, we decided the MDL for Fe/c(8×4) silicide, Fe/p(2x2) silicide, and Fe/Si(111)-7x7 to be 3 ML, 5 ML and 7.5 ML, respectively. Our results indicate that the c(8×4) iron silicide surface prevents further silicide formation effectively than the p(2×2) silicide and Si(111)-7×7 surface.

1. Introduction

Magnetic dead layer (MDL) is the layer which has no magnetic moments at interfaces.[1] MDL has been a concern since no MDL would make the spin transport efficient.[2] Plenty of research have been devoted to analyze the magnetic properties of Fe thick films on Si substrates.[3,4] So far not enough experiments have not been conducted for the investigation of the MDL of iron silicide surfaces.[5] A detailed study of the interfacial magnetism of the ultrathin Fe film on iron silicide phases, c(8×4) and p(2×2), and Si(111)- 7×7 surfaces by magneto-optical Kerr effect (MOKE). The interfacial MDL for Fe film on iron silicide phases, c(8×4) and p(2×2), and Si(111)- 7×7 surfaces was estimated by the MOKE. In particular, we show that the MDL for c(8×4) silicide, p(2×2) silicide, and Si(111)- 7×7 surfaces are 3 ML, 5 ML, and 7.5 ML respectively.

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 facilitates for surface analytical technique (LEED) and magnetic properties analysing technique (MOKE). The ultrasonic cleaning with ethanol was done before introducing the Si(111) crystal on a nonmagnetic sample holder into the chamber. The sample was degassed by direct current heating at 800 K for 5-12 hours. After that, repeated flash heating was done at approximately 1400 K, a clean reconstructed Si(111)-7×7 surface was confirmed by Low Energy Electron Diffraction (LEED).

Two iron silicide phases, c(8×4) and p(2×2), were prepared by the deposition of 1.7 monolayer (ML) Fe on Si(111)-7×7 surface and the subsequent annealing at 900 K for c(8×4) and 700 K for p(2×2).[6]

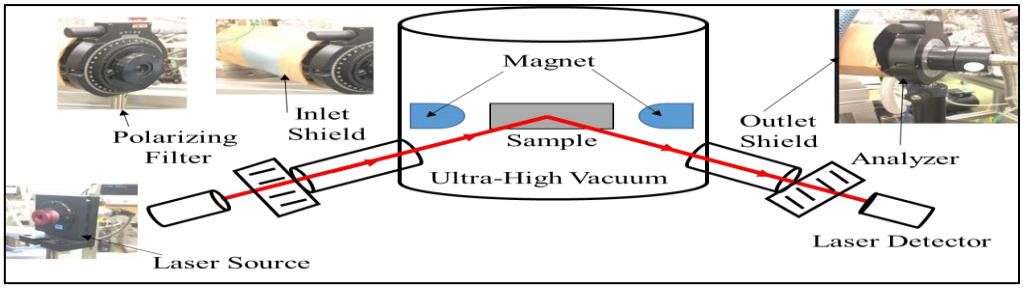

Figure 1. Experimental set-up for Magneto-optic Kerr Effect

Fe thin films were prepared on these iron silicide, (p(2×2) and c(8×4)) and Si(111)- 7×7 surfaces at room temperature (RT). The magnetic properties were characterized by *in situ* of magneto-optic Kerr effect (MOKE) in polar and longitudinal geometries (see Fig. 1). Fe deposition rate was calibrated by Quartz crystal microbalance (0.2 ML/min). The MOKE experimental process shown in Fig. 2. Each MOKE measurement was done after the deposition of 2 ML of Fe on the (p(2×2) and c(8×4)) and Si(111)-7×7 surfaces and continued upto 30 ML of Fe film on the sample. The whole experiment was followed the similar experimental process. Afterwards, all the MOKE data was analyzed to explored the magnetic dead layer of each sample.

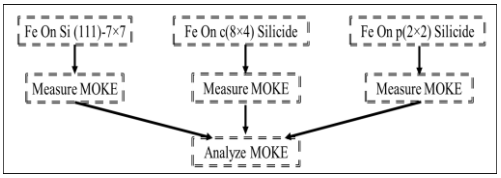

Figure 2. Flow-chart for experimental process.

3. Results

3.1. Low Energy Electron Diffraction

Fe growth on Si(111) surface was observed by LEED. The LEED patterns indicated three different surface structures, which are c(8×4) silicide, p(2×2) silicide and Si(111)-7×7 surface respectively. At the Fe coverage of 1.7ML, the surface is fully covered with the p(2×2) or c(8×4) silicide films depending on the annealing temperature. The p(2×2) phase appeared at the annealing temperature of 700 K. With increasing the annealing temperature upto 900 K the p(2×2) structure transformed to the c(8×4) silicide, which is in good agreement with previous reports.[4,6,7] The c(8×4) phase was oriented with three orientation, each of this orientation is rotated by 120°. The c(8×4) iron silicide phase did not appear at the higher coverage of θ_{Fe}~4ML, while the p(2×2) silicide phase appeared at higher Fe coverages (θ_{Fe}>4ML).[4] Observing the LEED patterns help us to identify each surface of iron silicides and Si(111)-7×7 towards the further study of the magnetic properties by MOKE.

3.2. Magneto-Optic Kerr Effect

The magnetic properties of the ultrathin Fe films upto 30 ML on the iron silicides (p(2×2) and c(8×4)) and Si(111)- 7×7 surface were investigated at RT. The presence of the ferromagnetic order of Fe/iron silicide surface and Fe/Si(111)- 7×7 surface was studied by several sets of magnetisation Kerr loops. We observed longitudinal geometry, i.e., the magnetic field in-plane of the film, throughout the whole Fe thickness range (see Fig. 3). Below the coverage of 5.5 ML, there was no indication of a ferromagnetic (FM) order, in the iron silicides and Si(111)-7×7 surface. This implies the absence of FM state in iron silicide and Si(111)-7×7 surface at lower Fe coverage. The MOKE result showed two significant results in p(2×2) and c(8×4) iron silicide surface respectively. Firstly, the FM order starts to appear at the coverage of 5.5 ML Fe on c(8×4) silicide surface. Secondly, the FM order occurs at the coverage of 8.2ML Fe on p(2×2) silicide surface. MOKE results did not show any FM order occurrence in Si(111)-7×7 surface below the 10ML Fe coverage at RT.

To identify the MDL on iron silicide and Si(111)-7×7 surface, we performed a thickness dependent study of Kerr rotation (KR). Figure 1 shows the KR of Fe films grown on iron silicides and Si(111)-7×7. Thickness dependence of Kerr rotation shows that the Fe film on c(8×4) silicide has higher KR than the p(2×2) silicide and Si(111)-7×7 surface. With increasing the Fe coverage, the KR linearly increases. On c(8x4) silicide, the extrapolated KR is zero at 3 ML, indicating that the magnetic dead layer (MDL) for c(8×4) is 3 ML. In the same way, Kerr rotation as a function of Fe coverage indicates that the MDL is 5 ML and 7.5 ML for p(2×2) silicide and Si(111)- 7×7 surface, respectively.

4. Discussions

The MDL for c(8x4), p(2x2), and Si(111)-

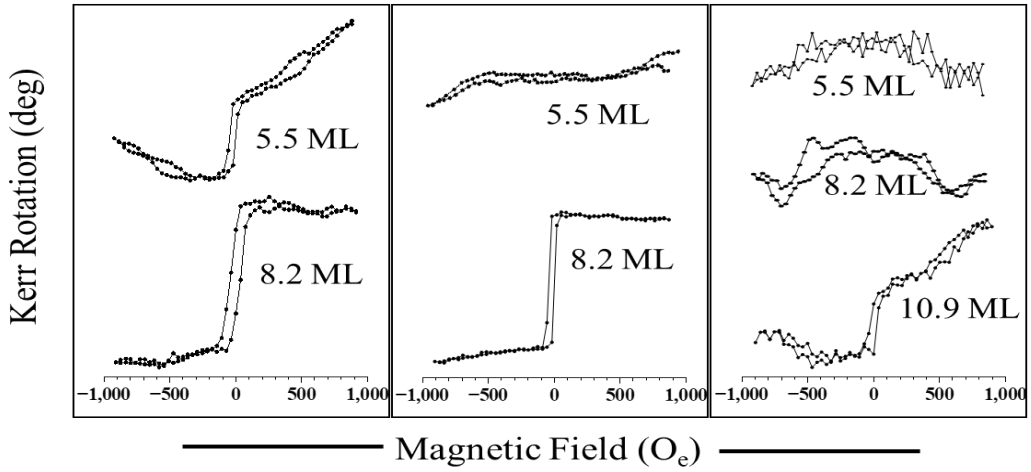

Figure 3. Magnetization loops in the longitudinal Kerr effect as a function of Fe coverage on (a) c(8×4) silicide, (b) p(2×2) silicide, and (c) Si(111)-7×7 surface. Fe coverage is indicated in the plots.

7×7 are 3, 5, 7.5 ML, respectively. This is due to the intermixing of Fe and Si leading to the formation of thin non-magnetic

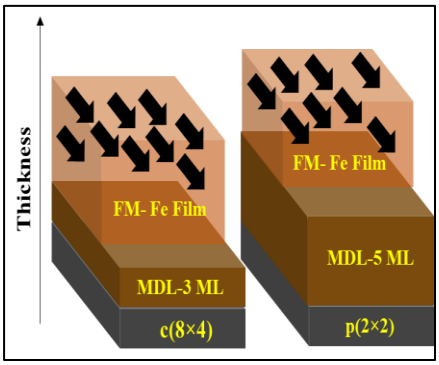

Figure 4. Magnetic Dead Layer Model. Middle layer is (a) MDL for c(8×4) and (b) MDL for p(2×2), Top layer is Fe film in both case. Arrow indicates the FM state of top layer in both system.

Fe-Si interfacial phases. The additional Fe deposition over the MDL interfaces produces the FM order for iron silicide and Si surfaces (see Fig 4.). As in the LEED result, the c(8×4) silicide on the clean Si(111)-7×7 surface is prepared at a higher temperature, compared with the p(2x2) silicide. Thermal stability is higher than the p(2×2) silicide as reported by M. Krause *et al.* and S. Hajjar *et. al.*[6,7] Our results indicate that the c(8×4) Fe silicide surface prevents further silicide formation effectively since the c(8×4) surface prepared at the higher annealing temperature would be rather stable.

5. Conclusion

To summarise, we have demonstrated the interfacial magnetism and a magnetic dead layer for ultrathin Fe film/iron silicide and Si(111)-7×7 interface at RT by MOKE. The results show that~5.5 ML Fe/c(8×4) silicide, 8.2 ML Fe/p(2×2) silicide and 10 ML Fe/Si(111)-7×7 interface is not FM ordered respectively. This different behaviour of the Fe film on the iron silicide and Si(111)-7×7 surfaces is due to the interfacial intermixing between Fe and Si atom. The thickness dependent study of Kerr rotation indicates the MDL for Fe/c(8×4) silicide is 3 ML, Fe/p(2×2) silicide is 5 ML and Fe/Si(111)-7×7 is 7.5 ML respectively. The interfacial iron layer does not contribute to the ferromagnetism. Our study explores the interfacial FM nature of the ultrathin Fe film on iron silicide and Si(111)-7×7 surface.

Reference

[1] G. Garreau, S. Hajjar, J. L. Bubendorff, C. Pirri, D. Berling, A. Mehdaoui, R. Stephan, P. Wetzel, S. Zabrocki, G. Gewinner, S. Boukari, and E. Beaurepaire, Phys. Rev. B **71**, 094430 (2005).

[2] W. Q. Liu, W. Y. Wang, J. J. Wang, F. Q. Wang, C. Lu, F. Jin, A. Zhang, Q. M. Zhang, G. van der Laan, Y. B. Xu, Q. X. Li, and R. Zhang, Scientific Reports **5**, 11911(2015).

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[3] Y. Shin, D. A. Tuan, Y. Hwang, T. V. Cuong, and S. Cho, J. Appl. Phys. **113**, 17C306 (2013)
[4] K. Kataoka, K. Hattori, Y. Miyatake, and H. Daimon, Phys. Rev. B **74**, 155406 (2006).
[5] K. Eguchi, Y. Takagi, T. Nakagawa, and T. Yokoyama, Phys. Rev. B **85**, 174415 (2012)
[6] M. Krause, F. Blobner, L. Hammer, and K. Heinz, Phys. Rev. B **68**, 125306 (2003)
[7] S. Hajjar, G. Garreau, S. Pelletier, D. Bolmont, and C. Pirri, Phys. Rev. B **68**, 033302 (2003)