e-J. Surf. Sci. Nanotech. Vol. 6 (2008) 251-253 Conference - ISSS-5 -

Growth Mode and Surface Structure of Cr Ultrathin Film on Fe/Cu(001)*

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(Received 9 October 2008; Accepted 6 November 2008; Published 18 November 2008)

We hereby report a growth mode and surface structure of ultrathin Cr films on fcc Fe/Cu(001). We have found a clear RHEED intensity oscillation during Cr deposition up to four monolayers on 3 and 6 ML Fe/Cu(001), indicating an layer-by-layer growth. Besides, the observed (2×1) LEED pattern at low Cr thickness is similar to that of fcc Fe/Cu(001) in the 5-11 ML thickness range. We have also demonstrated the Cr/Fe multilayer growth with single monolayer of Cr inserted between fcc Fe layers. [DOI: 10.1380/ejssnt.2008.251]

Keywords: Magnetic films; Low energy electron diffraction (LEED); Reflection high-energy electron diffraction (RHEED); Iron; Chromium

I. INTRODUCTION

Low-dimensional magnetic materials have received a lot of attention because of anomalous electric and magnetic properties, which are much different from those of bulk systems. Among them, two dimensional systems such as ultrathin films have been actively studied due not only to a fundamental interest but also to a possibility for application to magnetic and magneto-optic storage technologies. Fe and Cr multilayer with body centered cubic (bcc) lattice is well known as the typical system for giant magnetoresistance (GMR) device, showing an in-plane magnetic anisotropy and an oscillatory interlayer magnetic coupling [1–4]. In contrast to this, Fe films with face centered cubic (fcc) lattice can be stabilized on Cu(001) substrate [5–12]. Up to 4 monolayer (ML), corresponding to the thinnest thickness region of Fe ("region $\mathrm{I_{Fe}}$" hereafter), the films show the face-centered-tetragonal (fct) structure elongated out-of-plane direction and exhibits out-of-plane magnetic anisotropy. Second, the thicker Fe films with 5-11 ML thickness (region $\mathrm{II_{Fe}}$) form unstrained fcc lattice while topmost two layers remain tetragonal (fct). In this thickness range, the magnetic properties are believed to be complicated compared to that in the thinnest region ($\mathrm{I_{Fe}}$). The topmost two layers exhibit a ferromagnetic property, while the inner layers are in the spin density wave (SDW) phase [11]. Above 11 ML (region $\mathrm{III_{Fe}}$), the films show bcc structure with an in-plane magnetic anisotropy, and Fe island begins to be formed. Fe/Cr multilayer grown on fct Fe/Cu(001) attracts a great interest because giant magneto-resistance (GMR) effect with perpendicular magnetic anisotropy could be expected. Recently, Yaji *et al.* studied structural and magnetic properties of Cr adsorbed Fe/Cu(001) in the sub monolayer region. They found the similarity of low-energy electron diffraction (LEED) *I-V* curve of Cr/3-ML Fe/Cu(001) to that of 6-ML Fe/Cu(001), which indicated the structural modification of Fe film upon Cr deposition [13, 14]. They also studied the magnetic properties through x-ray magnetic circular dichroism (XMCD) in core-level absorption spectra. It was demonstrated in their report that Fe specific magnetic moment decreases with increasing Cr thickness. It was suggested that the magnetic property of the Fe film was strongly correlated with structural modification upon Cr deposition. In the present work, we have tried to clarify the structural properties of Cr/Fe/Cu(001) in more detail. We have obtained a clear indication of epitaxial film growth of Cr through the oscillation of reflection high-energy electron diffraction (RHEED) spot intensity during the Cr deposition, which has not been elucidated so far. Here, we focus on the growth mode and the structural properties of Cr on Fe/Cu(001) studied by RHEED and LEED techniques.

II. EXPERIMENTAL

Sample preparations and measurements were carried out in situ in a ultra-high vacuum chamber with a base pressure below 6×10^{-8} Pa. A clean Cu(001) surface was obtained by repeated cycles of $\mathrm{Ar^+}$ ion bombardment (1 keV) and annealing (850K), whose cleanliness was subsequently confirmed by Auger electron spectroscopy (AES) and a sharp (1×1) LEED pattern. Fe and Cr films were grown at room temperature on the Cu(001) surface in the pressure below 9×10^{-8} Pa during evaporation. The Fe film thickness was carefully monitored by means of the intensity oscillation of RHEED specular spot and

*This paper was presented at International Symposium on Surface Science and Nanotechnology (ISSS-5), Waseda University, Japan, 9-13 November, 2008.

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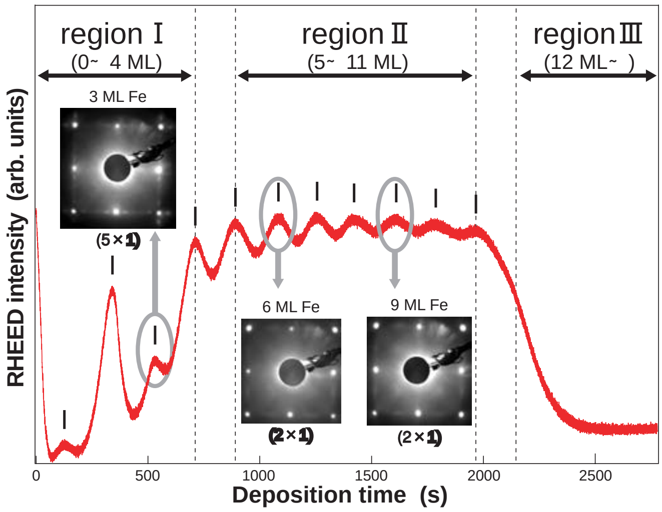

FIG. 1: RHEED intensity oscillation and LEED images for Fe on Cu(001) grown at room temperature. Incident electron energy for LEED was set at 110 eV.

also cross-checked by Auger electron spectroscopy (AES) spectra. Cr was deposited on the Fe/Cu(001) by the e^- beam evaporation from well outgassed Cr pieces heated by electron bombardment.

III. RESULTS AND DISCUSSION

First, we show the RHEED intensity curve during the Fe film growth and the LEED patterns obtained for selected Fe coverages as described in Fig. 1. A clear RHEED intensity oscillation is observed up to 11 ML, indicating the layer-by-layer Fe growth. Besides, the clear extra spots are observed at the surfaces of 3, 6 and 9 ML Fe/Cu(001) films. The observed LEED patterns indicate the change of surface periodicity from (1×1) Cu(001) surface. Here, the LEED pattern of 3 ML Fe film shows the (5×1), and 6 and 9 ML films show the (2×1) surface periodicities. These RHEED and LEED results are in a good agreement with the formerly reported result [12]. Since the contaminations like oxygen and carbon atoms or molecules are below the detection limit of AES, the layer-by-layer growth and the epitaxial Fe films on Cu(001) are confirmed.

Next, the growth mode and the film structure of Cr on Fe/Cu(001) will be revealed by RHEED and LEED techniques. Figure 2 (a) shows the intensity of RHEED spot as a function of Cr deposition time on the bare Cu(001), 3 ML Fe, 6 ML Fe, 15 ML Fe/Cu(001). Here, negligible oscillation of RHEED intensity versus Cr thickness is observed for bare Cu(001) and 15 ML Fe/Cu(001), indicating the Cr island formation on the surface. However, for 3 ML and 6 ML Fe films, clear oscillations with well-separated intensity maxima are commonly observed, where the second intensity maxima are much suppressed compared to the other three. It is noted here that alloying at the Fe-Cr interface is found to be negligible because the Fe and Cr intensity ratio of Auger electron well match with the attenuation curve. These results indicate the presence of Cr layer.

Figure 2 (b) show the LEED patterns of the Cr films

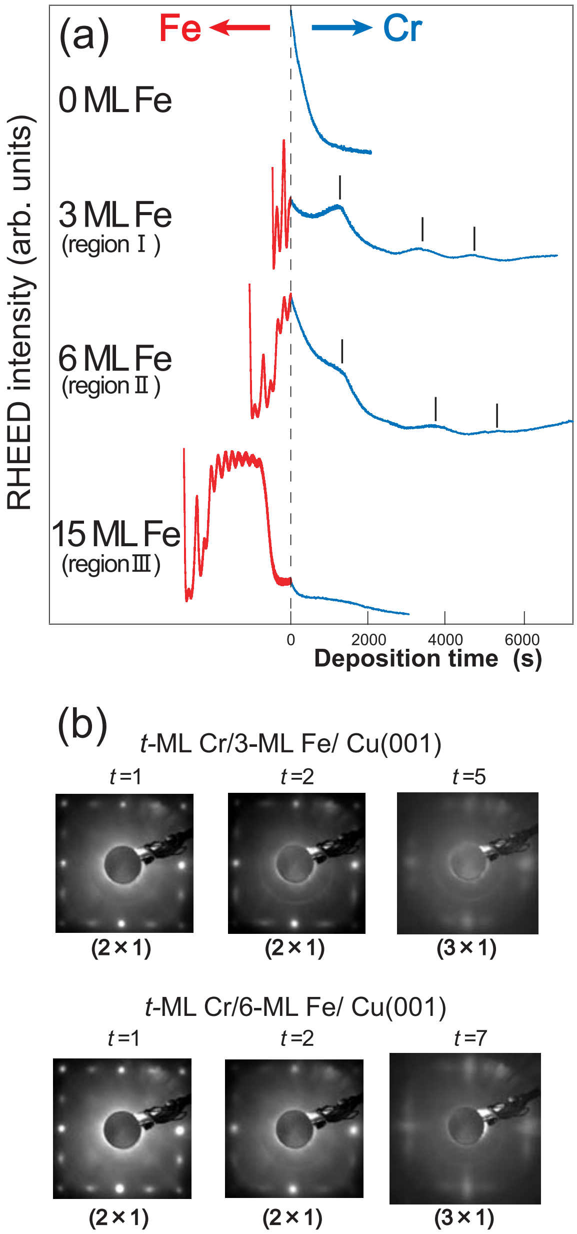

FIG. 2: (a) RHEED intensity as a function of deposition time for Cr on 0, 3, 6 and 15 ML Fe/Cu(001). (b) LEED patterns for *t*-ML Cr on 3 and 6 ML Fe/Cu(001). Incident electron energy for LEED was set at 110 eV.

on 3 and 6 ML Fe/Cu(001) with several thickness. We find that the LEED pattern is modified upon 1 ML Cr deposition on the 3 ML Fe. Namely, the (5×1) periodicity of 3 ML Fe is changed into p2mg (2×1) after the single layer of Cr is formed. The LEED image with 2 ML Cr film also shows the (2×1) pattern. Further Cr deposition promotes (3×1) periodicity from (2×1) as observed for 5 ML Cr/3-ML Fe/Cu(001). In the similar way, Cr on 6 ML Fe (region $\mathrm{II}_{\mathrm{Fe}}$) also produces nearly the same property of LEED pattern as shown in Fig. 2 (b). The LEED patterns of both 1 and 2 ML Cr films on 6 ML Fe show the (2×1) periodicity, which is followed by the change into (3×1) after 7 ML Cr deposition. Here it should be noted that the (2×1) LEED pattern of 1 ML Cr on Fe resembles to that of fcc Fe/Cu(001) in the thickness region $\mathrm{II}_{\mathrm{Fe}}$. Besides, the (3×1) LEED pattern of thick layers of Cr on Fe resembles to that of Fe in region $\mathrm{III}_{\mathrm{Fe}}$. And as

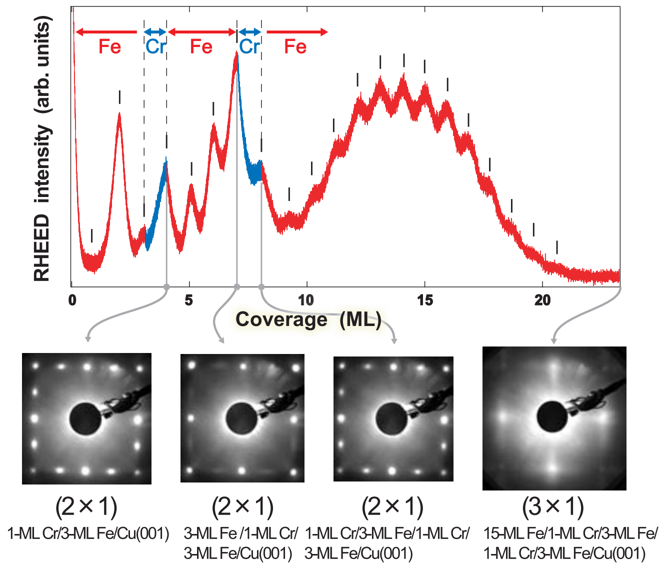

FIG. 3: RHEED intensity of Fe/1-ML Cr/3-ML Fe/1-ML Cr/3-ML Fe/Cu(001). LEED patterns taken with incident electron energy of 110 eV after a completion of the first Cr layer and before and after the second Cr layer is inserted.

these extra spot of LEED images are more clear than that of region $\mathrm{II}_{\mathrm{Fe}}$ Fe/Cu(001) in Fig. 1, it is considered the well crystallinity for Cr/Fe/Cu(001). Recently, Yaji *et al.* have shown a similarity of the LEED *I-V* curves of the surface structures with (2×1) and (3×1) LEED patterns of Cr/3-ML Fe/Cu(001) with those of bare Fe/Cu(001) in the thickness regions $\mathrm{II}_{\mathrm{Fe}}$ and $\mathrm{III}_{\mathrm{Fe}}$ [13].

Now we know that the epitaxial 1 ML Cr film can be certainly fabricated on the 3 ML and 6 ML Fe/Cu(001) films. Finally, we have tried to fabricate the Fe/Cr multilayer while the Cr thickness is fixed at 1 ML. Figure 3 shows the RHEED intensity for the Fe and Cr depositions with 1 ML Cr inserted between the Fe films. Here, one can see a clear oscillatory behavior in the diffraction intensity v.s. film thickness as shown in Fig. 2. After the growth of 3 ML Fe film on 1 ML Cr/3-ML Fe(001), a clear (2×1) LEED spots are observed. This means that the (2×1) LEED spots are still found with additional single layer of Cr on it. The result demonstrates the layer-by-layer growth of alternate Fe/Cr layers on 3 ML Fe/Cu(001). We also need to notice that additional thirteen intensity maxima by the further growth of Fe can be recognizable even after the second insertion of monolayer Cr as shown in Fig. 3. This result tells us that the layer-by-layer growth of Fe has been improved by inserting 1 ML Cr.

IV. CONCLUSION

The growth mode and surface structure of Cr ultrathin films on Fe/Cu(001) have been studied by RHEED and LEED techniques. For the 3 and 6 ML Fe films, the layer-by-layer growth of Cr film has been clearly observed up to 4 ML. In the low and high Cr thickness regimes, the (2×1) and (3×1) LEED patterns have been obtained. Finally, we have successfully demonstrated that the Fe/Cr multilayer can be fabricated on the fcc like Fe ultrathin film on Cu(001) with 1 ML Cr. It is now expected that the existence of the Cr epitaxial layers could modify the structural and magnetic properties, which will be further studied in near future.

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