Growth and Characterization of Ultrathin Fe Films on Molecule-Adsorbed MgO Surfaces

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Effects of the molecule-adsorption on a MgO surface on the growth of ultra-thin Fe films were investigated. Surface observation by reflection high-energy electron diffraction and ultra-high vacuum atomic force microscopy showed that the adsorption of molecules on the MgO surface affected the morphology of Fe films grown on the MgO surface. It was revealed that the surface flatness of Fe films was improved by appropriate molecule-adsorption on the MgO surface. [doi:10.2320/matertrans.M2009218]

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1. Introduction

Ultra-thin films have attracted a lot of attention from the viewpoint of understanding physics in two-dimensional electron systems. Two-dimensional electron systems are formed typically in semiconductor hetero-junctions. These systems show interesting phenomena, such as Shubnikov-de Haas oscillation1) and quantum Hall effect2) at very low temperatures. Two-dimensional electron systems formed in ultra-thin metallic films also show quantum effects due to interference and confinement of electrons. It is known that thin films of ferromagnetic metals clearly exhibit spin-dependent quantum well states.3,4) In previous studies, ultrathin metallic films were grown on metallic buffer layers. If the ultra-thin metallic films are grown on an insulator, the further development of spintronic devices such as spin-polarized resonant tunneling transistors which are demonstrated by gate-control of spin-dependent quantum well states is expected.5,6) However, the growth of extremely thin metallic films with a few atomic layers on insulators is quite difficult because three-dimensional island structures are easily formed. Hence, only a few studies on the growth of ultra-thin metallic films on insulators have been reported to date.7-11)

In the first stage of film growth, the metals that have higher surface energies than that of an insulating substrate are generally grown three-dimensionally. The migration of metallic atoms promotes the formation of island structure, and not continuous structure. The growth of metallic thin films using adsorption of atoms or molecules on surfaces of insulators was reported.12,13) M. Lust et al. reported that crystalline qualities of ultrathin Fe and Cu films grown on MgO were improved by adsorption of CO molecules on a MgO surface.14) In addition, it was reported that dissociative adsorption of H2O molecules occurs on defect sites of the MgO surface, which seems to be an advantage to grow epitaxial films on MgO substrates.15,16) Therefore, the adsorption of CO or H2O molecules on the MgO surface has a possibility of realizing the growth of ultra-thin continuous ferromagnetic films.

In this paper, we have investigated the effects of molecule-adsorption on a MgO surface on the growth of ultra-thin Fe films. CO and H2O were adsorbed on MgO surfaces, and Fe films with a nominal thickness of a few atomic layers were grown on the molecule-adsorbed surfaces. Surface morphology was observed by reflection high-energy electron diffraction and atomic force microscopy. A characteristic feature in this study is that these direct methods were used to investigate effects of adsorption.

2. Experimental Procedure

All the growth processes were performed at room temperature by molecular beam epitaxy with evaporation sources in an ultra-high vacuum (UHV) chamber (base pressure: 1 × 10−7 Pa). MgO(001) substrates were annealed at 600 °C for 30 min in UHV, and MgO buffer layers (5 nm) were grown at room temperature. Then, clean MgO(001) surfaces were obtained by annealing at 600 °C for 30 min. Ultra-thin Fe films with a nominal thickness of 0.3 nm were grown on the MgO surfaces. The CO-adsorbed MgO surface was prepared by introduction of CO gas with a partial pressure of 4 × 10−6 Pa from a variable leak valve for 10 min equipped in the UHV chamber. The growth of Fe film was started after closing the valve, and the partial pressure of CO gas decreased to the order of 10−8 Pa. To adsorb H2O molecules on a MgO surface, the MgO substrate with the buffer layer mentioned above was unloaded from the UHV chamber, and dipped into ultra-pure water for 5 s. The H2O-adsorbed MgO surface was annealed again at 100 °C for 3 min in the UHV chamber, and an Fe film was grown on the surface. The surface morphology was monitored by reflection high-energy electron diffraction (RHEED) just after deposition and after annealing. The surface profile and the surface flatness of the Fe films were investigated by ultra-high vacuum atomic force microscopy (AFM) using a contact mode.

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on CO-adsorbed MgO (Fig. 2(g)) and on H
also observed in the magnified images of the Fe films grown
particles were grown on non-adsorbed MgO. Fe particles are
Figs. 2(a), (b), (c) and (d) are shown in Figs. 2(e), (f), (g)
morphology of the Fe thin film. Magnified images of
incident beam was directed along the azimuth of MgO
A RHEED pattern was also observed for the Fe layer grown on the
relationship of Fe epitaxial island growth of bcc-Fe with an epitaxial orientation
showed a spotty pattern as shown in Fig. 1(b). This RHEED pattern indicates the
from the Fe layer grown on the H2O-adsorbed MgO surface (Fig. 2(c)). A RHEED pattern
Fe thin films. Although small Fe particles are grown, the
Table 1. Here, Ra is defined as an arithmetic average of the absolute values of heights. Ra is expressed as
\[ Ra = \frac{1}{x_{\text{max}} y_{\text{max}}} \iint_{0}^{x_{\text{max}}} \iint_{0}^{y_{\text{max}}} |z(x,y) - z_0| \, dx \, dy, \]  
where \( x_{\text{max}} \) and \( y_{\text{max}} \) are side lengths of an arbitrary rectangle region, and \( z(x,y) \) and \( z_0 \) are the height at \( (x,y) \) and the average height in the whole region, respectively. Ra of the
Fe film grown on non-adsorbed MgO is larger than that of the MgO buffer layer. On the other hand, Ra’s of Fe films grown on CO-adsorbed and H2O-adsorbed MgO are smaller than that on non-adsorbed MgO. Particularly, Ra’s of both the Fe films estimated by excluding void regions are considerably smaller than those of the MgO buffer layer and of the Fe film on non-adsorbed MgO. This indicates that the surface flatness is improved by molecule-adsorption on the MgO surface.

The results shown above reveal the improvement of the surface flatness of Fe films by the adsorption of CO and H2O on MgO. A possible mechanism for this effect is considered as follows. Fe islands are three-dimensionally grown on MgO, because the surface energy of Fe is higher than that of MgO. Therefore, the migration of Fe atoms promotes the aggregation of Fe particles. In the case of CO-adsorption and H2O-adsorption, the migration of Fe atoms is possibly blocked by CO or H2O molecules. As a result, the formation of rough islands is suppressed, and the surface flatness is improved. In order to elucidate more details on the mechanism, however, all the experiments should be performed in-situ, and precisely controllable introduction of H2O molecules is needed.

4. Summary

The effect of molecule-adsorption on the MgO surface on the growth of ultra-thin Fe films has been investigated. It has been revealed that the adsorption of CO and H2O on the MgO surface apparently influences the morphology of Fe thin films. Although small Fe particles are grown, the surface flatness of Fe films is improved by the adsorption of CO or H2O. This result indicates a possibility of the growth of an ultra-thin continuous Fe film with an atomically flat surface by optimizing a suitable condition of the molecule-adsorption.
REFERENCES


Fig. 2 AFM images of the surface of (a) a MgO buffer layer and Fe layers with a thickness of 0.3 nm grown on (b) non-adsorbed MgO, (c) CO-adsorbed MgO, (d) H$_2$O-adsorbed MgO. (e), (f), (g) and (h) are magnified images of (a), (b), (c) and (d), respectively.