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To cite this article: Eun-Sang Cho et al 2003 Jpn. J. Appl. Phys. 42 5536

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Phases of Ag-Adsorbed Si Surfaces Studied by Low Energy Electron Diffraction and Auger Electron Spectroscopy

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(Received February 10, 2003; accepted for publication May 8, 2003)

The Ag-adsorbed Si(110)2×16 surfaces were investigated using low-energy electron diffraction (LEED) and Auger electron spectroscopy (AES). When Ag was deposited on a Si(110)2×16 surface at room temperature (RT) and annealed at several elevated temperatures, diffuse 1×1 , 1×2 +streak, 1×2 , and $(-1, 6) \times (-7, 0)$ structures were observed by LEED. The relative Ag coverage of the reconstructed structures were estimated from Ag(*MNN*)/Si(*LVV*) AES intensity ratios and previous results. The structural model of the Ag/Si(110)1×2 surface was proposed from the LEED and AES results. [DOI: 10.1143/JJAP.42.5536]

KEYWORDS: Si(110), Ag, phase transition, low energy electron diffraction, Auger electron spectroscopy

1. Introduction

Metal adsorption to Si(110) surfaces has received significantly less attention in last years than that of metal adsorption to low-index Si surfaces such as Si(111) or Si(100) due to lack of fundamental information about clean Si(110) surface. The " 2×16 " structure has been observed only as a reconstructed phase of the clean Si(110) surface. It was reported that the reconstructions, such as 5×4 , 1×2 , 1×5 , and 1×9 , were induced by a small amount of nickel impurity.¹⁻³⁾ The " 2×16 " reconstructed Si(110) surface consists of a periodic up and down sequence of terraces at a step height of the Si(110) bulk-layer spacing (1.9 Å).^{4,5)} The width of the up and down terraces in the [110] direction is the same $(30.72 \text{ \AA} = 8 \times 3.84 \text{ \AA})$. The scanning tunneling microscopy (STM) images of the Si(110)2×16 surface revealed the presence of zigzag chains consisting of Si adatoms on both the upper and lower terraces.⁶⁾ The reconstructed structure is not aligned along the bulk symmetry axes-the matrix notation is

$$\begin{pmatrix} 17 & 2 \\ 2 & 2 \end{pmatrix}.$$

Noble metal, such as Ag, adsorption to Si surfaces is a very important subject for understanding the fundamental physical properties of metal/semiconductor interfaces and metal ultrathin films on semiconductor substrates.^{7,8)} Due to the chemical non-reactivity of Ag with Si, Ag atoms rarely diffuse into Si substrates. Moreover, due to the great technological interest of Ag/Si systems such as the idealmetal contact and Schottky barrier, a large number of results on phase transition of Ag adsorption to Si(111) and Si(100) surfaces have been reported.

The $(9,3) \times (-9,3)$, 5×4 , and 1×1 structures were reported for the Ag/Si(110) system from a study using reflection high-energy electron diffraction-total-reflection angle X-ray spectroscopy (RHEED-TRAXS).⁹⁾ However, these structures were not observed in our carefully performed lowenergy electron diffraction (LEED) experiment. In this paper, we report results of LEED and Auger electron spectroscopy (AES) for Ag-adsorbed Si(110)2×16 surfaces.

2. Experimental

The experiments were performed in an ultrahigh vacuum chamber equipped with LEED and AES. Before the silicon sample was put into the chamber, it was cleaned chemically by Shiraki's method;¹⁰⁾ degreasing in organic solution such as trichlorethylene and methyl alcohol, HNO3 boiling at 130°C to remove carbon contaminants, and boiling in a $NH_4OH : H_2O_2 : H_2O$ solution of (1:1:3)and $HCl: H_2O_2: H_2O$ (3 : 1 : 1) for removal of metal contaminants and formation of a thin oxide layer to protect the substrate. Careful attention was paid to avoid nickel at contamination during the sample preparation. In an ultra high vacuum, it was thoroughly degassed at 600°C for about 6 h and then flashed at 1200°C approximately 10 times. Then, we acquired a sharp double-domain 2×16 LEED pattern with a low background, the same as the previously reported one. The cleanliness of the $Si(110)2 \times 16$ surface was checked by inspection of AES spectra that did not reveal any trace of contamination either before and after evaporation. The Ag-coated tungsten filament was used as the evaporating source; An Ag rod was put into a tungsten filament coil and sufficient current was passed through the tungsten filament in UHV. The Ag melts and the melted Ag diffuses and coats the tungsten filament. The pressures during Ag deposition and sample heating did not exceed 1.0×10^{-9} Torr. The Ag-adsorbed surface was annealed for 2 min after RT evaporation. The substrate temperature was monitored by optical pyrometer. The relative coverages of Ag-adsorbed surface structures were measured by the relative peak-to-peak intensity ratio of Ag MNN (359 eV) with respect to that of Si LVV (96 eV).

3. Results and Discussions

Figure 1 shows the Ag *MNN*/Si *LVV* AES intensity ratio of Ag-deposited samples as a function of annealing temperature with LEED results. The AES intensity ratios of three (R1, R2, and R3) samples are R = 0.85, 0.57, and 0.46, respectively, which correspond to the Ag amount deposited at RT, as seen in Fig. 1. When Ag was deposited to the Si(110)2×16 surface at RT, the "2×16" pattern was



Fig. 1. Ag(MNN)/Si(LVV) AES intensity ratio as a function of annealing temperature for various Ag-deposited surface at RT with observed LEED patterns.

gradually changed to the very diffuse 1×1 pattern with high background with increasing deposition time. With further deposition, no ordered pattern was observed as in R1. With elevation of the annealing temperature, the AES intensity ratios for R1 and R2 decreased, but that for R3 almost did not. After annealing at a temperature of approximately 230°C, the AES intensity ratio of each Ag-deposited sample (R1, R2, and R3) became the same, R = 0.45, and the diffuse 1×1 pattern was observed, as shown in Fig. 2(a). Although the annealing temperature was raised gradually from 230°C to 340°C, the diffuse 1×1 pattern with high background did not change into a sharp 1×1 pattern with low background. When the Ag-deposited surface was annealed at 340°C, the diffuse 1×1 pattern was changed to



Fig. 2. LEED patterns of (a) diffuse 1×1 (b) 1×2+streak (c) 1×2 (d) (-1, 6)×(-7, 0) structures. Electron beam energies were (a) 54 eV (b) 51 eV (c) 51 eV (d) 35 eV, respectively. The bold line and dashed line indicate the 1×1 unit cell and structure unit.

the 1×2 +streak pattern, as seen in Fig. 2(b). The pattern consists of sharp 1×2 spots and a weak half-order streak. By increasing the annealing temperature (> 340° C), the 1×2 spots become sharper and the half-ordered streaks disappear as shown in Fig. 2(c). The 1×2 +streak structure may be an intermediate structure in the transformation from the diffuse 1×1 to the 1×2 structure. The Ag/Si AES intensity ratio in Fig. 1 shows that the Ag coverage of the 1×2 +streak structure is slightly than one of the 1×2 structures. The excess Ag on the 1×2 surface would cause the half-order streaks, that is, a disturbance in the periodicity in the [001] direction as indicated in Fig. 2. Within the range of 340-500°C, a sharp 1×2 LEED pattern with low background was observed, as shown in Fig. 2(c). Successive annealing at 500-600°C enabled observation of the $(-1, 6) \times (-7, 0)$ pattern on the screen of the LEED, as shown in Fig. 2(d). The $(-1, 6) \times (-7, 0)$ pattern without the 1×2 or the 2×16 pattern appeared in a narrow range of temperature. The Ag on the Ag/Si(110) surface was perfectly desorbed at approximately 620°C as shown in Fig. 1. In the case of the Ag/Si(100) surface, $^{11,12)}$ Ag film grows in a Stranski– Krastanov mode at 350°C and the Ag saturation coverage of the 2D layer is approximately 1 ML. At coverage greater than 1 ML, the growth of 3D Ag islands was reported. After depositing Ag to the Si(111) surface¹³⁾ at RT, annealing at about 300°C changed small Ag islands into $\sqrt{3} \times \sqrt{3}$ domains on the terraces without diffusion of Ag atoms to the step edges. As mentioned above, it was reported that Ag atoms do not diffuse into the Si bulk. Also, for the Si(110) surface, no evidence of diffusion of Ag into bulk was observed. These results suggest that for the Si(110) surface, silver atoms form single-layer islands at the initial stage of deposition at RT and form clusters in the island, similar to Ag/Si systems of other low-index Si surfaces.^{11–13)}

In the case of the Ag/Si(111) surface, it was reported that the Ag desorption temperature is from 550 to $650^{\circ}C^{14,15)}$ and the linearity of the isotherms clearly shows zero-order desorption from the experiment of isothermal ($T = 587^{\circ}$ C) desorption, that is, the desorption rate is independent of the adsorbed amount.^{13,14} Therefore, it seems that the Ag desoprtion temperature for the Ag/Si(110) surface is approximately 620°C. Yamamoto proposed the structural models of the Au/Si(110) surfaces.¹⁶⁾ According to the suggested model, the Au/Si(110)1×2 surface is shown in Fig. 3. The Au coverage is 0.25 ML, which is consistent with that of the experimental value of 0.08-0.26 ML. Because the valence electrons of Ag and Au are the 5s and 6s electrons, respectively, at sub-monolayer coverage without interaction between absorbates, it is expected that the adsorption site of Ag and Au atoms on the Si(110) surface could be identical. If so, it seems that the 1×2 structure of Ag and Au/Si(110) surfaces is the same in the geometrical arrangement of absorbate on the Si(110) surface. Since the Au coverage is 0.25 ML of the Au/Si(110)1×2 surface, 16 the Ag coverage of the Ag/Si(110)1×2 structure is 0.25 ML and the Ag coverage of the diffuse 1×1 structure at approximately 230°C is approximately 1 ML. In conclusion, we can suggest from analysis of the LEED and AES results that the $Ag/Si(110)1 \times 2$ surface has the same structure as the Au/Si(110)1×2 surface and consists of the well-aligned Ag wires with approximately 1.1 nm spacing in the [001]



Fig. 3. Structural model of Ag/Si(110)1×2 surface. Open, filled and shaded circles represent Si, Ag and Au atoms, respectively. The shaded rectangle represents the unit cell of the Ag/Si(110)1×2 surface.

direction, as shown in Fig. 3. The $Ag/Si(110)1 \times 2$ surface will be reported elsewhere together with our scanning tunneling microscopy (STM) and photoemission data.

4. Conclusion

We present the results of LEED and AES studies for the Ag-adsorbed Si(110)2×16 surface depending on the annealing temperature. The diffuse 1×1, the 1×2+streak, the 1×2, and the $(-1, 6)\times(-7, 0)$ structures depending on annealing temperature of the Ag-adsorbed sample were observed using LEED. From measurement of AES intensity ratios, the relative Ag coverage was estimated. We propose the surface structure as shown in Fig. 3 for the Ag/Si(110)1×2 surface from the analytical results of LEED and AES and based on the structural model of the Au/Si(110) surface suggested by Yamamoto.

Acknowledgements

This work was supported by Korea Science Foundation through the CNNC (Center for Nanotube and Nanostructured Composites) at SungKyunKwan University.

- T. Ichinokawa, H. Ampo, S. Miura and A. Tamura: Phys. Rev. B 31 (1985) 5183.
- Y. Yamamoto, S. Ino and T. Ichikawa: Jpn. J. Appl. Phys. 25 (1986) L331.
- 3) B. A. Nesterenko: Appl. Surf. Sci. 33-34 (1988) 21.
- H. Ampo, S. Miura, K. Kato, Y. Ohkawa and A. Tamura: Phys. Rev. B 34 (1986) 2329.
- A. J. Hoeven, D. Dijkkamp, E. J. Van Loener and P. J. G. M. Van Hooft: Surf. Sci. 211–212 (1989) 165.
- T. An, M. Yoshimura, I. Ono and K. Ueda: Phys. Rev. B 61 (2000) 3006.
- 7) S. Kono: Surf. Rev. Lett. 1 (1994) 359.
- 8) J. Nogami: Surf. Rev. Lett. 1 (1994) 395.
- 9) Y. Yamamoto: Jpn. J. Appl. Phys. **31** (1992) 2241.
- 10) A. Ishizaki and Y. Shiraki: J. Electrochem. Soc. 133 (1986) 666.
- 11) X. F. Lin, K. J. Wan and J. Nogami: Phys. Rev. B 49 (1994) 7385.
- 12) X. F. Lin, K. J. Wan and J. Nogami: Phys. Rev. B 47 (1993) 13491.
- 13) H. Ohnishi, I. Katayama, Y. Ohba, F. Shoji and K. Oura: Jpn. J. Appl. Phys. **32** (1993) 2920.
- 14) G. Le lay, M. Manneville and R. Kern: Surf. Sci. 72 (1978) 405.
- 15) S. Hasegawa, H, Daimon and S. Ino: Surf. Sci. 186 (1987) 138.
- 16) Y. Yamamoto: Surf. Sci. 271 (1992) 407.