The epitaxial growth of Ag on Si(111)–(7×7) surface and its ($\sqrt{3} \times \sqrt{3}$)–R30 surface phase transformation

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Abstract. Ag is adsorbed in ultra-high vacuum on to the (7×7) reconstructed Si(111) surface with submonolayer coverage control with a deposition rate of 3.3×10^{12} atoms/cm²/sec. The initial stages of growth and intermediate equilibrium phase formation are determined by using low energy electron diffraction (LEED) and X-ray photoelectron diffraction (XPD) for structural information, and auger electron spectroscopy (AES) and electron energy loss spectroscopy (EELS) for composition and interaction analyses. Room temperature (RT) adsorption results in the nearly epitaxial (1×1) surface phase growth in the simultaneous multi-layer growth mode. The quenching of the dangling bond states during adsorption is observed by monitoring the *p*-character of the Si LVV auger peak. For depositions carried out at high temperatures (HT), several plateaus in the auger uptake curve with the ($\sqrt{3} \times \sqrt{3}$)–R30° LEED structures are formed. It is observed that a minimum coverage of 0.33 monolayer (ML) is required for the formation of the ($\sqrt{3} \times \sqrt{3}$) phase and this phase causes the reappearance of the *p*-electron-related states that were quenched by 1.0 ML adsorption at RT. However the ($\sqrt{3} \times \sqrt{3}$) is observed for higher coverages (0.66 and 1.0 ML) also. The polar angle anisotropy of Si(2*p*) emission in XPD indicates the rearrangement of substrate Si atoms for the formation of the ($\sqrt{3} \times \sqrt{3}$) phase. The EELS data also shows relevant changes due to adsorption of Ag at RT and upon annealing. The results suggest the importance of controlled deposition parameters, the lack of which may have kept the determination of the nature and coverage of the ($\sqrt{3} \times \sqrt{3}$) surface phase unresolved in literature.

Keywords. Solid phase epitaxy; metal–semiconductor interfaces; surface phase transitions; Auger electron spectroscopy; low energy electron diffraction; X-ray photoelectron diffraction.

1. Introduction

Motivated by the need to produce high performance and reliable devices of diminishing size, the VLSI/ULSI R&D has encouraged the studies of extremely low-dimensional structures. Modern growth techniques with submonolayer control of structure, composition and doping, enable the synthesis of new materials with novel properties (Gossmann and Schubert 1993). Of the many issues under this broad scheme, the semiconductor to metal contact remains one of the principal priorities for metallization (Ohmic contacts, Schottky barrier control) or delta-doped and buried layer structures. The precise relationship between the crystallographic structure, the chemical composition and the electrical properties at the boundary between metal and semiconductors are of critical technological and fundamental interest (Monch 1990). Most of the conventional theoretical treatments of metal/semiconductor interfaces have made the key assumption that the interface is well ordered and perfectly

abrupt on an atomic scale. But in reality, strong chemical interactions, intermixing and diffusion occur at surfaces which necessitate a re-evaluation of conventional ideas, both theoretically and experimentally. Due to the stringent experimental requirements for the formation and accurate characterization of the interfaces, precise control of the very initial stages of growth are observed to determine the nature of growth (Shivaprasad *et al* 1995, 1997).

Of the several metals on Si systems studied in the last two decades, Ag/Si the prototype system, has been the most intensively studied mainly due to minimal chemical interaction between the two elements on both Si(111) and (100) surfaces. The Si(111) surface attracted more attention (Le Lay 1983; Lifshits *et al* 1994), initially due to the early observation of the ($\sqrt{3} \times \sqrt{3}$) superstructure, while the Si(100) was said to be without any new superstructure. However, with improvements in experimental techniques and control of deposition parameters, the interest in these systems has been renewed and has led to the observation of new superstructural equilibrium states in the Ag/Si(100) (Shivaprasad *et al* 1995). Differences still exist in the details of the Ag/Si(111)

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$(\sqrt{3} \times \sqrt{3})$ superstructure (Saitoh *et al* 1981). It has recently been observed that a systematic control of deposition rates at RT can result in the epitaxial growth of Mn on Si(111) at RT and also form many equilibrium surface phases for the Mn/Si(111) system (Shivaprasad *et al* 1997).

1.1 The $(\sqrt{3} \times \sqrt{3})$ structure

Several results (Wan *et al* 1993) indicate that Ag grows at RT on Si(111) (7×7) surface in the Stranski-Krastanov (S-K) mode. The nature and coverage of this intermediate 2-D has no consensus and is controversial in literature, with the (7×7) reconstruction observed to be vanishing in the formation process. At higher temperatures the S-K mode displays an intermediate layer of $(\sqrt{3} \times \sqrt{3})$ -R30 surface phase reconstruction. This reconstruction is the second smallest of the Si(111) surface and occurs frequently in metal/Si interface systems (Kono 1988). It has been established that the $(\sqrt{3} \times \sqrt{3})$ symmetry appears due to various atomic arrangements, depending on the energetics of the overlayer coverage (Northup 1984; Kono 1994). In case of Gr. III and Gr. IV metals the atoms are recognized to be adsorbed at the two kinds of three-fold hollow sites T_4 and H_3 on Si(111) (see figure 1) and require a coverage of 0.33 ML. However, for Gr. V metals, the $(\sqrt{3} \times \sqrt{3})$ was observed for a coverage of 1 ML which has been attributed to the presence of metal trimers centred above the T_4 and H_3 three-fold hollow sites, referred to as the milk-stool model. In the Ag on Si(111) case, the coverage of this structure has remained controversial and has reported values between 0.33 to 1.0 ML and is recently said to be preparation history dependent (Raynerd *et al* 1992). A modified honeycomb-chained trimer (HCT) model (Katayama *et al* 1991) with a Ag coverage of 0.66 ML has found wide acceptance (also shown in figure 1). In the present work, the Ag/Si(111) system is studied with a view of addressing some of the unresolved issues.

In this study it is observed that Ag grows epitaxially in the simultaneous multilayer mode at RT and assumes the S-K mode upon post-annealing or upon deposition at higher substrate temperatures with the intermediate layer having a $(\sqrt{3} \times \sqrt{3})$ structure. The molecular-beam evaporation is probed *in situ* with a multi-technique approach using auger electron spectroscopy (AES), low energy electron diffraction (LEED), X-ray photoelectron spectroscopy (XPS), electron energy loss spectroscopy (EELS) and X-ray photoelectron diffraction (XPD). The epitaxial (1×1) and the $(\sqrt{3} \times \sqrt{3})$ structural phases observed are discussed in terms of the dangling bond manifestation and the coverages involved.

2. Experimental

The experiments were performed in two UHV systems: (i) a Varian VT-112 equipped with a single-pass

CMA with a 0–10 keV electron gun and LEED optics with a 0–3 keV electron gun, and a home-made Knudsen cell with a graphite crucible and a shutter for *in situ* Ag adsorption, operating at a base pressure of 3×10^{-11} mbar, and (ii) a Perkin Elmer (PHI) system with a 280 mm HSA and a dual Anode (Mg/Al) K_{α} X-ray source and a 0–4 keV electron gun. Ag was evaporated from a water-cooled W-filament at a base pressure of 3×10^{-10} mbar.

The Si substrates were suitably cut from Si(111) *p*-type, 5–10 $\Omega \cdot \text{cm}$ wafers and chemically cleaned by the modified Shiraki Process (Enta *et al* 1989) before being introduced in the UHV chambers. These samples were mounted on high-precision manipulators (with four degrees of freedom x, y, z, θ), designed to accurately place the sample in front of the sources, analyzer and LEED optics etc. The samples were heated *in situ* in the two UHV systems resistively and by electron bombardment respectively, to 1200°C for a few min and then annealed at 900°C for 20 min, to obtain a sharp (7×7) LEED and a characteristic XPD of Si(2p), respectively. The impurities like C and O were below the detection limits of AES and XPS. The cleanliness of the Si(111) surface is also evident by the observation of at least seven multiple plasmon losses of 17 eV each in the EELS spectrum. The temperatures were measured by a thermocouple (for $T < 500^\circ\text{C}$) and an optical pyrometer (for $T > 600^\circ\text{C}$). The Ag films were deposited on to the substrates with a slow deposition rate of typically 0.2 ML/min, where 1 ML corresponds to 7.83×10^{14} atoms/cm², the atomic density of a bulk-terminated Si(111) (1×1) surface.

AES was measured by a single-pass CMA, with 0.18% energy resolution, using a primary beam energy E_p of 3 keV by lock-in techniques in the dN/dE mode, with peak-to-peak voltage of 10 V. EELS was measured by the same system in the second derivative mode for E_p of 250 eV with a peak-to-peak voltage of 2 V for improved resolution. The LEED patterns were observed in a 4-grid optics with electron beam energy varying from 20 eV to 500 eV. XPS data was acquired in the pulse counting mode by a computer interfaced to the 280 mm hemispherical analyzer with a typical pass-energy of 50 eV, using Mg K_{α} X-ray source at 1443.3 eV, while the valence band features were observed with a pass energy of 10 eV for better resolution. Polar Angle-XPD was performed by manually rotating the sample to change the angle about an axis passing through it and parallel to the surface by 2° steps. The flat response of the analyzer in the angular range studied and the acceptance angle of $< 2^\circ$ were ascertained beforehand. Though the experiments were performed in two different systems and probed by different techniques, identical preparation conditions were adopted and monitored for stoichiometry and coverage by AES in both cases.

3. Results and discussion

The results obtained for RT deposition and those for higher temperatures are presented under two sub-sections (3.1 and 3.2) for clarity of presentation. The results are discussed in light of the various models shown in figure 1 for the $(\sqrt{3} \times \sqrt{3})$ surface structural phase.

3.1 Room temperature

Figure 2 shows the Ag-uptake curve on the Si(111) surface. The curve is obtained by rotating the samples to face the K-cell for Ag adsorption and then to the CMA to obtain the AES spectrum after each deposition.

Figure 1. Shows schematically the models for the adsorption sites of Ag (open circles) on the (1×1) Si (filled circles) surface which result in the $(\sqrt{3} \times \sqrt{3})$ LEED pattern: (a) $\theta = 0.33$ ML, (b) for $\theta = 1.0$ ML and (c) hexagonal chained trimer (HCT) model with $\theta = 0.66$ ML.

The X-axis shows the time of deposition while the Y-axis is the Auger amplitude of the 92 eV LVV peak for Si and the 356 eV MNN transition for Ag. As more Ag is deposited, the Ag signal increases while the Si signal is reduced. The initial segment of the Ag amplitude, which is close to being linear, shows a change in slope at about a deposition time of ≈ 5 min. This change in slope indicates the completion of the first adsorbed layer, after which the signal from the first layer is attenuated by the presence of the second layer atoms (Argile and Rhead 1989). The break in the linearity is clearer in the Ag signal than in the Si signal due to the varying depth of information in the two species. This not only provides a calibration for the first monolayer and deposition rate, but also clearly indicates that the first layer is flat and that the growth is not in the Volmer-Weber (Island) growth mode. The latter part of this curve appears to be linear as in the case of a simultaneous multilayer growth mode which will be discussed later.

Figure 3a shows the LEED image at 50 eV of a clean Si(111)- (7×7) reconstructed surface while figure 3b shows the characteristic polar angle (PA)-XPD pattern of Si(111) along (110) direction (Bischoff *et al* 1992). The LEED pattern taken at 50 eV incident beam energy shows clear six-fold symmetry in the (1×1) spots, between which are the six less intense spots manifesting the (7×7) reconstruction in reciprocal space. Figure 3b is the polar angle plot of the XPD signal, clearly showing the anisotropy in the Si(2p) emission, due to the predominant forward scattering of electrons, of these ener-

Figure 2. Adsorption of Ag on Si(111) plotted as the auger intensity of Ag (356 eV) and Si(92 eV) versus the deposition time. The break in slope at 1 ML obvious in the Ag signal, indicates a deposition rate of 3.3×10^{-12} atoms/cm²/sec.

gies, originating from one atom by the neighbouring atoms (Egelhoff 1990; Chambers 1991). Since the information depth of the Si(2p) (≈ 1340 eV) electrons in XPS is quite large, the pattern is not expected to manifest the reconstruction of the first few layers of the substrate.

Figures 4a and b are respectively the LEED and XPD (polar angle) pattern modified after deposition of 1 ML of Ag. Though the experiments have been performed for several coverages, the 1 ML LEED and XPD patterns are presented as being representative. The LEED pattern shows clearly that now the (7×7) spots have disappeared

while the (1×1) six-fold spots are weak but sharp (Kohmoto and Ichimiya 1987). However the dominant spots are the slightly elongated spots radially above each of the (1×1) spots. These spots are attributed to the Ag(111) reflexes, which are commensurate with the Si(111) (1×1) spots. This indicates that Ag is growing epitaxially on Si(111) at these slow rates at RT (Bera and Shivaprasad 1995). This was also manifested in the AES uptake curve as a linearity of the later segment of the plot. However the Ag(111) (1×1) reflexes are not sharp, and even show a weak full circle, indicating that

Figure 3. a. Typical LEED pattern of clean Si (7×7) reconstructed surface, obtained at 50 eV incident beam energy and b. corresponding XPD pattern obtained by rotating the sample along the θ axis (polar angle).

the Ag has adsorbed probably in the simultaneous multilayer growth mode, with several two-dimensional flat islands, with some misorientation between them (Bauer 1982). The (1×1) spots indicate that the Ag(111) grows parallel to the Si(111), with little chemical interaction between the two elements at the interface. The corresponding PA-XPD in figure 4b, also shows significant changes in its features. Note that the XPD obtained in one quadrant experimentally has been presented by laterally inverting it in the other quadrant. This change in pattern can be attributed to the scattering of Si(2p) electrons by the presence of Ag adatoms. The presence

of the Si(1 $\times$ 1) pattern in LEED dissuades us from interpreting the XPD results as due to the rearrangement of Si atoms in the first few layers.

Figure 5 represents the Si LVV auger peak fingerprinting results for both room temperature and higher temperature deposition. The deconvolution of the Si(LVV) auger peak in the $N(E)$ mode, enables the extraction of the contribution of the p -electron states to the Auger transition (Ramaker *et al* 1986). The density of the dangling bonds (valence band states), which are predominantly p - in character, can thus be monitored by observing changes in the intensity of the corresponding

Figure 4. a. LEED pattern obtained with energy of 50 eV after adsorbing 1 ML of Ag on Si (7×7) surface at room temperature and b. the XPD polar plot of Si(2p) signal along $(1\bar{1}0)$ obtained by Mg K_{α} . The second quadrant is created by symmetrically inverting the data obtained in the first.

components. This becomes easily accessible in the Auger spectra acquired in the first derivative mode, since the upper excursion of the peak corresponds directly to the p - p electron state contribution (L_{pp}), and the lower excursion is due to the s - s and s - p states (L_{ss}). Thus in figure 5 the plot of the ratio of the positive to the negative excursion (L_{pp}/L_{ss}) of the Si (LVV) 92 eV peak as a function of Ag deposition, manifests the change in the valence band due to the changing dangling bond density. The figure shows clearly that the dangling bonds are quenched monotonically with increased Ag deposition, and reduce to zero intensity at 1 ML. This confirms the observations by LEED during deposition, where the 1/7th order spots also diminish at 1 ML, removing the (7×7) reconstruction.

Figure 6 shows some EELS spectra obtained with primary energy of 650 eV, both during the Ag uptake sequence (a-d) and annealing (e-f) of a 5 ML Ag deposited system at different temperatures. The origins of all the loss peaks observed for clean Si(111) have been assigned previously (Ibach and Rowe 1974; Sharma *et al* 1988a). The clean Si(111) (7×7) surface shows the characteristic loss to the 17 eV ($\hbar\omega_p$) bulk plasmon and the 11 eV ($\hbar\omega_s$) surface plasmon, and an intraband transition at about 5.5 eV (E_2). The loss of peaks at 7.5 eV (S_2) and 14.5 eV (S_3) are attributed to transitions involving surface states. As the deposition of Ag at RT proceeds, the Si surface-related peaks disappear quickly, while the bulk features decrease gradually. At the com-

pletion of 1 ML of Ag deposition, the Ag-related peak excitations (Jaspard *et al* 1980) become prominent. At a coverage of 5.0 ML, the EELS pattern resembles that of bulk Ag with features at 4.5 eV and 7.5 eV. This has been explained to be due to strong transitions from the Ag d-band to states in the sp conduction band just above the Fermi level. The absence of the formation of any interfacial peak shows lack of interaction between the two species. The changes due to annealing of the system (e,f) will be discussed in the next section.

3.2 High temperature

In this section we discuss the effects of temperature on the structure of the Ag/Si(111) system. As seen in figure 4, the Si (1×1) and the disordered Ag (1×1) reflexes are clearly observed in the LEED pattern. After annealing to about 150°C, the rearrangement of the Ag and Si atoms are manifested in LEED and PA-XPD as shown in figures 7a and b, respectively. The LEED pattern shows that the Ag spots get sharper and the Si (1×1) spots also intensify, suggesting the enhancement of long range order of the surface structure. Though there are some new and sharp spots, the transition in this intermediate state is clearly not complete. The changes are

Figure 5. The ratio of the upper excursion (L_{pp}) to the lower excursion (L_{ss}) of the 92 eV Si LVV peak obtained in the derivative mode as a function of Ag deposition at room temperature (open circles) and others at different substrate temperatures (+, $\diamond$, Δ), 100°C, 150°C and 250°C, respectively.

Figure 6. The EELS spectra obtained with an incident beam energy of 650 eV. (a) clean Si(111) 7×7 , (b) 1 ML Ag deposited surface, (c) $\theta = 2$ ML, (d) $\theta = 5$ ML, (e) d annealed to 150°C and (f) d annealed to 250°C.

also very clear in figure 7b showing the PA-XPD at this stage. The relatively isotropic pattern in figure 4b, has clearly changed to show more prominent features, suggesting a better ordering of the atoms in the overlayer and the substrate selvedge.

Further annealing to about 250°C, completes the phase transition as seen in figure 8. Figure 8a shows a different, yet very sharp LEED pattern and the background is also considerably reduced, showing a homogeneity in this surface phase. The inner hexagon is clearly rotated by 30° with respect to the outer hexagon whose side is $\sqrt{3}$ times the side of the inner hexagon and is termed as the $(\sqrt{3} \times \sqrt{3})\text{-R}30^\circ\text{-Ag}$ pattern. The corresponding XPD pattern again changes in figure 8b which can either be due to scattering of the Si(2p) electrons by the

presence of the ordered Ag overlayer, or due to the rearrangements of the Si substrate itself.

AES uptake curve for deposition of Ag onto Si(111) substrate held at different substrate temperatures is presented in figure 9. The curves clearly show that at higher temperatures, the Ag/Si auger ratio behaves differently, showing a sudden flattening at about 0.33 ML (1.0 ML coverage is attained by deposition time of 5 min), characteristic of the Stranski-Krastanov growth mode. In this flat region corresponding to a surface structural phase, the LEED is observed to be (7×7) , but with some modifications in intensity, suggesting possibly the $\delta(7 \times 7)$ surface phase as reported earlier (Kohomoto and Ichimiya 1987; Shivaprasad *et al* 1997). For substrate temperature of 100°C, after 1 ML, the Ag again begins

Figure 7. a. The LEED pattern of the 1 ML Ag/Si(111) surface annealed to 150°C showing an intermediate surface phase between the (1×1) and (3×3) and b. the corresponding XPD-PA pattern along $(1\bar{1}0)$.

to build on the (7×7) surface phase, until a sufficient density of Ag atoms are available for the formation of the next surface phase. Again for both the 100°C and 150°C curves, it is clear that they show two more plateaus which also correspond to structural surface phases with $(\sqrt{3} \times \sqrt{3})$ symmetry as observed by LEED.

Figure 5 which consolidates the fingerprinting (*p*-component study) results of the auger studies for the Ag deposition at room and higher temperatures shows the dangling bond intensity versus the deposition time. It is very clear from this figure that the +ve to -ve excursion ratio (L_{p1}/L_{s0}) of the Si LVV 92 eV peak almost remains constant (with some scatter) around a ratio of 0.15 for all temperatures and coverages. However for RT deposition this ratio has clearly decreased to 0 for 1 ML deposition indicating the complete quenching of

the Si dangling bonds. This indicates that the valence band features related to *p*-electrons are quenched only partially and the surface phase that gives the $(\sqrt{3} \times \sqrt{3})$ LEED pattern, actually causes the re-formation of the dangling bonds. The small amount of quenching also indicates a small coverage of Ag necessary to form the ordered surface phase, as seen in the plateau formation in figure 9. Annealing at 250°C shows that the plateau is for a coverage of 0.33 ML, on which excess Ag atoms agglomerate to form islands, thus occupying only a small fraction of the Si surface.

The EELS spectra in figure 6 also shows the annealing sequence of the 5 ML Ag coverage deposited system at higher temperatures (curves e, f). The features show the re-occurrence of the Si bulk and surface plasmon-related features (Sharma *et al* 1988b). The dip before the 17

Figure 8. a. The LEED pattern of the $(\sqrt{3} \times \sqrt{3})$ R-30 structural surface phase obtained by annealing 1 ML Ag/Si(111) system annealed to 250°C and b. the corresponding XPD pattern along $(1\bar{1}0)$ direction.

Figure 9. The Ag uptake curve shown by plotting the Ag(LMM)/Si(LVV) peak intensity ratio, obtained for different substrate temperatures: (a) $\circ$, room temperature, (b) $+$, 100°C, (c) $\diamond$, 150°C and (d) $\blacktriangle$, 250°C.

eV peak also deepens as in the clean Si case. However the features now appear slightly broadened. The widths of the observed peaks and shifts of the 12 eV peak to 11 eV and the peak at 8 eV to 7 eV in the case of curves e and f with different Ag coverages, may indicate the differences in the two $(\sqrt{3} \times \sqrt{3})$ structural phases.

4. Conclusion

The adsorption of sub-monolayer coverages of Ag onto Si(111) surface is studied *in situ* by AES, LEED, XPD and EELS techniques. It is observed that Ag grows epitaxially on Si(111) with the Ag(111) parallel to Si(111) at RT. The *p*-character of the Si auger emission (dangling bond states) are sharply quenched at 1.0 ML coverage. At higher substrate temperatures (or with post annealing), a $\delta(7 \times 7)$ surface phase is observed for coverages lesser than that required for the onset of the $(\sqrt{3} \times \sqrt{3})$ -R30° phase. The dangling bond states reappear in the $(\sqrt{3} \times \sqrt{3})$ phase, and the EELS also assumes the clean Si features. The sharp $(\sqrt{3} \times \sqrt{3})$ phase is seen at a minimum of 0.33 ML coverage. The auger uptake curve shows some more surface phases as plateaus, but the LEED observed is still $(\sqrt{3} \times \sqrt{3})$, indicating a possibility

of different atomic structures with characteristic densities, leading to the $(\sqrt{3} \times \sqrt{3})$ phase.

The presence of many models (Lifshits *et al* 1994) for the $(\sqrt{3} \times \sqrt{3})$ phase of Ag/Si(111) (7×7) shows that the problem of determining the exact structure of a stable surface phase is still unresolved. Our experiments using a multi-technique approach and a careful observation of temperature dependence, suggest that the minimum coverage necessary to form the $(\sqrt{3} \times \sqrt{3})$ phase is 0.33 ML, while other subtle phases with different Ag density (coverages of 0.66 and 1 ML), but the same LEED pattern, are also observed. However, the new approach of looking at the *p*-electron contribution shows that though the dangling bonds are quenched by adsorption of Ag at RT epitaxially, the $(\sqrt{3} \times \sqrt{3})$ phase shows the re-appearance of the *p*-electron character. This is observed by our EELS measurements also. Our PA-XPD has evidence for the rearrangement of Si substrate. It has been shown recently for the Ag/Si(100) system, that a massive reconstruction of the Si substrate is observed by scanning tunneling microscopy (Wan *et al* 1993). Thus, further experiments are necessary to determine the atomic structural model for each of the coverage dependent stable surface phases that have the same $(\sqrt{3} \times \sqrt{3})$ LEED symmetry. Thus Ag of 0.33 ML probably results in the adsorption of adsorbates at the T_4 and H_3 sites, while the 1 ML may be because of the Ag trimer adsorption at the above sites. There is also a stable $(\sqrt{3} \times \sqrt{3})$ phase at 0.66 ML, which has been explained by the HCT model. The XPD patterns with adsorption and annealing show significant changes and since the scattering of Si(2*p*) electrons from several layers by even 0.33 ML Ag atoms may be small, the results suggest a restructuring of several layers of the substrate Si atoms also.

A more complete polar and azimuthal angle XPD experiments with single/multiple scattering calculations and simultaneous probe with other complementary techniques are necessary to reveal the details of the surface phases. Detailed EELS experiments are underway to obtain further information on the electronic structures of the various phases. Observation of an epitaxial growth of Ag on Si(111) at RT and the recent works on Ag/Si(100) (Shivaprasad *et al* 1995) and Mn/Si(111) (Shivaprasad *et al* 1997) clearly indicate that a proper control of the deposition rate and temperature determine the formation of various surface phases, suggesting the need to re-examine many metal/semiconductor systems in general and metal/Si in particular.

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