Island formation in Sb films deposited at room temperature on Si(100)2 × 1 surfaces

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(Received 21 April 1993)

The early stages of Sb films deposited at room temperature on Si(100)2 × 1 surfaces have been investigated by angle-integrated and angle-resolved Auger spectroscopy. A comparison between the experimental results and the predictions of simple deposition models indicates that the growth of the Sb film proceeds by island formation. Without any annealing, a uniform overlayer never develops up to films 4 nm thick.

INTRODUCTION

A knowledge of the growth mode is crucial when investigating Schottky barriers and heterojunctions in the early stages of the interface formation. Indeed, the starting point for any experimental study of interdiffusion, surface chemical reaction, and surface segregation is the characterization of the sample morphology. In particular, island formation is a problem often encountered when overlayers are grown onto substrates at room temperature. As a result of experimental difficulties inherent in distinguishing islands, uniform films, or other overlayer structures, this matter has often been controversial. In fact, the growth of Sb on Si(100)2 × 1 surfaces has attracted much attention recently,[1–7] and a controversy over the growth mode with the sample kept at room temperature has arisen. In particular surface-extended x-ray-absorption fine-structure data[4] indicate the formation of a disordered overlayer with three-dimensional Sb clusters while transmission channeling data[5] show that a uniform monolayer of Sb symmetric dimers develops. Auger electron spectroscopy is a powerful tool with which it is possible to monitor overlayer growth on a substrate.[8,9] In fact different types of growth can be distinguished with Auger spectroscopy by plotting the Auger signals for both the adsorbate and substrate as functions of time.[10–12]

In this paper we present angle-integrated (AES) and angle-resolved (ARAES) Auger data on the early stages of Sb films deposited at room temperature on Si(100)2 × 1 surfaces. By comparing our data with results calculated using a simple method[13] based on the ratio of the Auger signals from the overlayer and the substrate, we find three-dimensional island growth up to a nominal coverage of 30 monolayers.

EXPERIMENTAL SETUP

AES and ARAES measurements have been performed in two different ultrahigh-vacuum (UHV) chambers at a base pressure of less than 2×10^{-10} mbar. Si(100) single-crystal P-doped ($\rho = 10 \ \Omega$ cm) was degreased and etched[14] before insertion into the vacuum chamber. In UHV it was thoroughly outgassed at 500 °C, and then annealed at 850 °C for 10 min. This cleaning procedure produces a

sharp two-domain diffraction pattern with low background in low-energy electron diffraction (LEED) and contaminant-free surface in AES spectra. In AES (ARAES) experiments Sb was evaporated by resistive heating of a supporting tungsten filament (Knudsen cell) at an evaporation rate of 0.5 monolayer (ML) per min as monitored by a quartz microbalance. One ML of Sb is defined as the site density for the unreconstructed surface which is 6.8×10^{14} atoms/cm^2. Pressure during Sb deposition and sample heating did not exceed 1.0×10^{-9} mbar. A double-pass cylindrical mirror analyzer (CMA) with coaxial electron gun was used to collect AES spectra while a hemispherical analyzer with angular resolution $\pm 1°$ was used to collect ARAES spectra.

EXPERIMENTAL RESULTS

In Fig. 1 typical derivative AES spectra in the electron energy range 30–550 eV are shown for different thickness of Sb films deposited at room temperature on Si(100)2 × 1 surfaces. The structure characteristics of the two ele-
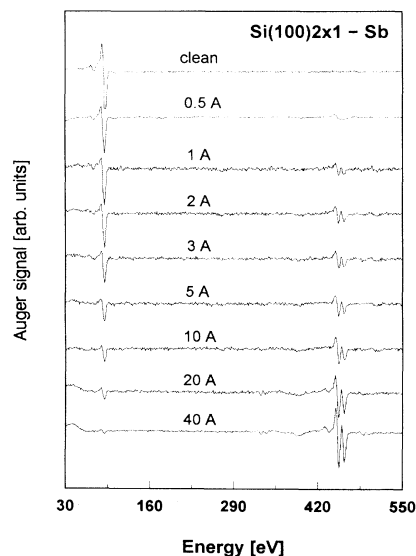

FIG. 1. First derivative Auger spectra of Sb films deposited on clean Si(100)2 × 1 surface as a function of nominal Sb coverage.

<u>48</u>   17 588

ments (Si at 92 eV and Sb around 460 eV) are clearly visible in this region and do not present appreciable shape changes during the evaporation of the Sb film.

The method used to evaluate different growth modes is described in Ref. 13 and consists of calculating the peak-to-peak intensity ratios of adsorbate and substrate Auger lines. Ratios for the uniform (layer-by-layer) growth [Frank–van der Merwe (FM) growth] differ markedly from those for nonuniform (three-dimensional island formation) growth [Volmer-Weber (VW) growth]. Such a ratio is defined as

$$R = \frac{(I_a/S_a)}{(I_s/S_s)} \; ,$$

where I_a and I_s are the peak-to-peak intensities in the derivative Auger spectrum, while S_a and S_s are sensitivity factors proportional to the cross section of the Auger process for the adsorbate and the substrate, respectively. The sensitivity factors are obtainable from tabulated data.[15] In the present study the substrate is silicon and the adsorbate is antimony so that the following ratio can be defined:

$$R_{Sb/Si} = \frac{I_{Sb}/S_{Sb}}{I_{Si}/S_{Si}} \; .$$

In the calculations an exponential attenuation $\exp[-d/(\lambda \cos\Theta)]$ of the Auger beam as it crosses each adsorbate or substrate layer is considered. The thickness d of the layer is, in this case, the distance between two adjacent (100) planes that we have put equal to 1.7 Å, which is the distance between the first adsorbed Sb layer and the underlying Si(100) plane.[4,16] A geometrical correction requires d to be divided by a $\cos\Theta$ factor, Θ being the angle of acceptance of the energy analyzer (42.3° for the CMA and variable for the hemispherical one). Several experimental determinations of λ vs electron energy are available.[17,18] The following empirical relation[17] can be usefully used:

$$\lambda = 1430 \times E^{-2} + 0.54 \times E^{1/2} \; , \tag{1}$$

where E is the electron kinetic energy in eV and λ is expressed in Å.

Figure 2 shows the behavior of $R_{Sb/Si}$ as a function of Sb coverage. The lines are the results of the calculation for different growth modes: the full and dashed lines refer to layer-by-layer and three-dimensional islands, respectively. The dashed curves are labeled by the percentage of the substrate top layer covered by islands. The experimental data are represented by dots.

From Fig. 2 it is evident that three-dimensional islands start to form. The experimental data are well reproduced by the calculated curve corresponding to islands covering only 40% of the Si(100) surface up to a nominal coverage of 10 ML. When the amount of deposited Sb increases above 10 ML, the islands get larger and the substrate-free surface is more and more reduced. Thus, the experimental points are now better fitted by a curve with a larger fraction of covered substrate.

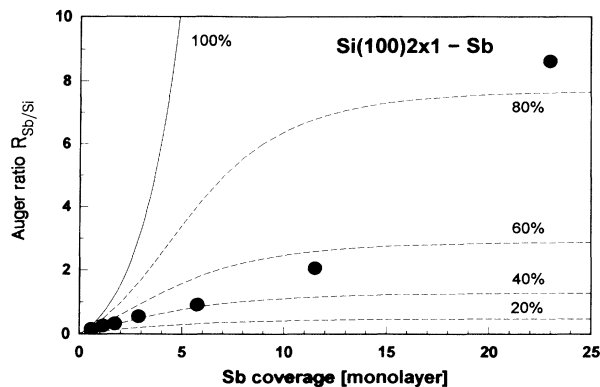Figure 3 shows the behavior of $R_{Sb/Si}$ as a function of collecting angle. This ARAES experiment was per-

FIG. 2. Normalized peak-to-peak Auger intensity ratio $R_{Sb/Si}$ vs Sb coverage. The full (dashed) line indicates the predicted behavior for the FM (VW) growth. The dashed lines are labeled with the value of the percentage of the substrate top layer covered by islands. Dots indicate the experimental data.

formed with a nominal coverage of 6 Å. The experimental data are represented by dots while the full lines refer to calculated different percentage of the substrate top layer covered by islands. It is clearly visible that the best agreement is with islands covering 35% of the surface, in quite good agreement with the 40% value coming from the results of Fig. 2 at the same coverage.

It is worth noting that the noise level in the spectra of Fig. 1 increases with Sb adsorption, particularly for coverages between 1 and 20 Å, indicating an increased roughness at the surface. This is also in good agreement with our LEED observation that shows a high background over very weak 1×1 spots with an electron-beam energy of 40–80 eV.

We deduce from the data point of Figs. 2 and 3 that Sb films deposited on top of Si(100)2×1 surfaces at room temperature never develop as a uniform overlayer.
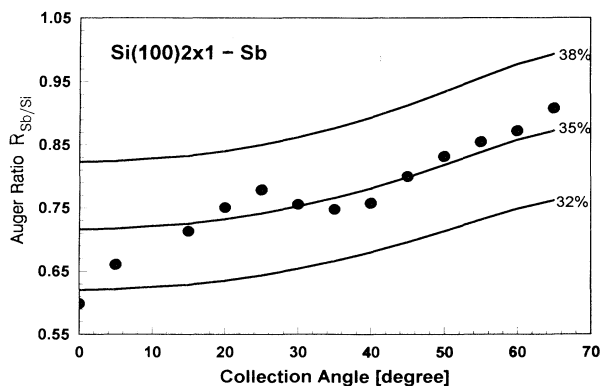

FIG. 3. Normalized peak-to-peak ARAES intensity ratio $R_{Sb/Si}$ vs collecting angle for a nominal 6-Å Sb coverage. The full lines indicate the predicted behavior for the VW growth and are labeled with the value of the percentage of the substrate top layer covered by islands. Dots indicate the experimental data.

SUMMARY

In conclusion, the growth of Sb films deposited on clean Si(100)2×1 surfaces has been studied. Our results show that Sb islands tend to form at the beginning. The size of the islands progressively increases with subsequent deposition but a uniform overlayer never develops up to a nominal coverage of 4 nm. This result indicates that great care should be taken when considering the morphology of the Sb/Si(100)2×1 system in the monolayer regime.

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