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Formation of Sb submonolayer phases on high index Si(5 5 12) surface

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Abstract

This work is the first report on the submonolayer adsorption of antimony (Sb) on the high index Si(5 5 12) surface, studied in UHV by in situ surface sensitive probes such as Auger electron spectroscopy (AES), electron energy loss spectroscopy (EELS), and low energy electron diffraction (LEED). The Auger growth curve which is a plot of the Sb(MNN)/Si(LVV) Auger peak intensity ratio with deposition time, provides a calibration of a deposition rate of 0.06 ML/min. A coverage of 0.2 ML is obtained by four different routes (a) adsorption at room temperature (RT), (b) adsorption at high substrate temperature (HT) of 680 °C, (c) annealing the RT adsorbed surface to 800 °C and (d) annealing the high substrate temperature (680 °C) adsorbed surface to 800 °C. The (2 2 5) facets are observed for the RT adsorbed system at coverage of 0.2 ML, while the pathway adopted to attain the 0.2 ML coverage by adsorption at elevated temperature shows two different atomic arrangements in the formation of the (3 3 7) facets. The HT adsorbed surface suggests the formation of nano-wire-like features while the 0.2 ML coverage obtained by annealing the HT as well as RT adsorbed surface suggests an anisotropic Sb atomic arrangement.

Keywords: Antimony; Si(5 5 12); High index surfaces; Metal–semiconductor interfaces; Epitaxy; Low energy electron diffraction; Auger electron spectroscopy; Electron energy loss spectroscopy

The equilibrium crystal shapes and growth of high index surfaces is not only scientifically interesting, but their stable reconstructions also provide excellent templates for the fabrication of well-defined and organized heteroepitaxial nanostructures. The unprecedented assembly and density of these epitaxial nanostructures, have potential

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applications in advanced devices such as quantum dot lasers, delta-doped structures and single electron tunneling devices [1–3]. The high index Si(5 5 12)-(2 × 1) reconstructed surface [4] is an exceptionally interesting surface consisting of primary rows that divide the large unit cell (0.77 nm × 5.35 nm) into row like trenches of Si(3 3 7) and Si(2 2 5) subunits along the $(\bar{1}10)$ direction. Despite the controversies over the structure of Si(5 5 12) it is generally agreed, that this unit cell has two types of (3 3 7) subunits [4–10]. These (3 3 7) and (2 2 5) faceted trenches of different widths and electron densities form ideal templates to form 1-D nanostructures with large aspect ratios [11–13]. Due to the unusual row like features, this high index surface has attracted several researchers not only to form metal nanowires of Au, Ag, Bi etc. [10,14–16] but also to probe the role of kinetics in the resulting superstructural phase formation.

We report here for the first time, studies on the formation of interface phases by kinetically controlled adsorption of Sb on the high index Si(5 5 12) surface. Our previous work of Sb adsorption on reconstructed Si(1 1 1) and Si(0 0 1) surfaces [17–20] has demonstrated that we can adopt various pathways to stabilize novel superstructural phases, thus stressing the critical role of aspects such as, surface orientation, surface reconstruction, lattice mismatch, surface stress etc. [21–24] in influencing the initial growth kinetics. The present studies involve Sb adsorption at a low flux rate of 0.06 ML/min, onto the Si(5 5 12) substrate to obtain a coverage of 0.2 ML by different adsorption/desorption pathways. The variations at different stages of growth and annealing are probed in situ by AES, EELS and LEED.

The experiments were performed in situ in an UHV chamber, at a base pressure of better than 5×10^{-11} Torr, housed with a high precision sample manipulator, a CMA with a resolution of 0.18% with a concentric 0–10 kV electron gun to perform AES and EELS, and a four grid optics for LEED studies. A 20×5 mm^2 piece is cut from a p-type boron doped Si(5 5 12) wafer having a resistivity of 10–15 Ω cm. The sample was cleaned by the modified Shiraki process [25] before mounting it onto a precision manipulator with Ta sample holder. The sample is degassed at 600 °C by direct resistive heating for 12 h followed by repeated flashing to 1150 °C for 5 s and cooling to RT at a very slow rate of 2 °C/s [4]. The sample temperature is monitored by a W–Re (5%, 25%) thermocouple mounted behind the sample, which is also calibrated with the help of an optical pyrometer. The atomic cleanliness of the sample was ascertained by the absence of carbon or other contamination on the surface by AES, and the observation of the characteristic sharp spots of the (2 × 1) reconstruction [10] in the LEED pattern of the Si(5 5 12). Antimony deposition was made from a home made tantalum-Knudsen cell, whose flux rate was controlled by regulating the current to the cell, and is measured in terms of the adsorbed monolayers [4]. The AES, EELS spectra and the LEED photographs were digitally acquired and analyzed.

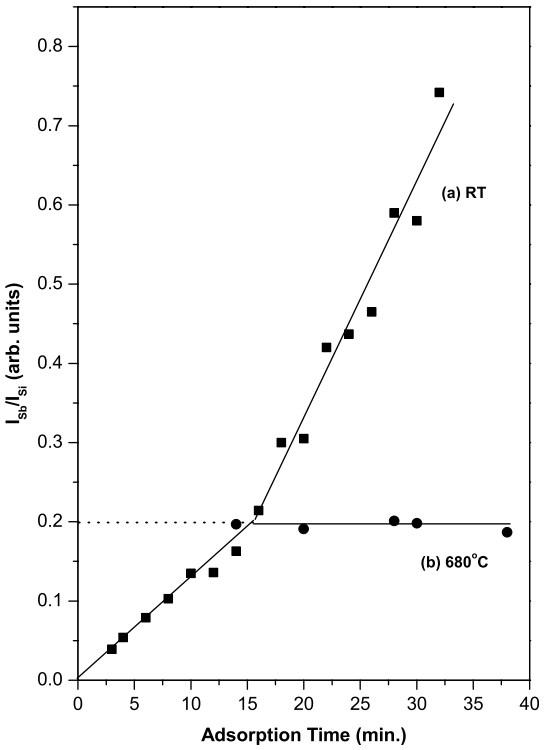

Fig. 1. Auger growth curves of peak intensity ratio (I_{Sb}/I_{Si}) versus adsorption time, for (a) adsorption at RT and (b) adsorption at HT (680 °C) providing calibration of 1 ML.