Growth of Ag Overlayers on Si(111)-(7×7) at Low Temperature

L. Basile,[1,2] Z. Wu,[2,3] H. Hong,[2] T.-C. Chiang,[1,2] H. Chen[4]
[1]Department of Physics, [2]Frederick Seitz Materials Research Laboratory (MRL), and [3]Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign (UIUC), Urbana, IL, U.S.A.
[4]Department of Physics & Material Science, City University of Hong Kong, Hong Kong.

Introduction

Ag overlayers on a Si(111) surface make up a metastable system of intriguing properties that can be grown by low-temperature deposition followed by thermal annealing. Fully wetting and atomically flat 2-D Ag overlayers — or, for lower coverage, islands of uniform preferred height — are metastable configurations that have been suggested to be defined by quantum size effects [1-3].

The energy contribution of quantized electrons confined in the metal overlayer stabilizes the film by a repulsive force between the overlayer and the substrate. The competing effect — charge spilling from the overlayer to the substrate — leads to an energy decrease, an attractive force that destabilizes the film. The balance between these effects governs the behavior of the free energy and determines a critical height below which a flat film is unstable [2].

This report describes a study of the thickness behavior of films grown incrementally on the same substrate. We observed film thicknesses higher than the nominally deposited, suggesting a nonwetting behavior.

Methods and Materials

The University-National Laboratory-Industry Collaborative Access Team (UNI-CAT) has a dedicated surface/ interface station. The ultrahigh vacuum chamber is coupled to a six-circle diffractometer, has molecular beam epitaxy capabilities, and is equipped with reflection high-energy electron diffraction. X-rays with an energy of 19.9 keV were used throughout the study.

Surface cleanness was checked by observing the 7 × 7 reconstruction. A chromel-alumel thermocouple was attached to the tantalum clip at the end of the sample to measure the temperature. The sample was cooled to -150°C by flowing liquid nitrogen. The temperature was controlled to within a few degrees through current flow during annealing.

One nominal monolayer (ML) of Ag was deposited at low temperature and then slowly annealed to room temperature. (One ML is defined as the surface density; for Ag, it is 1.5×10^{15} atoms/cm^2.) Reflectivity scans were taken at room temperature. After the sample was cooled down to low temperature, another dose was deposited, and the cycle was repeated. The coverage was afterward increased by 0.5 ML up to 4 ML. A conventional hexagonal Si(111) unit cell was used, in which the lattice parameter perpendicular to the surface (L direction) is given by $\sqrt{3}\, a_{Si}$, where a_{Si} = the cubic lattice parameter for Si (5.43 Å).

Results

Fig. 1 shows L scans taken at room temperature for each coverage. Offsets were included. An L scan of the clean Si substrate is shown for reference. For a nominal coverage of 1 ML, the plot shows three layers formed, which agrees with Ref. 1. It was reported that Ag forms islands with a preferred height on top of the wetting layer (0.5 ML) up to 2.2 ML. Each island is two layers thick, as reported there. Further Ag deposition results in films with 6-, 8-, 10-, 12-, and 14-ML thicknesses, although we deposited only 0.5 ML per cycle. Table 1 summarizes the experimental and nominal film thicknesses of the films.

According to Ref. 3, 6 ML is the critical thickness. Our result cast doubt on this. If 6 ML is the most energetically favored thickness, even this nonequilibrium growth should lead to a proliferation of 6 ML.

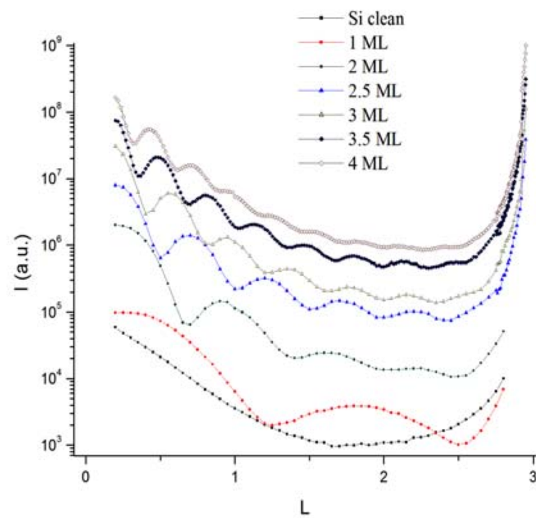

FIG. 1. L scans taken at room temperature for each coverage.

Table 1. Summary of the experimental and nominal thicknesses of the films. (The first column is the total amount of Ag after a cycle.)

Nominally deposited (No. of MLs)	Experimentally observed (No. of MLs)
1	3
2	6
2.5	8
3	10
3.5	12
4	14

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