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Scaling behavior of island density in submonolayer growth of CaF_2 on vicinal Si(1 1 1)

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Abstract

We have studied the scaling behavior of two-dimensional island density during submonolayer growth of CaF_2 on vicinal Si(1 1 1) surfaces using scanning tunneling microscopy. We have analyzed the morphology of the Si(1 1 1) surfaces where CaF_2 partial monolayers with coverages of about 0.1 monolayer are deposited at ~600 °C. The number density of terrace nucleated islands increases with substrate terrace width l as $\sim l^4$ in a low island density regime. This scaling behavior is consistent with predictions for the case of the irreversible growth of islands.

Keywords: Scanning tunneling microscopy; Growth; Nucleation; Surface structure, morphology, roughness, and topography; Silicon; Vicinal single crystal surfaces

1. Introduction

Growth of atomically ordered thin epitaxial film is desired for many technological applications. Understanding of nucleation phenomena is a long-standing problem for epitaxial growth techniques. In submonolayer growth on singular surfaces, scaling forms on island sizes and number densities are well known [1–3], and have been used to analyze experimental data [4–6]. However, despite its technological importance, there have been rather limited investigations into island nucleation on vicinal substrates [7–11], which is frequently used to achieve stable step flow growth.

CaF_2/Si(1 1 1) is a suitable experimental model system to study the kinetics of heteroepitaxial growth [12], and its growth morphologies have been widely investigated [12–17]. For submonolayer growth, well known growth features such as step flow growth and two-dimensional island nucleation and growth have been observed

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[17–19]. Furthermore, it is known that at sufficiently high temperatures above ~600 °C, chemical reaction occurs between isolated CaF_2 molecules and the Si surface, and that a Ca-terminated interfacial layer with CaF stoichiometry is formed [12,20–22], with desorption of SiF_x species [12]. At lower growth temperatures below 600 °C, there are divergent views on the issue whether a Ca- or F-terminated interface is formed [11–17], and our understanding is that the interface structure is still controversial.

The purpose of this study is to examine the scaling behavior of island densities on vicinal surfaces, employing CaF_2/Si(1 1 1) as an experimental model system. We analyze surface morphologies showing competition between terrace and step nucleated islands at an early stage of CaF_2 growth at ~600 °C. Although the stoichiometry of each island is uncertain under our growth conditions, previous investigations [17–19] suggest that the surface morphology after submonolayer CaF_2 deposition at relatively low temperatures is governed by diffusion and aggregation of the adsorbed species without significant effects from the interface reaction. We show the terrace width dependence of terrace-nucleated island density, and compare the experimental results with the theoretical prediction for the island nucleation rate on vicinal surfaces.

2. Experimental

The experiment was conducted in an ultrahigh vacuum chamber equipped with a scanning tunneling microscope (STM). Samples were cut from a nominally flat n-type Si(1 1 1) wafer. The sample was resistively heated by direct current and its temperature was monitored by an optical pyrometer. After degassing at 500 °C for 12 h, clean Si(1 1 1) surfaces were obtained by flashing at 1200 °C for 1 min. Terraces of width ranging from 50 up to 400 nm were formed by applying the electromigration effect from the direct current sample heating or annealing above 1100 °C. CaF_2 was deposited onto the 7×7-reconstructed Si(1 1 1) surface for 30 s at 600 and 630 °C by evaporation from a tungsten boat. The deposition rate was in the range of 0.1–0.3 ML/min. After deposition, the samples were quenched to room temperature and then the growth morphologies were observed by STM.

3. Results

Fig. 1 shows typical 1 μm × 1 μm STM images of the Si(1 1 1) surfaces after CaF_2 deposition for 30 s at substrate temperatures of 630 °C [(a) and (b)] and 600 °C [(c) and (d)]; images obtained at two regions with different step densities in the same sample are shown for each temperature. The brighter and darker regions correspond to areas covered by CaF_2 and Si(1 1 1) substrate surfaces, respectively. The coverages measured from the STM images are about 0.13 and 0.08 for 630 and 600 °C, respectively. Both step flow growth and two-dimensional island nucleation can be seen on the terrace. The island density becomes larger at lower substrate temperatures and on wider terraces. The critical terrace widths at which terrace nucleated islands begin to form at 630 and 600 °C are 130 and 70 nm, respectively. Our observations are basically coincide with the kinetic

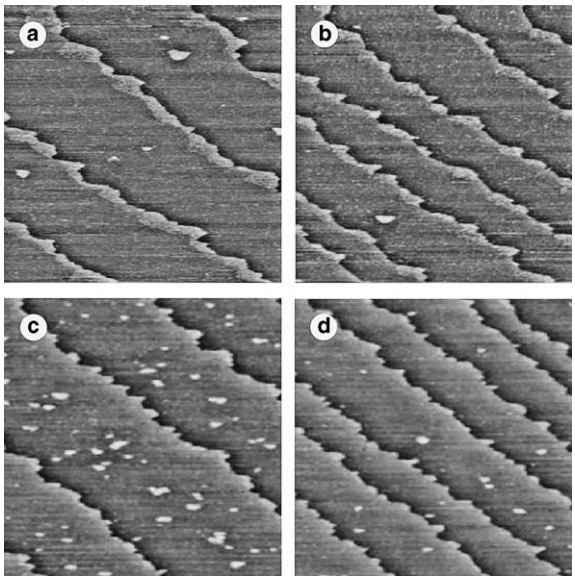

Fig. 1. 1 μm × 1 μm STM images of Si(1 1 1) surfaces after CaF_2 deposition at 630 °C [(a) and (b)] and 600 °C [(c) and (d)]. Brighter regions correspond to areas covered by CaF_2.