

DECAY CHARACTERISTICS OF SURFACE NANOSTRUCTURES: (100) vs (111) SURFACES*

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The rapid decay process of 2D atom nanoclusters at a descending step edge is studied here as a function to the edge geometry by comparison of the decay process on Cu(100) and Cu(111) surfaces at room temperature. Strong edge orientation dependence is observed on the (100) surface while almost no orientation dependence is observed on the (111) surface. This different edge orientation dependence may be associated with a radically different behavior in the decay of 3D mounds on the two surface orientations. Here it is observed that the (100) surface mounds decay from the bottom first with increasing sidewall angle while the (111) surface mounds decay uniformly and maintain a preferred sidewall angle.

Introduction

The stability of nanostructures after their creation is a critical issue for nanotechnology. Here we study the fundamental mechanisms of atomic scale mass transport on surfaces with regard to the stability of surface nanostructures. Surface structures are created which include 2-dimensional islands and step edges as well as pyramidal mounds on Cu(100) and (111) surfaces at 297 K by molecular beam deposition of Cu atoms. The stability of these nanostructures was then observed with an STM for up to 24 hours with images saved every 26-60 seconds. Assembled into movie sequences, the decay processes of the nanostructures on the two surfaces show striking differences. The primary difference is associated with the rapid decay [1] or avalanche process of a 2-dimensional island upon migration to a step edge. This process is highly orientation dependent on the (100) surface and orientation insensitive on the (111) surface.

Results and discussion

Figure 1a shows the surface morphology on Cu(100) 10 minutes after the deposition of approximately 1 monolayer of Cu atoms. The first growth layer is incomplete with irregular shaped vacancy islands while the second layer has been initiated with the formation of square, monolayer height islands. Figure 1b shows the same surface area 40 minutes later. In this time interval, it can be seen that some of the islands have moved and changed size. The irregularly shaped vacancy island shows a radical shape change into an essentially square form. Both the island motion [2] and the reshaping [3] have been attributed to diffusion of atoms along edges. In this study, we are interested in the interaction of the moving adatom islands with the edges of the vacancy islands. The key observation here comes from comparing the histories of adatom islands that are in different circumstances. Island 3, which is located on a curved edge of a vacancy island vanishes in the 40 minute interval. Island 2, initially slightly smaller than island 3 and also on the edge of the vacancy island is still present in the second image. Island 4 decays rapidly at first, but the decay rate has slowed by the time of the second image and exhibits only minor decay over the next 20 hours. The important observation here is that the islands experience rapid decay as has been reported for the Cu(111) surface only when they are in contact with non-close packed step edges. When an island is in contact with a close packed step edge, there is no significant increase in the decay rate. This selective behavior is in direct

contrast to the case of islands on Cu(111) which are observed to undergo a rapid decay process upon contact with step edges having any orientation.

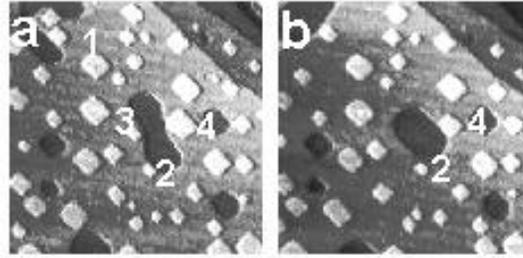


Fig. 1: STM images (a) 10 minutes and (b) 50 minutes after deposition of 0.96 monolayers of Cu on Cu(100) by MBE at 297 K.

When the growth process is continued on the (100) and (111) surfaces, square and hexagonal pyramidal mounds are formed, respectively. Movies produced from sequential scans show that the mounds are unstable and the decay process is profoundly different for the (100) and (111) surfaces. Decay of the (100) mounds proceeds by removal of atoms from the base of the mounds and subsequent transport to the bottom of pyramidal holes. The mound walls therefore become steeper with time. In contrast, the (111) mound decay is characterized by loss of atoms on all terrace levels producing a constant average slope [4]. The mechanism for the decay on both surfaces at 297 K involves the diffusion of islands or terraces by periphery diffusion to an edge where a rapid decay or avalanche process may take place. The observations after 1 monolayer of growth discussed above show that this avalanche process is site selective on the (100) surface, but is not selective on the (111) surface. A recent theoretical study utilizing Kinetic Monte Carlo simulations [5] at 400 K addressed the effects of site selectivity for atom descent at step edges on the qualitative decay behavior of mounds. Even though the delivery mechanism of atoms to the step edge is different at 400K, i.e. evaporation of atoms from island edges and diffusion across terraces to reach a descending step edge vs. the diffusion of whole islands that we observed near 300K, the qualitative behavior is the same.

Conclusions

In summary, the rapid decay of a monolayer high island at a step edge is observed to be strongly dependent on the orientation of the step edge in the case of a Cu(100) surface and to be relatively independent of the edge orientation in the case of a Cu(111) surface. The decay of pyramidal mounds on these two surfaces also demonstrates sharply contrasting behaviors that may be attributed to the site selectivity of the edge barriers against the rapid decay process.

References

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