Dynamics of Step Fluctuations on Al/Si(111)-(Ö3xÖ3) Surface

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Small structures can respond to changes in their environment with substantial changes in shape, if their structural binding energies are comparable to thermal energies. Shape changes will be initiated by atomic motion on the surface of the structure, near crystalline edges (also called steps) where binding energies are weakest, as shown in Figure 1.
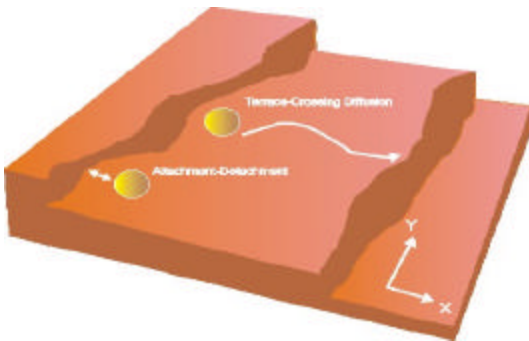

Figure 1. Schematics of two possible mechanisms for atomic motion at step edges that will give rise to changes in shape of the surface of a small structure.

The details of atomic structure on surfaces and at steps can be very complex, as shown for the terrace and step structure of an aluminized silicon surface in Fig. 2. Under equilibrium conditions, constant exchange of atoms at the step edges will cause the step edge position to
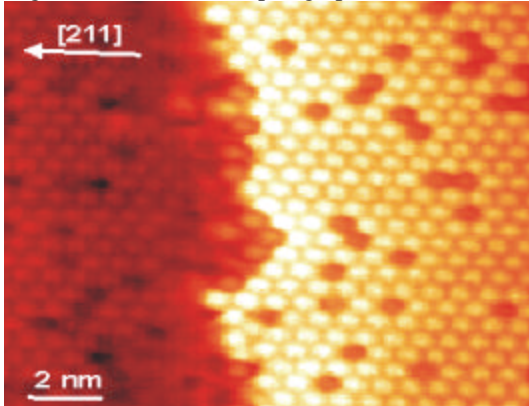

Figure 2. STM filled-state image, T = 300K, showing two layers of the atomic structure of the Al/Si(111)-(√3x√3) surface phase, separated by a step. At this temperature, thermal motion is unobservably slow. Bright sites are Al atoms, and dark sites are Si substitutions of Al atoms in the (√3x√3)-overlayer.

fluctuate, similar to the Brownian motion observed, for instance, for dust particles suspended in air. Fortunately, the complicated details of the atomic motion aren't important for understanding the mass transfer in this process. Instead, the net displacements of the steps can be observed and measured to predict how small structures will respond.

For the aluminized silicon surface, such fluctuations become observable at a temperature about 800K. They can be seen by repeatedly scanning across a single position on the step edge. Each scan occurs at a different time, so the step edge appears at a different position in each scan, as shown in Figure 3.
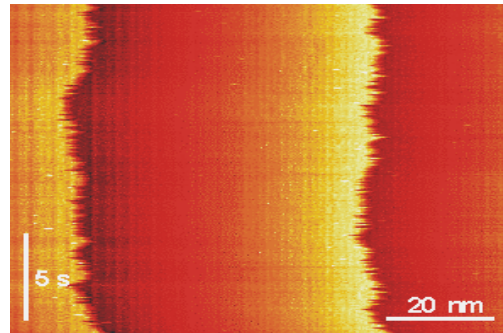

Figure 3. STM time-image of repeated scans of a line perpendicular to two step edges showing the temporal step fluctuations at 970 K.

Similar measurements have been made over a temperature range of 820-1020 K. In this temperature range, step fluctuations up to ~2 nm are observed at time scale of few seconds. The data are analyzed by measuring the step positions and calculating the the temporal step-correlation function,

$$G(t) = \left\langle \left[x(y,t) - x(y,0) \right]^2 \right\rangle,$$

where x(y) is step position (x,y are coordinates perpendicular and parallel to the step edge, respectively), and t is the time. The measured time correlation functions scale as $t^{1/2}$, and the analysis yields a rate of atomic motion at each position of the step edge from 25 atoms/second at 820 K to 3000 atoms/second at 1020 K.