Transformation of mechanically loaded Ge(111) surface

S. N. Zhurkov, V. E. Korsukov, A. S. Luk'yanenko, B. A. Obidov, V. N. Svetlov, and A. P. Smirnov
A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

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Scanning tunneling microscopy reveals that the degradation of a Ge(111) surface in a mechanical force field increases as time elapses. The degradation is reversible when the load is removed.

Scanning tunneling microscopy makes it possible to learn about the nature of, and the physical mechanisms for, damage processes at the nanometer level, on the basis of the profiles of the surfaces formed as a result of the damage.[1] More informative, in our opinion, is direct observation of the processes at the free surface of a loaded sample. The features of the atomic dynamics of surfaces[2] and direct experimental evidence of intense damage to a deformed Ge(111) surface[3] indicate that the surface is the nucleating region for the damage to the entire sample.

Germanium samples were cut from a single-crystal starting material (99.99%) as circular plates 25 mm in diameter and 0.2 mm thick. Their surfaces were polished mechanically and then chemically. The orientation was monitored by x-ray diffraction; the deviations did not exceed 1°. The chemical composition was monitored by Auger-electron spectroscopy. A layer-by-layer analysis after the experiments revealed that the oxide layer was no more than 15 Å thick. Experiments were carried out in air with the help of the scanning tunneling profilometer described in Ref. 4. The experimental layout is shown in Fig. 1. An isotropic planar-stress state at the surface was arranged by placing the sample on a supporting ring 20 mm in diameter and by pressing a plunger down on it. The plunger, which weighed 67 g, had a contact of annular profile 10 mm in diameter. A given load P was applied to the plunger. In this ring-to-ring method for loading a thin plate (the membrane case), a region of isotropic tension was formed at the middle of the plate. The magnitude of this tension could be calculated.[5] A tip was brought up to the region of maximum tension in order to create a tunneling contact (Fig. 1) Profiles of a diffraction grating of known period were recorded at various stages in the experiment in order to monitor the state of the tip.

Figure 2 shows the results of one series of experiments. The topograms are arranged in order of increasing load. Shown here are some typical 2×1-μm^2 areas; the scanning was carried out over a larger area. The topogram in Fig. 2(a) corresponds to the original surface of the sample, squeezed by the weight of the plunger ($\sigma = 0.6$ kgf/mm^2). The original surface was observed for an hour; essentially no changes in it were observed. This result is evidence, in particular, that the strong electric field in the tunneling gap and the oxidation processes which are occurring are not important in this case. The scale dimensions of the irregularities in Fig. 2(a) are 50 nm vertically and 500 nm horizontally. Increasing the load to $\sigma = 3.6$ kgf/mm^2 smoothes out the large-scale structure and gives rise to a random "ripple" with a vertical scale dimen-

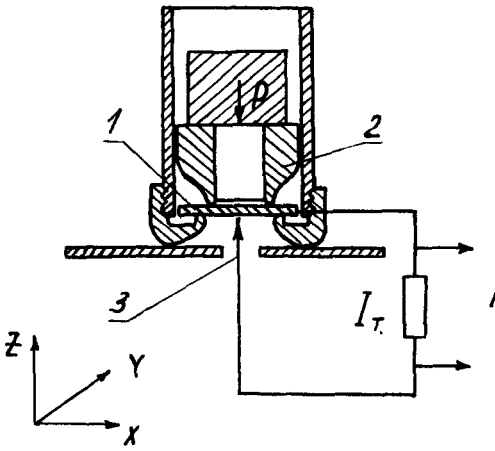

FIG. 1. Experiment layout. *1*—Sample; *2*—plunger; *3*—tip with tunneling-current (I_T) circuit.

sion from 1 to 10 nm and a horizontal scale dimension of 20 nm. This is a critical load in the sense that a slight further increase, to 0.4 kgf/mm^2, results in the appearance of isolated large-scale structures; see the wave with a height on the order of 100 nm in Fig. 2(b). Similar isolated structures were subsequently observed repeatedly at the same load. The lifetime of these structures ranged from a few minutes to tens of minutes. After this time, we observe a gradual increase in the amplitude of the ripple to a level on the order of 100 nm over the entire scanned surface, and the ripple

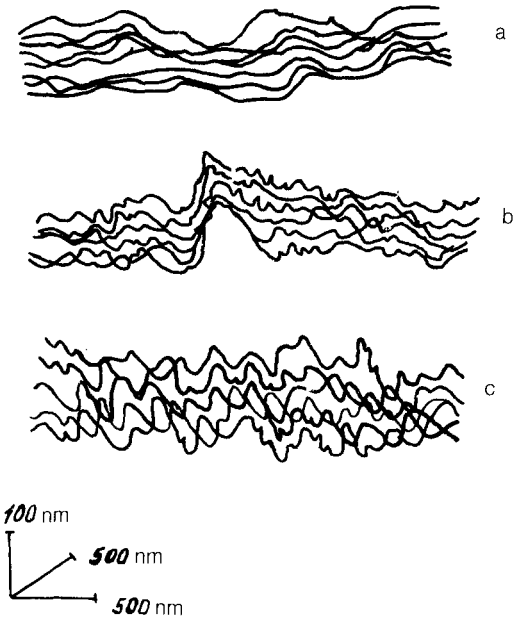

FIG. 2. Topograms of the loaded Ge(111) surface in various states. a—Original surface of sample, loaded by the weight of the plunger ($\sigma = 0.6$ kgf/mm^2); b—an hour after the application of a load $\sigma = 4$ kgf/mm^2; c—2 h after the application of a load $\sigma = 4$ kgf/mm^2.

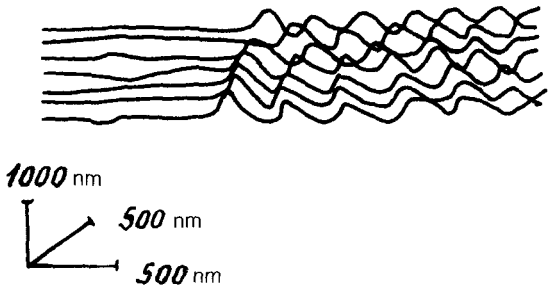

FIG. 3. Quasiordered structure on a stretched Ge(111) surface ($\sigma = 4$ kgf/mm^2).

becomes more random [Fig. 2(c)]. The structure here is of a fractal nature: The profile found at a given resolution turns out to be equally chopped up when the resolution is increased. Further observation for an hour revealed no change in the pattern.

In several cases we observed the appearance of quasiordered structures (Fig. 3), but they became random over a time on the order of a few minutes. When the load was removed, the random ripple disappeared completely in a time on the order of a few minutes and then reappeared when the load was reapplied. This quasielastic behavior of the ripple and its homogeneous nature indicate that we are observing a special form of the response of the Ge(111) surface to the tensile stress, due to the reduced thermodynamic stability of this surface. When the load is subsequently increased, we observe the formation of breaks, cracks, and steps. Removing the load from the sample results in damage to the surface, but the latter heals completely over a time on the order of 10 h, and the original topography reappears [Fig. 2(a)].

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