Transformation of the surface of the amorphous alloy $Fe_{70}Cr_{15}B_{15}$ under stress

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The nucleation and growth of a roughness on the surface of an amorphous iron alloy as the result of the application of a uniaxial tensile stress have been studied by scanning tunneling microscopy. Removal of the load causes the roughness to disappear in a process in which a cracked structure forms at the surface.

The application of tensile stress to a single-crystal Ge (111) surface was studied by scanning tunneling microscopy in Ref. 1. Large-scale dynamic fluctuations of the surface relief, with vertical dimensions of tens to hundreds of nanometers, were observed there, even at low loads (on the order of a few kgf/mm^2). These fluctuations are evidence that this surface has a reduced thermodynamic stability. The dynamic nature of these processes—in particular, their reversibility when the load is removed—force one to assume that they are based on a rapid mass transport as a result of accelerated self-diffusion along the surface in the stress field. On the other hand, one cannot completely rule out the possibility that processes operating in a skin layer of the crystal affect the surface relief. We are thinking of the nucleation of dislocations and their emergence at the surface. We hasten to add that the formation of steps and cracks was observed in our experiments at high loads (on the order of several tens of kgf/mm^2). These are completely definite processes in terms of their scale and nature; in particular, they are irreversible. Since the dynamic fluctuations in question are fairly small in scale and homogeneous, they can be linked with a natural microscopic surface roughness which is amplified by the load. Whatever the case, we would naturally like to observe these surface effects on other materials, in particular, materials with an extremely disordered structure, in order to rule out the crystallographic factor in the problem of interpreting the observed effects.

The mechanical properties of amorphous alloys have been studied quite thoroughly.[2] These materials, which are produced by quenching upon extraction from the melt, have a wide range of elastic deformation, although they are in a state unstable with respect to crystallization. In our experiments, the surface of a strip of foil of the amorphous alloy $Fe_{70}Cr_{15}B_{15}$, 10 mm wide and 0.2 mm thick, was polished mechanically and then washed with acetone and ethyl alcohol. A scanning tunneling and micrograph of the surface profile of the unloaded sample was then recorded. The original surface was observed for half an hour. No significant changes in its profile were found (Fig. 1).

The strip was then lapped around and soldered to a cylindrical drum 12 mm in diameter, so the outer surface of the strip became stretched. The corresponding stress is estimated to be $\sigma \approx 50$ kgf/mm^2. Figure 2 shows a scanning tunneling micrograph of

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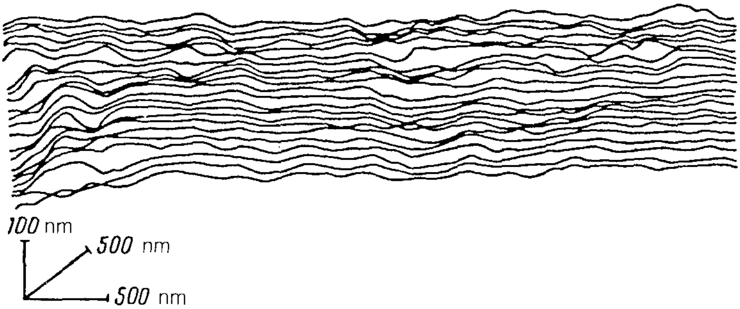

FIG. 1. Profile of the unloaded surface generated by scanning tunneling microscopy.

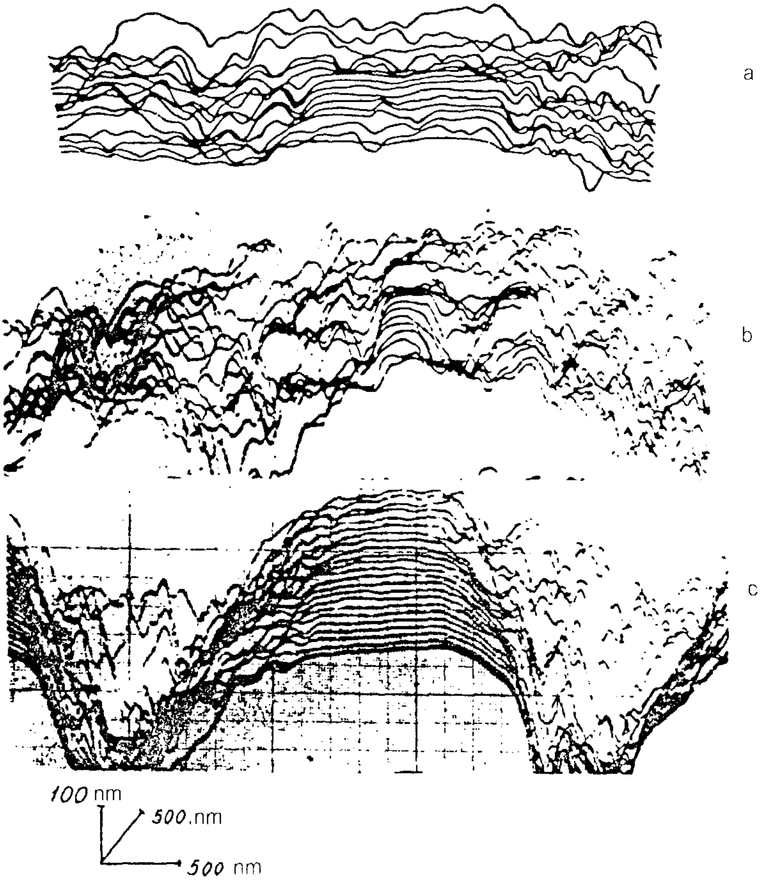

FIG. 2. Transformation of the surface as time elapses after the load is applied. a—10 min; b—120 min; c—140 min.

the surface profile of the stressed sample at various time intervals after the beginning of the loading. Figure 2a shows the pattern 10 min after the loading. We see a significant increase in the roughness over the entire surface, with characteristic vertical dimensions on the order of 10^2–10^3 nm. Against this background, however, we still see some islands with a relatively smooth relief, with horizontal dimensions on the order of 10^3 nm. These smooth regions are covered with a network of pits, whose horizontal and vertical dimensions are both 10^2 nm. Later we see a gradual degradation of the smooth regions, with the result that the surface becomes completely rough (Fig. 2b).

This step in the increase in the surface roughness ("degradation" is a suitable term, in our opinion) lasts several hours and then terminates in an abrupt transformation of the relief. A system of cracklike formations arise. They look like bands with characteristic dimensions of 10^3 nm (both width and depth; Fig. 2c). This system of bands forms a nearly periodic structure over the entire part of the surface which was scanned. The period is 3×10^3 nm; the structure is oriented perpendicular to the loading axis. The time scale of this transformation is on the order of 10 min. Interestingly, the parts of the surface between these bands become just as smooth as the original unstressed surface. This structure then remains stable over many hours of observation, except for the relief "at the bottom" of the cracklike formations. There, the relief undergoes some large-scale transformations under the influence of the load.

At this point we do not have enough information to draw definite conclusions about the nature of this large-scale structure. It can probably be identified with a system of fault bands which have been observed in the same materials by scanning electron microscopy.[3]

On the other hand, the very fact that a system of bands forms means there is a relaxation of stress on the parts of the surface bounded by neighboring bands. We believe that this circumstance is the reason for the sharp decrease in the roughness in these regions.

This interpretation of the observations leads to the conclusion that the mechanical load is the driving force for an accelerated mass transport at the surface, which in turn leads to a growth of the surface roughness. When the load is removed (in our case, when the system of fault bands forms), the roughness disappears. The effect is therefore reversible. This reversibility was observed in Ref. 1, when the stress was actually removed.

We would like to point out that such effects of mechanical stress are seen in the epitaxial growth of films.[4]

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