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Initial stages of nanoindentation in cubic semiconductors

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Abstract: The initial stages of nanoindentation in cubic semiconductors have been studied by atomic force and transmission electron microscopy. The evolution of the indentation using a diamond tip on (001) indium phosphide indicates the presence of three stages involving (a) displacement of the oxide layer, (b) surface deformation to conform the tip shape, and (c) slip causing large volumetric displacements.

It is now evident that alterations of the near-surface crystal structure can be used for growth of semiconductor nanostructures at specific surface sites. Atomic force microscope and nanoindentation tips have recently been used to produce surface patterns in order to control the site nucleation of quantum dots.[1] The patterns were created by shallow indentation of small pits on the semiconductor surface, which resulted in mechanical deformation of the semiconductor with the introduction of dislocations.[2] We have found three initial indentation stages. First, we observe the displacement of the oxide layer that is typically present on semiconductor surfaces that have been exposed to air.[3] The displacement produces an increase in the contact area between the indentation tip and affects the stress-strain curve. Second, when the advancing tip encounters the semiconductor crystal, the latter accommodates the shape of the tip by producing displacements at the nanometer scale. The {111} planes slip one by one while the top surface conforms to the tip. The glide occurs simultaneously on the four slip planes, creating a deformed volume with the shape of an inverted pyramid. This volume contains a high density of slip planes, and the top of the inverted pyramid coincides with the surface region displaced by the tip. Third, when the total stress exceeds a certain value, similar to the measured bulk yield stress of the material, a sudden slip process occurs which leads to a significant displacement of the volume beneath the tip, and the generation of dislocations loops extending deep into the crystal. This stage is often called a *pop-in*.

[1] H. D. Fonseca-Filho, R. Prioli, M. P. Pires, A. S. Lopes, P. L. Souza, and F. A. Ponce. *Atomic force nano-lithography of InP for site control growth of InAs nanostructures.* Appl. Phys. Lett. **90**, 013117 (2007).
[2] H. D. Fonseca-Filho, R. Prioli, M. P. Pires, A. S. Lopes, P. L. Souza, and F. A. Ponce. *Growth of InAs nanostructures on InP using atomic-force nanolithography.* Appl. Phys. A **89**, 945 (2007).
[3] C. M. Almeida, R. Prioli, and F. A. Ponce. *Effect of native oxide mechanical deformation on InP nanoindentation.* J. Appl. Phys. **104**, 113509 (2008).