3D Stress State of Buried Quantum Dots Determined by Dark-Field Electron Holography and Finite-Element Modeling

N. Cherkashin[1], S. Reboh[1], A. Claverie[1], V.V. Chaldyshev[2], and M.J. Hÿtch[1]

[1]CEMES, CNRS and Université de Toulouse, 29 rue J. Marvig, 31055 Toulouse, France
[2]Ioffe Physico-Technical Institute of the RAS, 194021, St Petersburg, Russia

Dark-field electron holography (DFEH) is a new technique for measuring strain at the nanoscale to high precision and for wide fields of view [1]. A diffracted beam emanating from an unstrained region of the sample (the reference area) and from a strained region of the crystal (the measurement area) are interfered with the aid of a biprism to form a hologram. The phase of the hologram encodes the information concerning the strain [2]. The technique has been used for a wide range of applications, notably semiconductor devices and thin films.

The samples under observation are, however, 3-dimensional in nature and the strain field is not uniform over the thickness of the foil. Furthermore, no *a priori* distinction can be made between local lattice parameter changes from compositional variations and mechanical strain. It is therefore essential to compare experimental measurements with computer modeling in order to determine the 3D structures in detail.

Here we present results of the study of In(Ga)As quantum dots embedded in a GaAs matrix. Experimental strain maps will be compared with predictions from finite element modeling (Figure 1). We will show how the compositional variations within the quantum dots can be determined along with the 3D stress and strain distributions in and around the dots (Figure 2).

TEM specimens were prepared by a combination of Tripod mechanical polishing and ion-beam thinning. Holography experiments were carried out on the SACTEM-Toulouse, a Tecnai F20 (FEI) operating at 200 kV in Lorentz mode, equipped with an image aberration corrector (CEOS) and rotatable biprism (FEI) [3]. Dark-field holograms were analysed using HoloDark 1.0 (HREM Research Inc.) a plug-in for DigitalMicrograph (Gatan). Finite element method calculations were carried out using COMSOL 3.5.

References

[1] M.J. Hÿtch et al., Nature 453 (2008) 1086.
[2] M.J. Hÿtch et al., Ultramicroscopy 111 (2011) 1328.
[3] F. Houdellier et al., Advances in Imaging and Electron Physics, 153 (2008) 6:1.
[4] This work was supported by the CNRS and the Russian Foundation for Basic Research via PICS 5577 program and the French National Agency for Research (ANR) in the frame of its program in Nanosciences and Nanotechnologies (HD STRAIN Project No. ANR-08-NANO-0 32).

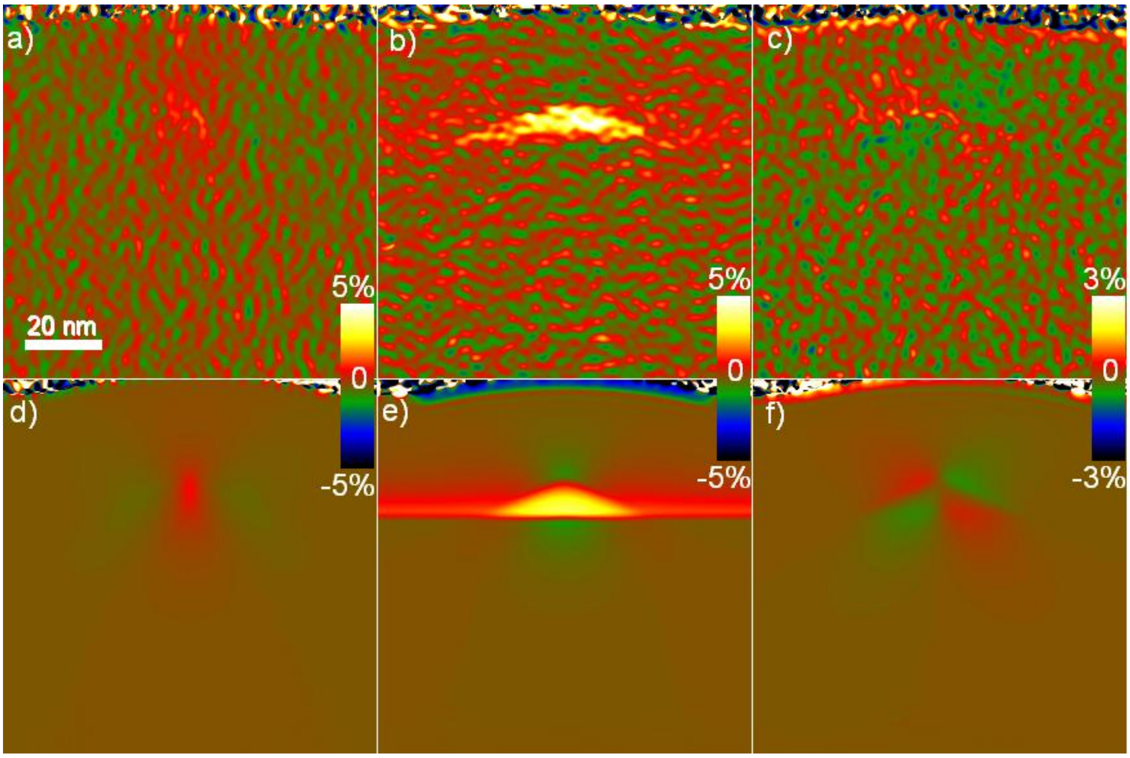

FIG. 1. Measurements of the strain relative to GaAs lattice obtained by dark-field electron holography (a), (b), (c) and by geometric phase analysis of the image generated by FEM (d), (e), (f) of the In(Ga)As QD almost totally embedded within a TEM lamella: (a), (d) in-plane strain, $\varepsilon_{xx}{}^{GaAs}$; (b),(e) out-of-plane strain, $\varepsilon_{zz}{}^{GaAs}$; (c), (f) shear strain, $\varepsilon_{xz}{}^{GaAs}$.

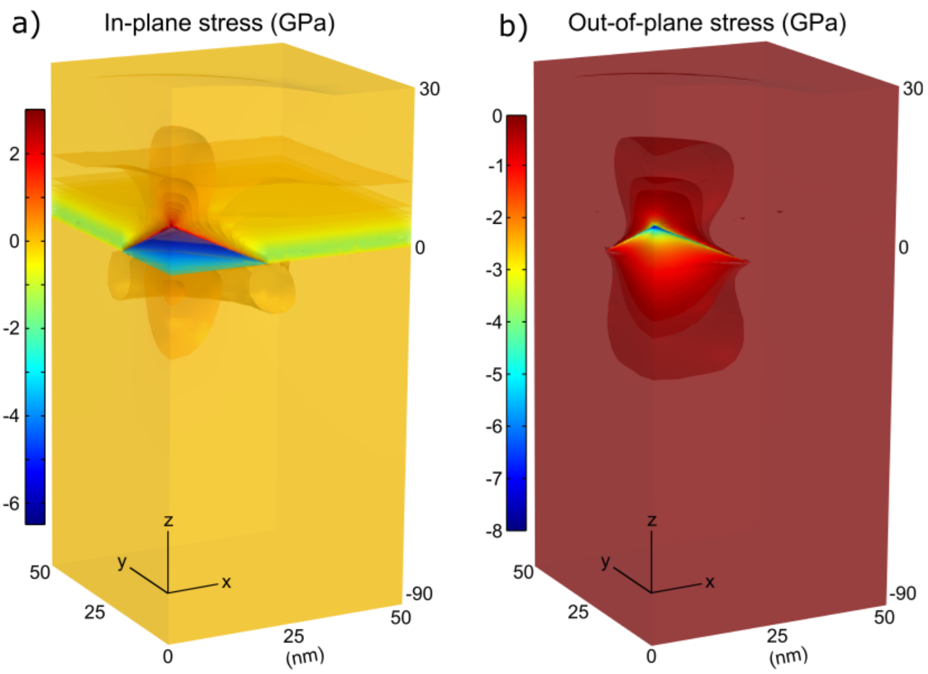

FIG. 2. 3D stress distributions modeled by finite-element method (FEM): (a) in-plane stresses; (b) out-of-plane stresses.