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Strain analysis of buried AlAs/oxide stressor layers by dark field holography

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Buried oxide stressor layers allow for site-controlled quantum dot (QD) growth, important, e.g., for single-photon emitters (SPE). The stressor is formed by partially oxidizing an AlAs layer beneath a GaAs layer. A locally varying strain field results from the length difference of Al-O and Al-As bonds which modulates the surface free energy of the GaAs (001) surface and thereby controls the QD-growth. This technique enables comparably thick buffer layers >100 nm between the buried stressor and the QD growth plane which enables growth of high quality QD for optical applications [1]. We used dark field holography (DFH) [2] in Lorentz mode to directly resolve the strain distribution within the layer structure over a large field of view. In DFH one interferes the image of the strained material on one side of the biprism with that of the unstrained bulk material on the other side. With the uniform thick specimen the strain gradient of the geometric phase can be directly obtained from the phase [3].

For specimen preparation focused ion beam (FIB, FEI Helios Nanolab 600) etching was used to fabricate an electron-transparent specimen (thickness of 100 to 200 nm) over the whole length of the mesa. Images were recorded by FEI Titan Berlin Holography Special 300 kV TEM at the TU Berlin equipped with a double biprism setup to reduce Fresnel fringes in the hologram.

The examined specimen was a rectangular mesa test structure with a buried oxidized AlAs layer [4]. Its layer sequence from substrate to surface comprises the stressor structure made of partially oxidized AlAs, a GaAs spacer layer, an InGaAs layer, and final capping layers. The stressor structure consists of a sandwich of $Al_{0.9}Ga_{0.1}As/AlAs/Al_{0.9}Ga_{0.1}As$ which was laterally oxidized from the mesa edges by water vapor [5] forming an oxide aperture (figure 1a). Upon oxidization, a volume reduction of the oxidized layer region takes place [4]. Figure 1b shows a cross section of the layer structure under bright field TEM conditions. The bright contrast region corresponds to the oxidized part of the AlAs layer. As revealed by Fourier transformation the oxidized region contained polycrystalline □-Al_2O_3 with a corresponding lattice constant of 7.93 Å (figure 1d). Interestingly, a separate oxide region was found at the tip of the oxide layer (figure 1c). This region shows less well defined contours and might have been evolved during overgrowth of the mesa structure.

Figure 2 shows the strain distributions along the growth direction (ε_{zz}) and along the in-plane direction (ε_{yy}) as obtained from DFHs of $(1\underline{1}\underline{1})$ and $(\underline{1}1\underline{1})$. In all four subimages strain-free regions of the GaAs substrate were used for the interference in DFH which allowed for quantification of the strain components. Figure 2a reveals an area of compressive strain in growth direction directly above the opening of the oxidization front. Correspondingly, the in-plane component (figure 2b) shows tensile character in the same area. Above the oxidized layer a slight shear component (figure 2c) and a strong rotation (figure 2d) of the matrix were observed.

Our analysis reveals strong strain fields induced from the stressor layer which agrees well with calculations of the strain distribution based on continuum elastic models [4]. Most notably, local tensile surface strains of up to 1% can be created by such stressors which is important for selective QD nucleation above the mesa center.

1. A. Strittmatter et al., Applied Physics Letters 100 (2012) 093111.
2. M. Hÿtch et al., Nature 453 (2008) 1086.
3. M. Hÿtch et al., Journal of Physics: Conference Series 241 (2010) 012027.
4. A. Strittmatter et al., physica status solidi (a) 209 (2012) 2411.
5. K. D. Choquette et al., IEEE Journal of Selected Topics in Quantum Electronics 3 (1997) 916.
6. R. D. Twesten et al., Applied Physics Letters 69 (1996) 19.
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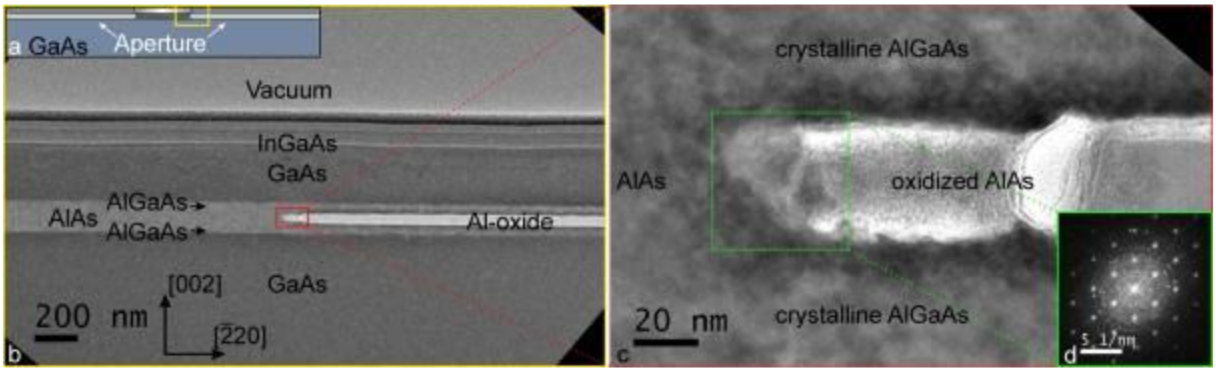

Figure 1. a) Sketch of the cross section of the mesa. b) Bright field conventional TEM overview of the middle of the mesa showing the right edge of the aperture. The oxidized layer is visible as bright contrast in the AlGaAs layer sandwich. c) Shows the oxidization front in the AlAs layer at higher magnification, d) the Fourier transformation of the marked area. The polycrystalline □-Al_2O_3 rings are visible as well as strong AlAs reflections.

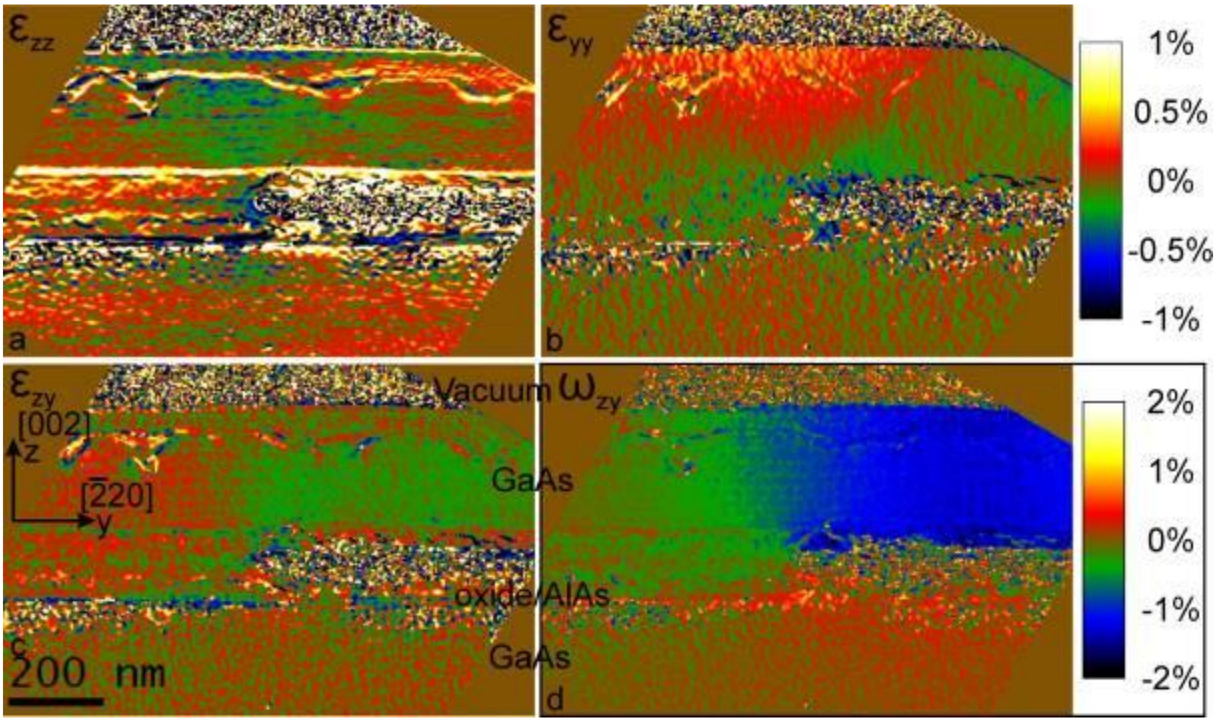

Figure 2. Local strain of the lattice in percent with a) strain of in growth direction ε_{zz} (002), b) strain in lattice direction ε_{yy} ($\bar{2}$20), c) shear component ε_{zy} and d) the rotation component ω_{zy}. The color in a), b) and c) corresponds to the upper scale bar, the lower scale bar corresponds to d).