Side-controlled quantum dot (QD) growth is a promising solution for single-photon sources. The nucleation of self-organized QDs can be influenced by a buried oxide stressor formed by a partially oxidized AlAs layer beneath a GaAs layer [1]. The length differences of Al-O and Al-As bonds form a locally varying strain field modifying the free energy of the GaAs (001) surface. We used dark field electron holography (DFH) [2] in Lorentz mode to directly measure the strain distribution over a large field of view. The resulting geometric phase contains the strain gradient which can be directly obtained for uniform thick specimen [3].

For specimen preparation, focused ion beam (FIB, FEI Helios Nanolab 600) etching was used to fabricate a specimen with a smooth thickness of about (110 ± 10) nm. Images were recorded by FEI Titan Berlin Holography Special 300 kV TEM at the TU Berlin.

The examined specimen was a linear wedge-shaped mesa test structure with a buried oxidized AlAs layer [4]. The layer sequence from substrate to the surface comprises only the stressor structure of partially oxidized AlAs and a GaAs spacer layer. 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 (1.08 ± 0.02) µm wide (fig. 1). The bright contrast region on both sides corresponds to the oxidized part of the AlAs layer.

Figure 3 shows the strain distributions as obtained from DFHs of (111) and (111). In all four images, strain-free GaAs substrate region below the AlAs were used to quantify the strain in the corresponding maps. Directly above the edges of the oxidization front symmetric to the opening, compressive strain in growth direction ($\varepsilon_{zz}$) (fig. 3a) and tensile strain in-plane ($\varepsilon_{yy}$) (fig. 3b) in the same area is detectable. The shear component (fig. 3c) is not detectable and the strong rotation (fig. 3d) exhibits an anti symmetrical behavior.

The behavior of our analysis corresponds well with calculated strain fields based on continuum elastic models [4] in the area of the aperture opening (fig. 2). The measured local tensile surface strain up to 0.5 % is by a factor of 4 smaller than the calculated one. This results from specimen relaxation, preparation artifacts and averaging due to the specimen tilt of about 15°. Such tensile surface strain can influence the QD nucleation in the aperture area.

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References:
Fig. 1: a) Sketch of linear wedge-shaped mesa with position of TEM lamella, b) bright field conventional TEM overview of the mesa showing the edges of the aperture. The oxidized layer is visible as bright contrast in the AlGaAs layer sandwich.

Fig. 2: Calculated line scans of surface strains $\varepsilon_{xx} + \varepsilon_{yy}$ across a circular mesa of 3 µm diameter exhibiting different aperture sizes; the horizontal line marks unstrained GaAs [4]. The magenta colored line is the central moving average of nine data points (27 nm width) from line scan in Figure 2b increased by a factor of 4 for better comparison.

Fig. 3: Local strain of the lattice in percent with a) strain of in growth direction $\varepsilon_{zz}$ (002), b) strain in lattice direction $\varepsilon_{yy}$ (220), c) shear component $\varepsilon_{zy}$, and d) the rotation component $\omega_{zy}$. Scale bar corresponding to the color in a)-d).