NBED investigations of coaxial (Al,In,Ga)As nanowires

Alina Friemel[1], Dr. Tore Niermann[1], Dr. Laura Niermann[1], Dr. Paul Schmiedeke[2], Dr. Gregor Koblmüller[2], Prof. Dr. Michael Lehmann[1]

[1]Technische Universität Berlin, Berlin, Germany, [2]Technische Universität München, Munic, Germany

Background incl. aims

GaAs-based semiconductor nanowire (NW) lasers exhibit many advantageous properties for telecom-band data communications and sensing applications, like e.g. their ultra-compact size and their compatibility to Si-based photonics. In comparison to other III-V semiconductors, GaAs allows a fairly mature Au-free NW growth on Si. However, within the coaxially grown multiple quantum wells (MQW) the strain resulting from lattice mismatch accumulates during the growth. This problem can be mitigated by the introduction of an InAlGaAs buffer layer in between the GaAs core and the active region of the MQW-stack [1]. For process control and further engineering of NW laser structures, the strain in the resulting devices must be monitored. We report on strain investigation by means nanobeam electron diffraction (NBED) for such structures.

Methods

GaAs NW cores were grown via a vapor-liquid-solid growth mechanism on pre-patterned Si substrates along the [111] direction. Subsequently, an In0.3Al0.3Ga0.4As buffer layer, followed by an In0.3Ga0.7As QW, an In0.23Al0.23Ga0.54As barrier layer, and a GaAs cap layer were grown coaxially onto the side walls of the GaAs core. A cross-sectional lamella was prepared from the NW using focused ion beams.

HAADF, EDX and eventually NBED measurements were performed using a JEOL GrandArmF2 microscope, operated at 300kV. The NBED data was recorded using the Quantum Detector's Merlin detector.

Results

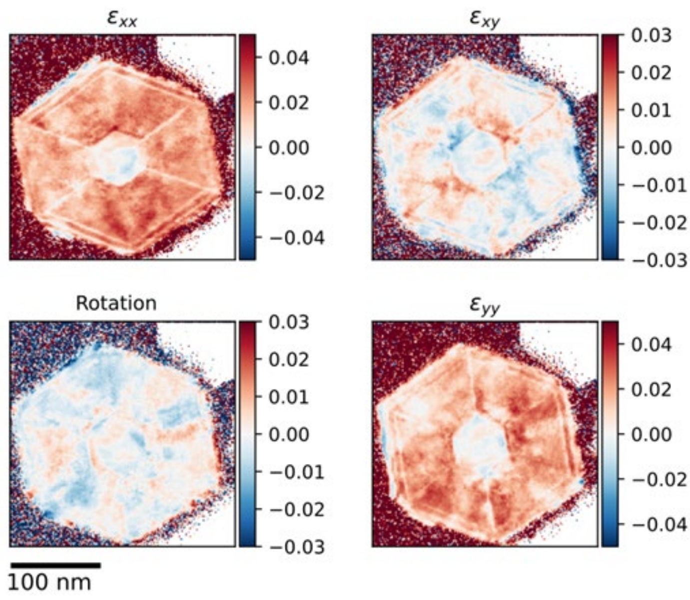
We applied a custom algorithm to determine the base vectors for the reciprocal lattice visible in the individual diffraction patterns for each scan point. Starting with an initial guess for the base vectors and the origin of the pattern, the algorithm consists of several steps: (i) for each lattice point spawned by the base vectors, a sub-region of the diffraction pattern is extracted; (ii) within each subregion the position of the reflection is determined with sub-pixel projection; (iii) a new set of base vectors is calculated by weighted linear regression, using the inverse precision from step (ii) as weights; (iv) unless the resulting set of base vectors has converged to a predefined precision, the algorithm is repeated from step (i) again. From the resulting base vectors of the reciprocal lattice observable in the diffraction patterns, the strain components can be calculated in reference to the GaAs core.

In comparison of the resulting strain data with finite element calculations short-scaled variations of the determined strain components are observed in areas where smooth strain components are expected. We attribute these variations to dynamical diffraction effects stemming from small specimen inhomogeneities created during preparation, for example from thickness variations. We discuss the influence of experimental and evaluation parameters, like the convergence angle or
the method used to determine the reflection position, on the precision of the obtained strain components.

Conclusion

NBED generally allows the evaluation of strain data with nanometer precision. However, the resulting strain maps suffer from dynamical diffraction effects, which can be further mitigated by optimized experimental parameters and optimized evaluation procedures.

Graphic:



Keywords:

4D-STEM, NBED, Strain

Reference:

[1] P. Schmiedeke, A. Thurn, S. Matich, M. Döblinger, J. J. Finley, G. Koblmüller; Appl. Phys. Lett. 118, 221103 (2021)