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Experiment Report Form

ESRF	**Experiment title:** Correlation of electrical and structural parameters of single GaAs nanowires grown by MBE onto silicon substrate	**Experiment number**: SI2480
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Names and affiliations of applicants (* indicates experimentalists):

BUSSONE Genziana (1,2), GEELHAAR Lutz (3), BIERMANNS Andreas (1), DAVYDOK Anton (1), PIETSCH Ullrich (1)

(1) Universität G H Siegen Fachbereich 7 -Physik D - 57068 SIEGEN

(2) ESRF 6 rue Jules Horowitz B.P 220 F - 38043 GRENOBLE Cedex

(3) Paul-Drude-Institut für Festkörperelektronik Hausvogteiplatz 5-7 D - 10117 BERLIN

Report title: Correlation of electrical and structural parameters of single GaAs nanowires grown by MBE onto silicon substrate.

Report Summary:

Semiconductor nanowires are possible candidates for future electronic application. Most of their properties strongly depend on structural parameters such as phase purity or lattice strain. Here we report on the correlation between electrical properties of single GaAs nanowires (NWs) grown by MBE on a highly doped silicon substrate (111) and their particular structural properties. Various single NWs, freestanding in their as-grown geometry onto the substrate, were measured using micromanipulators in a Focused Ion Beam (FIB) system at Siegen University (Germany), providing individual Current-Voltage characteristics. In order to understand the origin of the different electrical responses, the structure of the same nanowires were then investigated using a nano-focused beam of synchrotron radiation at beamline ID01 at the ESRF in Grenoble (France). In particular, the crystalline structure of different single nanowires, i.e. the presence of twinned planes and the phase composition, have been investigated.

Experimental details:

For this study, (111)-oriented GaAs nanowires with diameters of 100nm and height of 1µm have been grown by molecular beam epitaxy at the Paul-Drude Institut für Festkörperelektronik, Berlin. NWs grown using this growth mechanism usually show a random crystallographic composition, with extended zinc-blende and wurtzite type segments arranged along the growth axis. In addition, stacking-faults are frequently observed along the NWs, and the structure of individual wires fluctuates randomly, with direct impact on their electrical and optical properties [1]. However, the correlation of electrical and structural properties is challenging. In order to address a single NW and to probe it with the nanofocused X-ray beam, the position of the wires was controlled by the use of a SiO_2 mask, with apertures in correspondence to the required growth positions. Figure 1 (left) shows a scanning electron micrograph of an array of the investigated NWs with pitch of 2µm between neighboring NWs. As visible, NWs didn’t grow in all the defined positions. Instead, islands-type crystallites are grown at many of the predefined places. Using a focussed ion beam system, several of these parasitic islands in the array were removed, in order to get the signal only from the single selected wire.

The electrical characterization of the individual, as-grown NWs was performed using micrometer-sized tungsten needles with a mean radius of 0.1 microns, driven by two micromanipulators to contact the substrate and the top of the nanowire. Figure 1 (right) shows current-voltage curves for the selected NWs, with different electrical responses. According to current understanding, such differences can be caused by different crystalline structure of the single nanoobjects, which was subsequently probed using nanodiffraction.

In order to identify the nanowires previously characterized in the FIB chamber, Pt-markers (easily detectable with an optical microscope) were deposited on the sample surface with the Focused Ion Beam. In addition, through the FIB, the arrangement of the nanowires was carefully observed under the SEM, and a mapping of the sample surface was performed trough the K-mapping method at ID01 [2]. That allowed to find the same NWs, already electrically characterized.

The nanodiffraction experiment was performed with the nanofocused X-ray beam set-up of beamline ID01, with an energy of 7.79 keV. The X-ray beam was focused with the available Fresnel Zone Plate setup down to a focal size of 400x700nm², thus providing the required spatial resolution. Data were collected by the 2-dimensional pixel detector MAXIPIX, which allows the collection of 3 dimensional intensity distributions in reciprocal space.

Reciprocal space maps of the structurally sensitive asymmetric zinc-blende (331) and (422) reflection as well as the wurtzite (10-15) reflection were collected for the NWs under investigation in order to probe their phase structure. Those two particular asymmetric ZB reflections allowed to detect the presence of twinned planes inside the NW.

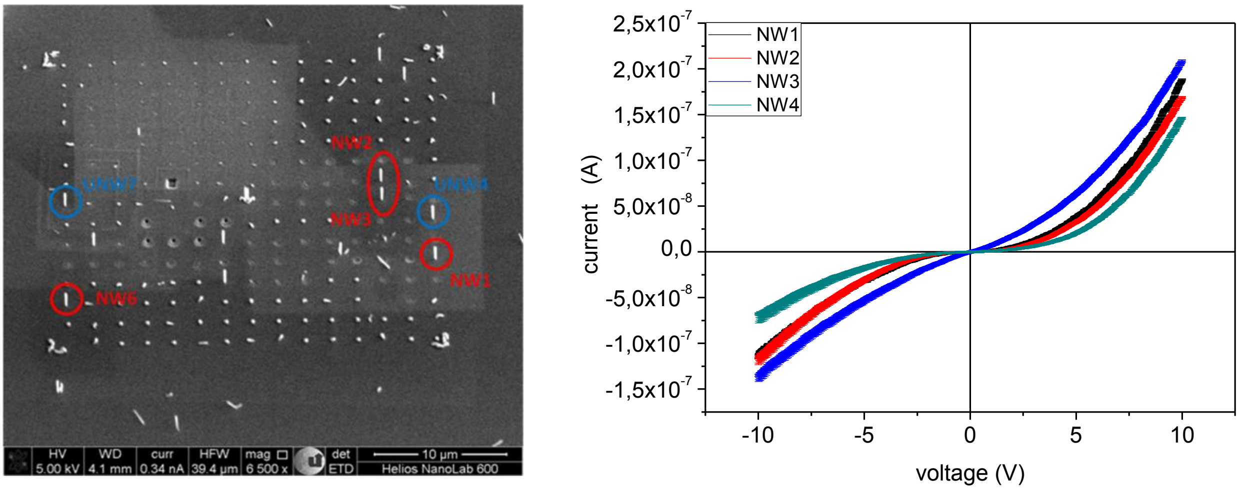

Figure 1 On the left, one of the NWs array investigated. The circles indicate the investigated NWs, they are red and blue to indicate respectively the NWs contacted inside the FIB chamber and a few untouched NWs, needed for a comparison. Other nanowires and several islands are visible. On the right, Current-Voltage curves collected for four different nanowires, located within a region having a diameter of few decines of micrometers.

Exemplarily, figure 2 (left) shows a slice of the 3D reciprocal space map of a single NW around the zinc-blende (331) reflection. Finite size oscillations are visible along both vertical and horizontal components of the momentum transfer, containing information of the height and diameter of the probed zinc-blende segments. By simulating the diffracted intensity for one or more segments of pure ZB, the experimental data can be modeled to obtain the size of the diffracting elements. In figure 2 (right), the fringes along qz for two different NWs are reported (respectively for NW3 with the highest maximum current, in blue, and NW4 with the lowest maximum current, in red).The lenght of the diffracting segment can be estimated from the periodicity of the fringes. It is (210±10) nm for NW3 and (75±10) nm for NW4. The other segments within the NWs have respectively similar lenghts. The combination of diffraction patterns from different Bragg reflections will allow to quantify the complete structural composition of the different NWs and to correlate their structure with the electrical measurement. The data analysis is still in progress, however, several information were extrapolated. In general, the inspected NWs are composed by several zinc-blende segments, alternating between the two possible ZB orientations. The size and number of this extended segments fluctuates among different NWs. However, no extended segments of wurtzite structure are observed, which agrees with the expected structural composition at the used growth conditions. According to the first estimations, the NW with the lowest maximum current has shorter segments within its structure, thus leading to a bigger number of interfaces, whose presence influences the current flow. A more detailed analysis is in progress.

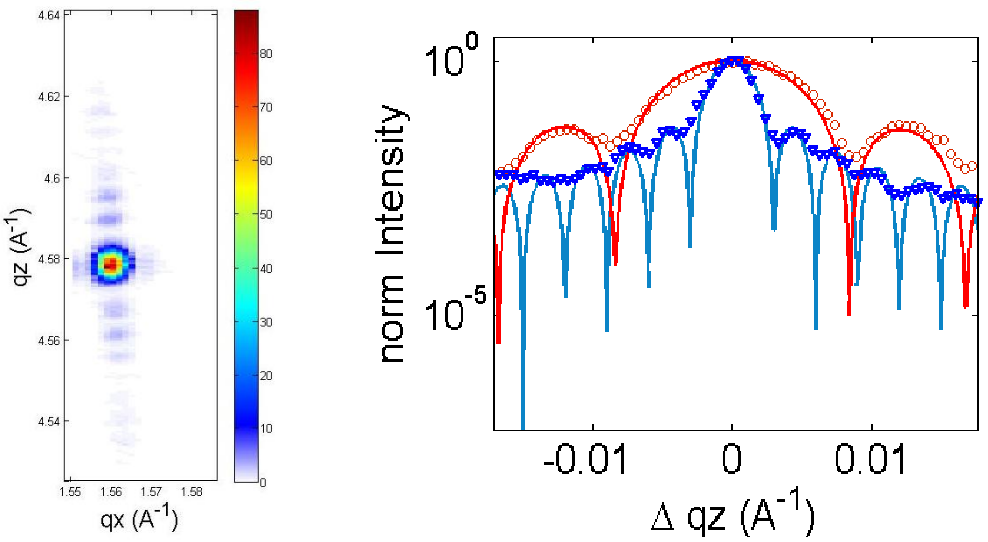

Figure 2 On the left, 2D reciprocal space maps for reflection (331). One of the detected peak, with the finite-size oscillation fringes is well visible. On the right, the data of the normalized intensity profile in function of Δqz (circular and triangular markers) and the modeled curve for two different NWs.

[1] Yang et al, J. Appl. Phys., 2002, 91 (1), 420(7)
[2] Experimental Report SI2302, A. Biermanns, A. Davydok, G. Bussone, U. Pietsch, 2011