Multiphysics 3D study of CS nano-structures via SPM

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While Silicon (Si) undoubtedly dominates the semiconductor market, compound semiconductors (CS) such as GaAs, InSb, GaN are becoming very important as they can offer solutions beyond capabilities of Si, in particular as light sources for data communications and lighting, and platforms for efficient high frequency and power electronics. The combination of CS with Si production technology can provide both cost-efficient manufacturing and unique functional capabilities. Moreover, the diversity of CS materials allows creating complex structures, such as multi-quantum wells (MQW), quantum dots (QDs) and nanowires (NW), as single layers or multilayer stacks. However, the implementation of CS technology presents serious problems, including propagation of defects originating at the interfaces of different materials, inhomogeneous strain, and the need to match often incompatible growth conditions of different layers. The best current methodology to image these nanoscale defects, the cross-sectional TEM, while imaging local strain, usually explores only small areas of the sample, that can not be fully representative, and is not capable of measuring mechanical, thermal and electronic properties of the CS structures.

Here we present a novel methodology for the 3D mapping of CS nanostructures, which combines the Beam Exit Cross-Sectional Polishing (BEXP™) with the material sensitive mapping via Scanning Probe Microscopies (SPM) to study the samples 3D physical properties with nano-scale resolution [1]. The BEXP™ uses Ar-ion beams to cut the sample at a shallow angle of 3-7 degrees with respect to the top surface, resulting in a flat section with roughness on the order of 1 nm, convenient for the SPM probe studies (Fig 1.a). The sample nanomechanical maps are produced via Ultrasonic Force Microscopy (UFM), which combines the Atomic Force Microscopy (AFM) with the ultrasonic excitation of the vertical vibrations of the sample, and therefore maps the sample local stiffness [2]. The analysis of the electrical and piezoelectric properties are performed by combining the AFM with the electrical excitation while monitoring the current flow to measure the electron transport, or the electrostatic forces acting on the cantilever to map the Contact Potential Difference (CPD) via Kelvin Probe Force Microscopy (KPFM) or the piezoelectric constants via Piezoelectric Force Microscopy (PFM), with the latter revealing the otherwise invisible crystalline orientation in piezoactive materials. All these provide key information on the materials composition, band structure, and doping, all of these being essential for the optoelectronic performance of CS devices [3].

Here we have studied the morphology of GaAs/AlGaAs MQW structures using the nanomechancial UFM and the local CPD by the KPFM images. We clearly observe the disruption of the MQW regular structrure and changes in the CPD in presence of Antiphase Domains (APD) (Fig 1.e-h) that can effectively create electrical "short" of the MQW structure. To study GaN NWs grown on a Si substrate we add a preliminar step in the sample preparation, embedding the NWs in spin-on-glass (SOG) to create an uniform layer directly suitable for the BEXP™ processing. The UFM and KPFM maps show clear contrast across the NWs, NW/SOG and NW/Si interfaces allowing us to identify the different materials and structures, whereas the PFM images visualised different piezoelectric domains inside the NWs corresponding with diverse polarities of the crystal growth (Fig 1.b-d) that canot be observed otherwise.

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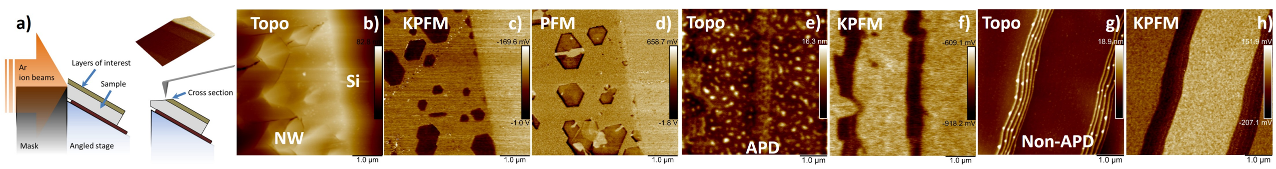

FIG 1. a) Principle of the BEXP™ nano-X-sectioning with 3D rendering of the sample cut. b) topography image of sectioned GaN NWs embed in SOG on Si. c) typical contact potential difference KPFM map of the GaN-Si at the NW-Si interface. d) PFM phase map corresponding with the d) area. e), g) topography and f), h) contact potential of the iii-v MQW structures grown on Si. e), f) with and g), h) without APD.

References

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