Piezoresponse force microscopy on semiconductor III-Nitride bulk, thin film and single nanowires

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Coupling between piezoelectric and semiconducting properties of piezoelectric semiconductor nanowires such as wurtzite ZnO or GaN has been proposed as a promising feature that can integrate a small mechanical movement to function electronic/photonic nano-devices [1]. These nano-objects have also been used for generating electrical energy from mechanical energy from tiny vibrations in our environments [2]. For fundamental studies and applications, it is crucial to access the electromechanical properties of these nanowires. Scanning probe microscopy (SPM) is considered as one of the most powerful tools; besides challenging, that are able to locally probe these properties in nanostructures.

Here, we applied piezoresponse force microscopy (PFM) to explore a reversed piezoelectric effect, in III-Nitride nanowires. It is known that the PFM signal can be strongly influenced by various parameters such as an electrostatic effect induced by a surface potential or surface charges, a non-uniform electric field caused by a nanoscale SPM tip's diameter, a contribution of lateral piezoelectric displacement of the material to a vertical movement of the SPM tip. Our intensive works done on different reference samples; i.e. Periodically Poled Lithium Niobate, Langasite, GaN bulks and GaN thin films, show that those mentioned factors significantly hinder quantitative PFM measurements in both amplitude and phase which directly correspond to the piezoelectric coefficient and the material polarity, respectively. The electrostatic contribution from the surface potential is probed by Kelvin probe force microscopy (KPFM). Its effect is minimized by applying a direct voltage on the substrate during the PFM measurements, by using high spring constant cantilever, or by depositing metallic electrodes on the sample surface. Those electrodes also improve the uniformity of the applied electric field but at the price of a reduced lateral resolution. We show that the vertical and lateral piezoelectric displacement can be observed separately by properly setting the sample configuration.

The studies on these reference samples were used as a general guideline for the PFM measurement of single nanowires i.e. GaN nanowires and GaN/AlN nanowire heterostructures. The vertical and lateral movements detected by the SPM tip are visible when a modulated AC voltage is applied on the nanowires. To be better spatially resolved, the measurements are further performed at the mechanical resonant frequency of the SPM cantilever to enhance the PFM signal. The origin of those detected PFM signals will be discussed.

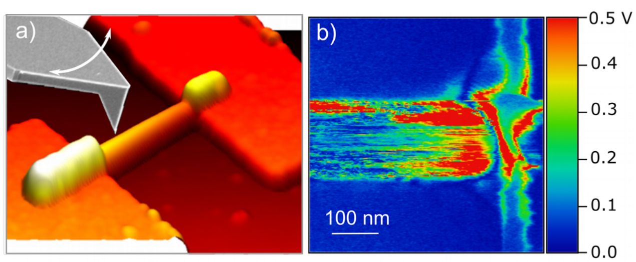

Figure 1 (a) Schematic representation of the PFM measurement on single contacted nanowire. White arrow shows the lateral movement direction of the AFM cantilever during the application of AC voltage. (b) Lateral PFM amplitude showing the mechanical movement along the nanowire axis.

[1] Z. L. Wang, Towards self-powered nanosystems: From nanogenerators to nanopiezotronics, Adv. Funct. Mater. **18**, 3553–3567 (2008)

[2] Z. L. Wang, J. Song, Piezoelectric nanogenerators based on zinc oxide nanowire arrays, Science. **312**, 242–246 (*2006)*