Site-specific in situ electron microscopy of strain engineering of electronic and optoelectronic properties of semiconductor nanostructures

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The understanding of the structure-property relation of individual nanostructures is of critical importance for the advancement of semiconductor technology. The methods of in situ electron microscopy are well suited for characterizing these relationships since the enable site-specific and direct correlation between atomic structure, electronic structure, mechanical behaviour, electrical transport and photoresponse. The results provide information for a basic understanding of the properties of these nanostructures and for tailoring device performances.

By in situ transmission electron microscopy (TEM), a direct correlation between mechanical and charge transport properties was determined for InAs nanowires [1]. Applying uniaxial tensile stress on individual nanowires, strain mapping was performed by using 4D scanning TEM (4D STEM), while electrical measurements were carried out simultaneously. A significant reduction of resistivity and enhanced piezoresistive response of the nanowires, compared to bulk InAs, were observed with increasing strain. Individual GaAs nanowires were also studied using the same in situ TEM approach [2]. Evidence for hole mobility modification by uniaxial strain was found. For bending deformation, the current-voltage (I-V) characteristics of the nanowires change from linear to nonlinear [3]. The nonlinear behaviour increases with strain which can be explained by a strain induced shift of the valence bands. It results in the formation of an energy barrier for charge carrier transport along the nanowire.

For individual GaAs nanowires with build-in radial p-i-n junctions, being equivalent to individual nanoscale solar cells, the photovoltaic properties, i.e., photocurrent and I-V characteristics, were investigated using an in situ scanning tunnelling microscope – scanning electron microscope (STM-SEM) setup [4,5]. A uniaxial tensile strain of 3% resulted in an increase of photocurrent by more than a factor of 4 during near-infrared (NIR) illumination. This increase is attributed to a decrease of 0.2 eV in nanowire bandgap energy, thus reflecting the effect of tensile strain on light absorption.

This talk will show how in situ electron microscopy studies enable a quantitative understanding of the intriguing interplay between atomic structure, electronic structure, charge transport and photocurrent. In addition, it will show how the three dimensional spatial distribution of individual dopants in organic semiconductors can be revealed [6]. It will also discuss crucial aspects of the studies and illustrate the importance of control experiments to ensure that the in situ experiments provide representative information of the correlation between atomic structure and properties.

References:

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Short biography Eva Olsson

Eva Olsson is a full Professor of Experimental Physics and is currently the Head of the Division of Nano and biophysics at the Department of Physics, Chalmers University of Technology. She obtained her PhD degree at Chalmers University of Technology and was thereafter a post doc at IBM T.J. Watson Research Center, Yorktown Heights, New York, USA. She was appointed full professor at The Ångström Laboratory, Uppsala University, followed by an appointment as a full professor at Chalmers University of Technology. She was a JSPS Fellow at University of Tokyo, Japan, in 2017. She is mainly interested in materials for emerging technologies, including catalysis, photovoltaic and quantum devices and her research group focuses on the development of novel characterisation techniques for these materials. Professor Olsson works with electron microscopy including in situ studies and quantitative imaging and spectroscopy. She has been the President of the Nordic Microscopy Society (Scandem) and is presently the Secretary General of the International Federation of Microscopy Societies (IFSM). She is also a member of the Royal Swedish Academy of Sciences.