L-04

QUANTUM DOTS IN THE LIGHT OF SYNCHROTRON RADIATION

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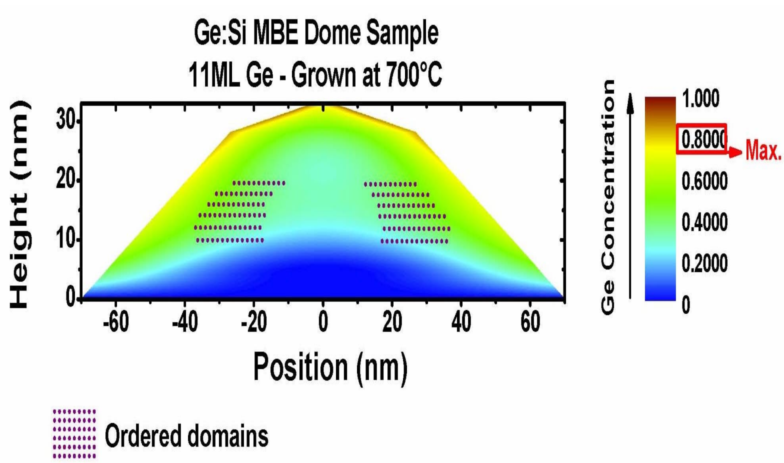
The concept of tuneable material properties under limited dimensions on the nao-metre scale has become a fascinating research topic in recent years. The related quantum confinement occurs in semiconductors, whenever the dimension of the structures become comparable to the deBroglie wavelength of the charge carriers. In semiconductors, this length can amount to hundred times the lattice constant. The most dramatic change is found for 0D confined quantum dots where the electron density of states is restricted to a set of delta functions ("artificial atoms").

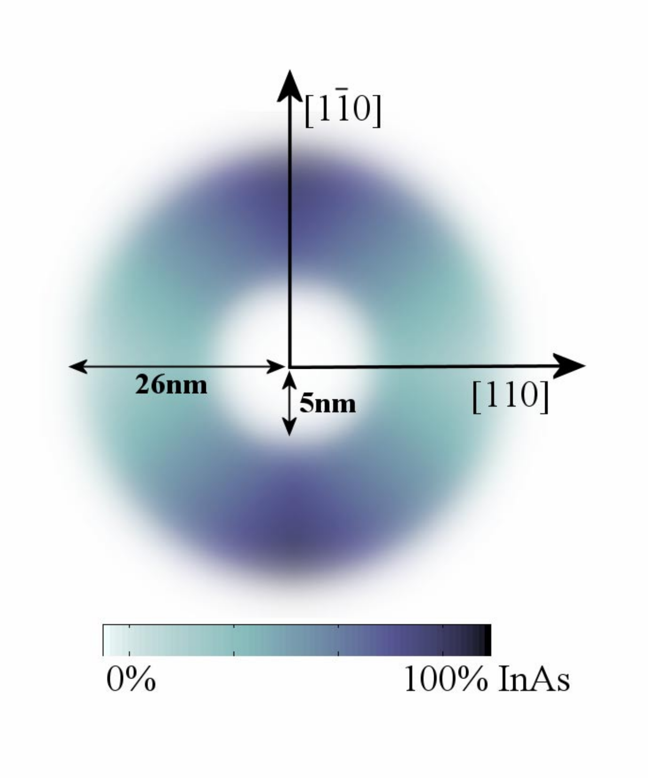
In strained layer hetero-epitaxy of semiconductors, nano-sized islands ("quantum dots: QD") are spontaneously formed after the deposition of only a few monolayers of the dot material on a substrate with a different lattice parameter. Growth temperatures that allow for dislocation-free crystals, often provoke a significant amount of inter-diffusion. Especially in self-organised QD produced by Stranski-Krastanow growth, a sufficient surface mobility of the deposited atoms requires temperatures that make inter-diffusion inevitable. The problems to be overcome in the exploitation of quantum size effects are mainly an understanding of the distortions in the crystals as well as the composition gradients caused by inter-diffusion. Quantum dots grown in self-organization represent a system that is far from thermodynamic equilibrium and whose state is caused by the competing effects of growth kinetics and elastic energy minimization. It is therefore of fundamental interest to resolve the influence of the growth conditions on quantities like the remaining elastic energy on an atomic and mesoscopic scale of the system.

Advanced X-ray diffraction methods using synchrotron radiation are perfectly suited for the characterization of semiconductor nano-structures. We demonstrate how "anomalous dispersion" is combined with grazing incidence diffraction to determine the size, strain and chemical composition in nano-structures, which are the most important parameters for the band structure tuning in these systems.

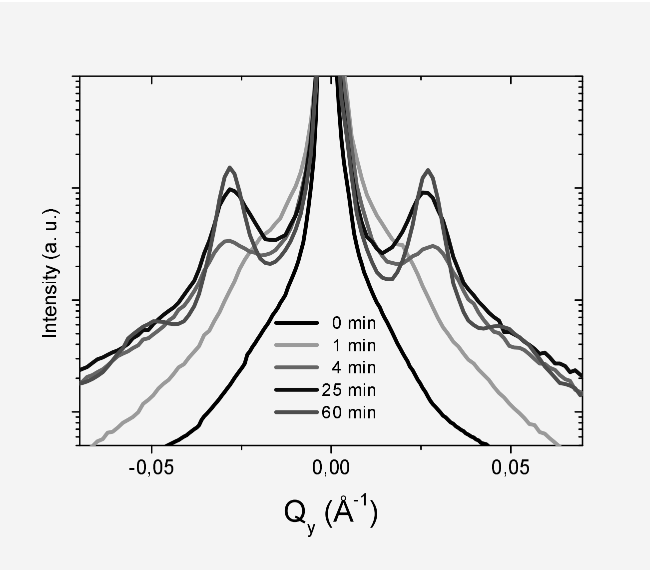
Three examples will be presented:



1) In the system Ge on Si, we show how the 3D chemical composition can be determined within dome-shaped GeSi islands. In addition, from the measurement of "forbidden reflections" the atomic ordering of the GeSi alloy, forming the dots, can be quantified. These results are obtained using the model of Iso-Strain-Scattering for data evaluation.



2) This approach breaks down for InAs islands which form quantum rings after MBE overgrowth with GaAs. From Finite Element Modelling of the experimental intensity maps in reciprocal space close to the (2-20) and (220) surface reflection, we reveal a highly anisotropic In distribution within the rings (see figure). From grazing incidence small angle scattering (GISAXS) the ring morphology is found to be of circular symmetry.



3) Finally, I will show first x-ray in-situ studies of GaSb under ion erosion. GISAXS measurements (see figure) show the evolution of form and lateral correlation of GaSb dots after various sputter times. In the present case (Ar+ energy of 1300 eV) the erosion process is completed after 3 minutes already. The highly ordered and mono-disperse nano-sized islands can now be studied as a function of sputtering energy, time and temperature on various semiconductor single crystals. The results will be used to develop appropriate theoretical models to explain formation and ordering of the dots.