HL 27: Doped Si nanostructures (DS with HL/TT)

Time: Tuesday 9:30–13:00 Location: H 2032

Invited Talk HL 27.1 Tue 9:30 H 2032

Electronic doping of crystalline silicon nanoparticles — •Rui N. Pereira — Walter Schottky Institut and Physik-Department, Technische Universitaet Muenchen, Germany — Department of Physics and I3N, University of Aveiro, 3810-193 Aveiro, Portugal

Crystalline silicon nanoparticles (NPs) have been attracting much research interest due to their remarkable electronic, optical, and chemical properties. Si NPs combine the processing advantages enabled by nanoparticles with the unique features of Si at the nanoscale such as wavelength tunable light emission and multiple exciton generation. The natural abundance of silicon and its dominant role in microelectronics industry may also facilitate the introduction of Si NPs in commercial products such as solar cells and light emitting devices. The essential role played by doping in semiconductor technology has in recent years triggered the study of doping of Si NPs with n- and p-type dopants. In this presentation a review of the current knowledge of doping in Si NPs will be given. Particular focus will be given to NPs synthesized from gas-phase in silane plasmas, with which most of the investigations reported so far have been carried out.

HL 27.2 Tue 10:00 H 2032

Silicon nanocrystal thin films for solution-cast electronics — •Willi Aigner[1], Markus Wiesinger[1], Stanislav Abramov[1], Hartmut Wiggers[2], Rui N. Pereira[1,3], and Martin Stutzmann[1] — [1]Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany — [2]Institute for Combustion and Gasdynamics - Reactive Fluids, Universität Duisburg-Essen, Duisburg, Germany — [3]Institute for Nanostructures, Nanomodelling and Nanofabrication, University of Aveiro, Aveiro, Portugal

In the last years, high-performance thin-film field-effect transistors (FETs) with an active layer of solution-processed semiconductor nanocrystals (NCs) films were demonstrated. However, few studies apply Si NCs, which are environmentally favorable and offer controlled n- and p-type doping. Recently, FETs using intrinsic Si NCs [1], as well as Si NC films doped with an electronic coupling agent [2] have been reported. In this work, we carried out a comprehensive study on the morphology and its influence on the electrical properties of Si NC thin films deposited by spray-coating. The effect of film thickness and NC size was investigated studying the electrical characteristics of FETs such as current-voltage behavior, hysteresis and ambipolar conduction under illumination. As we observe a strong dependence on morphology, we optimized our deposition parameters and achieved FETs with field-effect mobilities one order of magnitude higher than reported in the literature so far [1,2].

[1] Z. C. Holman, *et al.* Nano Lett. **10**, 2661 (2010) [2] R. N. Pereira, *et al.* Nano Lett. **14**, 3817 (2014)

Invited Talk HL 27.3 Tue 10:15 H 2032

Impurity doping of Si nanocrystals studied by single-quantum-dot spectroscopy — •Jan Valenta[1], Ilya Sychugov[2], Jan Linnros[2], and Minoru Fujii[3] — [1]Department of Chemical Physics & Optics, Charles University, Prague, Czechia — [2]Materials and Nano Physics, Royal Institute of Technology, Kista-Stockholm, Sweden — [3]Department of Electrical & Electronic Engineering, Kobe University, Nada, Japan

Recent research effort proved that doping of nanostructured semiconductors is much more complicated than in bulk due to the self-purification effect, increasing formation energy of substitutional doping sites etc. In order to get a deeper insight on impurity effects in Si nanocrystals (NCs) we applied single NC spectroscopy to study luminescence of two types of samples: (i) random quantum dots prepared by etching of highly doped (B, P, As, Sb) SOI wafers, (ii) highly B and P co-doped Si NCs formed by sputtering, annealing and etching. The effect of B, P, As, and Sb impurities on individual emission spectra are determined by comparison with the undoped NCs. From the statistical analysis of the luminescence spectra, the donor ionization energies for NCs emitting in the range of 1.5-2 eV are estimated to be 140-200 meV, while the exciton-impurity binding energy for As and Sb-doped NCs is found to be about 40-45 meV. It means that both the donor ionization energy and the excitonic binding energy are increased by an order of magnitude compared to bulk Si. The luminescence spectra of heavily B,P co-doped Si NCs are characterized by a very broad emission band (>0.2eV) even at low temperature (10 K).

Invited Talk HL 27.4 Tue 10:45 H 2032

Active Silicon Nanovolume Doping: Failure and Alternatives — •Dirk König — University of New South Wales, Sydney, Australia

We report on phosphorous (P) doping of SiNC/SiO2 systems [1]. Relevant P configurations within SiNCs, at SiNC surfaces, within the sub-oxide interface shell and in the SiO2 matrix were evaluated by hybrid (h-) DFT. Atom probe tomography (APT) and its statistical evaluation provide detailed spatial P distributions. We obtain ionisation states of P atoms in SiNC/SiO2 systems at room temperature using X-ray absorption near edge structure (XANES) spectroscopy. P K shell energies were confirmed by h-DFT. While P diffuses into SiNCs and predominantly resides on interstitial sites, its ionization probability is extremely low; free localized electrons to SiNCs are not provided.

As alternative, SiO2 and Si3N4 create substantial energy offsets of electronic states in SiNCs [2]. h-DFT, interface charge transfer and experimental verifications arrive at the same NC size below which the embedding dielectric dominates their electronic properties. An increased energy gap was found for Si NCs in Si3N4 vs. SiO2 by h-DFT and confirmed in experiment. We describe the interface impact as nanoscopic field effect and show that the energy offset is very robust and controllable. As application example, we propose an undoped CMOS-able and CMOS technology-compatible Si-Nanowire MISFET.

[1] D. König, S. Gutsch, H. Gnaser et al., Nature Sci. Rep., accepted for publication (2014)

[2] D. König, D. Hiller, S. Gutsch et al., Adv. Mater. Interf. (2014); http://onlinelibrary.wiley.com/doi/10.1002/admi.201400359/abstract

15 min. break.

Invited Talk HL 27.5 Tue 11:30 H 2032

Doping issues in semiconductor field-effect transistors — •Joachim Knoch — Institute of Semiconductor Electronics, RWTH Aachen University, Aachen, Germany

The functionality of silicon devices such as transistors, solar cells etc. rely on the ability to create doping profiles. However, due to the continued downscaling of device dimensions doping becomes increasingly difficult due to a number of fundamental reasons. First, dopants will be statistically distributed within the silicon nanostructures leading to a dopant fingerprint that results in fluctuations of e.g. electronic transistor characteristics from device to device. Second, studying the resistivity of in-situ doped, VLS-grown nanowires we were able to show that with decreasing nanowire diameter the resistivity increases due to a deactivation of dopants. The reason for the deactivation was shown to be the modified effective dielectric environment if the nanowire diameter is scaled down. In turn, the deactivation results in larger parasitic resistances of the contacts of e.g. transistors, substantially deteriorating their performance. Third, ultimately scaled conventional field-effect transistors (FETs) and in particular novel device architectures such as band-to-band tunnel FETs require extremely small nanowire diameters and eventually lead to one-dimensional (1D) electronic transport. While 1D transport is beneficial to conventional FETs, in the case of tunnel FETs the 1D density of states leads to an inability of appropriate doping (even if deactivation and the statistical dopant distribution could be avoided). The effects will be discussed particularly with respect to their impact on device functionality.

Invited Talk HL 27.6 Tue 12:00 H 2032

Probing composition and conductivity in 3D-structures and confined volumes. — •Wilfried Vandervorst — Imec, Kapeldreef 75, B-3001 Leuven, Belgium

Developing and implementing next technology nodes is a complex task involving innovation in materials engineering, process development and device design. The down scaling of devices into non-planar structures has led to physical phenomena which can only been seen in 3D-structures and confined volumes such that the metrology is now pushed into dealing with analysis on a scale commensurate with device dimensions. Concepts like Atomprobe tomography with its inherent 3D-resolution are obviously a potential solution although its routine application is still hampered by localization problems, reconstruction artifacts due to inhomogeneous evaporation, sensitivity due to the limited statistics, poor tip yield, etc. On the other hand concepts like scanning probe microscopy are inherently 2D can be extended towards 3D appear either by the design of dedicated tests structures or by novel approaches such as mechanical scalping. Recent applications of Scalpel SPM have unraveled the filament formation in RRAM-devices and highlighted the conduction paths in NAND devices. Despite the apparent 1D-nature of Secondary Ion Mass Spectrometry, novel concepts like Self-focusing SIMS enable to probe layer composition within trenches as narrow as 20 nm.

Invited Talk HL 27.7 Tue 12:30 H 2032

Silicon Nanowire Devices and Applications — •Thomas Mikolajick[1,2,3] and Walter Weber[1,3] — [1]NaMLab gGmbH, Nöthnitzer Str. 64, 01187 Dresden — [2]Institut für Halbleiter und Mikrosystemtechnik, TU Dresden, 01062 Dresden — [3]Center for Advancing Electronics Dresden (CfAED), TU Dresden, 01062 Dresden

Due to the quasi 1-dimensional nature of nanowires the controlability of elctrical fileds and currents are significantly enhanced. Therfore silicon nanowires are in development in the semiconductor industry as a very promision option for end of roadmap CMOS devices. Additionally new device concepts that are hard to realize in planar structures are enabled [1]. In this talk, first the fabrication of silicon nanowires and related device structures are explained. In the second part interesting transport properties that enable new device options will be shown. Based on these observations the most important nanowire device concepts will be deduced. The reconfigurable field effect transistor (RFET) will be explained as one interesting example that makes use of the specific advantage of the nanowire geometry. Finally an outlook to other applications of silicon nanowires like chemical sensing will be given.

[1] T. Mikolajick et al., Silicon nanowires - a versatile technology platform, Phys. Status Solidi RRL 7, No. 1, p. 793-799 (2013)