HL 30: Si/Ge

Time: Wednesday 9:30–13:00 Location: POT 51

HL 30.1 Wed 9:30 POT 51

Comparison of the top-down and bottom-up approach to synthesise nanowire-based Si/Ge heterostructures — •Andreas Wolfsteller, Nadine Geyer, Trung-Kien Nguyen-Duc, Nikolai Zakharov, Manfred Reiche, Wilfried Erfurth, Ursel Doss, Horst Blumtritt, Peter Werner, and Ulrich Gösele — Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle (Saale), Germany

Si nanowires (NWs) and nanowire-based Si/Ge heterostructures are expected to be building blocks for future electronic and optical devices, e. g. new field-effect transistors or sensors. In principle two approaches can be applied to synthesise NWs: i) the 'top-down' approach and ii) the 'bottom-up' approach. The most common method for the latter is the vapour-liquid-solid (VLS) mechanism, which can also be applied to grow NWs by molecular beam epitaxy (MBE). However, the VLS mechanism prevents the synthesis of heterostructures with sharp interfaces and high Ge concentrations due to the general nature of the growth process via an eutectic. Furthermore, Au, which acts as the catalyst, can be incorporated into the crystal structure, possibly resulting in a significant loss of optical properties. In the 'top-down' approach the Si/Ge heterostructure is first grown by MBE as a multilayer leading to sharper interfaces and higher element concentrations with the drawback of the generation of misfit-dislocations. The NWs (40 nm diameter) are then produced by electron beam lithography and reactive ion etching. The morphology, structure and chemical composition of both kind of NWs was analyzed by TEM, SEM, and EDX.

HL 30.2 Wed 9:45 POT 51

Interplay between Si dangling bond states and P doping in freestanding Si nanocrystals — •Andre R. Stegner[1], Rui N. Pereira[1,2], Jinming Lu[1], Hartmut Wiggers[3], Martin S. Brandt[1], and Martin Stutzmann[1] — [1]Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, 85748 Garching — [2]University of Aveiro, 3810-193 Aveiro, Portugal — [3]Universität Duisburg-Essen, Institut für Verbrennung und Gasdynamik, Lotharstrasse 1, 47048 Duisburg

Electron paramagnetic resonance (EPR) and secondary ion mass spectroscopy (SIMS) have been used to investigate the phosphorus doping of freestanding silicon nanocrystals (Si-NCs) with mean diameters selected between 4 nm and 45 nm which were produced by microwave-induced decomposition of silane and phosphine in a low-pressure plasma reactor. SIMS results do not indicate a size dependence of the P incorporation efficiency. However, it is found that approx. 95% of the P segregates to the Si-NC surface region during growth, which is oxidized after exposure to air. The concentration of electrically active, paramagnetic P detected by EPR further falls below this SIMS concentration by about one order of magnitude for Si-NCs with diameters larger than 15 nm. Charge compensation by Si dangling bonds, which are investigated using room temperature EPR and which can be passivated by H, is shown to be the reason for this deviation and can quantitatively be described by a statistical model. For smaller Si-NCs, a further strong drop of the concentration of paramagnetic donors is observed, which cannot be explained by the compensation model alone.

HL 30.3 Wed 10:00 POT 51

Fabrication of Silicon Nanostructures by Laser Interference Lithography and Metal-Induced Etching — •Johannes de Boor, Nadine Geyer, Dirk Hagen, Volker Schmidt, and Ulrich Gösele — Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany

Nanostructured silicon is the foundation of nowadays electronics. Trying to meet the demand for increasing device densities, much scientific and industrial effort has been spent on the fabrication of silicon nanostructures by various approaches.

We present a simple, fast, and cost-effective method to produce virtually defect- free and strictly periodic arrays of silicon nanowires and other nanostructures.

In a first step photoresist patterns with square symmetry are created by laser interference lithography. The applied frequency doubled argon-ion laser has a wavelength of 244 nm and the period of these patterns can be varied continuously between 130 nm and 1000 nm. In a second step a noble metal film is deposited onto the exposed silicon parts and the photoresist is removed. In a HF/H_2O_2 solution the silicon in contact with the metal film is dissolved in a redox reaction, i.e. the metal film sinks into the substrate. As result an array of single crystalline nanowires with narrow size distribution is formed, the diameter of the wires can be chosen between several hundred and 80 nm. By varying illumination times and angles other structures like nanofins can be formed as well, all periodic over several cm^2.

HL 30.4 Wed 10:15 POT 51

Electronic and transport properties of semiconducting nanoparticles — •Andreas Gondorf[1], Martin Geller[1], Daniel Tadych[1], Axel Lorke[1], Cedrik Meier[2], and Hartmut Wiggers[3] — [1]Experimental Physics and CeNIDE, University of Duisburg-Essen, Duisburg — [2]Department of Physics, University of Paderborn — [3]Combustion and Gas Dynamics, University of Duisburg-Essen

We investigate the charge carrier concentration and mobility in Ge and Si nanoparticle pellets. These transport properties are crucial for future Si or Ge based optoelectronic devices, as they determine the conductivity, for instance, in printable electronics. We use current-voltage (I-V) and Hall-measurements and find a very weak but measurable Hall-effect in compressed powder pellets. In pellets based on Si nanoparticles a very low charge carrier concentration of about 10^{12} cm^{-3} is measured at 250°C while Ge nanoparticles show at 25°C two order of magnitude higher concentration of about $4 \cdot 10^{14}$ cm^{-3}. These numbers are comparable to the intrinsic charge carrier concentration in the corresponding bulk materials. Ge nanoparticles have a very small mobility of 0,1 cm^2/Vs at 25°C which is comparable to the mobility of organic semiconductors. Surprisingly for Si nanoparticles we find mobilities of up to 100 cm^2/Vs at 250°C which is not understood yet. Furthermore we show a simulation of I-V characteristics of semiconducting nanoparticles embedded in a dielectric matrix. The model includes the size dependent band gap and capacitance and the size distribution of the particles. The simulation is in good agreement with experimental results [C. H. Cho et al. Appl. Phys. Lett. **89** 013116 (2006)].

HL 30.5 Wed 10:30 POT 51

Doping of vertical silicon nanowires by ion implantation — •Pratyush Das Kanungo[1], Reinhard Kögler[2], Nikolai Zakharov[1], Kien Ngyuen-Duc[1], Peter Werner[1], and Ulrich Gösele[1] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle, Germany — [2]Forschungszentrum Dresden - Rossendorf, FWIM, 01314 Dresden, Germany

Ion implantation is one of the key processing steps in fabricating planar silicon devices and circuits in the ultra large scale integration (ULSI) technology. With ion implanatation one can selectively dope specific areas on a planar silicon device defined by lithographic masks and confine the vertical penetration depth of the dopant atoms into the bulk of silicon at that region. However, this process has so far not been fully exploited in nanoelectronics, especially in doping silicon nanowires (Si NWs). Si NWs which are promising candidates for future nanoelectronics have mostly been doped in situ. We demonstrate that ion implantation can also effectively dope vertical Si NWs both n and p-type. We implanted boron as p-type dopant, and separately phosphorus and arsenic as n-type dopants on the Si NWs grown by molecular beam epitaxy. We demonstrate homogeneous doping [1] along the length of the NWs, as well as formation of an axial p-n junction inside the NWs and performed detailed structural and electrical characterizations of individual NWs. For the p-n junction formation a combined approach of in situ p-doping [2] and ex situ n-doping was used. Our results show significant differences between n and p-doping which conform to theory.

HL 30.6 Wed 10:45 POT 51

Polycrystalline silicon layers for large area electronics prepared by aluminum-induced layer exchange — •Christian Jaeger, Tobias Antesberger, Michael Algasinger, and Martin Stutzmann — Walter Schottky Institut, Am Coulombwall 3, 85748 Garching, Germany

Polycrystalline silicon thin films on low cost substrates are attractive for large area electronics. Besides laser-annealing, metal-induced

methods for crystallization of amorphous silicon are of general interest for this purpose. In particular, the aluminum-induced layer exchange (ALILE) process is a promising approach to obtain large-grained high quality polycrystalline Si films at low process temperatures. In a typical ALILE process, an Al/amorphous Si layer stack, separated by a thin oxide film, is annealed at temperatures below the eutectic temperature (570°C) of the Al-Si system, leading to a layer exchange and the crystallization of the a-Si. Due to the high solid solubility of Al in Si, the resulting layers are p-doped with hole carrier concentrations of about 10^{19}cm^{-3}.

In this work, a hydrogen plasma is used to passivate the Al acceptors, thereby reducing the hole carrier concentrations in the crystallized poly-Si films. Field-effect structures in bottom-gate configuration made from hydrogenated ALILE films are prepared and characterized. The influence of different gate insulators like thermally grown SiO_2, HfO_2, and Ta_2O_5 will be shown. Furthermore, the dependence of field effect mobilities, threshold voltages, and interface state densities on the device properties will be presented.

HL 30.7 Wed 11:00 POT 51

Electrical transport in undoped laser-crystallized polycrystalline silicon-germanium thin films — •Lars-Peter Scheller[1], Moshe Weizman[1], N. H. Nickel[1], and Baojie Yan[2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Kekuléstr. 5, 12489 Berlin, Germany — [2]United Solar Ovonic Corporation, 1100 West Maple Road Troy, MI 48084, USA

Due to its enhanced optical absorption in the IR and visible spectral range polycrystalline silicon-germanium (poly-SiGe) is a promising absorber material for future thin film and tandem solar cells.
In this study we report on the electrical transport properties of intentionally undoped laser-crystallized poly-$Si_{1-x}Ge_x$ thin films ($0 \leq x \leq 1$) on quartz. Temperature dependent Hall and conductivity measurements reveal a strong dependence of the main transport mechanism on both, the alloy composition and the crystallization procedure. At low temperatures most of the intentionally undoped films show an unexpected high p-type conductivity with a characteristic temperature dependence of either variable range hopping (VRH) or metallic like transport. Moreover, a post hydrogen treatment of the laser-crystallized samples causes a strong decrease of the conductivity. In some cases this reduction is accompanied by a change in the dominating low temperature transport mechanism from either metallic to hopping or hopping to activated behavior. This effect will be explained with an intrinsic transport path along grain boundaries caused by Ge dangling bonds.

15 min. break

HL 30.8 Wed 11:30 POT 51

Strained delta SiGe Layer for increasing ON current of Tunnel Field Effect Transistors (TFET) — •Helmut Lochner, Peter Iskra, Dorota Kulaga-Egger, Martin Schlosser, Thomas Zilbauer, Torsten Sulima, and Ignaz Eisele — Universität der Bundeswehr München, Institut für Physik, Werner-Heisenberg-Weg 39, 85577 Neubiberg

To meet the high demands of process and information technology the semiconductor industry gets into problems in the development of new devices. Continuous downscaling leads to increasing importance of quantum mechanical effects, such as the band to band tunnelling mechanism which has to be avoided or reduced in standard CMOS technology. Instead of avoiding the Tunnel Field Effect Transistors (TFET) uses this tunnel current as an advantage, but the ON current cannot fulfil the International Technology Roadmap for Semiconductors. We attempt to adjust this demerit for example by band gap engineering. We fabricated vertical TFETs in silicon with different silicon-germanium delta layers grown epitaxially in a Centura Cluster Tool by means of LPCVD. The device structure is a common p-i-n diode with gated intrinsic layer. To distinguish the influences of strained silicon-germanium we varied the strain in the interface layers between the intrinsic channel and source or drain respectively by different germanium concentrations. The experimental I-V characteristics show the advantages of these SiGe delta layers. The subthreshold slope increases clearly and the ON current considerably. The theoretical border will be shown in simulations.

HL 30.9 Wed 11:45 POT 51

Electronic structure and effective masses in strained silicon — •Mohammed Bouhassoune[1,2] and Arno Schindlmayr[2] — [1]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department Physik, Universität Paderborn, 33095 Paderborn, Germany

Metal-oxide-semiconductor field-effect transistors (MOSFETs) based on strained silicon hold considerable interest for modern microelectronics, because they are compatible with existing manufacturing technology and promise higher carrier mobility and faster switching times. Here we quantitatively examine the effect of strain on the electronic structure of silicon, combining density-functional theory within the local-density approximation and the GW approximation for the electronic self-energy. Quasiparticle band structures, deformation potentials and effective masses are obtained for tetragonal, orthorhombic and trigonal distortions of the unit cell, corresponding to biaxial strain in the (100), (110) and (111) planes with full relaxation, respectively. The tetragonal and orthorhombic distortions lift the sixfold degeneracy of the conduction-band minimum. Furthermore, strain in any direction causes the band structure to warp, and an energy split between light and heavy holes occurs at the top of the valence band. The inclusion of proper self-energy corrections within the GW approximation in our work not only yields band gaps in much better agreement with experimental measurements, but also predicts slightly larger electron effective masses. Even for small strain values, these changes in the electronic structure significantly affect the mobility of the charge carriers.

HL 30.10 Wed 12:00 POT 51

Phosphorus doping by chemical vapour deposition for vertical p-MOSFETs — •Peter Iskra, Dorota Kulaga-Egger, Thomas Zilbauer, Helmut Lochner, Torsten Sulima, and Ignaz Eisele — Universität der Bundeswehr München, Institut für Physik, Werner-Heisenberg- Weg 39, 85577 Neubiberg

The major advantage of a vertical MOSFET concept is the capability of defining the channel length by the thickness of the deposited layer. This allows an inexpensive fabrication of short channel devices. The deposition of the epitaxy stacks can be realized by LP-CVD (low pressure chemical vapour deposition). But, while the CVD process for p-type doping provides sharp doping profiles, the n-type doping suffers from surface segregation. This leads to an inhomogeneous doping profile and to redistribution of dopands from an underlaying doped layer into subsequent layers. A suppression of this effect can be achieved by optimizing the deposition parameters, the use of additional precursors or an ex situ wafer cleaning process.

Epitaxial pnp-structures were grown using a commercial LPCVD system. Dichlorosilane, phosphine and diborane were used as silicon and dopand sources. The n-type process was investigated with respect to growth temperature and dopand precursor flow. Additionally n-doped SiGe layers ware deposited for studying the influence on the phosphorus surface segregation. The germanium content was adjusted by germane flow. Furthermore, an ex situ oxidation cleaning process was investigated. All samples were characterised by secondary ion mass spectrometry (SIMS).

HL 30.11 Wed 12:15 POT 51

Optical spin injection and two-color interference effects in Ge — •Julien Rioux[1,2] and John E. Sipe[1] — [1]Department of Physics and Institute for Optical Sciences, University of Toronto, Canada — [2]Department of Physics, University of Konstanz, Germany

We discuss spin population and currents in bulk germanium injected by one- and two-photon absorption. For monochromatic circularly-polarized light, we calculate the spectral dependence of the spin polarization of photoexcited carriers. In the case of two-color irradiation, currents are generated and coherently controlled by interference of one- and two-photon transitions. In particular, we look at the contribution of the holes to these all-optical effects. Calculations are performed with a full-zone $\mathbf{k} \cdot \mathbf{p}$ band structure.

HL 30.12 Wed 12:30 POT 51

Vanadium:Silicon - an ion-beam generated diluted magnetic semiconductor? — •Sibylle Gemming, Mike B. Thieme, and Kay Potzger — Forschungszentrum Dresden-Rossendorf, P.O. Box 510119, D-01314 Dresden, Germany

The generation of dilute magnetic semiconductors (DMS) by ion-beam implantation of magnetic centres into semiconducting materials has experienced renewed interest since the generation of magnetic thin films from the Cobalt-doped wide-gap semiconductor TiO2. Since the magnitude of the magnetic moment in such films is strongly varying

and since the implementation in a standard, Silicon-based semiconductor device is challenging, we have concentrated on the binary and fully integrable system Vanadium:Silicon. At higher doping concentrations, Vanadium and Silicon form several binary compounds; the most well characterised structures have the compositions V:Si= 3:1, 5:3, 6:5, 1:2, and bear the potential to exhibit magnetism. At higher dilution, Vanadium may form point defects in the crystalline Silicon host matrix. Here, we investigate different combinations of substitutional and interstitial vanadium atoms in a silicon crystal matrix.

HL 30.13 Wed 12:45 POT 51

Properties of Vacancies in Germanium Probed by Fast Diffusing Transition Metals — Ludmila Lerner and •Nicolaas Stolwijk — Universität Münster, Institut für Materialphysik, 48149 Münster

The equilibrium concentration and diffusivity of vacancies (V) in Ge were assessed as a function of temperature from a detailed analysis of the diffusion behaviour of Co and Fe in electronic-grade Ge wafers. Surprisingly, it was found that the resulting equilibrium concentrations C_V^{eq} exceed the published experimental data by one order of magnitude. Accordingly, the diffusivities D_V fall below existing estimates by roughly a factor of ten in order to reproduce the well-established Ge self-diffusivity via the vacancy mechanism. In addition, the enthalpy of vacancy formation appears to be much smaller than the values calculated by ab initio theoretical methods.

Diffusion experiments were performed with the radiotracers ^{57}Co and ^{59}Fe over the temperature range 600-900 °C. The sensitivity of Co and Fe diffusion for the vacancy properties of the Ge host lattice relies on the observation that these impurities migrate via the dissociative mechanism involving V-mediated interstitial-substitutional exchange. In particular, Co was found to be an interesting probe atom as it crosses the borderline - upon increase of temperature - between a V-controlled mode of diffusion and a Co-interstitial-controlled one. Also the fact that the solubility of substitutional Co proved to be similar in magnitude to C_V^{eq} constitutes a crucial feature in the evaluation of the V-related data.