HL 19: Silicon and Germanium

Time: Monday 14:30–18:00 Location: POT 251

HL 19.1 Mon 14:30 POT 251

Phase Separation and Size Controlled Nanocrystal Formation in GeO — •Christoph Sahle[1], Christian Sternemann[1], Alexander Nyrow[1], Alexander Schwamberger[1], Florian Wieland[1], Manuel Zschintzsch[2], Johannes Borany[2], Achim Hohl[3], and Metin Tolan[1] — [1]Fakultät Physik/DELTA Technische Universität Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany. — [2]Institute of Ion Beam Physics and Materials Research, Forschungszentrum Dresden-Rossendorf e.V., P.O. Box 510119, 01314 Dresden, Germany. — [3]Institute for Materials Science, Darmstadt University of Technology, 64287 Darmstadt, Germany.

Semiconducting group IV nanocrystals (NC), such as Ge- and Si-NC, have drawn a lot of attention in recent years because of their potential use in new generations of light emitting diodes, fast and stable non-volatile flash memories or highly efficient solar cells. Although intensive research has been conducted regarding the photoluminescence and charge storage properties of readily produced oxide embedded NCs little is known about the phase separation and NC formation process. Here, we present *in* and *ex situ* X-ray absorption near edge structure (XANES) spectroscopy data of the temperature induced disproportionation, i.e phase separation of GeO_x ($x \approx 1$) into Ge and GeO_2, which leads to the formation of Ge NCs embedded in a Ge oxide matrix. The formation of size controlled Ge NCs is achieved using a GeO_x–SiO_2 superlattice approach. The influence of reducing hydrogen in the annealing ambient on the phase separation process and resulting NC density is discussed.

HL 19.2 Mon 14:45 POT 251

Structural modifications of low energy heavy ion irradiated Ge — •Tobias Steinbach, Jan Wernecke, and Werner Wesch — Institute of Solid State Physics, Friedrich Schiller University Jena

During LEI irradiation of germanium extreme structural changes can be observed. To study the effects and the mechanism of porous layer formation in Ge in more detail samples were irradiated with different ion species, ion energy and angle of incidence. In order to increase the penetration depth, irradiations were performed with ion energies in the range of several MeV. We present ion induced morphological changes in Ge over a wide range of ion fluence N_I, beginning with the amorphization process of c-Ge followed by the formation of voids in the amorphous phase and its transformation into a porous structure at high N_I. Depending on N_I different regimes of porous layer formation are observed (SEM and TEM investigations) and we could demonstrate that the rate of the volume expansion depends only on nuclear energy deposition ϵ_n. However, the formation depth of the voids as well as the shape and the dimension of the porous structure depend on the ion species (chemical properties of the irradiated ions) and irradiation temperature, respectively. In addition, for all perpendicular ion irradiations a formation of a microstructure at the surface occurs whereas for non-perpendicular ion irradiation a plastic deformation, i.e. a surface shift, without a microstructure formation was observed. The effect of plastic deformation will be discussed in detail and provides an explanation for the different surface structures observed for different ion incidence.

HL 19.3 Mon 15:00 POT 251

Structure characterization on selective Ge CVD-heteroepitaxy on free standing Si (001) nanopatterns — •Grzegorz Kozlowski, Peter Zaumseil, Yuji Yamamoto, Joachim Bauer, Bernd Tillack, and Thomas Schroeder — IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany

Ge is attracting increasing interest to build up future photonic technologies. The main reasons for choosing Ge is given by its superior optoelectronic properties with respect to Si and its compatibility with Si CMOS processing in contrast to III-V materials. The major stumble block for the integration of high quality Ge films on Si is however given by the 4.2% lattice mismatch which causes misfit and threading dislocations (TD). It is known that Ge deposited in smaller window tends to show lower TD density. We focus our work on the growth studies of selective Ge heteroepitaxy on nanopatterned Si (001) wafers with SiO_2 mask. Synchrotron-based grazing incidence X-ray diffraction is applied to study the structure, defect and strain characteristics with high resolution and sensitivity in a non-destructive way. In addition, special focus is devoted by Raman, transmission electron microscopy (TEM) and finite element method (FEM) simulation to determine the influence of SiO_2 growth masks on the quality of a) patterned Si substrates and b) the overgrowing Ge epilayers.

HL 19.4 Mon 15:15 POT 251

Surfactant-mediated epitaxy of germanium layers on vicinal silicon substrates — •Jasper Ruhkopf[1], Tobias F. Wietler[1], Eddy P. Rugeramigabo[1], Dominic Tetzlaff[1], Jan Krügener[2], and Eberhard Bugiel[1] — [1]Institute of Electronic Materials and Devices, Leibniz Universität Hannover, Schneiderberg 32, 30167 Hannover — [2]Information Technology Laboratory, Leibniz Universität Hannover, Schneiderberg 32, 30167 Hannover

Ge layers on vicinal Si wafers can be used as virtual substrates for GaAs growth. This provides the opportunity to combine the benefits of GaAs, needed for example for high-efficiency photovoltaic cells, with the advantages of silicon technology. The necessary strain relaxation of the Ge layers can be achieved by surfactant-mediated epitaxy (SME) employing Sb as surfactant. Ge layers were grown by SME on vicinal Si(001) substrates with different miscut angles. The surface reconstruction and step arrangement were analyzed in situ with electron diffraction methods. The dislocation pit density was examined by atomic force microscopy. The crystalline quality and the degree of strain relaxation were studied by high resolution X-ray diffraction (HRXRD). A small tensile strain was found which conformed well to calculations of the thermal stress induced in the cooling process.

HL 19.5 Mon 15:30 POT 251

Enhanced luminescence of self-assembled germanium islands in silicon photonic crystal nanocavities — •Stefan Lichtmannecker[1], Norman Hauke[1], Thomas Zabel[1], Fabrice Laussy[1], Dominique Bougeard[2], Gerhard Abstreiter[1], Yasuhiko Arakawa[3], and Jonathan Finley[1] — [1]Walter Schottky Institut, Garching — [2]Universität Regensburg — [3]University of Tokyo, Japan

We present optical investigations of two dimensional silicon photonic crystal defect nanocavities with high density ($10^9\,cm^{-2}$) germanium islands acting as an internal light source. Power and time dependent micro photoluminescence (μ–PL) spectroscopy at a lattice temperature of 25K reveals an enhancement of the photoluminescence signal recorded from the cavity modes by a factor of 350x compared to the unprocessed regions of the device. This enhancement is not fully accounted for spatial redistribution of the emission profile through the cavity mode. Quantitative analysis of power dependent μ–PL measurements and comparison with time resolved measurements suggest that the observed enhancement of the cavity mode emission is due to an enhanced internal quantum efficiency via the Purcell effect.

By systematically investigating the dependence of the emission intensity on the cavity Q-factor we observe a clear trend that lower Q-cavities produce the most intense emission. These observations are supported by simulations of our system using a dissipative master equation approach. Supported financially by the DFG via NIM, TUM IGSSE and TUM IAS.

HL 19.6 Mon 15:45 POT 251

Extrinsic doping in silicon revisited — •Udo Schwingenschlögl[1], Alexander Chroneos[2], Cosima Schuster[3], and Robin Grimes[2] — [1]PSE Division, KAUST, Thuwal 23955-6900, Kingdom of Saudi Arabia — [2]Department of Materials, Imperial College London, London SW7 2BP, United Kingdom — [3]Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany

Both n-type and p-type doping of silicon is at odds with the charge transfer predicted by Pauling electronegativities and can only be reconciled if we no longer regard dopant species as isolated atoms but rather consider them as clusters consisting of the dopant and its four nearest neighbor silicon atoms. The process that gives rise to n-type and p-type effects is the charge redistribution that occurs between the dopant and its neighbors, as we illustrate here using electronic structure calculations. This view point is able to explain why conventional substitutional n-type doping of carbon has been so difficult.

Reference: Appl. Phys. Lett. 96, 242107 (2010)

HL 19.7 Mon 16:00 POT 251

In-situ incorporation and distribution of boron dopants in silicon nanowires — •Pratyush Das Kanungo[1], Xin Ou[2], Reinhard Koegler[2], Alexander Tonkikh[1], Wolfgang Skorupa[2], and Peter Werner[1] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle, Germnay — [2]Forschungszentrum Dresden - Rossendorf, FWIM, 01314 Dresden, Germany

Silicon nanowires (Si NWs) are promising candidates for future nanoelectronic devices and circuits. However, controlled doping and measurement of doping profiles are two of the biggest challenges that need to be addressed before using them as building blocks for functional devices. By measuring the current-voltage characteristics of a molecular beam epitaxy-grown and heavily in-situ boron-doped Si NW of diameter around 100 nm, and separately measuring the local spreading resistance across the cross-section of a NW of the same doping level, we have analyzed the incorporation, distribution and deactivation of boron atoms. It was observed that the incorporated and active boron atoms form a multi-shell structure. The area very near (around 5 nm) to the outer surface is fully depleted of active dopants because of the surface states existing at the outer surface of the NW. Underneath this depleted shell, two heavily doped cores are formed. The first one is relatively thinner (around 30 nm), but it contains relatively higher active boron concentration than the thicker (around 70 nm) inner core. We further establish that this nonuniformity in active boron concentration is related to the in-situ doping process itself which can offer two different pathways for incorporation of boron.

15 min. break

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Kelvin probe force microscopy on doped semiconductor nanostructures with local, carrier-depleted space charge regions — •Christine Baumgart[1], Anne-Dorothea Müller[2], Falk Müller[2], Manfred Helm[1], and Heidemarie Schmidt[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Institut für Ionenstrahlphysik und Materialforschung, P.O. Box 510119, 01314 Dresden — [2]Anfatec Instruments AG, Melanchthonstr. 28, 08606 Oelsnitz

Failure analysis and optimization of semiconducting devices require knowledge of their electrical properties. Kelvin probe force microscopy (KPFM) is the most promising non-contact electrical nanometrology technique to meet the demands of today's semiconductor industry. We present its applicability to locally doped silicon structures. Quantitative dopant profiling by means of KPFM measurements is successfully demonstrated on a conventional static random access memory (SRAM) cell and on cross-sectionally prepared Si epilayers by applying a recently introduced new explanation of the measured KPFM signal [1]. Additionally, the influence of local, carrier-depleted space charge regions and of the electric fields across them is discussed. It is explained how drift and diffusion of injected charge carriers in intrinsic electric fields influence the surface region of the investigated semiconductor and thus may disturb the detected KPFM bias.

[1] C. Baumgart, M. Helm, H. Schmidt, Phys. Rev. B 80, 085305 (2009).

HL 19.9 Mon 16:45 POT 251

New luminescence line at 1.09 eV in two stage deformed silicon — •Matthias Allardt, Sabine Kolodinski, Ellen Hieckmann, and Jörg Weber — Technische Universität Dresden, 01062 Dresden, Germany

This work focuses on photoluminescence (PL) and cathodoluminescence (CL) in Fz silicon, deformed in a two stage process: a low-stress uniaxial predeformation at 8 MPa @ 800 °C and a subsequent high-stress deformation at 300 MPa @ 420 °C. Slip lines on the sample surface show that two glide systems have been activated during the deformation process. A new spectral line at 1.09 eV could be observed both in the PL and CL investigations. A line shape analysis at different temperatures give evidence that this line originates from a free-to-bound transition with a trap binding energy of 80 meV. The nature of the luminescence center will be discussed. The work was funded under the SAB Project-Nr. 14255/2423.

HL 19.10 Mon 17:00 POT 251

Raman scattering study of ro-vibrational modes of interstitial H_2 in crystalline Si — •Sandro Koch, Edward Lavrov, and Jörg Weber — Technische Universität Dresden, 01062 Dresden, Germany

Raman scattering studies of Si samples hydrogenated in a rf plasma have been performed. Ro-vibrational $Q(J)$ transitions for rotational quantum number $J = 0, 1, 2$, and 3 have been investigated in the temperature range from 90 to 388 K. We demonstrate that the $Q(2)$ transition appears in the Raman spectra above 200 K as suggested by Hiller et al. [PRB 74, 235214 (2006)]. Additionally, the $Q(3)$ transition is detected at 388 K. From the temperature dependence of the phonon spectrum of the Si host, we can show that the coupling between rotational states of H_2 depends on the temperature.

HL 19.11 Mon 17:15 POT 251

Thermally stimulated current in solid phase crystallized poly-Si thin films — •Markus Moser, Lars-Peter Scheller, and Norbert Nickel — Helmholtz-Zentrum Berlin für Materialien und Energie, Kekuléstr. 5, 12489 Berlin, Germany

Polycrystalline silicon (poly-Si) is an attractive material for many thin film electronic devices due to its improved carrier mobility and long term stability compared to amorphous silicon (a-Si). Furthermore it can be deposited on large areas of cheap substrates such as glass or plastic. However, the use of such low cost substrates limits process temperatures to values below 600°C which strongly influences the electrical and structural properties of the material. In particular, the performance of electronic devices containing poly-Si is affected by grain boundaries, impurities and lattice defects that cause localized states in the band gap. These defect states can trap charge carriers and can act as efficient recombination centers limiting the performance of thin-film transistors and solar cells. Thermally stimulated current measurements (TSC) are a helpful tool to detect these states. In this work, TSC is applied to poly-Si films on Corning glass which are produced by electron beam evaporation and subsequent solid phase crystallization. The measurements reveal a superposition of contributions from different gap states. A thermal cleaning procedure is used to resolve the individual components. Six states with activation energies ranging from 116 meV to 543 meV are obtained. The results are discussed in terms of possible intrinsic and extrinsic defects.

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Contact materials for sulphur hyperdoped black silicon — •Thomas Gimpel[1], Kay-Michael Günther[1], Anna Lena Baumann[2], Augustinas Ruibys[2], Stefan Kontermann[2], and Wolfgang Schade[1,2] — [1]Clausthal University of Technology, EFZN, EnergieCampus, Am Stollen 19, 38640 Goslar — [2]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19, 38640 Goslar

Irradiating a plane silicon surface with a train of intense femtosecond-laser pulses in a sulphur-containing atmosphere leads to a structured surface with enhanced absorption properties in the visible and near infrared spectral range, even at wavelengths below the bandgap. Because the resulting layer system shows photovoltaic activity it is proposed to turn this absorption into an efficient charge carrier generation for photovoltaic applications. Extracting those charge carriers is difficult, because of a structured, nanocrystalline covering surface layer with thickness of d<1μm and a sulphur content of about 1 at.% which influences the mechanical adhesion and contact resistances. Deposition techniques like screenprinting, sputtering, pulsed laser deposition and thermal evaporation are compared. We use different metal layer systems like silver, titanium/palladium/silver, chromium/gold and transparent contacts like indium tin oxide. By means of impedance spectroscopy we evaluate the contact behaviour finding the appropriate contact material.

HL 19.13 Mon 17:45 POT 251

Determination of the complex refractive index in the infrared region for femtosecond-laser-formed silicon surfaces using ray-tracing — •Augustinas Ruibys[1], Christian Lehmann[2], Thomas Gimpel[3], Anna Lena Baumann[1], Stefan Kontermann[1], and Wolfgang Schade[1,3] — [1]Fraunhofer Heinrich Hertz Institute, Energie-Campus, Am Stollen 19, 38640 Goslar — [2]FU Berlin, Fachbereich für Experimentalphysik, Arnimallee 14, 14195 Berlin — [3]Clausthal University of Technology, EFZN, Energie-Campus, Am Stollen 19, 38640 Goslar

The femtosecond-laser processing of silicon surface in the SF6 gas creates cone-shaped structures, which have a thin 0.1 - 1 μm layer of multi-crystalline substance with approximately 0.5 at.% of sulphur. This layer is known to be photovoltaically active in the visible wavelengths as well as in the infrared and has the potential for cost effective solar cells. However, not much is known about the fundamental properties of this multi-crystalline layer. Measuring the optical properties

in the infrared and simulating ray-traces in the coned surface, allows calculating the complex refractive index and the associated absorption coefficient. The simulated refractive index spectra are presented for samples processed in SF6 gas and vacuum in the wavelength range 1100 nm - 2500 nm. The obtained absorption coefficient spectra for samples processed in SF6 are of the order of 10^4 cm-1. This high absorption in the infrared is discussed from the point of view of the introduced sub-band-gap energy levels on the one hand and high free carrier absorption on the other hand.