HL 45: Photovoltaics: Silicon-based Systems I

Time: Wednesday 9:30–11:00 Location: ER 270

HL 45.1 Wed 9:30 ER 270

Selektive Ablation dünner dielektrischer Schichten von Silizium mittels ultrakurzer Laserimpulse — •Tino Rublack[1], Martin Schade[2] und Gerhard Seifert[3] — [1]Zentrum für Innovationskompetenz (ZIK) * SiLi-nano, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [3]Naturwissenschaftliche Fakultät II, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

Eine Strukturierung von Silizium-Solarzellen durch selektives Entfernen der dünnen dielektrischen Passivierungs- bzw. Antireflexschichten wird derzeit bei hocheffizienten Solarzellen im Labor meist fotolithographisch durchgeführt. Eine kosteneffiziente und industrietaugliche Alternative hierzu stellt die selektive Ablation dieser Schichten mit ultrakurzen Laserimpulsen dar. In unserer Arbeit haben wir mit verschiedenen Lasersystemen, deren Pulsdauern zwischen 50 fs und 2000 fs variierten, den Mechanismus der selektiven Ablation untersucht. Hierbei wurden zusätzlich zum Einfluss der Pulsdauer auch die Einflüsse der Wellenlänge im Bereich von 266 nm bis 10 μm und des Fokalradius untersucht. Es konnte mittels Licht- und Rasterkraftmikroskopie, Raman-Spektroskopie sowie Rasterelektronen- und Transmissionselektronenmikroskopie gezeigt werden, dass eine selektive Ablation von SiO_2, Si_xN_y und Al_2O_3 auf Silizium unter Erhalt der Kristallstruktur im geöffneten Bereich möglich ist.

HL 45.2 Wed 9:45 ER 270

Microstructuring of silicon with femtosecond laser pulses — •Waldemar Freund[1], Jan P. Richters[2], Jürgen Gutowski[1], and Tobias Voss[1] — [1]Institute of Solid State Physics, Semiconductor Optics Group, Universitiy of Bremen — [2]Department of Physics, University of Grenoble

"Black silicon" has been a field of intense studies in recent years. To fabricate this material, a crystalline p-doped silicon wafer is structured with ultrashort laser pulses in a sulfurhexafluoride (SF_6) atmosphere. The physics on the ultrashort time scale results in two processes: the formation of laser-induced periodic surface structures (LIPPS) and the simultaneous doping of the silicon with sulfur far above the solubility limit creating a p-n^+-junction which acts as a solar cell under illumination. The periodic surface structures considerably enhance light absorption in "black silicon" at energies below the silicon bandgap. The extremely high doping with sulfur results in the formation of a distinct defect band which is the origin of high absorptance in the near-infrared spectral region. Silicon treated with this process therefore constitutes a promising material for applications in thin film solar cells. We show experimental results on optimization of black-silicon solar cell efficiency through passivation of surface defects after treatment with HF. A significant increase in short circuit current of black silicon solar cells is observed when using thinner p-silicon substrates. Our studies represent important steps towards the fabrication of efficient thin-film solar cells with increased infrared sensitivity on base of easy-to-produce black silicon.

HL 45.3 Wed 10:00 ER 270

Formation of Black Silicon by differently polarized femtosecond laser pulses — •Stefan Kontermann[1], Anna Lena Baumann[1], Thomas Gimpel[2], Kay Michael Guenther[2], Augustinas Ruibys[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19, 38640 Goslar, Germany — [2]Clausthal University of Technology, Institute of Energy Research and Physical Technologies and EFZN, EnergieCampus, Am Stollen 19A, 38640 Goslar, Germany

Irradiating a silicon surface with femtosecond laser pulses results in a low reflecting surface structure consisting of cone like features. Adding sulfur to the atmosphere, where the light material interaction takes place, yields an enhanced infrared absorption of this Black Silicon substrate. Due to the sub band gap absorption, Black Silicon allows a better exploitation of the light energy contained in the sun spectrum. Therefore Black Silicon is one of the materials that are about to enter the photovoltaic research and development stage. In earlier studies the influence of different parameters on the Black Silicon structure like laser pulse number per spot, laser fluence, pressure in the processing chamber, or the crystal orientation were investigated. In this work we present results from a study of the Black Silicon structures when laser pulses of different polarization are applied. We examine the correlation between surface properties and polarization and compare these results to the structure formed by linearly polarized fs-laser pulses using scanning electron microscopy and absorption measurements.

HL 45.4 Wed 10:15 ER 270

Crystal structure at the surface of femtosecond-laser microstructured silicon for photovoltaics — •Thomas Gimpel[1], Ingmar Höger[2], Fritz Falk[2], Stefan Kontermann[3], and Wolfgang Schade[1,3] — [1]Clausthal University of Technology, EFZN, 38640 Goslar — [2]Institute of Photonic Technology, 07745 Jena — [3]Fraunhofer Heinrich Hertz Institute, 38640 Goslar

Black Silicon structured by means of femtosecond (fs) laser pulses in a sulfur containing atmosphere is an attractive candidate for intermediate band photovoltaics. A single fs-laser step yields a light trapping structure and the implementation of sulfur far above equilibrium concentration. Incorporated sulfur states within the silicon band gap realize n-doping and form an intermediate band which allows photons with energies below the silicon band gap to be absorbed.

Nevertheless, structuring silicon by means of fs-laser pulses partially destroys the crystal structure of the monocrystalline substrates. Former transmission electron microscope (TEM) investigations point out only a small sample area and could barely take any annealing processes into account. Therefore we perform electron backscatter diffraction (EBSD) measurements on differently structured samples. We show how light trapping structures are partially monocrystalline after fs-laser irradiation and how annealing influences the crystal structure. The results are promising to improve the crystal quality of fs-laser structured Black Silicon.

HL 45.5 Wed 10:30 ER 270

Surface recombination in black silicon — •Michael Algasinger, Julie Paye, Svetoslav Koynov, Martin S. Brandt, and Martin Stutzmann — Walter Schottky Institut, Technische Universität München, 85748 Garching, Germany

Nanotextured silicon, also referred to as black silicon (b-Si), shows a reflectivity of around 2-5% in the whole range of Si absorption [1]. The needle-like structure is in a scale of the wavelength of the incident light. According to the model of Stephens and Cody [2] such a surface is an effective medium with a graded optical density, which provides no interface where a reflection could appear. Furthermore, this nanostructure shows light trapping effects, increasing the optical path by a factor of up to 15 [3]. Both effects make b-Si interesting for application in thin film solar cells. The nanostructure is produced by a wet etching process which increases the surface area. This leads to an elevated recombination of photo-induced carriers. In order to benefit from the good optical properties of b-Si in solar cells, the loss in efficiency due to the additional surface recombination needs to be minimized. Effects of different surface treatments on the surface recombination velocity will be compared. First results of diffusion length measurements and electrical detected magnetic resonance (EDMR) will be presented.

[1] S. Koynov, M. S. Brandt, and M. Stutzmann, Appl. Phys. Lett. 88, 203107 (2006).

[2] R. B. Stephens and G. D. Cody, Thin Solid Films 45, 19 (1977).

[3] S. Koynov, M. S. Brandt, and M. Stutzmann, J. Appl. Phys. 110, 043537 (2011).

HL 45.6 Wed 10:45 ER 270

Black silicon passivation by conformal thermal ALD deposited Al_2O_3 coatings — •Martin Otto[1], Matthias Kroll[2], Thomas Käsebier[2], Roland Salzer[3], and Ralf B. Wehrspohn[1,3] — [1]Martin-Luther-University Halle-Wittenberg, μMD Group - Institute of Physics, Halle, Germany — [2]Friedrich Schiller University Jena, Institute of Applied Physics, Jena, Germany — [3]Fraunhofer Institute for Mechanics of Materials Halle, Halle, Germany

Upon inductive coupled plasma reactive ion etching (ICP-RIE) of Si surfaces needle-like nanostructures with aspect ratios up to 10 emerge showing excellent anti-reflection and light-trapping properties with absorption over 97% throughout the UV and VIS spectral range. In addition, the absorption at the band edge of silicon is enormously en-

hanced due to scattering. In this work we report on the feasibility to deposit conformal Al_2O_3 dielectric layers on these very rough silicon surfaces which enable adequate surface passivation. Lifetimes over 170 μs have been measured on deep structured b-Si substrates. The optical properties of black silicon (b-Si) and the possible influence of applied alumina passivation layers as well as their passivation performance are discussed.