Group "Silicon to Light" – towards active silicon-hybrid photonics

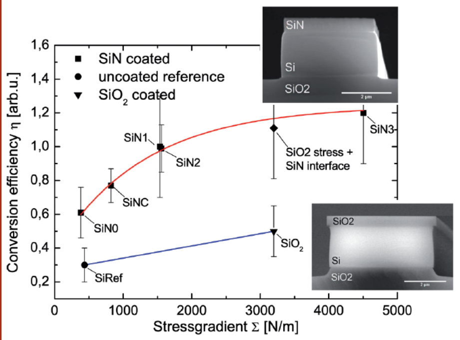
Prof. Dr. Jörg Schilling
Group Leader

Silicon represents a formidable material for passive 2D photonic applications due to its high refractive index and transparency in the near and mid IR. However, if active functionality like light emission or nonlinear optical processes are required, silicon has severe drawbacks due to its indirect bandgap, the centrosymmetry of its lattice and a relatively high two-photon absorption. The research of the group "Silicon to Light" aims to overcome these challenges by either modifying the optical properties of silicon itself or combining silicon with different materials of desired optical functionality creating hybrid photonic devices.

Currently, the following topics are actively investigated:

1) Formation of a second order nonlinearity ($\chi^{(2)}$) in silicon based on symmetry breaking of the crystal lattice due to inhomogeneous mechanical stress and applied electric fields.
2) Efficient third order nonlinear optical processes (e.g. four wave mixing) for wavelength transformation/generation in the near IR using a combination of chalcogenide glasses and Si waveguiding structures in hybrid photonic devices.
3) Enhancement of on-chip light sources embedded in silicon photonic elements employing photonic crystal cavities and Mie-resonances.
4) Plasmonic metamaterials for ultra-tight focussing and high light field concentration applied to subwavelength imaging and surface enhanced Raman scattering.

Introducing this active functionality into silicon based integrated photonic circuits will pave the way to a cost-effective "optics on a chip", enabling further integration of optical information technology and microelectronics.



Efficiency of Second harmonic generation as a measure of second order nonlinearity due to inhomogeneous strain in silicon waveguides. Values for nitride-coated waveguides are additionally increased due to fixed charges and the consequential electric field at the SiN/Si interface.

Email: joerg.schilling@physik.uni-halle.de

Group "Light to Silicon" – Laser micromachining for photovoltaic materials processing

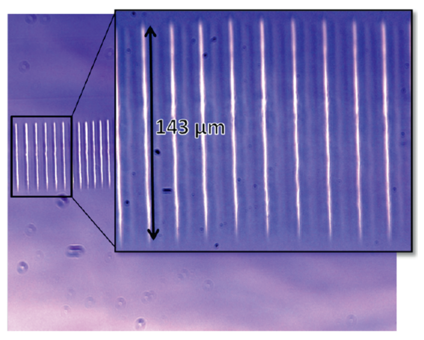
Dr. Paul Miclea
Group Leader

The intention to improve solar cell efficiency applying photon management has been driving the research of the group "Light to Silicon" since the beginning. Besides the investigation of up- and down conversion processes in rare earth doped glasses, femtosecond laser ablation and structuring gained more and more importance. Laser structuring processes have been investigated for their potential in solar cell fabrication and –modification involving laser written diffractive structures to improve light harvesting as well as the use of laser ablation for effective manufacturing of solar cell contacts.

1) *Laser ablation for contact manufacture*
Applying femtosecond laser pulses, thin layers of different materials can be cleanly blast off from an e.g. underlying silicon substrate. The ultra-short pulse-length and corresponding high momentary intensity results in a sudden evaporation of a thin interfacial layer without causing any considerable thermal damage to the surrounding material, leaving a well defined, nearly undamaged area for further contact processing.

2) *Laser structuring of phase gratings for light deflection*
Intensive laser pulses can also be used for structuring inside the glass matrix. By focusing a femtosecond laser into glass, an interplay of non-linear defocusing and refocusing optical processes leads to the formation of long intensity "filaments" inside the glass, resulting in a change of refective index there. Extended periodic index gratings have been "written" into the glass leading to light diffraction into several higher diffraction orders. This allows to guide light around optically inactive regions in a solar cell towards light sensitive areas for improved energy harvesting.

Adjusting the pulse energy, repetition rate and wavelength of the femtosecond laser, femtosecond laser processing techniques can be adapted very flexibly to the specific absorption conditions of different materials allowing the future structuring of a large variety of materials beyond Si and SiO_2.



Periodic lines of higher refractive index generated by intensity filaments form a phase grating.

Email: paul-tiberiu.miclea@physik.uni-halle.de

Group "Light for High-Voltage Photovoltaics" – Multiferroic materials for photovoltaic applications

Dr. Akash Bhatnagar
Group Leader

The main focus of the Group "Light for High-Voltage Photovoltaics" is to study the anomalous photovoltaic effect (APV) in ferroelectric / multiferroic materials. The APV effect results in an open circuit voltage (V_{oc}, in volts), which is greater than the bandgap (in eV) of the illuminated material. This distinguishes the effect from the semiconductor-based photovoltaics, wherein the V_{oc} is limited by the bandgap of the material. In addition, the APV effect does not require a *pn*-junction for the generation of photovoltaic current.

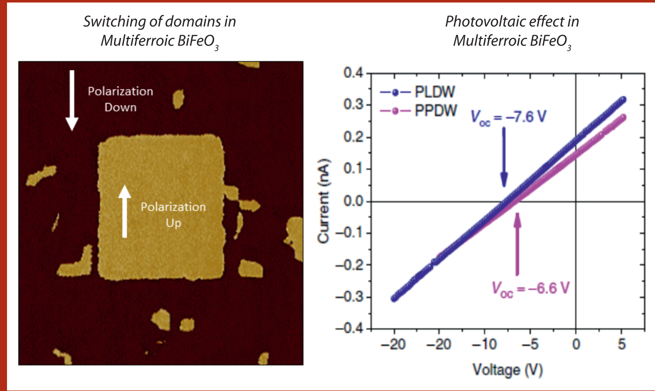
The group actively works in the following areas:

1) Growth of multiferroic and complex oxide material systems in the form of superlattices and heterostructures.

2) Bandgap engineering of oxides via substitutional doping and strain from the substrate.

3) Interplay between photovoltaic and ferroic properties.

The research activities also involve investigation of functional oxide materials for device applications, such as sensing and actuation. The piezoelectric, ferroelectric and ferromagnetic properties of the materials are harnessed to achieve the desired objectives.



Ferroelectric (left) and Photovoltaic (right) characteristics measured in $BiFeO_3$ thin films at room temperature.
PLDW and PPDW indicate parallel and perpendicular, respectively, orientation of domain walls with respect to electrodes.

Email: akash.bhatnagar@physik.uni-halle.de

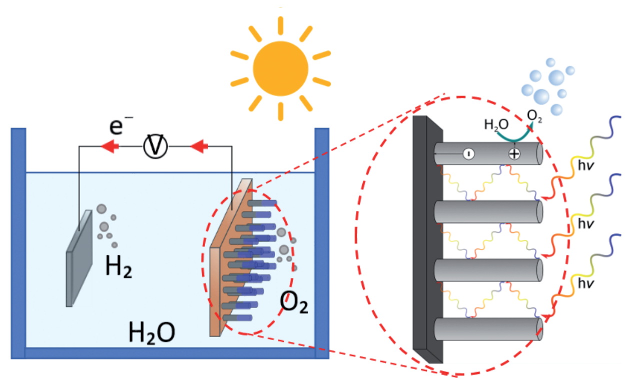
Group "Light for Hydrogen" – Nanostructure design for photocatalytic water splitting

Jun.- Prof. Dr.
Wouter Maijenburg
Group Leader

Our goal is to use specifically designed nanostructures for increasing the light-to-hydrogen efficiency of photocatalytic materials. The basic principle of photocatalytic water splitting is very simple: the photocatalyst (as a suspension or attached to an electrode) is immersed in water and irradiated with sunlight upon the formation of hydrogen gas. If hydrogen can be generated in an efficient and environmentally friendly manner, hydrogen can be the most important energy carrier of the future.

We aim to enhance the light-to-hydrogen efficiency using the following projects:

1) Design of Metal Organic Framework (MOF) nanostructures via electrochemical oxidation,
2) Photocatalytic nanostructures made via templated electrodeposition,
3) Photocatalytic nanofibers made by electrospinning via sol-gel chemistry,
4) Investigation of the physical and chemical suitability of different types of nanostructures for photocatalytic water splitting,
5) Combination of different photocatalytic nanostructures and materials for the design of photocatalytic cells for improved photoelectrochemical and autonomous water splitting,
6) Metallurgical grade silicium nanostructures and efficiency enhancement by co-catalysts.



Basic principle of photoelectrochemical water splitting using nanostructures.

Email: wouter.maijenburg@chemie.uni-halle.de