Project 1: Ion migration in perovskite solar cells
Daily supervisor: Lucie McGovern

Perovskite solar cells are on the verge to large-scale commercial application, but the most efficient perovskites are still not long-term stable. Ion migration has been attributed to cause long-term degradation. In the hybrid solar cells group we recently established a novel technique, transient ion-drift (TID) to accurately quantify ion migration. The technique relies on measurements of the transient capacitance decay after a voltage pulse at various temperatures. It allows to measure the activation energy, density, and diffusion coefficient of the mobile ions.

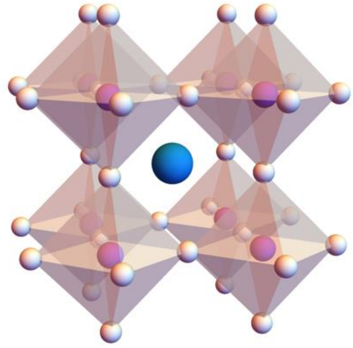


Figure 1. Perovskite crystal structure

In this project you will study where ions migrate in the perovskite films. You will fabricate perovskite solar cells with varying grain size, and study the migration of anions an cations with TID. The results will allow to distinguish the ion migration in the bulk and on grain boundaries, which can guide the development of future perovskite materials for stable solar cells.

Project 2: Solar cell efficiency limit of singlet fission solar cells
Daily supervisor: Benjamin Daiber

Singlet fission is a process by which the absorption of one high-energy photon leads to two lower-energy excited states. In solar cells this can lead to a current-doubling from the high-energy photon, and thereby, in principle, to efficiencies exceeding the Shockley-Queisser limit.

In this project you will calculate how efficient the singlet fission solar cells could become if we used realistic parameters. You will use and extend a computational model recently developed in the group, and predict the power conversion efficiency, compared to conventional silicon cells and to tandem solar cells. The results of the project will guide the research on future singlet fission solar cells.

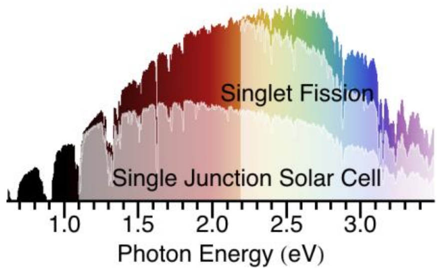


Figure 2. Light harvesting of the solar spectrum with singlet fission

About the group

The Hybrid Solar Cell Group focuses on novel paths towards more efficient solar cells using both organic and inorganic materials. We aim at combining the unique properties and the richness of organic materials with the highly efficient, well-characterised inorganic materials. We provide a highly collaborative environment, both within the group and with our national and international collaborators.

You will be part of a sub-group relating to the topic, and supervised by an experienced PhD student. Duration of both projects is 10 months full time.

More information about the group at https://amolf.nl/research-groups/hybrid-solar-cells, on Twitter @brunoehrler and via email at ehrler@amolf.nl.

LMPV

AMOLF's Light Management in New Photovoltaic Materials Program

Check our website: www.lmpv.nl

Internship possibilities: see: www.amolf.nl

Nanoscale Solar Cells group (PI Erik Garnett):

1. Halide perovskite back contact and tandem solar cells (supervisor: Hongyu Sun)

Perovskite solar cells are undergoing an extremely fast development and attracting intense research attention due to their unique features such as low-cost, easy to fabricate and excellent optical/electrical performance. However, most of the state-of-art works are focusing on traditional planar solar cell designs. In this project, you will study how perovskite film performs on nanoscale patterned back contact substrates and also explore its potential for perovskite/Si tandem solar cells. The main activities of this project include synthesizing, characterizing, analyzing several different types of perovskites and further fabricating solar cells. Meanwhile many scientific equipment skills will be obtained such as SEM, XRD, probe station, spin coating, etc.

2. HfN nanoparticles for long-lived hot electrons (supervisor: Sven Askes)

Collective oscillations of conduction band electrons in metals (plasmons) have recently been shown to have improved selectivity for certain chemical reactions. Although the exact mechanism is still debated in literature, there is growing evidence that "hot electrons" – showing an energy distribution very different from the standard room temperature Fermi-Dirac distribution – play an important role. Traditional plasmonic materials (Au, Ag, Cu) have very strong electron-electron and electron-phonon interactions, leading to rapid carrier cooling to the room-temperature energy distribution (few ps timescale). HfN has been shown to have carrier cooling that is approximately 1000 times slower, which should improve the efficiency of hot carrier effects. In this project you will repeat a very recent literature report for HfN solution synthesis and characterize the plasmonic properties of the nanoparticles in solution and at the single particle level.

3. Lasers via perovskite nanocube assembly (supervisors: Jian-Yao Zheng, Harshal Agrawal)

Bottom-up fabrication strategy has emerged as one of the unique routes to realize complex nanodevices. In the *Nanoscale Solar Cell* group, we are able to synthesis, assemble and chemically weld together high-quality perovskite nanocubes various single-crystalline pre-designed patterns (Figure 1a). This project aims to fabricate ring resonator lasers by assembling the perovskite nanocubes by stamping, a technique being actively explored in our group (Figure 1b). These ring resonators will show lasing with the mode dependening on the cavity length (Figure 1c). By integrating perovskite nanocubes with different emission wavelength, we can realize multicolor lasers from the same ring cavity (Figure 1d). We can also couple two ring resonators - one providing gain, the other providing loss. Many of the fascinating aspects of parity-time symmetry can be explored in such devices, such as the "exceptional points" - conditions where a system's allowed modes coalesce into a single mode (Figure 1e).

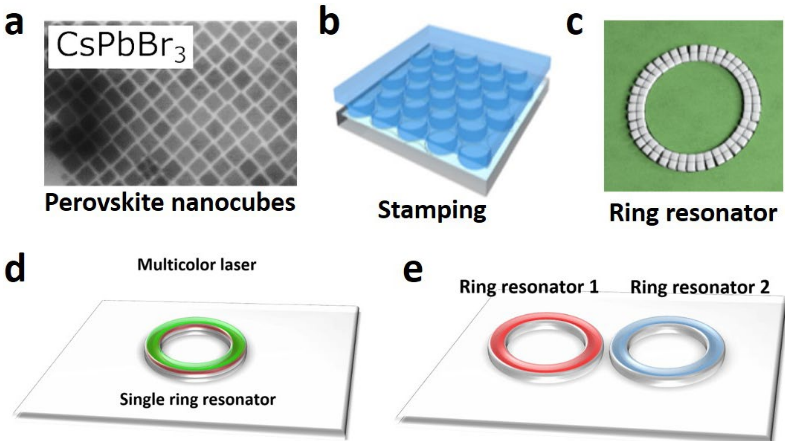


Figure 1. (a) Perovskite nanocubes synthesized in our group; (b) Sketch of the stamping technique; (c) Schematic of a ring resonator; (d) A single ring resonator with two layers of perovskite nanocubes; (e) Two coupled ring resonators.

4. Improving stability and quantum yield of 2D halide perovskites (supervisor: Biplab Patra)

2D perovskites are ideal candidate as a source of quantum confined excitons which can be very interesting for applications in luminescent solar concentrators and as well as for polariton-induced room-temperature superconductivity. Unfortunately, to date 2D perovskites are either not stable enough or not bright enough for these demanding applications. Therefore, the central goal of this project is to make stable 2D perovskites with high photoluminescence quantum yield. Both the synthesis of new 2D perovskites and the improvement of existing ones from literature, will be pursued. You will work with an experienced chemist as well as physicists to understand the formation and the stability of perovskites and measure their photoluminescence quantum yield.

Photonic Forces group

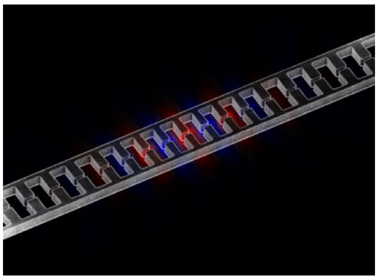
PI: Ewold Verhagen (verhagen@amolf.nl, www.optomechanics.nl)

Research theme The *Photonic Forces* group studies light-matter interactions in nanophotonic systems, trying to push the boundaries of our abilities to measure and control both light and motion at the nanoscale. We are particularly interested in the interaction between photons and phonons in nano-optomechanical systems, where radiation pressure allows unusual quantum and classical behavior.

Project 1. Quantum control of mechanical motion through nanophotonic measurement

Supervisors: Giada la Gala, Jesse Slim, and Ewold Verhagen

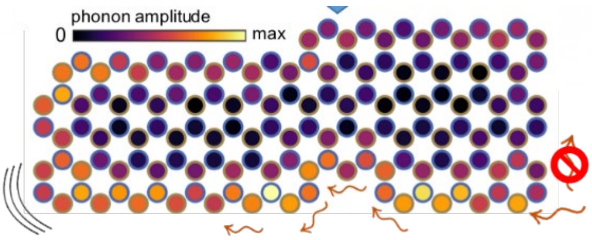
In this project, you will confine light in tiny optical cavities to both measure and control mechanical vibrations in the quantum regime. To this end, you will make special nano-optomechanical resonators that allow light to be used to sense mechanical displacements smaller than the diameter of a proton. Combining such measurement with radiation pressure forces, we will attempt to cool and control the mechanical resonator in the regime where quantum fluctuations dominate its motion. This project combines nano-engineering, advanced optical interferometry, and cryogenic measurements.



Project 2. Topological phonons in optomechanical chains

Supervisors: Javier del Pino and Ewold Verhagen

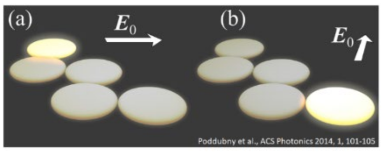
The concept of topology has revolutionized condensed matter physics, leading to exciting phenomena such as one-way electron transport and states that are protected from imperfections. In this theoretical project, you will explore topological physics for *phonons* in optomechanical arrays. We have recently shown that light fields can mediate the transfer of a mechanical vibration from one resonator to another through radiation pressure, and impose the same effect as a magnetic field has on electron transport. You will learn how this can be used to create topological states of sound in one- and two-dimensional resonator lattices. Then, you will look for the emergence of new topological states that do not have electronic counterparts, through the inclusion of naturally occurring nonlinearity in optomechanical systems.

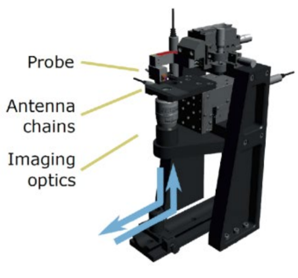


Project 3. Nanoscale particle detection with optical antennas

Supervisors: Robin Buijs and Ewold Verhagen

The ability to detect and image objects with subwavelength dimensions is an important challenge for a wide variety of applications. Optical nano-antennas (metallic nanoparticles) scatter light very strongly, but can be coupled together to form chains that are dark almost everywhere, through so-called topological modes. In this project, you will investigate how such topological chains can be used to effectively detect a nanoscale object in their optical near field. To this end, you will position an ultrasharp needle with few-nanometer precision near the antennas, and study how this affects their optical scattering properties. This project combines nanofabrication, theoretical modeling, and optical nano-imaging.





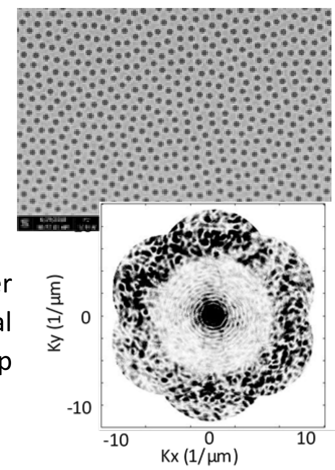
3D Photovoltaics Group

Esther Alarcon (e.alarconllado@amolf.nl)

Research Theme: The ultimate goal of the group 3D Photovoltaics is to push the frontiers of nano-PV by aiming towards the achievement of low-cost semiconductor nanostructures as building blocks. We focus on the fundamental understanding of the potential benefits and/or limitations of semiconductor nano-structures when used for solar energy conversion. These include exploring non-traditional conversion principles enabled by the nano geometry or the fundamental development of cost-effective nanofabrication methods.

Project 1: Exploring photonic properties of hyperuniform arrangement of vertical nanowires for ultrathin tandem solar cells

Supervisors: Nasim Tavakoli and Esther Alarcon Llado

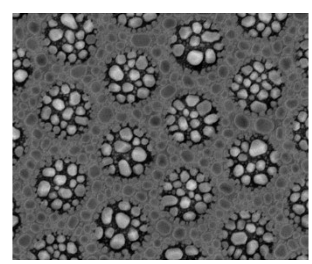


We have explored the photonic behavior of vertically standing array of nanowires (NW) with different geometries on Si ultrathin bottom cell. Optical coupling between the two cells gives dual functionality to the NW array: High absorption in the top cell and light trapping in the bottom cell. This theoretical project is designed to push the conversion efficiency of this system even further by optimizing light scattering in the k-space. We would like to explore even smarter arrangement of the NWs –hyperuniform- with different diameters/height. Optical FDTD simulation gives us the opportunity to build up this complicated system step by step to gain a thorough understanding of its unique photonic properties.

Project 2: Electrochemical mediated InGaAs growth for thermal photovoltaics

Supervisors: Marco Valenti and Esther Alarcon Llado

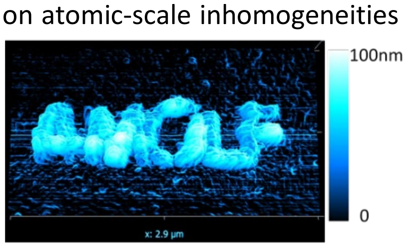
Thermal photovoltaics (TPV) exploits the thermal radiation emitted from hot materials to generate electricity in the same way as in PV, but with a short bandgap semiconductor. InGaAs has a composition-tunable short bandgap which is a promising light absorbing material for TPV. This ambitious project consists in making InGaAs with control over its size, morphology and composition dependent optoelectronic properties for its use in TPV. In our lab, we have demonstrated the growth of InAs by using an electrochemical set-up with in-situ optical monitoring. Beyond InAs bulk, nanostructures are being pursued by using Indium nanoparticles.



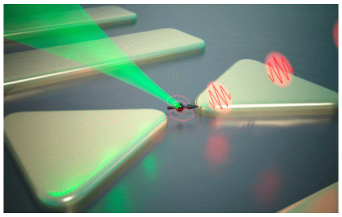
Project 3: Investigating Polarized Solid-Electrolyte Interfaces by Atomic Force Microscopy during electrochemical growth

Supervisors: Mark Aarts and Esther Alarcon Llado

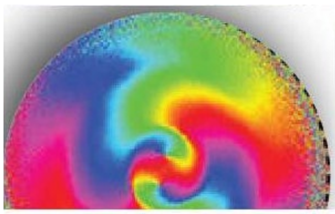
Chemical reactions at the solid-liquid interface are widely used in industrial applications for material fabrication, and are also critical for the production of sustainable fuels such as hydrocarbons and hydrogen. While it has become apparent that the processes arising at the phase boundary are dependent on atomic-scale inhomogeneities such as kinks and defects, they are still poorly understood. We use an atomic force microscope to detect ionic forces at and near the surface, by using a nanometer-sized probe and collecting force-distance curves at high frequencies, within the framework of local electrochemical deposition. We will investigate fundamental questions regarding the makeup of this interface as a function of salt concentration, polarization, and topography.



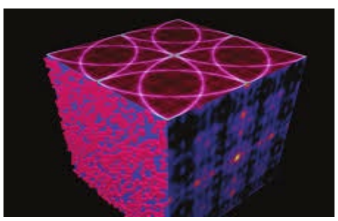
Resonant Nanophotonics group - contact Femius Koenderink



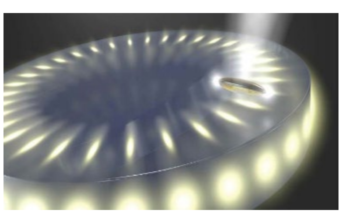
About the group - The Resonant Nanophotonics group investigates the fundamental physics of light-matter interactions at the nanoscale, with as main strengths plasmonics, metamaterials, hybrid nanophotonic resonators, and their coupling to fluorophores and single quantum systems. The group also explores applications in solid-state lighting, optical metrology and microscopy. More information about the group at https://amolf.nl/research-groups/resonant-nanophotonics and at http://www.koenderink.info and via email at f.koenderink@amolf.nl



Project 1: Partially-coherent Fourier interferometry for optical metrology
[Daily supervisor – Ruslan Röhrich] Fourier or k-space imaging is a fast and precise optical microscopy technique for single-shot measurements of the angle-resolved far-field scattering properties of small objects, even single nano-scatterers. Previously, our group has implemented a Fourier imaging setup with polarization and phase sensitivity for scatterered light, using a holography approach. The next step is to include a spectrally tuneable, partially-coherent light source, so that we can perform partially-coherent Fourier interferometry. The significance for fundamental nanophotonics is that radiation pattern tomography in polarization, phase *plus* wavelength, allows for a full understanding of nano-antennas and metasurface building blocks. This project mainly requires affinity with interferometry experiments and imaging processing algorithms. It has direct applications in semiconductor metrology.



Project 2: spatially programming gain in plasmon lattices and metasurfaces
[Daily supervisor – Radek Kolkowski & Isabelle Palstra] In our group we have recently studied plasmonic lattice lasers. These consist of arrays of nanoscale plasmonic particles covered in a gain medium of dye. By an interplay of strong scattering and local "lightning-rod" field enhancement, these systems act as a laser. An outstanding question is how these systems behave on the level of a few or even single unit cells. By spatially structuring the pump light that excites the gain medium, you can selectively and locally program the gain and loss inside the plasmonic array. By studying how the laser responds to this structured illumination, which you will generate with a programmable liquid-crystal "Spatial Light Modulator" (SLM) you can study which parts of the gain medium are participating in the lasing process and how this process of lasing happens on the scale of a few unit cells. For this project the `set up is running' – it requires the drive to do clever optics tests to elucidate conceptually challenging physics.



Project 3: Flow-cells to probe high-Q plasmonics with single emitters
[Daily supervisor – Isabelle Palstra & Ilan Shlesinger] Our group studies resonators for light in which light-matter interaction is enhanced in exceedingly narrow gaps (5 to 25 nm). Examples are recently realized "hybrid resonators" composed of high Q microcavities and plasmon antennas. Using these requires emitters to be placed in very narrow gaps between plasmonic particles. Unfortunately, these systems are notoriously difficult to fabricate using lithographic techniques. One pathway lies in the creation of a flow cell around the antenna structures, so that emitters can freely diffuse into and out of the gap. The objective of this project is to fabricate systems of antennas inside a flow cell and to do time-correlated single-photon counting measurements on them, focusing on fluorescence bursts to quantify light-matter interaction. This project is for students that have a drive for nanofabrication technology combined with fluorescence microscopy.

Interacting Photons

*David van der Flier, Zhou Geng, Kevin Peters, Said R. K. Rodriguez**
**s.rodriguez@amolf.nl*

Research theme: We investigate physics emerging from photon interactions in tunable optical micro-cavities. Our fundamental interests include quantum simulation, critical phenomena, noise-assisted transport, and cavity-enhanced materials. We are also interested in applications of interacting photonic systems, e.g. optical memories, switches, isolators, sensors, and quantum networks.

Master's projects & Internships: To give you a flavor of research projects available in our group, we propose 3 projects below. All projects involve experimental work in state-of-the-art setups, and accompanying theoretical work depending on your interests and skills.

Project 1. ***Light-induced superconductivity***
Supervisors: David van der Flier and Said Rodriguez

In this project you will explore how to dynamically and locally enhance (up to infinity) the electrical conductivity of materials inside an optical cavity. Recently, it was predicted that the coupling between a two-dimensional electron system and an excitonic system (i.e., a semiconductor) inside a cavity can enable electrical current to flow without resistance. This transition to a superconducting state depends on the number of photons in the cavity, which can be controlled with a laser. To explore this effect, you will measure the electrical conductivity of two-dimensional (2D) materials inside a laser-driven tunable cavity. For this purpose, you will first fabricate micron-scale electrodes to contact 2D materials; this part of the research will be done in collaboration with the group of E. Garnett at AMOLF. Next, you will measure conductivities while varying the cavity length and the laser power. You will perform these experiments across a wide range of temperatures, from ambient down to 4K. To achieve this, you will use a new closed-cycle cryostat (see Fig. 2) specially designed for experiments demanding extremely high mechanical stability; this is the first system of its kind in Europe.

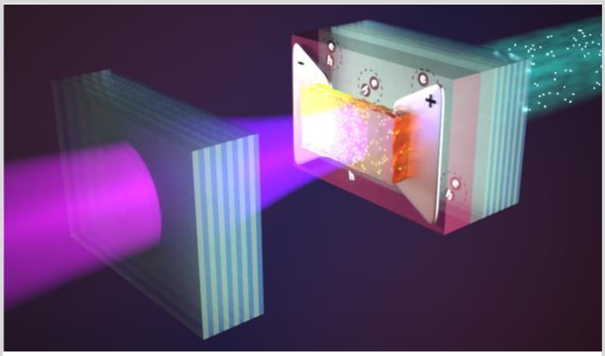


Figure 1. An optical cavity contains 2 semiconductors, one hosting excitons (under the electrodes) and another conducting charges. Light-induced superconductivity has been predicted for this system.

Project 2. ***Quantum nonlinear optics in a tunable micro-cavity at 4K***
Supervisors: David van der Flier and Said Rodriguez

In this project you will probe the quantum nonlinear dynamics of a tunable optical micro-cavity containing 2D materials. For these experiments you will cool the sample to 4K using our state-of-the-art stabilized closed-cycle cryostat (Fig. 2). At low temperatures we expect to observe the formation of excitons with high principal quantum number, i.e. Rydberg excitons. These Rydberg excitons are associated with an extremely strong optical nonlinearity, which is promising for accessing the quantum regime of single-photon nonlinearity. Your goal will be to strongly couple Rydberg excitons in 2D materials to micro-cavity modes, and to measure the linear and nonlinear optical response of the hybrid exciton-photon system. This project involves collaborative work with the group of E. Garnett, who is fabricating the 2D materials you will use.

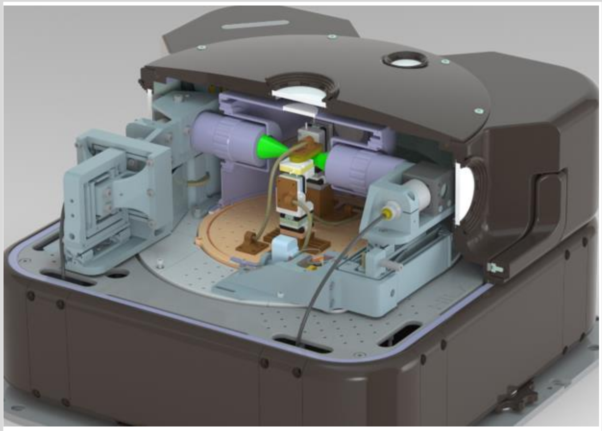


Figure 2. Our tunable cavity in a closed-cycle cryostat with free-space optics.

Project 3. ***Spontaneous symmetry breaking in coupled nonlinear optical micro-cavities***
Supervisors: Zhou Geng and Said Rodriguez

Spontaneous symmetry breaking (SSB) occurs when a symmetric system ends up in an asymmetric state. SSB is one of the most fundamental processes in physics, underlying for example the Higgs mechanism, Bose-Einstein condensation, and the laser. In this project, you will explore the SSB phase transition of two coupled nonlinear optical micro-cavities. To evidence this effect, you will use a state-of-the-art tunable cavity setup which our group recently constructed. The system already enjoys a strong optical nonlinearity (necessary for SSB), and we can measure the cavity dynamics across ~5 orders of magnitude in time. In this project, you will extend the capabilities of the setup so that you can measure the cavity-resolved dynamics of two strongly coupled micro-cavities simultaneously. You will model your experiments with a system of coupled nonlinear stochastic differential equations. Our group is already experienced with nonlinear stochastic differential equations. On the theory side, your task will be to build upon our recent efforts by extending our model to deal with coupled systems and apply it to the SSB problem, i.e. to model your experiments.

Photonic Materials group

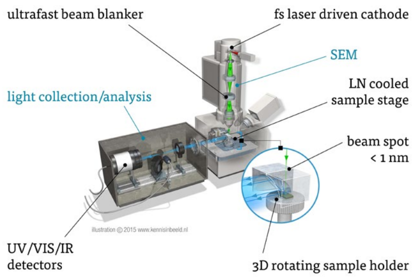
Albert Polman (polman@amolf.nl; www.erbium.nl)

Research theme The *Photonic Materials* group studies the interactions between light, electrons, and matter at the nanoscale. We develop new materials and concepts for solar cells with improved efficiency, create optical metasurfaces that can perform mathematical operations (optical computing), and develop time-resolved cathodoluminescence spectroscopy to study ultrafast optical phenomena at the nanoscale. All these topics are strongly linked and we have a strong culture of collaboration within our group.

Project 1. Pump-probe cathodoluminescence spectroscopy of ultrafast phase transformations

Supervisors: Magda Sola Garcia, Kelly Mauser and Albert Polman

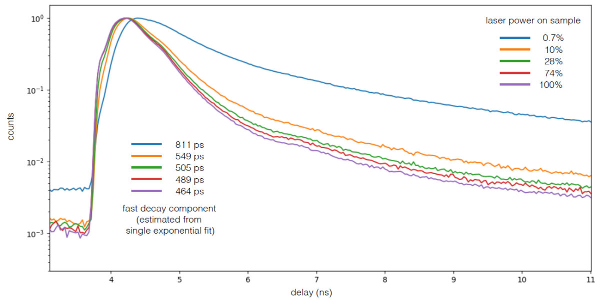
In this project you will use our group's newly developed ultrafast cathodoluminescence (CL) microscope. You will use 200-fs laser pulses (λ=345, 517 nm) to excite materials and probed them with 1-picosecond 5-30 keV electron pulses to generate CL with nanoscale spatial resolution. You will use the new technique to investigate ultrafast light-induced excitations in nanostructures and metasurfaces made of Si, indium-tin-oxide and InGaN. The pulsed laser creates phase transformations and carrier dynamics that reflect themselves in ultrafast changes in the resonant cathodoluminescence spectra. In this way you will obtain fundamental insight in light-electron-matter interactions at ultra-small and ultra-fast time scales.



Project 2. Ultrafast electron-induced carrier dynamics in photovoltaic semiconductors

Supervisors: Matthias Liebtrau and Albert Polman

In this project, you will reveal the generation and recombination dynamics of carriers in photovoltaic semiconductors generated by 5-30 keV electron pulses. You will use our time-resolved cathodoluminescence (CL) microscope to generate dense cascades of electrons and holes that recombine by emission of CL. From the CL decay dynamics you will probe the carrier recombination mechanisms and learn details of the electron cascade dynamics. By varying the energy, number of electrons per pulse and pulse duration you develop and test models to obtain fundamental insight in the mechanism of electron-induced carrier generation in semiconductors.



Project 3. Resonant metasurface spectral splitters for tandem solar cells

Supervisors: Tom Veeken, Andrea Cordaro, and Albert Polman

In this project, you will develop optical metasurfaces to control scattering of light in order to create solar cells with improved efficiency. We will develop spectrally selective surfaces composed of metallic and dielectric nanoantennas that serve as a spectrum splitter for a multi-junction solar cell in which the individual cells are arranged in parallel, rather than in series. We will use inverse-design algorithms and concepts of neuromorphic computing to develop light scattering architectures with optimized performance. The structures will be made using cleanroom nanofabrication and applied to create a Si/GaAs parallel tandem solar cell.