Information on available Bachelor / Master projects in the PSN group
(applies to TU/e students only)

**General:**

- For a description of the group's research topics and teams: [https://www.tue.nl/en/research/research-groups/photonics-and-semiconductor-nanophysics/](https://www.tue.nl/en/research/research-groups/photonics-and-semiconductor-nanophysics/)
- For general information on Bachelor End Projects: Contact PSN secretary, secretariaat.psn@tue.nl
- Master projects and Bachelor projects for Q1-Q3 will be defined on demand – you can contact the staff member(s) responsible for the research topics of interest
- A short description of Bachelor projects for Q4 is given in the following pages. For specific information on the project and to apply for it you can directly contact the staff member in charge. All projects can be defined for 10 or 15 ECTS.
Active nano-optomechanics (BSc/Master project)

Supervisors: Pierre Busi/Matteo Lodde/Andrea Fiore (a.fiore@tue.nl)

Radiative transitions such as spontaneous and stimulated emission are directly related to the interaction between emitter and electromagnetic field. In optimized structures where the field varies with a physical displacement of the cavity boundaries, this leads to a coupling of the state of the quantum emitter, the cavity field and the mechanical oscillator. This effect, theoretically proposed in our group, can lead to new protocols for generating and controlling quantum states of the mechanical oscillator (e.g. single phonons), for application in quantum information processing. In this project, you will investigate structures designed to realize this effect, and particularly measure the optical and mechanical properties of waveguide-coupled opto-mechanical photonic crystal cavities with quantum emitters.
Nanophotonic fiber-optic sensors (BSc/Master project)

Supervisors: Luca Picelli/Gustav Lindgren/Andrea Fiore (a.fiore@tue.nl)

Photonic crystals are nanophotonic structures based on a periodic modulation of the refractive index. They allow defining sharp spectral resonances whose wavelength depends on the environment (temperature, refractive index, force, etc), making them exquisite optical sensors. Our group is exploring photonic crystal sensors placed on the tip of optical fibers and optimized for read-out via the fiber. In this project, you will explore the optical properties of these structures and their application to a practical sensing problem. Depending on timing and personal interests, the project could include the design of optimized structures, the measurement of the reflectance spectrum and optimization of the read-out method, and/or the demonstration of sensing of forces and mass in gaseous or liquid environments.
Nanophotonic spectrometers (BSc/Master project)

Supervisors: Kaylee Hakkel/Anne Sauermann/Andrea Fiore (a.fiore@tue.nl)

Our group is working on highly integrated microspectrometers for application in the food production and supply chain, for example to monitor the growth of plants and the ripeness of fruit, by measuring the reflection or transmission spectrum. These spectrometers use advanced nanophotonic concepts to produce complex spectral responses in an extremely compact and integrated device. In this project you will investigate the optical and electro-optical properties of integrated spectrometers, and assess their potential application for near-infrared spectrometry. Depending on the personal interests, the activities could include the design of advanced optical structures, the experimental characterization of the optical response, dark current and noise on fabricated spectrometers, and their application in a food sensing experiment.
Supermodes in nanophotonics (BSc project)

Supervisors: Gabriel Castellanos Gonzalez / Jaime Gómez Rivas (j.gomez.rivas@tue.nl)

Optical cavities are characterized by the storage of electromagnetic energy in the form of optical modes. These optical modes define the performance of cavities in various applications, such as lasers, switches and sensors. Losses of electromagnetic energy from the cavity are characterized by the quality (Q-)factor of the cavity, which provides the number of optical cycles that can be stored before the energy is lost. The Q-factor defines the life-time of the optical mode, its spectral line width and the ultimate performance of the cavity. The losses can be of two kinds: electromagnetic absorption by the materials forming the cavity or radiation leakage from the cavity.

A careful design of the cavity structure can lead to the full suppression of the radiation leakage from the cavity by destructive interference of the scattered electromagnetic fields. If the cavity is made of non-absorbing dielectrics, the absorption losses can be also suppressed. In this situation, supermodes with an infinite life-time and an infinitely narrow line width (infinite Q-factor) are formed. These supermodes can be used to reduce the threshold of optically pumped lasers, or to increase the sensitivity of optical sensors.

In this project, you will investigate the properties of supermodes in nanocavities formed by non-absorbing nanoparticles. These supermodes will be used to reduce the threshold of organic nanolasers. Skills that you will acquire during the project are: Modelling cavity modes in nanophotonic cavities, working with (ultra-fast) laser systems, performing high precision optical measurements, analyzing these measurements to obtain information such as Q-factor, mode lifetime, lasing threshold, spatial and temporal coherence, beaming, etc.

Figure: photograph of arrays of nanolasers emitting at different wavelengths
Near-field terahertz spectroscopy of organic semiconductors (BSc project)

Supervisors: Stan ter Huurne/Jaime Gómez Rivas (j.gomez.rivas@tue.nl)

Organic materials have attracted great interest over the years for their unique characteristics and potential in optoelectronic applications - for example as organic transistors, organic light emitting diodes and organic solar cells. In comparison with inorganic devices, their organic counterparts are lightweight, flexible and inexpensive. Consequently, a lot of efforts are dedicated to increase the efficiency and stability of these materials.

We have recently developed a unique near-field microscope that can generate and detect radiation in the deep infrared region of the electromagnetic spectrum, i.e., the terahertz (THz) frequency range. This microscope can detect the time dependent free carrier absorption of materials after photo-excitation with ultrashort optical pulses and with subwavelength spatial resolution, which allows to determine the carrier mobility and free carrier density.

In this project we will investigate the properties of organic semiconductors using THz near-field microscopy and, more specifically, how these properties can be modified and enhanced using resonant (nanophotonic) structures, which can interact with the semiconductor. The impact of this research is in improving the performance of organic opto-electronic devices using novel nanophotonic concepts and to use THz microscopy to characterize this improvement.

Skills that you will acquire: working with (ultra-fast) laser systems and THz systems, performing high precision optical measurements, analyzing these measurements and obtaining information to decide further steps to improve the behavior of organic semiconductors and optoelectronic devices.
Strong light matter interaction to manipulate singlet fission in photovoltaic materials (MSc or BSc Project)

Supervisors: Matthijs Berghuis/Jaime Gómez Rivas (j.gomez.rivas@tue.nl)

When light is absorbed by an organic semiconductor, an electron hole pair (exciton) is created. Understanding and controlling these states is very important for optoelectronic applications. Some materials have the remarkable property that one excited (bright) singlet exciton can split into two (dark) triplet excitons. This process is called singlet fission. Singlet fission can enhance the efficiency of solar cells, by creating two energy carriers out of one photon. To achieve enhanced photovoltaic performance, it is important to have efficient singlet fission.

In this project we will investigate how the singlet fission rate can be influenced by strong light-matter interaction. When an excitonic material is put in an optical cavity with the electromagnetic mode tuned to the energy of an exciton, the two modes interact and influence each other. When the interaction is strong enough this leads to the formation of two new modes, called polaritons. These polaritons have partial photonic and excitonic character. This hybrid character can have a large influence on many properties of the excited states in the material, such as the effective mass, delocalization of the wave function and energy levels. As the coupling only affects the bright states and not the dark states, one can tune singlet energy with respect to the triplet energy. The goal of this project is to investigate how the tuning of these two levels may affect singlet fission.

During this project you will do simulations on the properties of polaritons in a plasmonic array of nanoparticles defining an optical cavity. You will have to design and characterize systems that support exciton-polaritons and investigate the properties of the hybrid material using advanced nanophotonic techniques.
THz radiation on demand (MSc or BSc Project)

Supervisors: Niels van Hoof/Jaime Gómez Rivas (j.gomez.rivas@tue.nl)

In the PSN group we are interested in the strong interaction between light and matter. This is a quickly evolving field of research in which new materials, experimental techniques and theories are realized continuously. In our group, we have developed a unique near-field microscope that can generate and detect radiation in the deep infrared region of the electromagnetic spectrum, i.e., the terahertz (THz) frequency range. This region holds great promise for applications in non-invasive testing, imaging and spectroscopy, as well as high speed wireless communication. These applications will benefit greatly from the development of structures that could achieve switching on ultra-fast timescales. We work with resonant structures that can strongly couple THz radiation with matter to achieve this ultra-fast switching. Our unique microscope can map the local electric field vectors near these structures (see Figure), thereby gaining new insight into the fundamental processes in these strongly coupled systems. Project goal: Design a resonant system that can capture, hold and release THz radiation on demand, showing ultimate control over the propagation of radiation through that system. This research will provide new ways to store and process information without the need of converting it to electrical signals. Skills that you will acquire: working with (ultra-fast) laser systems, working with optics, simulate, create and measure your own photonic structures.

Figure 1: (left) Schematic representation THz near-field measurement. (right) Resonant THz near-field amplitude measured on a dolmen structure formed by a horizontal gold rod and two vertical gold rods.
Nanofabrication of crystalline semiconductor nanoantennas for chiral light-matter interaction (MSc project)

Supervisors: Rasmus Godiksen / Raziman TV /Ershad Mohammadi/ Alberto Curto (A.G.Curto@TUE.nl)

Light gives us information about the chemical and structural composition of matter. Circular dichroism (CD) is one of the most successful and precise optical spectroscopy techniques. It reveals tiny asymmetries in the conformation of nanometric objects of interest like proteins or drugs. CD signals reflect the normalized difference in absorption of a compound when illuminated with light of right- and left-handed circular polarizations. Chiroptical signals are, however, very weak, limiting their potential applications.

In this project, you will experimentally investigate the enhancement of chiral light-matter interaction using nanostructures known as optical nanoantennas. The project revolves around nanofabrication using electron beam lithography and etching of crystalline semiconductor films for achieving high-quality optical resonators. Using circular-polarization-resolved photoluminescence microscopy, the goal of this project is to achieve stronger chiroptical signals by exploiting the optical resonances of the nanoantennas.

Figure: Array of nanodisks supporting localized resonances at visible wavelengths. By exploiting their resonances, it is possible to enhance both the intensity of the fields and their chirality. Different metrics must be used for specific applications, which requires a carefully chosen nanostructure for enhancing chiral fields.
Chiral light emitters: experimental characterization (MSc or BSc project)

Supervisors: Sara Elrafey/Ershad Mohammadi/Raziman TV/Alberto Curto (A.G.Curto@TUe.nl)

Circularly polarized light is widely used to detect chiral molecules. Other applications of chiral light include polarization control for displays or the generation/detection of magnetization. Because most chiral light emitters have very weak circular polarization, some of the fundamental electrodynamic properties of chiral emitters are still unknown.

In this project, we will exploit new materials that show very high circular polarization to elucidate the nature and properties of their optical transitions. In particular, we will use spin-polarized light emission in atomically thin semiconductors as a benchmark case. This project involves experimental work and theoretical modeling. Experimental techniques include photoluminescence spectroscopy, polarization analysis, and the measurement of angular radiation patterns.

Figure: Angular radiation patterns of different types of sources of circularly polarized light. The pattern shape reflects the radiated power in a given direction, whereas the color represents the degree of polarization of the emitted light.
Brightening excitons in two-dimensional semiconductors (MSc or BSc project)

Supervisors: Sara ElRafey/Rasmus Godiksen/Alberto Curto (A.G.Curto@TUe.nl)

Atomically thin semiconductors such as monolayer molybdenum disulfide or tungsten disulfide are promising materials for nanoscale optoelectronics and nanophotonics. Still, their light emission efficiency (quantum efficiency) is generally low. Their low efficiency is due to the complex internal dynamics of excitons, which result in non-radiative decay, exciton-exciton annihilation, or the creation of dark excitons with forbidden optical transitions.

Using nanophotonic resonators, the goal of this project is to enhance the light emitted by a two-dimensional semiconductor coupled to an array of metal nanoparticles. This project involves experimental techniques including photoluminescence microscopy and spectroscopy, low-temperature optical measurements using a cryostat, and fluorescence lifetime imaging. The project might also include electrodynamic simulations depending on the duration and type of the project (BSc/MSc).

Figure: The emission of an atomically-thin semiconductor like monolayer WS$_2$ can be enhanced by depositing it on an array of metal nanoparticles. Left: reflection optical microscopy image. Right: scanning electron microscopy image.
Controlling the flow of excitons with nanophotonics for improved light emission (BSc project)

Supervisors: Raziman TV/Alberto Curto (A.G.Curto@TUE.nl)

Excitons are electron-hole pairs and their recombination can result in light emission. In some of the most promising semiconductor materials like perovskites or atomically-thin semiconductors, excitons can diffuse after their creation and propagate as an expanding cloud for micrometric distances. Such diffusion has an impact on the efficiency of light emission and poses both a problem and an opportunity for nanoscale engineering.

In this Bachelor End Project, you will theoretically combine nanophotonic structures with exciton diffusion to investigate the impact of the exciton transport on the light emitted by semiconductors near optically resonant nanostructures. You will model, design and optimize the response of these systems using available numerical techniques.

Figure: Schematic representation of the problem (left): an exciton near a metal nanostructure emits light. After generation at a given point, the exciton cloud expands. The spatial dependence of the light emitted by the exciton (right) is modified as a result of exciton diffusion.
Guiding light with atomically thin semiconductors (BSc project)

Supervisors: Sara Elrafey / Raziman TV / Alberto Curto (A.G.Curto@TUe.nl)

Future photon-based technologies rely on our ability to control light at an increasingly small scale, with the potential to improve our daily life through impact in information technologies and biochemical sensors. To fully realize the promises of nanophotonics, materials that can interact with light at a correspondingly stronger rate are required to keep up with the miniaturization trend. Thanks to the uniquely high absorption of excitons in atomically thin semiconductors, which produces a dramatic oscillation in the permittivity around the exciton energy, these ultrathin materials can host a range of guided optical modes.

In this Bachelor End Project, you will theoretically study the guided modes and optical resonances supported by atomically thin semiconductors. You will model, design and optimize the response of these systems using available semianalytical and numerical techniques to investigate how light propagates through 1-nm-thick materials.

*Figure: an atomically thin semiconductor supporting excitons (electron-hole pairs).*
Tailoring nanophotonic structures for metrology applications (BSc project)

Supervisors: Raziman TV/Alberto Curto (A.G.Curto@TUE.nl)

The semiconductor industry demands an ever increasing accuracy in the fabrication of nanostructures. An important aspect that could contribute to improved nanofabrication is the ability to obtain nanoscale information about the produced nanostructures using light. Using concepts from nanophotonics, this project aims to identify the most promising sensing strategies for detecting the presence of minute geometrical or material changes.

In this Bachelor End Project, you will simulate the optical response of nanostructures specifically designed for metrology applications. You will use a numerical solver for Maxwell’s equations in order to predict and quantify the sensitivity of different nanophotonic structures and to optimize the structure design and measurement conditions for robust metrology. The goal is to propose realistic designs to achieve sub-nanometer optical metrology in situations of industrial interest.

Figure: an array of nanophotonic structures.
Extracting light from a nanophotonic resonator for quantum measurement of mechanical motion (BSc project at AMOLF, Amsterdam)

Supervisors: Giada la Gala/Jesse Slim/Ewold Verhagen (verhagen@amolf.nl)

In the Photonic Forces group at AMOLF we aim to explore quantum mechanics with macroscopic mechanical systems. To this end, we study special mechanical resonators that incorporate nanoscale optical cavities, such that light can be used to sense mechanical vibrations with extreme sensitivity. Such measurements could allow seeing and controlling quantum fluctuations of the resonators. This project focuses on an important challenge towards reaching the quantum regime: to efficiently couple the light that measures the motion in and out of the nanocavity. Assisted by numerical simulations, you will design a nanophotonic device that explores a new coupling strategy. You will investigate the efficiency in experiment using an optical laser interferometry setup on nanoscale devices fabricated at AMOLF.
Topological phonons in optomechanical chains (BSc project at AMOLF, Amsterdam)

Supervisors: Javier del Pino/Ewold Verhagen (verhagen@amolf.nl)

The field of optomechanics explores the interaction of confined light fields and macroscopic mechanical oscillators via radiation pressure forces. These systems offer excellent optical control over phononic (mechanical) interactions and straightforward scalability, paving the way towards macroscopic simulation of solid state physics on a chip. Our group has recently explored a platform where the (linear) interaction of two phononic modes is tailored through an input laser, imprinting behavior on the phonons that is reminiscent of electrons in a magnetic field (the Aharonov-Bohm effect). Even more exotic phenomena, such as formation of non-bosonic particles, has been predicted if non-linearities are present. In this theoretical project, you will analyze a simple model system, gaining analytical insight and learning how to calculate numerically the phonon states of the system in the presence of light fields. With the know-how acquired you will extend this study to a one-dimensional phononic chain of resonators. There, you will explore how so-called topological phases emerge, allowing states with special properties not normally observed in mechanical systems. You will learn how to characterize these in terms of physical observables.
Optical 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. Perturbing these chains with a sharp probe can lead to a very strong optical signal. We want to turn this effect into a powerful detector for nanoscale objects. Our newly built setup allows us to image samples with optical antennas while we bring a nanoscale probe into their optical near-field. In this project, you will investigate how well topological chains can be used to optically detect nanoscale objects. You will perform optical measurements on systems of interacting optical antennas and image their nanoscale light fields. Then, you will operate a scanning probe setup and study how the probe affects the optical properties of the antennas.
Study and manipulation of individual hydrogen passivated N atoms in GaAs (BSc project)

Supervisors: Douwe Tjeertes/Paul Koenraad (p.m.koenraad@tue.nl)

Does observing and manipulating solid state materials on the scale of single atoms sound interesting to you?

Replacing a small amount of arsenic (As) in gallium arsenide (GaAs) with nitrogen (N) has a remarkable effect on the bandgap, instead of increasing towards the larger value of GaN, the bandgap decreases significantly. This effect can be passivated by exposing the material to a hydrogen plasma. The passivation process is done in collaboration with the Plasma and Materials Processing (PMP) group and a research group in Italy. In this project you will be involved in improving the passivation process together with the PMP group and the study individual N-centers in the passivated N:GaAs with a scanning tunneling microscope (STM). With the STM we can observe single N atoms in the GaAs lattice and manipulate hydrogen on the atomic scale which allows to gain a deep understanding of their atomic scale properties.