Master in Photonics – "PHOTONICS BCN"
Master ERASMUS+ "EuroPhotonics"

MASTER THESIS PROPOSAL

Dates: April 2020 - September 2021

Laboratory: Nonlinear Optics and Lasers Laboratory, DONLL Research Group
Institution: Physics Department**.** Universitat Politècnica de Catalunya
City, Country: Terrassa, Spain

Title of the master thesis: "Nonlinear frequency conversion in strategic materials for nanophotonics"

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Keywords: Nonlinear optics, harmonic generation, nano-optics, nano-materials

Summary of the subject:
This project aims contributing to two important research areas in Photonics: **nonlinear optics** and **sub-wavelength nano-structured optical materials (nanomaterials)**. These interconnected fields provide a major impact for applications in the development of **photonic devices at nanoscale (NanoPhotonics)**. Nowadays nanomaterials are produced and integrated in an important number of devices and applications of Photonics. At these scales new strategies must be sought in order to understand and develop methods to harness the performance of deeply sub-wavelength optical materials having geometrical features that are a few atomic diameters in size.

Nonlinear Optics (NLO) covers different processes, such as parametric frequency conversion, nonlinear scattering, ultrashort pulse generation and characterization and sensing, to name a few. Traditionally, most efforts have been focused towards the study of efficient harmonic generation in phase-matching (momentum conservation) condition in thick materials having large nonlinearities (NL), when the harmonic generation is dominated by the electric dipole ("bulk") contribution to the polarization density of the materials. However, when the material size is reduced to the nanoscale, the efficiency of the bulk contribution is drastically reduced or even vanish and other nonlinear contributions, arising from electric quadrupole or magnetic dipole interactions, become important and must be considered. For instance, in centrosymmetric materials like metals or Si the bulk quadratic nonlinearity vanishes, so that other nonlinear sources become essential to explain NL effects, such as surface harmonic generation. The presence of these terms can account for NL conversion in different situations

traditionally considered as hostile environments for harmonic generation. The experimental detection of very weak harmonic signal generated at nanoscale is essential to obtain unique and unprecedented information in surface characterization and optical microscopy, for example.

The interest of **understanding nonlinear frequency conversion in metals and semiconductors at nanoscale is crucial** since the use of semiconductors as GaAs, GaP, InP or Si, metals as Au and Ag or conductive oxides (ITO, CdO) is pivotal in the fabrication of actual photonics devices at nanometer scales and for implementing very sensitive characterization techniques. Light localization at dimensions smaller than the wavelength is possible using the properties of electric field enhancement by plasmonic resonances in metal-dielectric boundaries, in metamaterials, or under conditions of epsilon-near-zero.

This proposal envisages **an experimental and numerical study aiming to highlight the different mechanisms that play a role in the generation of SH and TH from metal and semiconductor nanolayers and nanomaterials, making special emphasis in the study of structured materials.** Student will first carry out experimental studies of harmonic generation in metal and semiconductor wafers and homogeneous nanolayers, which will be compared with detailed numerical simulations based on a mathematical model that we develop with the aim to explain nonlinear frequency conversion in very thin layers. Secondly, we will extend these results to modulated nanostructures and study the effect of the periodicity and geometry on these NL effects. Interpretation of the experimental results based on the detailed NL model, will allow us to understand the most relevant contributions to the NL effects at nanoscale surfaces.

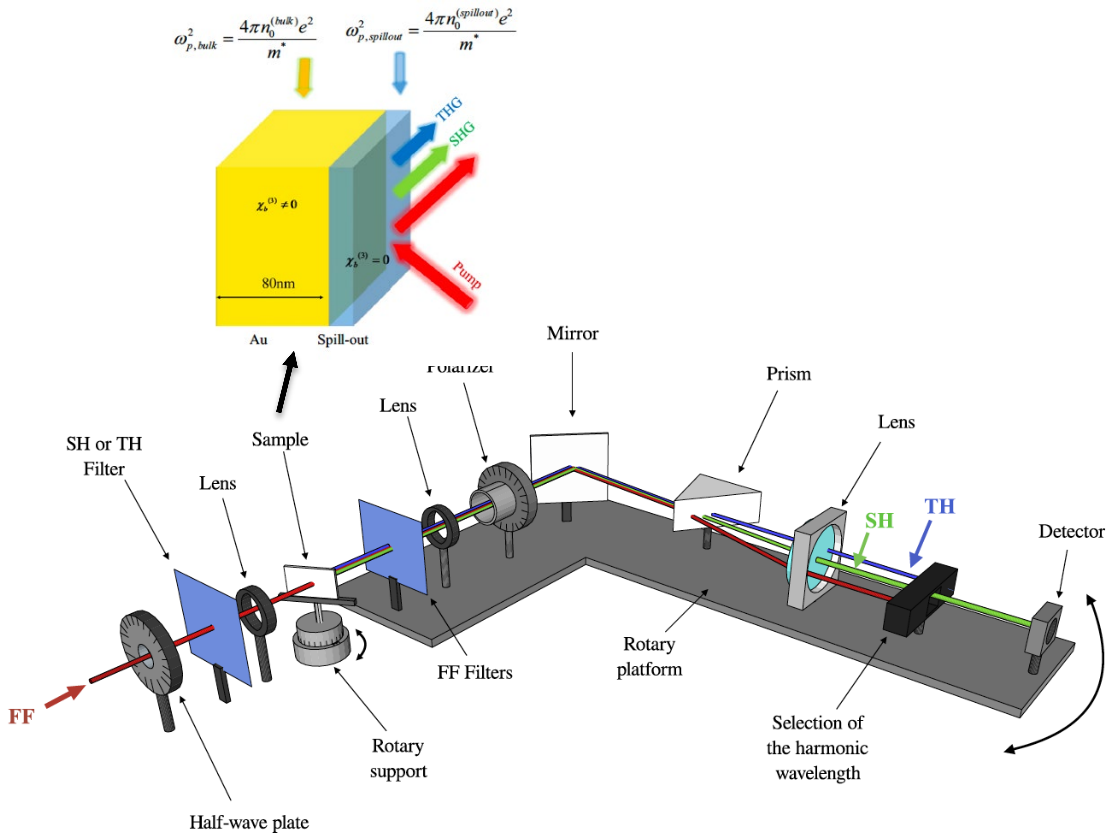

Figure: Schematic representation of the experimental set-up for second and third harmonic generation in nanolayers.

The main objectives for the six months of this thesis can be summarized as follows:
Objective 1: Harmonic generation in homogeneous nano layers: metals and semiconductors.
Objective 2: Enhancement of harmonic generation in conductive oxides (close to their epsilon-near-zero condition) and in structured geometries made of the materials studied in the previous objectives.

Additional information:

* **Required skills:** background in electromagnetic optics and photonics and a strong motivation for setting up and conducting experiments in a lab. Previous experimental skills in optics would be beneficial.
* **Miscellaneous:** This position is particularly suitable for students interested in gaining experimental experience. The candidate will have his/her own project, but will participate in the group activities and meetings in order to maximize the learning experience.
The project could represent the first step towards a future PhD (PhD grant available). Partial monthly allowance is available to cover the travel and daily expenses during the project.