PROPOSAL FOR DOCTORAL THESIS

RECONFIGURABLE PLASMONIC MATRIX ANTENNAS FOR INFRARED EMISSION CONTROL

Director of doctoral thesis:
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Keywords: Nano-optics, plasmonics, nano-antennas, graphene, infrared radiation, light control, electroluminescence, thermal emission, optical near field, SNOM

Profile and skills required: Engineering school and/or Research Master 2
Optics, nanophotonics, taste for experimentation

The aim of this project is to create nanostructured infrared plasmonic antennas based on the repetition of a single sub-wavelength metal pattern (sub-λ) forming the basic building block of an NxN matrix structure. We will design reconfigurable infrared sources by addressing a subset of the sub-λ patterns making up the matrix antenna with visible laser heating forming specific patterns, in particular to control the polarization and spectral position of resonances with a view to creating smart reconfigurable infrared surfaces. We will describe the coupling between sub-λ patterns using simulations based on the quasi-normal mode method.

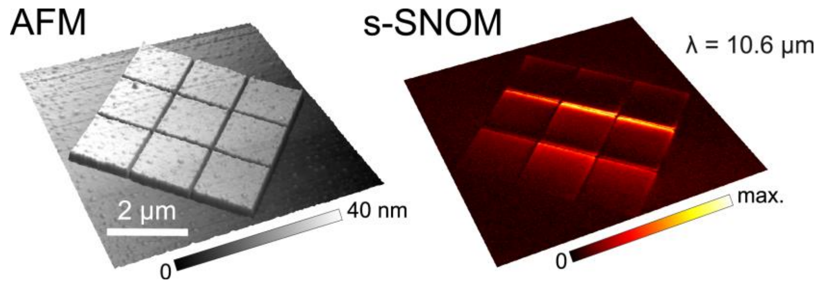

Figure 1: AFM and infrared SNOM (scanning near-field optical microscopy) images of a 3x3 matrix antenna.

The Institut Langevin team and the ONERA team proposing this project have been collaborating for several years on the theme of plasmonic antennas. The basic patterns of these antennas are metallic nanostructures of sub-λ size that possess resonance in the mid-infrared, at a wavelength that depends on both the size of the antenna and the materials that make it up. Observing the spectrum of individual plasmonic antennas is an experimental tour de force, as the signals to be detected are very weak due to the very small antenna size and the overwhelming infrared background. In previous work, we were able to measure the spectral resonance in the thermal radiation spectrum of individual metal-insulator-metal (MIM) antennas consisting of a square metal patch placed on a thin dielectric layer above a continuous metal film [Li2018]. We then combined this type of antenna to form MIM dimers, and demonstrated by spectroscopic measurements the hybridization of certain modes due to near-field coupling between the MIMs [Abou_Hamdan2021]. Finally, we have begun studying more complex systems consisting of arrays of 3x3 antennas [Abou_Hamdan_these]. Until now, the approach used to model the electromagnetic behavior of multi-element plasmonic antennas has been based solely on the use of commercial software (COMSOL, LUMERCIAL).

In this thesis, we will study matrix plasmonic antennas with mid-infrared resonances, whose radiative properties we will control using reconfigurable visible laser heating. The antennas will consist of gold (Au) nanostructures structured in an NxN matrix on a dielectric substrate, which we will heat by absorption of a visible laser beam in order to stimulate their thermal emission in the infrared or modify the dielectric medium to shift the resonance frequencies. The use of a spatial light modulator will enable us to modify the spatial configuration of this laser heating on the antenna array. The result will be a reconfigurable light converter from visible to infrared.

Infrared plasmonic matrix antennas formed by N x N elements of sub-λ size spaced by a gap distance of 100-500 nm will therefore be the focus of our studies, which will be divided into the following main themes:
1) Modeling and design of matrix antennas using quasi-normal modes (Wu2023);
2) Selection of resonant modes (spectrally, in polarization) and control of emission by visible laser heating and an SLM (spatial light modulator);

3) Active control of the spectral position of a plasmonic antenna resonance using near-field couplings and textured illumination, or using an active material.

4) Plasmonic antennas combined with scanning probe microscopy [DeWilde2006] will also be used to couple to the far field infrared electroluminescent radiation produced in hBN encapsulated graphene based devices under [Abou_Hamdan2025].

The experimental methods that will be exploited during the thesis are ultrasensitive and/or super-resolved infrared imaging and spectroscopy methods in which we are specialists, and which we will have to adapt and develop according to the needs of the project: infrared spatial modulation spectroscopy [Li2018, Abou_Hamdan2021], which will need to be adapted to implement heating laser illumination, the TRSTM thermal radiation near-field microscope [DeWilde2006, Babuty2013], and an infrared scattering tip near-field optical microscope (s-SNOM) operating at ambient using tunable laser sources giving access to a very broad spectrum. **The experiments will be complemented by electromagnetic numerical simulations.** These will be carried out using commercial software (COMSOL, LUMERICAL) or developed using the open source software MAN (Modal Analysis of Nanoresonators) developed by Philippe Lalanne and his colleagues.

The doctoral thesis will be carried out in collaboration between the Institut Langevin and ONERA, and in partnership with C2N.

Other collaborations are already at play, notably with the Laboratoire de Physique de l'Ecole Normale Supérieure (Emmanuel Baudin), the Laboratoire Charles Fabry - IOGS (Jean-Jacques Greffet), and the Laboratoire Photonique, Numérique et Nanosciences LP2N- IOGS (Philippe Lalanne). The research will be directed by Yannick De Wilde (Institut Langevin) and Patrick Bouchon (ONERA).

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