POST-DOCTORAL FELLOWSHIP

QUANTUM-EMITTERS-EMBEDDED DIELECTRIC LIGHT-EMITTING METASURFACES

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- Multidisciplinary topic based on the expertise of two laboratories from Toulouse (France).
- Funding by the NanoX EUR for 12 months (starting end of 2024)

KEY WORDS : single photon sources, colored centers, nanodiamond, high-index dielectrics, BICS, metasurfaces, time-resolved optical microscopy, photon correlation, directed assembly, nanoxerography, Atomic Force Microscopy (AFM), numerical simulation of optical properties.

Introduction and context - In order to face the future challenges in communication and data processing, integrated optics and in particular nanophotonics offering deep integration at the nanoscale [1], is an appealing approach that might lead to disruptive technologies. Thus, the development of **advanced integrated light-emitting optical components** is **mandatory** to support this trend. An approach based on individual optically resonant nanostructures ('nanoantennas') has demonstrated the capability to control the emission of quantum emitters (QE) accurately positioned in their optical near field [2]. It has been extensively explored, notably by the partners (Fig 1(a)), unveiling the complex mechanisms of this coupling. Yet **performances of QE-nanoantennas have reached a plateau as the number of degrees of freedom is limited**. Our project provides therefore an original path for a breakthrough with the design, the fabrication and the characterization of complex plasmonic, dielectric or hybrid metal-dielectric **light-emitting 2D metasurfaces for the control of accurately positioned QE**.

Topic - The Q-META project aims to control and enhance the emission properties of quantum emitters (QE) with 2D optical metasurfaces, well beyond performances offered by the single nanoantennas at the state-of-the-art (Fig 1(a)). To do so, the nanosources of non-classical light will be accurately positioned in the near field of 2D dielectric arrays hosting Bound In the Continuum States (BICS). The 2D dielectric arrays will be specifically designed to control the directivity, brightness, chirality, polarization of the QE emission via coupling to localized and collective (BICS) resonances, in the visible/near infrared.

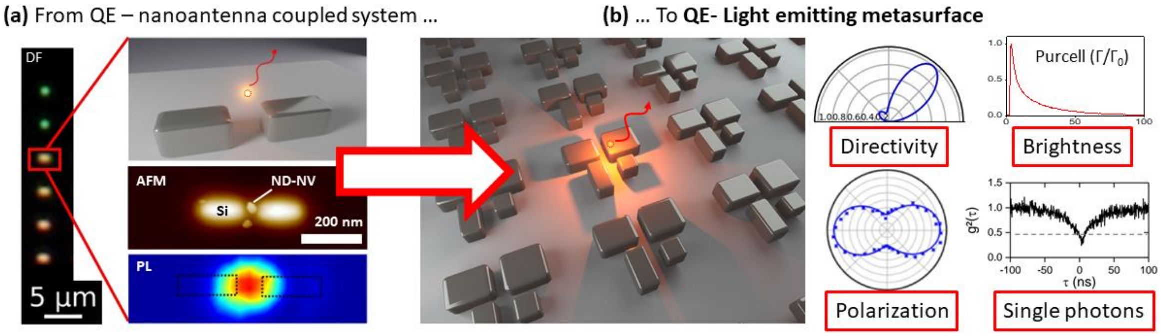

Figure 1. (a) ***Preliminary results from the Q-META partners****: Darkfield (DF)/Atomic Force Microscopy (AFM)/Photoluminescence (PL) images of Si nanoantennas made by ebeam lithography (different sizes/resonances), with a controlled number of nanodiamonds (NV centers) positioned in their gap by AFM nanoxerography [3]. (b)* ***Artistic view of a 2D metasurface embedding a single-photon QE****. Depending on the array design and the building blocks geometry, specific optical features of the QE emission will be controlled in the far field: directivity, brightness, polarization/orbital angular momentum (OAM).*

In this project, the quantum emitters will be colored centers in colloidal nanodiamonds, with typical diameters of few tens of nanometers [4]. NV centers will be preferentially used, but others colored centers available at CEMES will be considered too (collaboration with an academic partner). These different emitters will be systematically characterized by optical methods on operational time-resolved confocal microscopes at CEMES. Wavelength-dependent lifetime measurements and intensity correlation will be used to analyze their temporal dynamics.

The dielectric metasurfaces will be fabricated by ebeam lithography on silicon on insulator (SOI) substrates, thanks to an active collaboration with the LAAS laboratory at Toulouse. The geometry of these 2D metasurfaces will be optimized in collaboration with LAAS by the mean of electrodynamic simulations (Green dyadic method (GDM) coupled to an evolutionist optimization (EO) multi-objectives algorithm) [5].

The spatial and quantitative positioning of the fluorescent emitters in the 2D periodical structure of the metasurfaces will be performed by a directed assembly technique called AFM nanoxerography [6,7]. This technique has been developed in the Nanotech team of LPCNO. It relies on the local injection of electrostatically charged dots by the mean of a polarized AFM tip positioned above the areas of interest. These charged dots will act as selective electrostatic traps for the emitters. The two labs (CEMES and LPCNO) involved in that project recently demonstrated the deterministic and reproducible positioning of nanodiamonds on a flat SiO2/Si film (Fig 2) [8] and on single silicon nanoantennas (Fig 1(a)) [3].

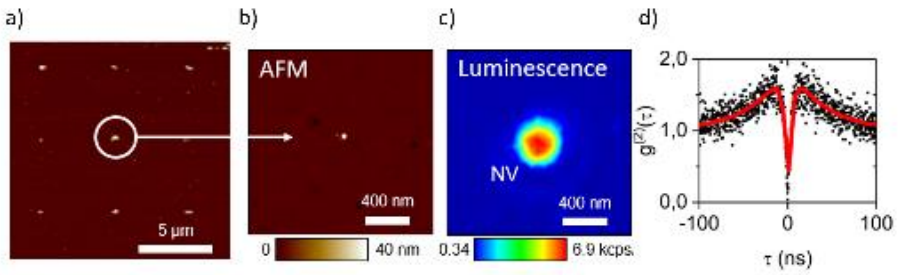

Figure 2: (a-b) Large-scale AFM images of an assembly of nanodiamonds fabricated by AFM nanoxerography. (c) Confocal image of the luminescence of the nanodiamond shown in (b). (d) Autocorrelation $g^{(2)}(t)$ function recorded on the nanodiamond in (b) and (c). The photon antibunching at zero-delay is the signature of a single NV center in the diamond particle.

Once the emitter-metasurface hybrid systems are done, the wavelength- and (dipole) orientation-dependent modification of the photodynamics of the emitters will be measured by 2D mapping of the time-resolved photoluminescence. The directivity and polarization control will be assessed by polarization-resolved back-focal plane imaging. These optical characterizations will be performed at CEMES on state-of-art time-resolved confocal microscopes. The experimental results will be systematically supported by GDM-based simulations.

We look for – A candidate holding a PhD diploma in nano-optics, plasmonics, nanotechnologies, or near-field probes with a solid background in general physics, electromagnetism and light-matter interaction. The postdoctoral fellow will be hosted by the NeO team of CEMES and the Nanotech team of LPCNO at Toulouse (France). The candidate will be involved in the experimental aspects of (i) electrical and topographical modes of AFM, (ii) the process of directed assembly of the quantum emitters by nanoxerography, (iii) the optical characterization at the single photon scale (quantum regime), and to the theoretical aspects of (iv) the methods of electrodynamics simulation. The candidate will have strong skills in experimental research, and prior experience in optical and/or AFM microscopies. Autonomy, dynamism, scientific curiosity and rigor are the key words to carry out this project.

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