Controlled single photon sources based on hBN color centers using nanophotonic structures

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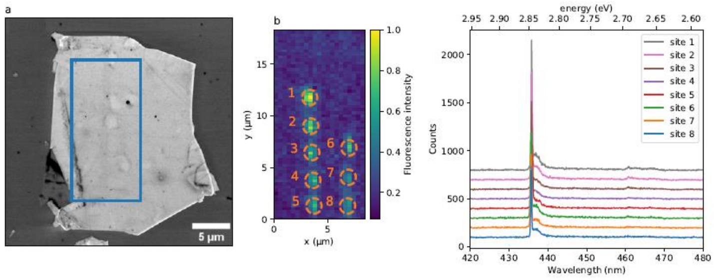
Optically active deep defects in the solid state (also called color centers) can be seen as artificial atoms [1]. They represent a major interest in quantum information science, owing to their potential as single photon emitters and their possible integration in nanostructures and devices. An emblematic example is the NV (nitrogen-vacancy) center in diamond [2]. Recently discovered color centers in the 2D material hBN (hexagonal boron nitride) bring new perspectives of integration and applications in quantum technologies [3]. In particular, the two-dimensional nature of the host material opens new possibilities for integration with nano-optical structures such as plasmonic resonators and antennas.

The project will take place in the Quantum Nanophotonics team, which combines an expertise in single-emitter nanophotonics [4] and quantum optics with individual color centers [5]. In particular, they have recently demonstrated deterministic positioning and photon indistinguishability of hBN color centers [5-7].



(a) hBN flake (single crystal of a few tens of nanometers thickness).
(b) Confocal photoluminescence map. Eight irradiation sites all gave rise to color centers.
(c) Emission spectra of the eight sites, revealing similar emission lines.

The objective is to realize integrated quantum devices based on visible-range single-photon emitters in hBN with controlled light-matter interaction by including the hBN emitters in nanophotonic structures including in-situ lithographic photonic structures and plasmonic resonators. The aimed Purcell enhancement (5 to 10) will allow photon indistinguishability greater than 90 % [7].

The first direction will consist in the deterministic fabrication of dielectric structures around pre-chosen quantum emitters using direct laser writing (DLW) based on a photosensitive polymer (SU8), in collaboration with the team of Ngoc Diep Lai in LuMIn laboratory (ENS Paris-Saclay). This technique has already allowed, through a fruitful collaboration between LuMIn and GEMaC, to realize photonic structures embedding colloidal quantum dots to increase their brightness and stability as well as to guide the emitted photons [8-10]. This approach also allows in-situ lithography for the realization of monolithic or hybrid photonic structures [11].

The second approach will make full use of the unique combination of the minimal thickness of hBN flakes (down to a few monolayers, i.e. a few nanometers) and the extreme light confinement that can be achieved in metallic nanostructures such as gap plasmons structures [12]. This allows very high Purcell enhancements that would not only inhibit the effect of pure dephasing but also of spectral diffusion, which we shown to be of the order of 20 natural linewidths [13]. This would enable emission of indistinguishable photons at timescales longer than the diffusion time, and would therefore open the way to indistinguishable photons from remote sources, an essential step for scalable integrated quantum optical computing.

The experimental studies will include sample fabrication and optical experiments that will be based on photoluminescence spectroscopy, resonance fluorescence and photon counting / interferometry techniques (Hanbury Brown and Twiss, Hong-Ou-Mandel), as well as near-field optical microscopy. Numerical simulations can also be envisaged.

[1] I. Aharonovich, D. Englund and M. Toth, Nature Photonics **10**, 631 (2016)
[2] H. Bernien *et al*., Nature 497, 86 (2013); B. Hensen et al., Nature **526**, 682 (2015)
[3] S. Azzam, K. Parto and G. Moody, Appl. Phys. Lett. **118**, 240502 (2021)
[4] T. P. L. Ung *et al*., Nanophotonics **9**, 793 (2020)
[5] C. Fournier *et al*., Nature Communications **12**, 3779 (2021)
[6] S. Roux *et al*., Appl. Phys. Lett. **121**, 184002 (2022)
[7] C. Fournier *et al*., arXiv:2210.05590 (2022)
[8] T. H. Au *et al.,* Nanoscale Adv. 1, 3225 (2019)
[9] T. H. Au *et al.*, ACS Photonics 6, 11 (2019)
[10] G. L. Ngo *et al.*, AVS Quantum Sci. 5, 011403 (2023)
[11] D. Gérard *et al.*, arXiv:2304.00130 (2023)
[12] G.-C. Li *et al*., Nanophotonics **7**, 1865 (2018); D. Kos *et al*., ACS Nano **15**, 14535 (2021)
[13] C. Fournier *et al.*, arXiv:2303.05315 (2023).

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