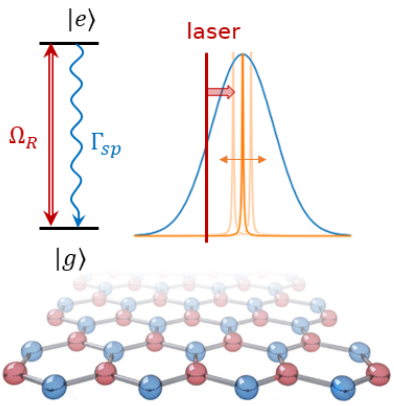
GEMaC

Groupe d'Étude de la Matière Condensée

NANOSTRUCTURES AND COLOUR CENTRES



This research topic aims at studying the physics of native or artificially induced colour **centres in wide gap semiconductor nanostructures** and integrating them in **devices for quantum technologies**.

Colour centres are optically active deep defects, which represent a major interest in quantum information sciences due to their potential as single photon emitters. For instance, NV (nitrogen-vacancy) centres in diamond are at the cornerstone of several major experimental implementations. It has been established during hte last decade that a few other wide gap materials can host colour centres with attractives properties, such as hBN, SiC, ZnO, GaN...

Our research is focused on the study and quantum engineering of colour centres in ZnO and hBN, and in particular in nanostructures made of these materials. These structures possess nanometric dimensions in at least one of the three directions of space (thin layers, nanowires, nanoflakes). They open the way to the realisation of miniaturised devices, integrating optical functionalities (waveguides, optical microcavities, plasmonic resonators) as well as electrical functionalities (contacts for Stark effect).

The research topic is organised into two axes:

- Study of physical properties of native and artificially induced defects

This axis is mainly based on an optical analysis of the fluorescence photon flux (photoluminescence, resonance fluorescence) using spectroscopy, interferometry and photon counting techniques, allowing to access important optical properties with respect to applications in quantum information science (for instance 1st and 2nd order coherence properties, indistinguishability...)

- Realisation of integrated devices based on colour centres

This axis is based on the one hand on the position control of the colour centres using local irradiation techniques, and on the other hand on engineering of the electromagnetic environment (waveguide, optical microcavity, plasmonic resonator) and/or of the electrostatic environment (electrical contacts) of the colour centres, with a view to enhancing and/or guiding the photon flux, and control the emission wavelength.

Our studies are made in collaboration with the team Semiconductors. The growth and study of wide gap materials are part of their research topics. Our research also benefits from external collaborations.

Examples of recent achievements:

- **hBN: spatially and spectrally controlled colour centres**

We have demonstrated local activation of single photon emitters in hBN flakes of a few tens of nanometre thick. We use a focused electron beam in a scanning electron microscope (SEM) [1]. This technique has the advantage of generating colour centres that have identical optical transition wavelengths (figure 1). Therefore, it has potential for generating indistinguishable photons from remote emitters, which solves one of the main drawbacks of hBN colour centres.

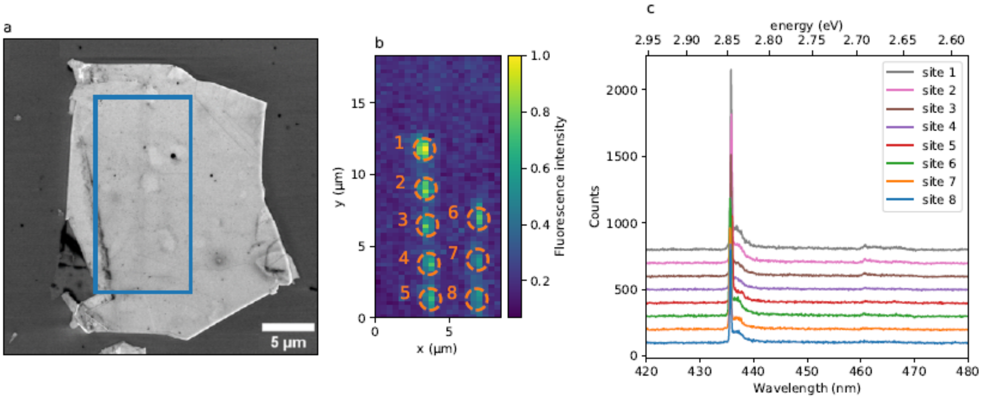


Fig. 1: (a) hBN flake (single crystal of a few tens of nanometres thickness). (b) Confocal photoluminescence map. Eight irradiation sites gave rise to colour centres. (c) Emission spectra of the eight sites, revealing similar emission lines.

Our work has led to the demonstration of indistinguishable photon emission [4] and laser-based coherent control [5] of the optical transition, opening the way to the use of these emitters for quantum information. Concerning integration, we have demonstrated in-situ monitoring of the emitter creation [3] as well as top-down integration in a monolithic waveguide [6] (figure 2).

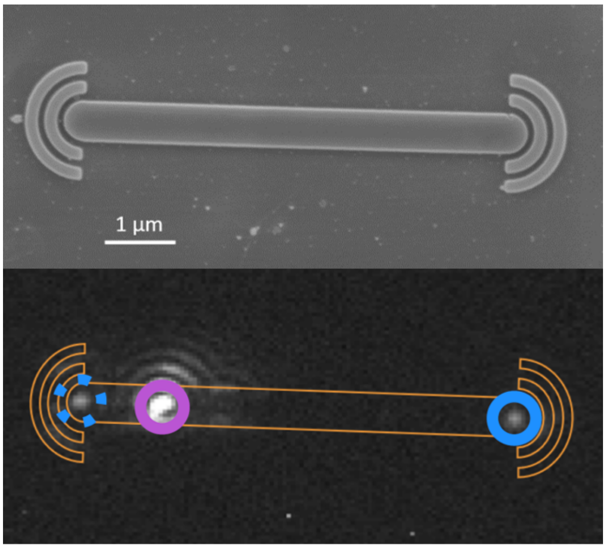


Fig. 2: upper panel: SEM image of a hBN nanofabricated waveguide. Lower panel: photoluminescence of a colour centre subsequently inserted in the structure in a controllable way. The luminescence is guided to the two Bragg couplers at the waveguide output ports.

» ZnO: quantum emitter at the tip of a nanowire.

In addition to there light guiding properties, nanowires can be individually manipulated and electrically contacted, opening the way to the realisation of quantum devices.

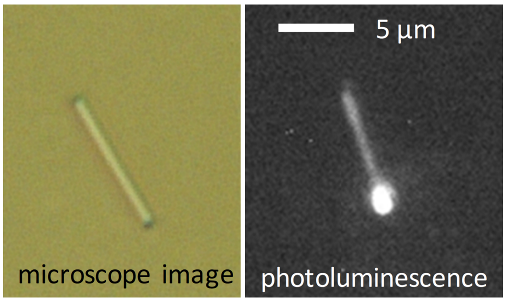


Fig. 2: ZnO nanowire - left: microscope image, right: fluorescence, revealing the presence of a colour centre at its tip.

» SiC: new near infrared optical transitions

In collaboration with MiNaLab (University Oslo), we investigate quantum properties of near infrared colour centres (silicon divacancies, a promising system for quantum information) [2].ometteur pour l'information quantique) [2].

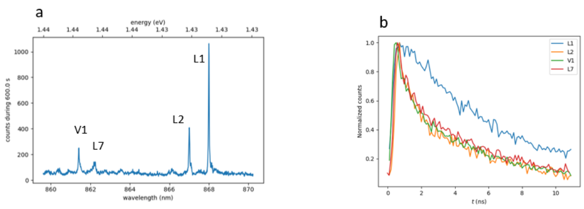


Fig. 3: (a) high resolution spectroscopy of the divacancy in helium-implanted 4H-SiC. The "L-lines" can be observed.
(b) Time-resolved photoluminescence after filtering using a transmission grating, revealing the dynamics and population transfer between the states.

[1] C. Fournier, A. Plaud, S. Roux, A. Pierret, M. Rosticher, K. Watanabe, T. Taniguchi, S. Buil, X. Quélin, J. Barjon, J.-P. Hermier, A. Delteil,
"Position-controlled quantum emitters with reproducible emission wavelength in hexagonal boron nitride",
Nature Communications **12**, 3779 (2021) (open access) – [HAL] – [arXiv] – [data]

[2] M. E. Bathen, A. Galeckas, R. Karsthof, A. Delteil, V. Sallet, A. Y. Kuznetsov, L. Vines,
"Resolving Jahn-Teller induced vibronic fine structure of silicon vacancy quantum emission in silicon carbide",

Phys. Rev. B **104**, 045120 (2021) – [HAL]

[3] S. Roux, C. Fournier, K. Watanabe, T. Taniguchi, J.-P. Hermier, J. Barjon, A. Delteil,
"Cathodoluminescence monitoring of quantum emitter activation in hexagonal boron nitride",
Appl. Phys. Lett. **121**, 184002 (2022) – [HAL] – [arXiv] – [data]

[4] C. Fournier, S. Roux, K. Watanabe, T. Taniguchi, S. Buil, J. Barjon, J.-P. Hermier, A. Delteil,
"Two-photon interference from a quantum emitter in hexagonal boron nitride",
Phys. Rev. Applied **19**, L041003 (2023) – [HAL] – [arXiv]

[5] C. Fournier, K. Watanabe, T. Taniguchi, S. Buil, J. Barjon, J.-P. Hermier, A. Delteil,
"Investigating the fast spectral diffusion of a quantum emitter in hBN using resonant excitation and photon correlations",
Phys. Rev. B **107**, 195304 (2023) – [HAL] – [arXiv] – [data].

[6] D. Gérard, M. Rosticher, K. Watanabe, T. Taniguchi, J. Barjon, S. Buil, J.-P. Hermier, A. Delteil,
"Top-down integration of a hBN quantum emitter in a monolithic photonic waveguide",
Appl. Phys. Lett. 122, 264001 (2023) – [HAL] – [arXiv] – [data]

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