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Master thesis proposal

Institut de Recherche de Chimie Paris
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Director: Emmanuel Lacôte

Title: Molecular membrane fabrication for quantum technologies

Keywords: quantum technologies, rare-earth ions, molecular crystals, exfoliation, high-resolution optical spectroscopy

Scientific description:

Rare-earth-based materials are promising platforms for quantum technologies because they combine long-lived optical and spin coherences, with nuclear spin coherence times reaching several hours in optimized crystalline hosts [1–4]. Their integration into nanophotonic structures, however, requires materials that preserve these quantum properties while being compatible with optical microcavities, waveguides and other on-chip architectures [3,5]. Molecular crystals provide an attractive alternative to conventional inorganic hosts, offering a high degree of chemical and structural tunability together with potentially versatile routes towards device integration [6].

We recently demonstrated europium molecular crystals with optical homogeneous linewidths in the tens-of-kHz range, several orders of magnitude narrower than those typically observed in molecular systems [7,8]. This platform has enabled efficient optical spin initialization, coherent light storage using an atomic frequency comb, and optical control of ion–ion interactions towards quantum-gate schemes [8]. More recently, optically detected nuclear magnetic resonance and millisecond nuclear-spin coherence were demonstrated in single crystals of the same [Eu(BA)$_4$(pip)] complex [9], further establishing these materials as promising optical–spin quantum interfaces.

So far, however, these properties have been investigated in millimetre-sized bulk crystals. Integration with photonic structures would instead benefit from thin, flat crystalline membranes that can be deterministically positioned onto a photonic chip while retaining the optical coherence of the bulk material. Adapting mechanical exfoliation and dry-transfer approaches originally developed for two-dimensional materials [10,11], and encouraged by the narrow optical lines recently reported in layered rare-earth crystals [12], we have recently started exploring the fabrication of thin membranes from europium molecular crystals (Fig. 1). Preliminary experiments have produced crystalline flakes tens of micrometres in lateral size and with thicknesses approaching or below the micrometre scale, together with a first successful transfer onto a silicon carbide substrate.

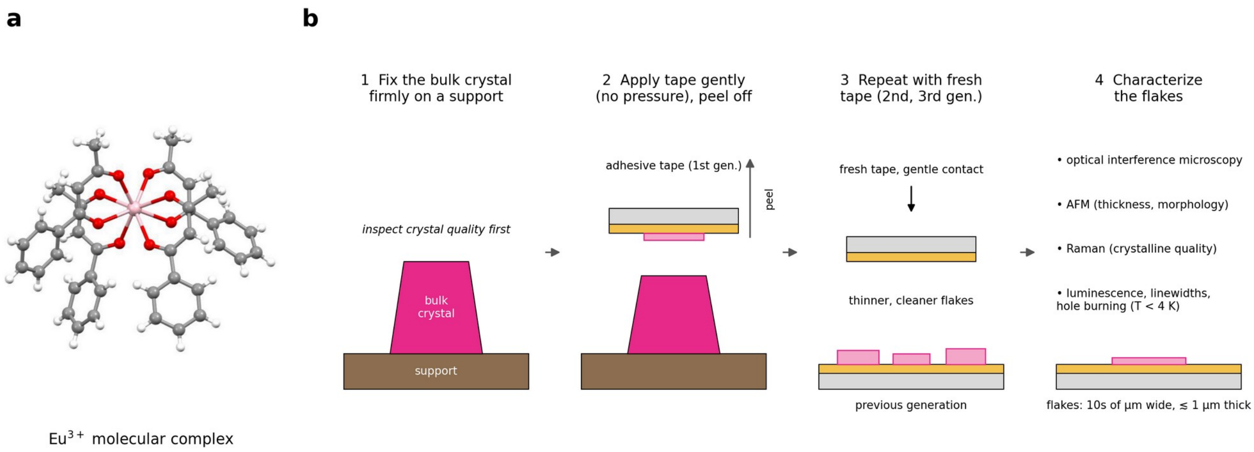

Figure 1. (a) Structure of the europium molecular complex [Eu(BA)$_4$(pip)] studied in [8,9]. (b) Fabrication of molecular membranes by successive mechanical exfoliation with adhesive tape, followed by structural and optical characterization.

The central objective of this internship is to establish a reproducible route for fabricating europium molecular membranes and, crucially, to determine whether their exceptional optical properties are preserved after exfoliation and transfer. The student will optimize the mechanical exfoliation conditions to increase the yield of thin, large-area flakes; develop deterministic dry-transfer protocols onto photonic substrates such as SiC, SiO_2/Si and glass; characterize membrane thickness, morphology and crystalline quality using optical interference microscopy, atomic force microscopy and Raman spectroscopy; and investigate their luminescence and optical homogeneous linewidths at cryogenic temperatures using spectral hole burning. Comparison with bulk crystals will allow the influence of exfoliation, reduced thickness and substrate coupling on the optical coherence of the molecular material to be established.

This work will be carried out within the CQSD team at the Institut de Recherche de Chimie Paris (IRCP). More information about the research group can be found at www.cqsd.fr.

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Techniques/methods in use: Mechanical exfoliation with adhesive tape, dry transfer, optical (thin-film interference) microscopy, atomic force microscopy (AFM), Raman and fluorescence microscopy, spectral hole burning (SHB) at cryogenic temperatures.
Applicant skills: Background in physics, materials science or physical chemistry. Taste for experimental work and careful sample preparation. Knowledge about optics and light-matter interactions, data collection and treatment by user-developed software (e.g. Matlab or Python).
Industrial partnership: N

Internship supervisor(s) (name, email, phone, …): Diana Serrano, diana.serrano@chimieparistech.psl.eu
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Possibility for a Doctoral thesis: Y