Nanoscale quantum controls and large-scale entanglement preparation with spin qubits in diamond

The main bottlenecks to the development of the Quantum Sciences and Technologies (QST) are certainly to create qubits with great coherence properties, provide them with efficient quantum controls, and prepare, preserve and exploit entanglement between them.

Toward those aspects the Nitrogen-Vacancy (NV) center in diamond, gathers both interesting quantum properties and substantial experimental assets [1]. Conventional quantum control methods however, relies optical and microwave fields and lack spatial resolution to address NV qubits with an individual selectivity such that preparing entanglement between several qubits remains an important challenge.

In this talk, I will present our latest instrumental progresses in twisting the use of a conventional Scanning Electron Microscope to generate a local magnetic field able to coherently control the NV center's spin with a nanoscale precision [2] .

When reaching the material, the electrons interact with it and are spread in an interaction volume that has a detrimental effect to the achievable spatial precision. I will present our strategy to overcome this issue with the engineering of diamond high aspect ratio nanopyramids imbedding localized overgrown NV centers with good coherence properties [2].

I will also present two related projects on the preparation of entanglement between a large number of NV centers. The first concerns a two-qubit entanglement machine that we developed in a collaboration with Prof. G. Haack and her former PhD student Dr. S. Khandelwal of the university of Geneva. I will detail a possible implementation that complies with our promising predictions off "passively" generated entanglement in both the transient and the steady states [3].

I will present another proposal about interrupting a superradiance phenomenon occurring in the microwave domain to prepare and "freeze" widely entangled Dicke states. I will present our first experimental results and question if this could be used to drastically enhance quantum sensing sensitivities.

My aim will be to show how those project synergize into a unique platform to prepare and study large-scale entanglement and open the way to thrilling research opportunities.

[1] H. Babashah, H. Shirzad, E. Losero, V. Goblot, C. Galland, and M. Chipaux, *Optically Detected Magnetic Resonance with an Open Source Platform*, SciPost Phys. Core **6**, 065 (2023).

[2] H. Shirzad, F. Morier-Genoud, E. Losero, G. Arne, C. Galland, P. Knittel, and M. Chipaux, *Towards an SEM-Based Single Spin Coherent Control*, in *Clebic* (Grenoble, (France), 2023).

[3] S. Khandelwal, S. Kumar, N. Palazzo, G. Haack, and M. Chipaux, *Dynamical Nuclear Polarization for Dissipation-Induced Entanglement in NV Centers*, Phys. Rev. B **108**, 174418 (2023).