Integration of localized single GeV centers into photonic structures

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Single photon emitters in diamond are promising platforms for the development of photonic quantum technologies. These optically active lattice defects can be engineered upon controlled introduction of impurities in the diamond using ion implantation [1], allowing control on their position within the substrate. Beyond the widely investigated NV center, which offers distinctive opto-physical and spin-related properties at room temperature, additional single-photon emitters with enticing attributes are emerging, including group-IV related centers and other impurity related defects [2].

However, the deterministic fabrication of these defects with properties optimized for quantum sensing and communication remains a major challenge. Recently, the combination of focused ion beam (FIB) technology with nanofabrication tools have opened routes towards the the scalability and integration of color centers into photonic and electronic devices. Among these systems, the Germanium-vacancy (GeV) center has gained increasing attention due to its high Debye Waller factor, sharp zero phonon line (ZPL), short lifetime and the demonstration of coherence times up to 2.5 s at cryogenic temperatures. Nevertheless, achieving reproducible GeV centers with optimal optical performance remains difficult, as the large mass of germanium induces significant local lattice strain during implantation which influence the energy levels of the defect inside the materials.

In this work, we investigate the optimization of GeV single-photon emitter fabrication and their integration into photonic structures to enhance the photon collection and formation efficiency. We explore different strategies starting from focused ion beam (FIB) implantation of Ge ions into flat diamond substrates [3]. In addition, we study the integration of these centers into bullseye structures aiming to lower the constraints on optical microscopy, as well as the fabrication of nanopillars in diamond membranes [4] with single GeV ions to enhance their emission properties. The optical performance of the fabricated systems is evaluated through photoluminescence (PL) characterization and Hanbury-Brown and Twiss interferometry. Overall, this work provides a pathway toward scalable and high-performance diamond-based single-photon sources for integrated quantum photonics.

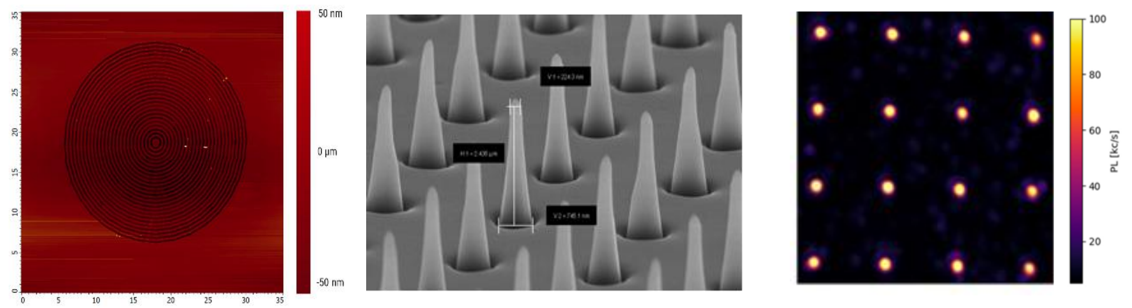

Fig. 1: *a) AFM image of bullseye structure fabricated through FIB nanopatterning. B) SEM image of etched nanopillars in diamond membrane. C) PL image of GeV centers in flat diamond.*

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References

[1]Schröder, T. et al. Quantum nanophotonics in diamond. J. Opt. Soc. Am. B 2016, 33, B65.

[2] Lühmann, T. et al. Screening and engineering of colour centres in diamond. J. Phys. D: Appl. Phys. 2018, 51, 483002

[3] Vanna Pugliese *et al.*; Formation yield of germanium-vacancy centers in diamond upon keV ion nano-implantation and thermal annealing. *J. Appl. Phys.* 28 July 2025; 138 (4)

[4] Redolfi, E., Pugliese, V., Scattolo, E. *et al.* Integration of germanium-vacancy single photon emitters arrays in diamond nanopillars. *EPJ Quantum Technol.* **12**, 25 (2025).