Fabrication of color centers in semiconductors by focused ion beam

Elena Missale[1], EliaScattolo[1], Alessandro Cian[1], Greta Andrini[2], Vanna Pugliese[3], Sara Garbolino[2], Marco Clementi[4], Matteo Galli[4], Mher Ghulinyan[1], Georg Pucker[1], Jacopo Forneris[3], Damiano Giubertoni[1], Rossana Dell'Anna[1]

1 Center for Sensors & Devices, FBK—Fondazione Bruno Kessler, 38123 Trento, Italy

2 Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, 10125 Torino, Italy

3 University of Torino, Department of Physics, 10125 Torino Italy,

4 University of Pavia, Department of Physics, 27100 Pavia, Italy

Abstract: Color centers in semiconductors are crucial for quantum technologies. We discuss focused ion beam technology to precisely position defects in silicon and diamond and fabricate single-photon emitters for integration into photonic devices.

Color centers in the semiconductors are progressively becoming key building blocks for applications in quantum technologies, spanning sensing, quantum computing, and quantum networks. Two essential requirements are needed for their technological exploitation: (i) fabrication at the single-photon emitter level, which enables control over key figures of merit such as purity and indistinguishability. Additionally, being single-point defects facilitates integration into nanometric photonic structures for optimizing signal collection [1]; (ii) the ability to precisely control the positioning of the source within the solid-state matrix, both in terms of depth relative to the material surface and of lateral spatial position. These requirements enable their integration into photonic devices and facilitate their rapid optical readout. In this work, we present results about the fabrication of color centers in two different semiconductors: silicon and diamond. In both cases, the fabrication uses focused ion beam (FIB) technology [2-3], which allows low energy ion implantation and thus shallow photon sources, precise control of defect lateral positioning (with spot sizes down to 10 nm) as well as depth through the modulation of the ion beam energy. Additionally, the instrument used in our studies can operate with ion currents of the order of pA and dwell times as short as 20 ns, enabling the nominal implantation of individual ions. We will discuss the formation of single-photon sources in diamond based on negatively charged germanium vacancies (GeV-) and silicon vacancies (SiV-) centers. These were created by implanting silicon and germanium ion species by FIB. FIB was also used to fabricate G centers in silicon-on-insulator (SOI) photonic structures through silicon ion implantation. We will discuss the tailored protocol developed for implantation and thermal annealing necessary to the controlled fabrication of the centres and the reduction of the photoluminescent background due to unavoidable carbon contaminations.

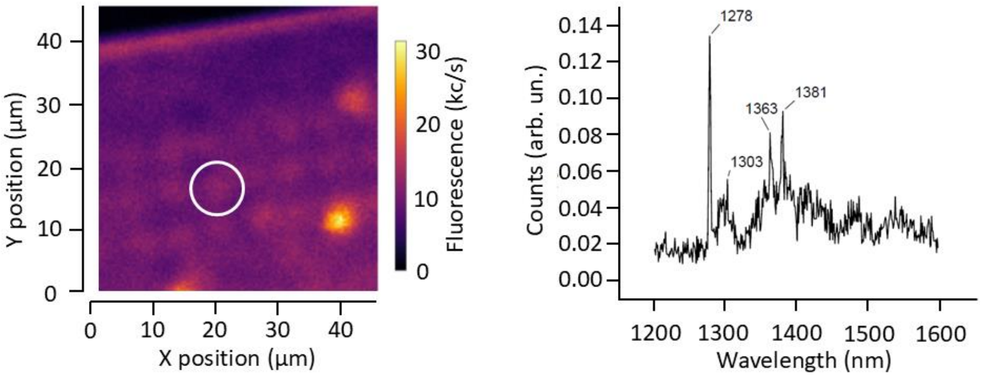

Fig. 1 A PL map from an SOI photonic structure and the corresponding single-spot spectrum exhibiting the G-center spectral fingerprint

References

[1] J. Lee et al., "Integrated single photon emitters," *AVS Quantum Science* **2,** 031701 (2020)

[2] Y. Zhou et al., "Direct writing of single germanium vacancy center arrays in diamond," New J Phys, **20**, 125004 (2018)

[3] M. Hollenbach et al., "Wafer-scale nanofabrication of telecom single-photon emitters in silicon," Nat Commun, **13**, 7683 (2022)