Light-Ion-Induced Telecom Quantum Emitters in Si-Based Heterostructures

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Abstract: We demonstrate that light-ion irradiation creates telecom-band C-centers in silicon heterostructures, establishing a practical route to integrated quantum emitters. This opens novel opportunities for silicon quantum photonics, including quantum-light sources and future spin-photon interfaces.

The advent of a future quantum internet promises a revolutionary leap in communication technologies by enabling generation, global distribution, storage, and processing of quantum bits [1]. Central to this vision is the need to connect quantum nodes via quantum states of light. In this context, defects in semiconductors show exceptional promise as non-classical light sources [2]. However, the operational wavelength of these systems currently lies at the border of the infrared, which poses significant challenges for long-distance quantum communications.

In this work, the so-called C-center, a quantum emitter based on interstitial oxygen-carbon complexes, was generated by H+ and He+ ions in pristine Si [3]. The effects of irradiation on the ensemble zero-phonon line, which falls at 1569 nm in the telecom L band, were investigated by means of photoluminescence spectroscopy (see Fig. 1). The strongest emission was observed in radiation-damaged n-type Si wafers and investigated by taking advantage of temperature-dependent measurements. These findings were then complemented by time-resolved spectroscopy, showing long-lived excitons and confirming the presence of distinct recombination pathways. Finally, we explored ion-irradiation strategies to seamlessly generate C-centers also in Ge-on-Si heterostructures, which offer novel routes for implementing integrated quantum relays and memories for long-haul communications.

Our analysis, informed by new measurements of the C-center in Si-based heterostructures and proof-of-principle experiments, indicates the prospects for implementing devices that store optical quantum information or provide a robust interface between quantum processors and optical networks.

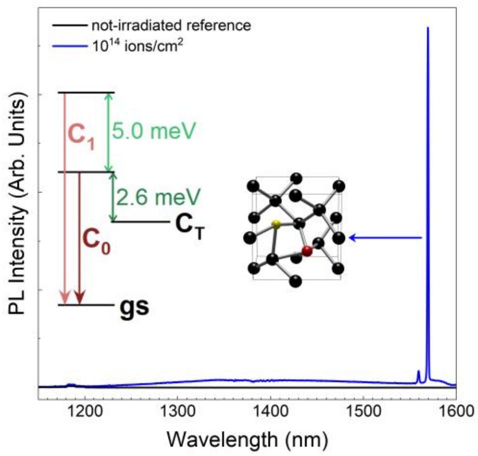

Fig. 1 Photoluminescence spectra at 4 K of a pristine and an irradiated Si sample with 1 MeV H^+ and a dose of 10^{14} ions/cm^2. The inset shows the atomic (Si, O and C atoms as black, yellow and red dots, respectively) and electronic structures of the C-center. Fundamental (C_0) and excited state (C_1) transitions are shown along with their energy separation, including the spin triplet state C_T [3].

References

[1] H. Kimble, "The quantum internet," Nature **453**, 1023-1030 (2008).

[2] M. Atatüre, D. Englund, N. Vamivakas, S.-Y. Lee, and J. Wrachtrup, "Material platforms for spin-based photonic quantum technologies," Nature Reviews Materials **3**, 38-51 (2018).

[3] C. Crosta, R. Nardin, P. Daoust, S. Achilli, I. Colombo, M. Campostrini, E. Bonera, J. Pedrini, O. Moutanabbir, V. Rigato, and F. Pezzoli "Formation of C-centers in Si-based systems by light ion irradiation" arXiv:2510.12690.