# *(Invited)* Self-Assembled Si Color Centers: Confinement to the Nanoscale Via Ultra-Low Temperature Molecular Beam Epitaxy

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## Abstract

Single photon emission in the telecom wavelength range from isolated silicon (Si) color centers (CCs) was recently demonstrated [1,2], renewing the interest in this well-known defect class [3], originating from radiation damage in Si. It can be envisioned that single SiCCs lead to scalable deterministic group-IV-based quantum light sources [4]. Moreover, recent results for the carbon (C) based G- and T-centers outline their promising spin properties [5,6] for realizing spin-photon interfaces on a scalable Si quantum photonics platform.

However, a severe obstacle remains towards their high-yield photonic integration, which is the standard SiCC fabrication process that includes single- or two-step ion implantation [1,7]. The resulting ion implantation profiles are broad and lead to a decisive lack of control over the vertical emitter position. This drawback significantly degrades the coupling efficiency to photonic structures such as resonators or waveguides. Additionally, no two SiCC emitters will be located vertically at the same position below the substrate surface, and determining the depth of isolated emitters is difficult, especially when using non-destructive methods.

This contribution presents a completely different, all-epitaxial approach for fabricating variable SiCCs, departing entirely from ion implantation [8]. The presented fabrication process enables us to restrict the formation of SiCCs to a specific epilayer and control their vertical position in a structure even with sub-nm precision [8]. They self-assemble *in situ* during ultra-low temperature (ULT) growth [9-11] of thin Si and Si:C layers deposited at $T_G$=200°C via molecular beam epitaxy (MBE). While the ULT growth just allows for the lattice disorder required for their formation, exceptionally pristine chamber conditions ensure a high optical quality of the SiCCs and allow fully crystalline Si overgrowth at higher $T_G$. To verify the vertical position control, we compare the photoluminescence signal of the created CCs for a systematic variation of $T_G$ of active layer and cap vs. undoped references. The emitter density can be conveniently controlled via C doping concentration and Si:C layer thickness. Furthermore, we show the first results for electrically-pumped self-assembled SiCCs by integrating the Si:C nanolayers into ULT-grown p-i-n light-emitting diodes.

References:

[1] W. Redjem et al., Nat. Electron. 3, 738 (2020)

[2] M. Hollenbach, et al., Opt. Express 28, 26111 (2020)

[3] G. Davies, Phys. Rep. 176, 83 (1989)

[4] M. Khoury and M. Abbarchi, J. Appl. Phys. 131, 200901 (2022)

[5] P. Udvarhelyi, et al., Phys. Rev. Lett. 127, 196402 (2021)

[6] D. B. Higginbottom, et al., Nature 607, 266 (2022)

[7] Y. Baron, et al., Appl. Phys. Lett. 121, 084003 (2022)

[8] J. Aberl et al., arXiv:2402.19227 https://doi.org/10.48550/arXiv.2402.19227

[9] A. Salomon, et al., Phys. Status. Solidi A. 219, 2200154 (2022)

[10] A. Fuchsberger et al., Advanced Electronic Materials 9 (6), 2201259 (2023)

[11] L. Wind et al., Small 18 (44), 2204178 (2022)