

# Enhanced Control of Molecular Quantum Emitters for Quantum Photonic Technologies

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**Abstract:** We present our advancements towards controlled, indistinguishable single-photon emission from individual organic molecules and towards efficient monolithic integration into micro-pillar cavities.

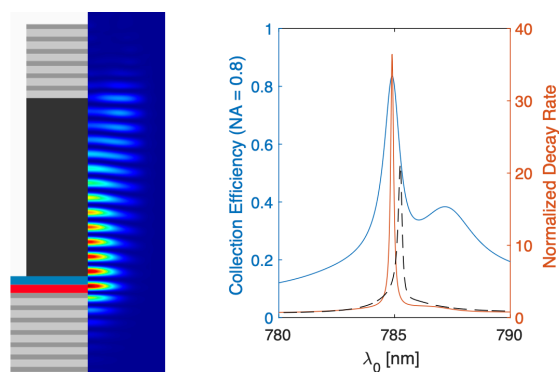
The generation of coherent and indistinguishable single photons is a key requirement for quantum photonic technologies. Single organic molecules at cryogenic temperature represent excellent solid-state emitters, combining high brightness, narrow linewidth and photostability at cryogenic temperatures [1].

Here we report experimental advances using dibenzoterrylene (DBT) molecules in anthracene as sources of coherent single photons. We demonstrate Hong–Ou–Mandel (HOM) interference between distinct molecules on the same chip [2], highlighting their potential as independent indistinguishable emitters. To overcome spectral mismatch and instability caused by charge noise, we implement a hybrid tuning approach based on electric fields and optically induced long-lived charges [3, 4]. This method enables precise frequency control while significantly reducing spectral diffusion and dephasing, preserving photon coherence.

Building on this level of control, we further explore the integration of molecular emitters into polymeric nanophotonic structures [5] with resonant effects. In particular, we investigate polymer-based micropillar cavities with distributed Bragg reflectors, providing three-dimensional optical confinement. Embedding DBT-doped crystals at the field antinode enables efficient light–matter coupling, leading to Purcell-enhanced emission, improved collection efficiency, and increased emission into the zero-phonon line. Importantly, simulations show that moderate quality factors ( $Q < 4000$ ) are sufficient to achieve significant enhancement, relaxing spectral matching constraints while reducing sensitivity to dephasing. The cavity design also allows suppression of side losses and tailoring of the emission properties. These structures are realized via direct laser writing and subsequent deterministic transfer [6] onto anthracene sublimated crystals doped with DBT, enabling scalable integration.

These results establish a pathway toward scalable, high-performance molecular quantum light sources for quantum photonic applications

**Fig.** LEFT: schematics of the micropillar integrated structure and electromagnetic field intensity map. Distributed Bragg reflectors (DBR) are placed on the top and on the bottom of a polymeric pillar (in black). A sublimated crystal of anthracene embedding DBT molecules (in red) is integrated at the basis and a polymer layer (in blu) is used for protection. RIGHT: simulation results for collection efficiency and Purcell enhancement highlighting the resonance behavior at the wavelength of emission of DBT molecules around 784 nm.



## Example References

- [1] Toninelli, C. *et al.*, *Nat. Mater.* **20**, 1615–1628 (2021).
- [2] Duquennoy, R. *et al.*, *Optica* **9**, 731–737 (2022).
- [3] Duquennoy, R. *et al.*, *ACS Nano* **18** (47), 32508–32516 (2024).
- [4] Colautti, M. *et al.*, *ACS Nano* **14** (10), 13584–13592 (2020).
- [5] Colautti, M. *et al.*, *Adv. Quantum Technol.* **3**: 2000004. (2020).
- [6] Den Hoed, F. M. *et al.*, *Adv. Funct. Mater.* **33**, 2214409 (2023).