

Eigenmode imaging of compact superconducting resonator arrays

Benedek Gaál^{1,2}

V. Jouanny^{1,2}, S. Frasca^{1,2}, C. Galland^{1,2},
P. Scarlino^{1,2}, and V. Goblot^{1,2}

¹Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

²Center for Quantum Science and Engineering, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

benedek.gaal@epfl.ch

Quantum simulation with engineered photonic environments provides a powerful approach to studying complex quantum phenomena. Coupled cavity arrays (CCAs) enable the realization of exotic lattice physics, including topological lattices, Dirac cones, flat bands, and non-Euclidean geometries [1]. A central goal of our work is to directly probe the photonic eigenmodes of such systems.

We develop CCAs based on compact lumped-element microwave resonators fabricated from high-kinetic-inductance disordered superconducting thin films. This platform offers high design flexibility, a small footprint, and a robust fabrication process, making it well suited for complex photonic lattices [2].

To directly probe the photonic eigenmodes of these systems, we employ weakly coupled nitrogen-vacancy (NV) center ensembles in diamond as local microwave detectors. By imaging the microwave field amplitude in NbTiN superconducting resonators, we obtain spatially resolved information on the mode structure of 1D and 2D subwavelength cavity arrays. We benchmark our imaging technique using a laser-based perturbative approach (Fig. 1e-f). [3] We apply these methods to image partial flat bands at the edge of photonic graphene.

Looking ahead, engineering strong coupling between NV ensembles and the resonators will open the door to studying collective emission effects and the

interaction of spin ensembles with tailored artificial photonic environments.

References

- [1] Carusotto et al., *Nat. Phys.*, vol. 16, no. 3, pp. 268–279 (2020).
- [2] Jouanny et al., *Nat. Commun.*, vol. 16, no. 1, p. 3396 (2025).
- [3] Wang et al., *Phys. Rev. Appl.*, vol. 11, no. 5, p. 054062 (2019).

Figures

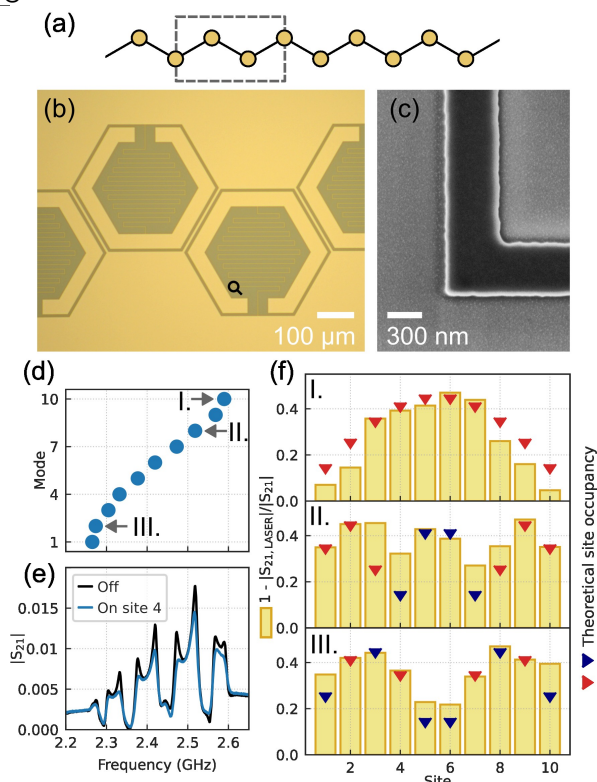


Figure 1: **a**, Schematic of a uniform linear array with 10 resonators. **b**, Optical microscope image of the area outlined in (a), showing compact lumped-element NbTiN superconducting resonators. **c**, SEM image of the nanoinductor, the critical feature for fabrication. **d,e**, Mode energies (f) and spectrum (e) of the 10-resonator array. The spectrum is measured as a function of the perturbation laser position, i.e., the site being addressed. **f**, Example measured mode shapes reconstructed using laser-scanning microscopy vs. the theoretical site occupancies.