Spontaneous Parametric Down-Conversion Beaming from a Lithium Niobate Nanostructured Resonator

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Abstract: We report the design and fabrication of lithium niobate nanostructured resonators for enhancement and directional beaming of spontaneous parametric down-conversion photons. Preliminary measurements achieved photon-pair production rates up to 300 Hz/W at telecom wavelengths.

Lithium niobate ($LiNbO_3$) is a prime material for photonics thanks to its strong electro-optical response, large second-order nonlinearity, and broad transparency window (0.35 μm to 4.5 μm). Albeit its hardness and resistance to chemical etching make for a challenging nanofabrication, recent advances enabled the realization of deeply sub-μm features in $LiNbO_3$, underpinning a series of breakthroughs in the fields of nano- and meta-photonics [1]. Leveraging its nonlinearity, several $LiNbO_3$ metasurfaces have been proven capable to enhance and steer the second-harmonic emission up to the visible range [2]. Similar designs [3] were also exploited for generating entangled photon pairs via spontaneous parametric down-conversion (SPDC)—see Fig. 1c, right [3].

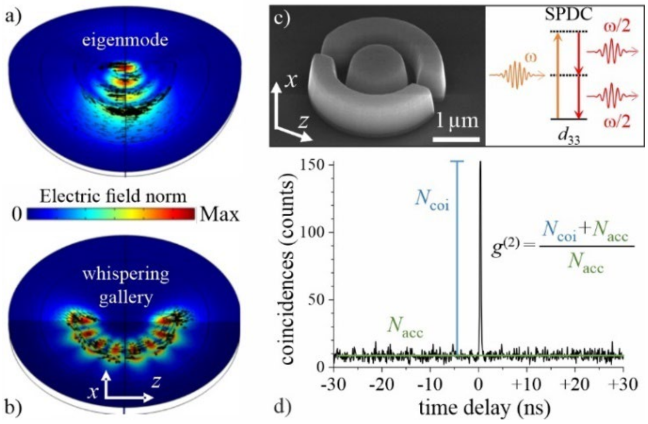

Fig. 1 a) Spatial distribution of the electric field norm at the targeted eigenmode (wavelength λ=1450 nm, quality factor Q=14) simulated with the finite-element method. b) Same as panel (a) for a spectrally adjacent non-radiative eigenmode (λ=1430 nm, Q=40). c) Left: Scanning electron micrograph of the resonator. Right: Energy-level diagram of degenerate SPDC pumped at frequency ω. d) Photon correlation measurement on a single resonator (excitation 5 mW power at λ=785 nm, 10 minutes exposure time). A peak of "true" coincidence counts, N_{coi}, emerges at zero delay against the background of accidental coincidences, N_{acc}, resulting in a second-order correlation function $g^{(2)}$ =20.

We report here the numerical design, nanofabrication, and optical characterization of a nanostructured $LiNbO_3$ photon-pair source in the optical telecom range featuring high directionality and ultra-compact footprint. The relaxation of the phase-matching constraint at the nanoscale provides us with ample freedom for engineering the resonant behavior. Specifically, our design aims to: (*i*) enhance (via the Purcell effect) the inherently low SPDC yield in such a small (≈ λ^3) interaction volume; and (*ii*) shape the two-photon emission pattern for efficient light harvesting in the far-field. We optimized the geometry starting from a systematic numerical study of the eigenmodes of a $LiNbO_3$ cylinder. Inspired by annular Bragg resonators, we verified that the directionality of the selected mode (Fig. 1a) is improved by the insertion of an annular groove, yielding a tightly beamed emission (numerical aperture NA ≈ 0.2) perpendicular to the substrate. Additional lateral cuts are introduced to suppress competing non-radiative modes (Fig. 1b). The resonators are directly milled into a 500 nm-thick commercial $LiNbO_3$ film on a silica substrate by a Ga^+ focused ion beam, see Fig. 1c (left). An exemplary photon correlation histogram in Fig. 1d displays a clear coincidence peak corresponding to the detection of photon pairs, with rates exceeding 300 Hz/W.

In perspective, nanostructure designs like the one we propose here can find application as miniaturized room-temperature sources of non-classical light in integrated devices for quantum communication and computing.

References

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