Room Temperature Fiber Coupled Single Photon Source Emitting Ultrafast and Highly Collimated Radially Polarized Photons

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We demonstrate an important step toward on-chip integration of single-photon sources at room temperature. Excellent photon directionality is achieved with a hybrid metal–dielectric bullseye antenna, while back-excitation is permitted by placement of the emitter in a subwavelength hole positioned at its center. The unique design enables a direct back-excitation and very efficient front coupling of emission either to a low numerical aperture (NA) optics or directly to an optical fiber. To show the versatility of the concept, we fabricated devices containing either a colloidal quantum dot (gQD) or a nanodiamond containing silicon-vacancy centers, which are accurately positioned using two different nano-positioning methods. Both of these back-excited devices display front collection efficiencies of ~70% at NAs as low as 0.5. The combination of back-excitation with forward directionality enables direct coupling of the emitted photons into a proximal optical fiber without any coupling optics, thereby facilitating and simplifying future integration.

Furthermore, we demonstrate a similar on-chip, room-temperature device, which generates highly directional radially polarized photons at very high rates. The photons are emitted from a gQD accurately positioned at the tip of a metal nanocone centered inside the hybrid metal-dielectric bullseye antenna. We show that due to the large and selective Purcell enhancement specifically for the out-of-plane optical dipole of the gQD, the emitted photons can have a very high degree of radial polarization (>93%), based on a quantitative metric. Our study emphasizes the importance of accurate gQD positioning for optimal radial polarization purity through extensive experiments and simulations, which contribute to the fundamental understanding of radial polarization in nanostructured devices and pave the way for implementation of such systems in practical applications using structured quantum light.

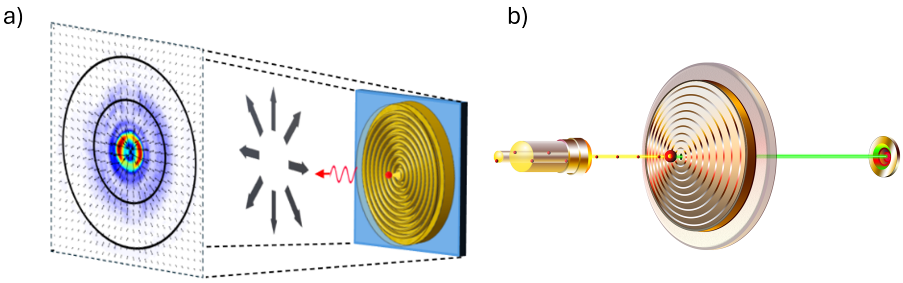

Figure 1: (a) Schematic sketch of the SPS emitting radially polarized single photons, with an experimental back focal plane image exhibiting a 'donut' shape structure associated with radial polarization. (b) Sketch of fiber coupled SPS with back excitation and forward directionality emission.

References

[1] H Abudayyeh, A Mildner, D Liran, B Lubotzky, L Luder, M Fleischer, R Rapaport, *ACS Nano* **15**, 11, 17384-17391 (2021).

[2] H Abudayyeh, B Lubotzky, A Blake, J Wang, S Majumder, Z Hu, Y Kim, H Htoon, R Bose, AV Malko, JA Hollingsworth, R Rapaport, *APL Photonics* **6**, 3, 036109 (2021).

[3] B Lubotzky, A Nazarov, H Abudayyeh, L Antoniuk, N Lettner, V Agafonov, AV Bennett, S Majumder, V Chandrasekaran, EG Bowes, H Htoon, JA Hollingsworth, A Kubanek, R Rapaport, *Nano Letters* **24**, 2, 640-648 (2024).

[4] A Nazarov[†], Y Bloom[†], B Lubotzky, H Abudayyeh, A Mildner, L Baldessarini, Y Shemla, EG Bowes, M Fleischer, JA Hollingsworth, R Rapaport, *ACS Photonics* **11**, 10, 4453-4460 (2024).

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