Metal-Superconductor Nanowire Single-Photon Detectors for On-Chip Quantum State Tomography

P. Brosseau, G. Adamo, J. Wang, A. N. Vetlugin, and C. Soci

Nanyang Technological University, Singapore 637371

Superconducting nanowire single-photon detectors enable ultrafast, low-noise photon counting but typically function as passive absorbers, requiring external optics for polarization-resolved quantum measurements. Here we demonstrate a metal-superconductor nanowire single-photon detector (MSNSPD) platform in which resonant plasmonic nanostructures define the quantum measurement basis directly at the point of absorption.

A gold nanowire integrated with a NbTiN superconducting nanowire forms a co-designed antenna-absorber system that engineers the local density of optical states and enables geometry-encoded state projection. Finite-Difference Time-Domain simulations guide the realization of anisotropic and chiral nanowire geometries inducing linear and circular dichroism at telecom wavelengths. U-shaped structures enable projection onto orthogonal linear polarization states, while chiral S-shaped geometries provide sensitivity to circular polarization.

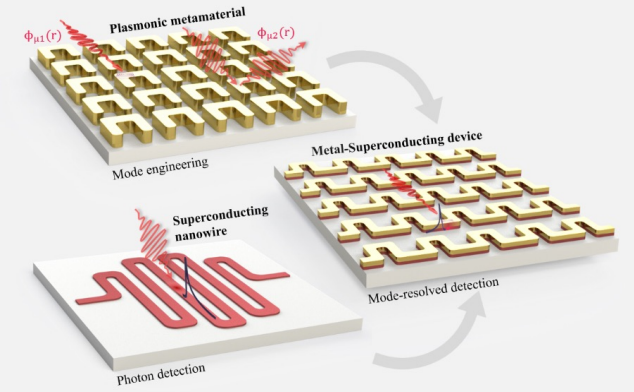

Fig. 1. *From uniform to mode-selective detection. Conventional nanowires exhibit unstructured absorption, whereas integration of a plasmonic layer enables engineered, mode-dependent coupling into the superconducting nanowire.*

The concept is experimentally validated using a four-pixel polarization-resolved MSNSPD array implementing the measurement bases for single-photon quantum state tomography. Measurements confirm polarization-dependent absorption consistent with simulations while preserving intrinsic detector performance, including sub-ns rise time, ~7 ns recovery time, and negligible increase in dark-count rate. Arbitrary single-photon polarization states at 1550 nm are reconstructed with a mean fidelity of 99.65% in less than 200 ms.

References

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[2] A. D. Semenov, G. N. Gol'tsman, and A. A. Korneev, Physica C. 351, 349-356 (2001).