Optimized plasmonic structure integrated single-photon detectors for quantum information processing

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Superconducting nanowire single photon detectors (SNSPDs) are extensively used for single-photon detection at telecommunication wavelengths. Quantum information processing applications require close to unity efficiency and read-out of encoded information with good fidelity. Besides large absorptance, sensitivity to specific polarization is particularly advantageous in these applications. Configurations optimal to maximize absorptance and polarization contrast were determined for 1550 nm infrared light illumination of three different plasmonic structure integrated SNSPDs. The inspected device types are nano-cavity-array (NCAI), nano-cavity-deflector-array (NCDAI) and nano-cavity-double-deflector-array (NCDDAI) integrated SNSPDs. For all device types three periodicity regions were inspected, where special nanophotonical phenomena are at play, namely periodicity commensurate with half-wavelength / three-quarter-wavelength / wavelength, where Bragg scattering / extraordinary transmission / Rayleigh phenomenon are expected, respectively. In addition to standard build-in algorithms, GLOBAL optimization methodology was implemented using LiveLink for MATLAB in RF module of COMSOL to determine the optimal configurations. The standard COMSOL/GLOBAL optimization results indicated that the optimal configurations are device design specific, and inspection of the integrated devices dispersion characteristics and near-field distribution revealed that the underlying nanophotonics can be fundamentally different in various devices.

In NCAI-SNSPD 94.2/94.2%, 74.7/75% and 72.7/72.8% absorptance is attainable at tilting corresponding to the plasmonic Brewster angle (PBA), where the light tunnels through the nano-cavities efficiently. However, in larger periodic NCAI-SNSPDs a pseudo plasmonic band-gap (PBG) appearing around 1550 nm prevents to achieve large absorptance at small polar angles. In NCDAI-SNSPD the array of single deflectors results in inverted PBG, as a result a plasmonic pass-band (PPB) appears at tilting sensitively dependent on the periodicity. Via half-wavelength periodic patterns 94.6/94.7% absorptance is attainable at 50.7° tilting/perpendicular incidence due to elimination of reflection, 93.3/93.3% absorptance is achieved at perpendicular incidence in three-quarter-wavelength patterns, while 85.7/85.8% absorptance is observable in wavelength-scaled devices at tilting corresponding to second order grating coupling of plasmonic waves. NCDDAI-SNSPD promotes the concentration of the PPB via first order grating coupling into backward propagating plasmonic waves at specific polar angles, which decrease by increasing periodicity. Half-wavelength scaled patterns are capable of resulting in 92.6/94.6% absorptance at 63.2°/60.9° tilting, in three-quarter-wavelength patterns 92.9/94.3% absorptance is achieved at 18.9°/21.9° tilting and wavelength-scaled periodic patterns makes possible to achieve 92.9/93% absorptance at very small 2.3°/0.7° tilting.

Polarization contrast on the order of $10^2/10^3$ is attainable via wavelength-scaled NCAI- and NCDAI-SNSPDs, while extremely large 10^7 contrast is achievable via NCDDAI-SNSPDs with half-wavelength-scaled periodicity. Specific advantage of double-deflectors in NCDDAI-SNSPD is the simultaneous enhancement both of the absorptance and polarization contrast, as a result this device type is proposed for QIP applications.

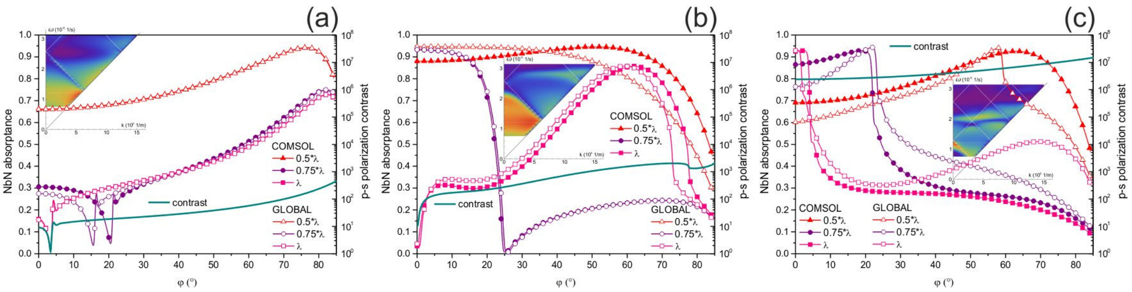

Figure: NbN absorptance and polarization contrast as a function of φ polar angle and the dispersion relation in plasmonic structure integrated single photon-detector designs optimized by standard COMSOL (filled symbols)/GLOBAL (empty symbols) algorithm: (a) NCAI-, (b) NCDAI- and (d) NCDDAI-SNSPD.

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[2] M. Csete, A. Szalai, Á. Sipos, G. Szabó: "*Impact of polar-azimuthal illumination angles on efficiency of nano-cavity-array integrated single-photon detectors*", Optics Express **20/15** (2012) 17065.