Modeling Plasmonic Structure Integrated Single-Photon Detectors to Maximize Polarization Contrast

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Abstract

Introduction: Single-photon detectors capable of ensuring high fidelity read-out of quantum information delivered via photons of specific polarization are crucial in QIP [1]. Our previous studies have shown that different types of one dimensional plasmonic structures enhance the absorptance of p-polarized light [2, 3]. The purpose of present study was to optimize four different types of superconducting nanowire single-photon detectors (SNSPDs) integrated with plasmonic structures with periodicity commensurate with half-, three-quarter and one SPP wavelength, to ensure maximal polarization contrast.

Use of COMSOL Multiphysics®:
COMSOL Multiphysics® software and the RF Module were applied to maximize the polarization contrast in case of 1550 nm light illumination of integrated SNSPD devices in S-orientation (90° azimuthal orientation), which promotes plasmonical phenomena. Meandered patterns of absorbing niobium-nitride (NbN) stripes were embedded into (1) nano-cavity-array (NCA-), (2) nano-cavity-deflector-array (NCDA-), (3) nano-cavity-double-deflector-array (NCDDA-) and (4) nano-cavity-trench-array (NCTA-) integrated I-P-SNSPDs (Figure 1a-d). All parameters of the integrated patterns were varied during optimization except the NbN stripes' t=4 nm thickness, while the upper bound of the polar angle was set to 80°.

The optimization was performed by applying an in-house developed GLOBAL algorithm, which was implemented using LiveLink for MATLAB™ in the COMSOL software [4]. The polar angle dependent p- and s-polarized light absorptance as well as the polarization contrast of the P-SNSPD devices was determined by parametric sweeps. Finally the dispersion characteristics was inspected in these quantities to understand the underlying physics.

Results: The optimization of NCAI-P-SNSPDs resulted in the largest absorptance at the plasmonic Brewster angle (Fig. 2a). All optimized NCDAI-P-SNSPD devices consisted of deflectors having a width equal to the distance between the nano-cavities. The maximal absorptance was achieved at the plasmonic Brewster angle of the extended nano-cavity array, except in 3*lambda/4 periodic device, where it is reached at 80° (Fig. 2b). The two deflectors almost touch each other in the lambda/4 pitch NCDDAI-SNSPD, they are symmetrical-asymmetrical in 3*lambda/4 - lambda periodic NCDDAI-P-SNSPD. The lambda/4 and 3*lambda/4 pitch NCDDAI-P-SNSPDs result in maximal absorptance at the Brewster angle,

while in lambda pitch NCDDAI-P-SNSPDs maximum is reached at 80° (Fig. 2c). The two in-plane deflectors almost touch each other in the lambda/4 and 3*lambda/4 pitch NCTAI-SNSPDs, while they are symmetrical and commensurate with the NbN loaded MIM cavities in ≅ lambda periodic NCTAI-P-SNSPD. In lambda/4 - 3*lambda/4 pitch NCTAI-P-SNSPDs maximal absorptance is reached at the Brewster angle, while in the lambda pitch NCTAI-P-SNSPD at perpendicular incidence (Fig. 2d). All optimized devices show maximal polarization contrast at 80°, except the lambda pitch NCTAI-P-SNSPD, where also the contrast maximum is reached at perpendicular incidence. Comparison of dispersion characteristics in p- and s-polarized absorptance shows that the polarization contrast maximum is determined to be at 80° by the rapid decrease of the s-polarized absorptance at large tilting (Fig. 3a-c).

Conclusion: Optimization of single photon detectors results in different configurations, depending on whether unity absorptance and maximal polarization contrast are used as objective functions. The most efficient optimization methodology can be realized by composite objective functions, and via appropriate constraint definitions.

Reference

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3. M. Csete et al.: "Plasmonic structure integrated single-photon detector vonfigurations to improve absorptance and polarization contrast" Sensors 15 3513-3539 (2015)

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Figures used in the abstract

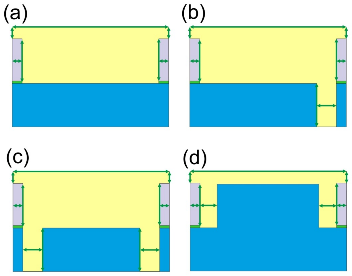

Figure 1: Inspected plasmonic structure integrated single photon-detector designs (a) NCAI-P-SNSPD, (b) NCDAI-P-SNSPD, (c) NCDDAI-P-SNSPD, (d) NCTAI-C-SNSPD.

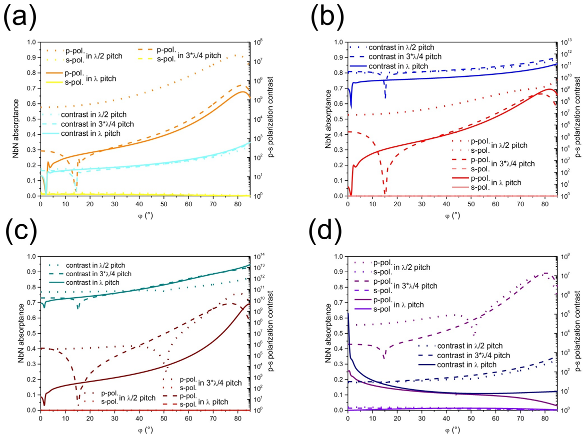

Figure 2: (a) Achieved NbN absorptance in case of p- and s-polarized light illumination and the polarization contrast as a function of fi polar angle in (a) NCAI-P-SNSPDs, (b) NCDAI-P-SNSPDs, (c) NCDDAI-P-SNSPDs and NCTAI-P-SNSPDs.

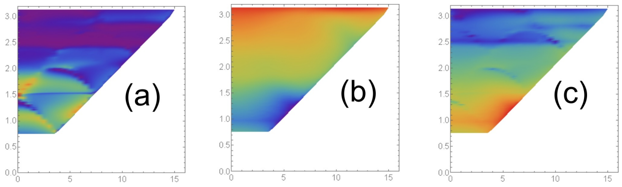

Figure 3: Dispersion characteristics of 3*lambda/4 pitch NCDDAI-P-SNSPD (a) in p-polarized and (b) in s-polarized absorptance and (c) in polarization contrast.

Figure 4