Unidirectional vectorial eigenmode propagation for multiscale tapered waveguides in 3D

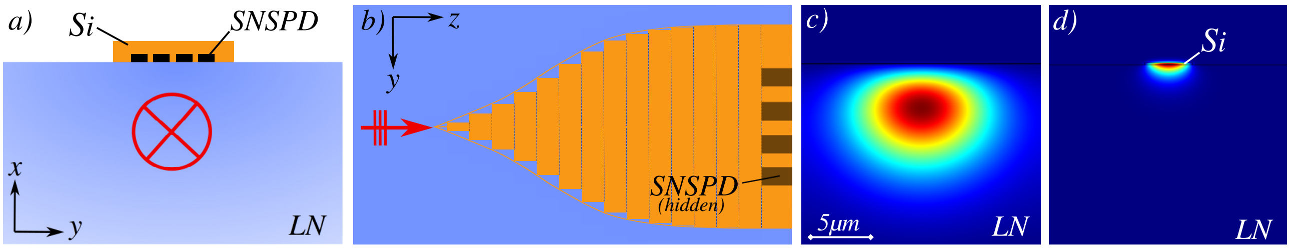
Lena Ebers [1], Manfred Hammer [1], Jan Philipp Höpker [2], Tim Bartley [2], Jens Förstner [1]

[1] *Theoretical Electrical Engineering, Paderborn University, Paderborn, Germany*
[2] *Applied Physics, Paderborn University, Paderborn, Germany*
lena.ebers@uni-paderborn.de

A fast and efficient method to calculate the light propagation along multiscale 3D tapered waveguides is discussed. Vectorial eigenmodes calculated with Comsol Multiphysics constitute the basis for our hybrid numerical/analytical mode matching model.

Superconducting nanowires on lithium niobate waveguides

High efficient and fast single-photon detectors are of huge interest in integrated quantum optics. The combination of Ti-indiffused lithium niobate (LN) waveguides and superconducting nanowire single photon detectors (SNSPDs) enables the observation of quantum effects in an integrated electro-optical platform [1]. Since the power of the incoming mode is concentrated in the LN substrate (Fig.1c), the field overlap with the nanowires, placed on top of the substrate (Fig.1a; without Si-layer), is small and with it the absorption. One possibility to increase the absorption rate is by placing an additional Si-layer on top of the wires to pull up the optical power from the LN mode into the tiny Si-mode (Fig.1d), hence into the region of the detectors. To counteract radiation losses and achieve smooth transitions the Si-layer is of a tapered shape before reaching the wires (Fig.1b). The design of these single-photon detectors require accurate and efficient simulations of these 3D multiscale tapered waveguides.



a) Cross section of the LN waveguide with detectors and Si-layer on top, b) sketch of a tapered waveguide with staircase approximation and view from above, c) guided mode in LN waveguide, d) guided mode in Si-layer.

Finite element modal matching method

We employed a modal matching technique [2], based on a staircase approximation of the tapered shape (Fig.1c), for the calculation of hybrid 3D structures, here transferred to the optical regime with open dielectric waveguides. Back reflections and power transfer through non-guided modes are neglected. Eigenmodes are propagated along the waveguide segments with constant 2D cross sections. Our vectorial 2D mode profiles are calculated with the finite element software Comsol Multiphysics to discretize the different scales of the tiny SNSPDs $(0.16\mu m \times 0.0035\mu m)$, the small Si-layer $(4\mu m \times 0.17\mu m)$ and the large LN substrate $(20\mu m \times 15\mu m)$ precisely. Hence, we call this the finite element modal matching method (FEMMM). By pre-calculating the power overlap products for each combination of cross-sections once, different taper geometries can be simulated within seconds, thus, enabling efficient optimization, e.g for photon detectors with high transmission and low radiation.

References

[1] J.P. Höpker et al., *Towards integrated superconducting detectors on lithium niobate waveguides,* SPIE Nanoscience + Engineering, San Diego, California, United States, 2017.

[2] A.D. Olver et al., *Microwave horns and feeds,* IEE Electromagnetic waves series 39, 1994.