Modeling of photon scanning tunneling microscopy by 2D quadridirectional eigenmode expansion

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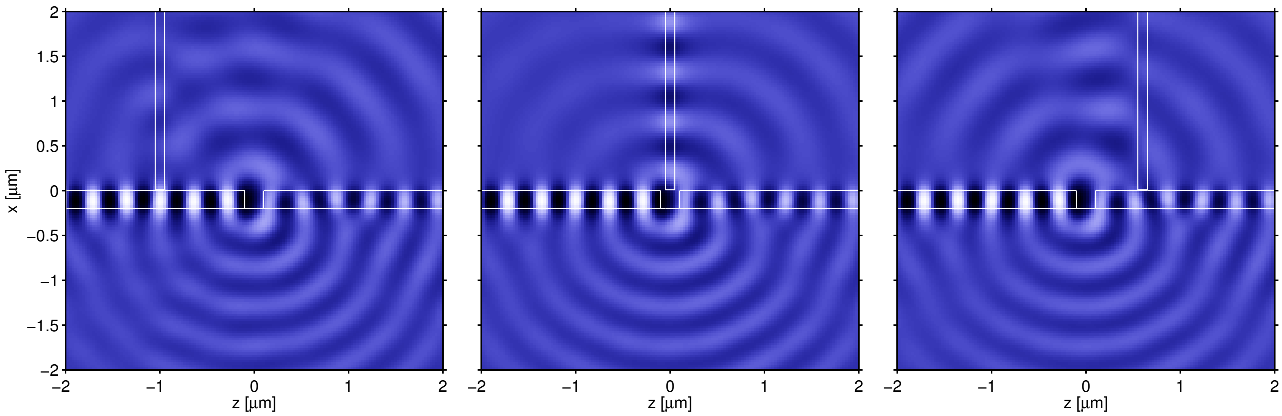
Photon scanning tunneling microscopy (PSTM) becomes increasingly popular as a tool to study the local optical electromagnetic field close to the surface of devices from integrated optics / photonics. Recent examples are the mapping of the field evolution in waveguide Bragg gratings [1] or the investigation of resonances in cylindrical microresonators [2]. The microscope probes the optical field by detecting the optical power that is transferred via evanescent or radiative coupling to the tapered tip of an optical fiber close to the surface of the sample. Scanning the tip across the surface leads to a map of the evanescent optical field, i.e. gives clues about the local light propagation through the device. As a step beyond the mere analysis of the sample device, one can consider simulations that include the sample as well as the probe tip. For the present contribution we looked at a — highly simplifying — 2D model of the microscope. Corrugated slab waveguides (cores with slits, short Bragg gratings) serve are samples. A half infinite piece of waveguide, oriented perpendicularly to the axis of the sample structures, represents the probe tip. All dielectric interfaces are parallel to one of the two coordinate axes; the propagation of light with fixed frequency and definite polarization is to be analyzed.

An only recently proposed semianalytical simulation algorithm (quadridirectional eigenmode propagation, QUEP) [3] constitutes a convenient tool for virtual experiments with this model, as an alternative to usually computationally quite expensive rigorous numerical computations (FD / FEM discretization of Maxwell equations, see e.g. [4]). Our simulations are based on bidirectional expansions of the electromagnetic field into eigenmodes associated with the piecewise constant refractive index structure, along each of the two relevant Cartesian coordinate axes. Although the sets of basis modes are discretized by simple Dirichlet boundary conditions, the subsequent combination of the perpendicular eigenmode expansions establishes an inner rectangular computational window with entirely transparent boundaries. Propagation along both coordinate axes is treated precisely alike; modeling of guided wave influx and outflux is straightforward. After a brief overview of this computational approach, a series of results for the PSTM model are discussed. The examples allow to estimate how the signal detected via the fiber is related to the field intensity at the probe tip, and how the presence of the probe influences the field distribution within the sample. Despite the simplicity of the model, we observed a reasonable qualitative agreement between these computations and a previous experimental PSTM investigation of a waveguide Bragg grating [1].



Snapshots of the electric field E_y for TE light propagation through the 2D microscope model, for three different probe positions. A slab waveguide (thickness $0.2\ \mu m$, refractive indices: 1.45, 2.0, 1.0) with a $0.2\ \mu m$ hole forms the sample. The vertical core (width $0.1\ \mu m$, refractive index 1.5) represents the fiber tip. The sample is illuminated from the left by the fundamental mode (vacuum wavelength $0.633\ \mu m$) of the horizontal channel. QUEP simulation with 80×80 expansion terms on a $6\ \mu m \times 6\ \mu m$ computational window.

References:

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