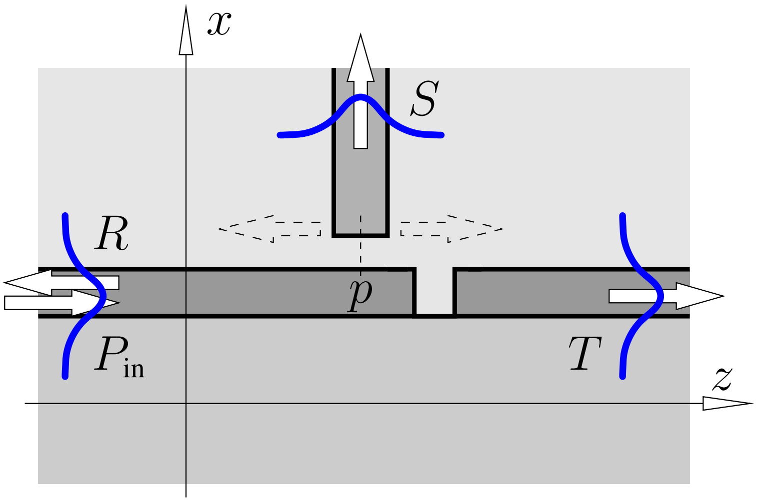
1 2-D PSTM modeling

Photon scanning tunneling microscopy (PSTM) or near-field scanning optical microscopy (NSOM, SNOM) becomes increasingly popular as a tool to study the local optical electromagnetic field close to the surface of devices from integrated optics/photonics. Here we are interested in a variant where 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.



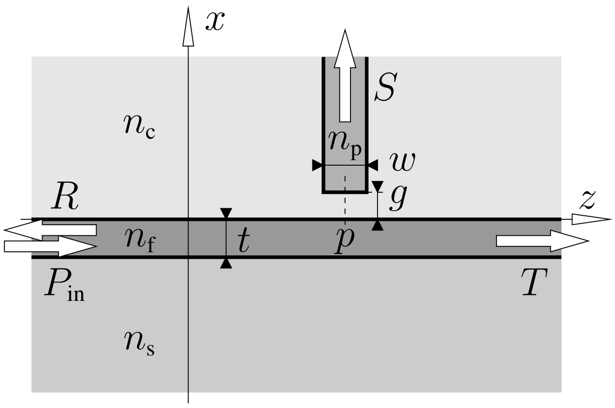
$$P_{\text{in}} = 1. \quad S(p) = ?$$
$$R(p) = ?, \quad T(p) = ?$$
$$S(p) \overset{?}{\longleftrightarrow} (\text{Optical Field})\big|_p$$

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[1]. We look at a — highly simplifying — 2-D model of the microscope. Corrugated slab waveguides (cores with slits, short Bragg gratings) serve as samples. A half infinite piece of waveguide, oriented perpendicularly to the axis of the sample structures, represents the probe tip. We apply a semianalytical method (quadridirectional eigenmode propagation, QUEP[2]) and a rigorous numerical tool (finite difference time domain, FDTD) to this problem. A series of computational experiments allow to estimate how the signal detected via the fiber is related to the field intensity at the probe tip (no proportionality, in general), how the presence of the probe influences the field distribution within the sample (significant influence for specific resonant configurations), and whether the specific probe tip configuration (metal coating) is of relevance (yes).

[1] M. Hammer, R. Stoffer, *PSTM/NSOM modeling by 2-D quadridirectional eigenmode expansion*, Journal of Lightwave Technology **23** (5), 1956–1966 (2005)

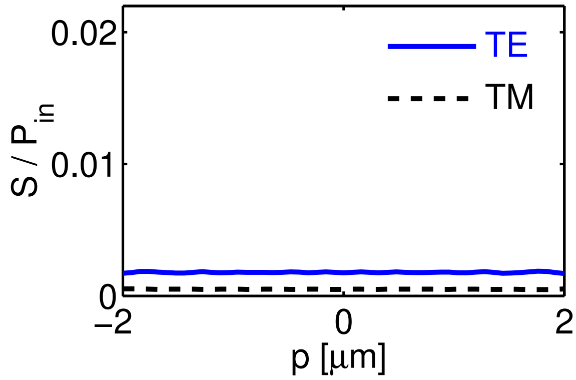
[2] M. Hammer, *Quadridirectional eigenmode expansion scheme for 2-D modeling of wave propagation in integrated optics*, Optics Communications **235** (4–6), 285–303 (2004); http://www.math.utwente.nl/~hammerm/Metric/

2 Probing evanescent fields, signals

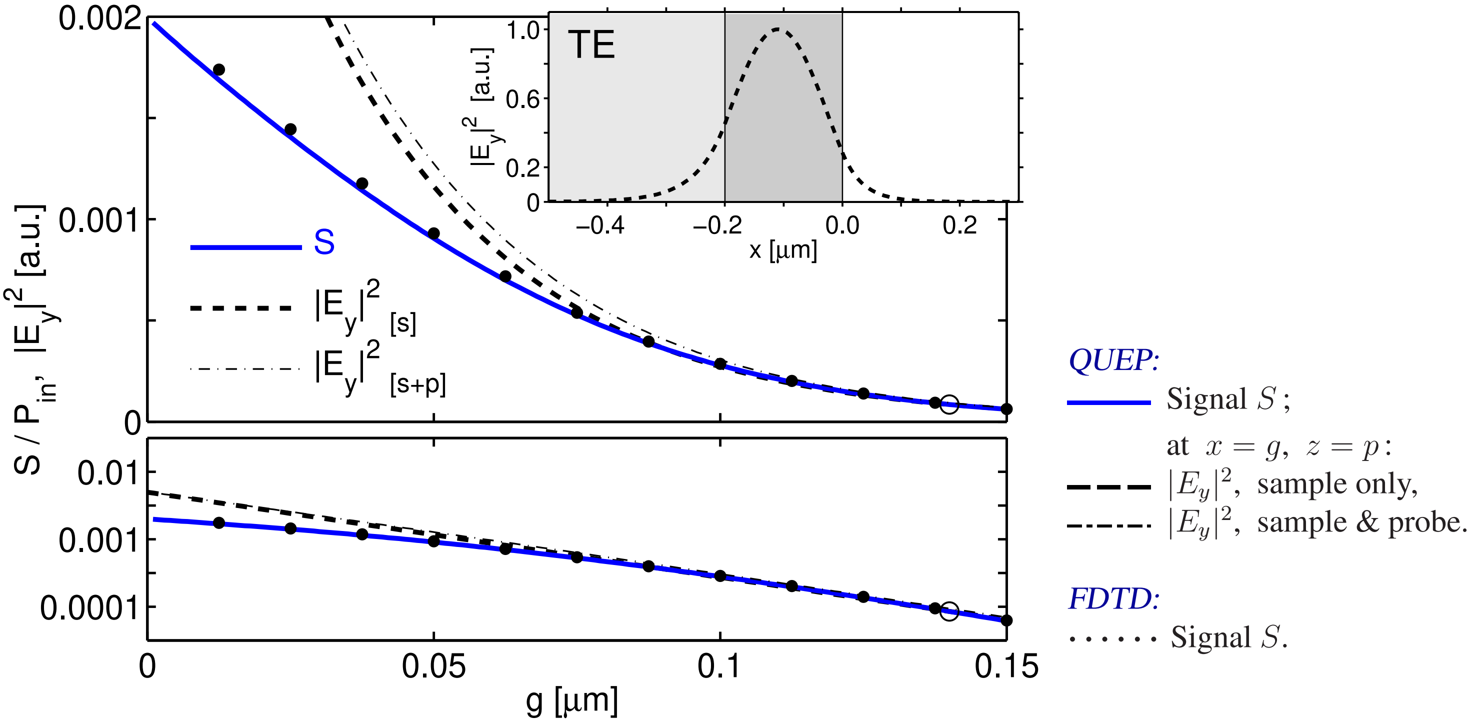


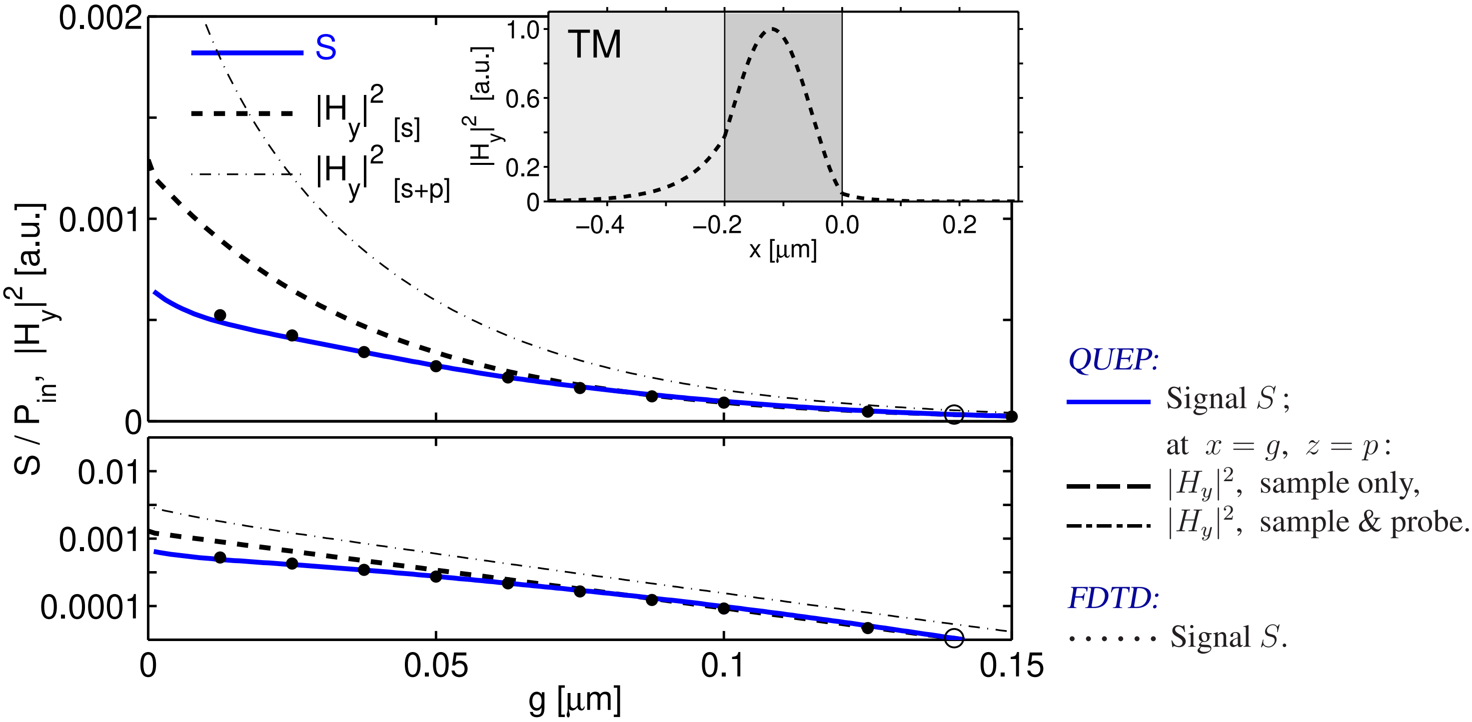
$\lambda = 0.633\,\mu$m,
$n_s = 1.45$,
$n_f = 2.0$,
$n_c = 1.0$,
$t = 0.2\,\mu$m,
$w = 100$ nm,
$n_p = 1.5$.

Horizontal scan: $g = 10$ nm



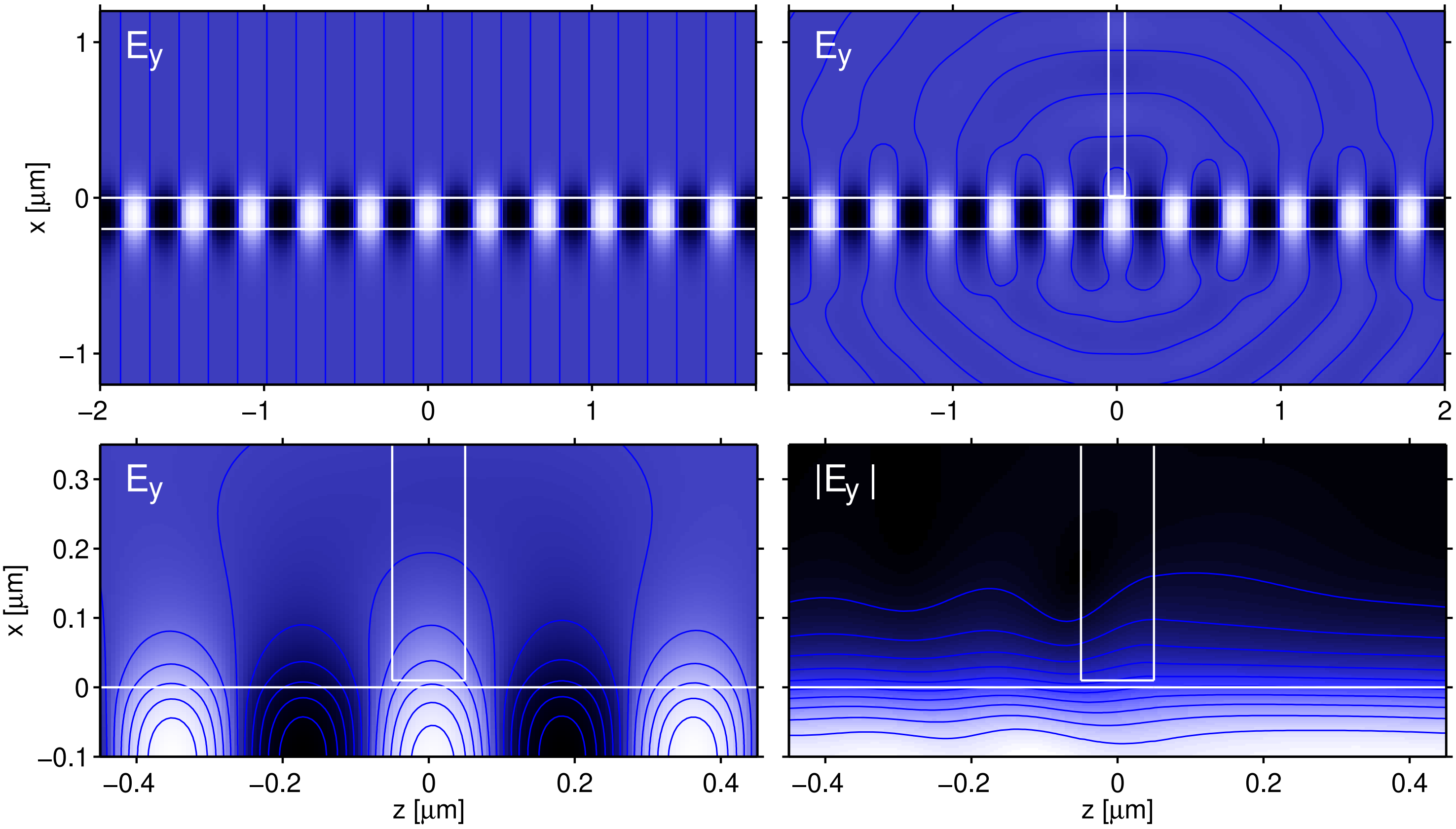
Vertical scan:



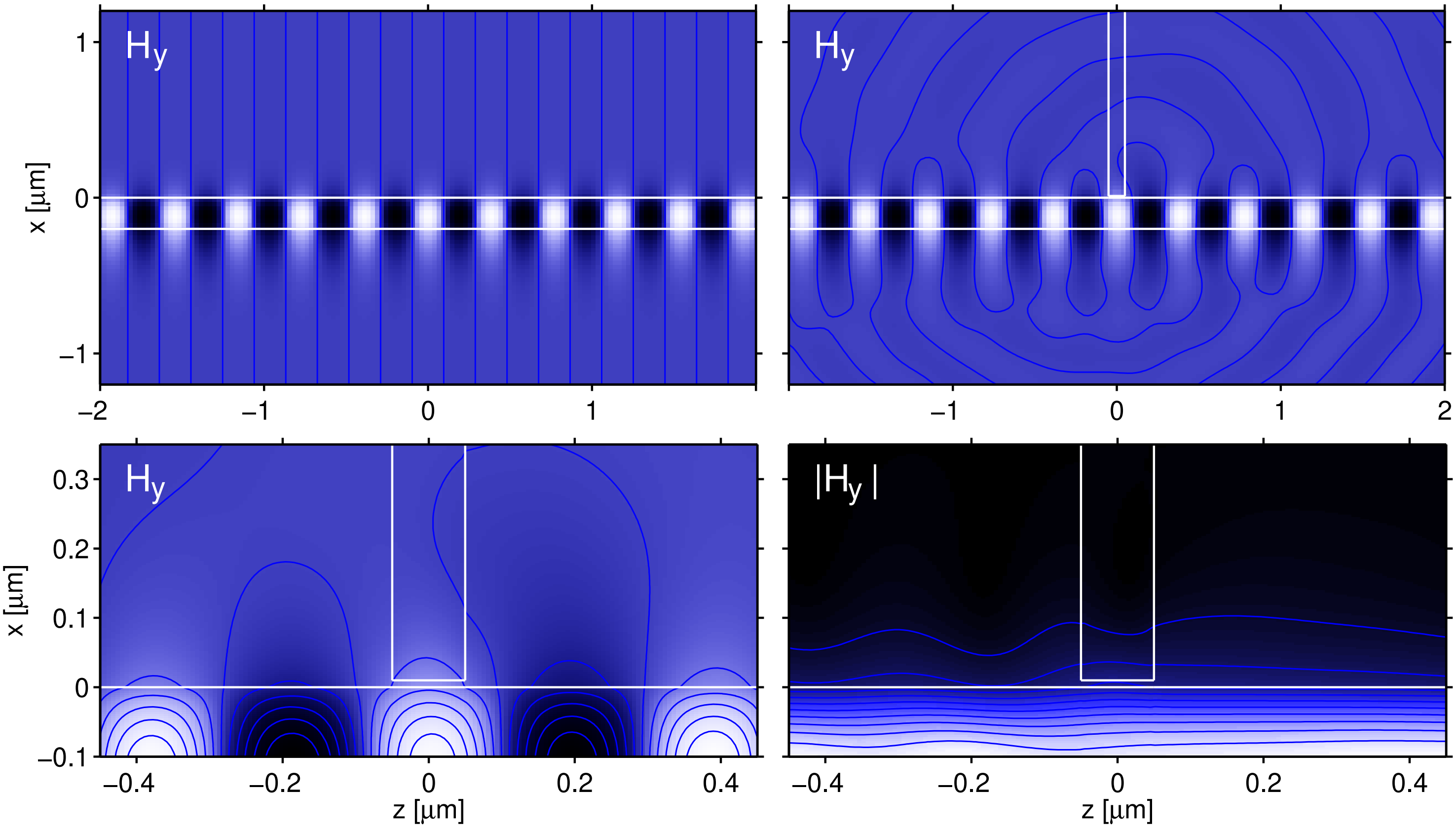


3 *Probing evanescent waves, field shapes*

TE:

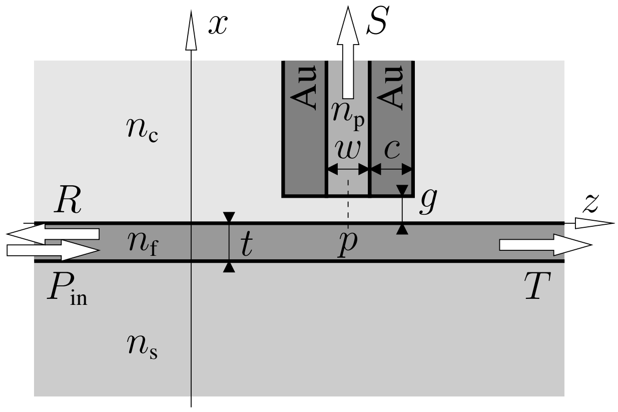


TM:



QUEP, non-coated probe tip, $g = 10\,\text{nm}$.

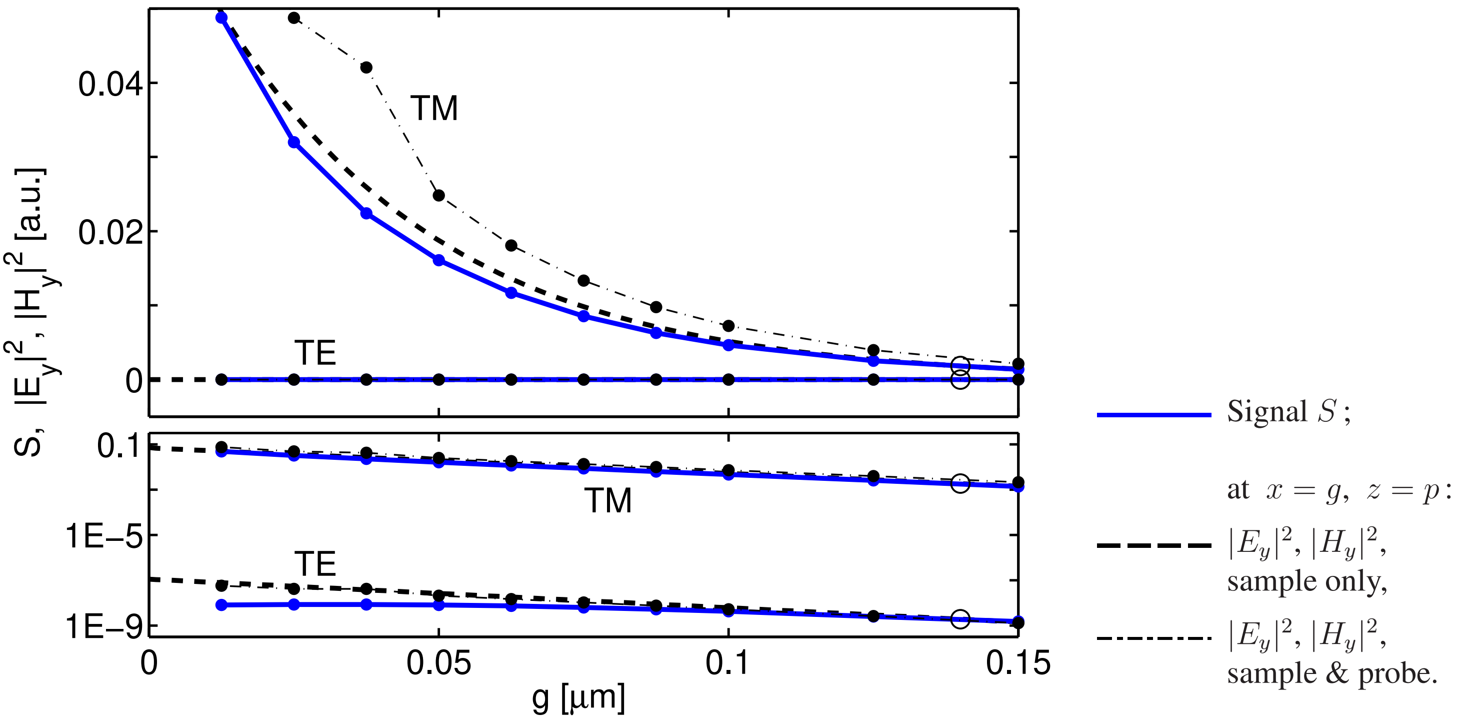
4 Probing evanescent fields, coated probe tip

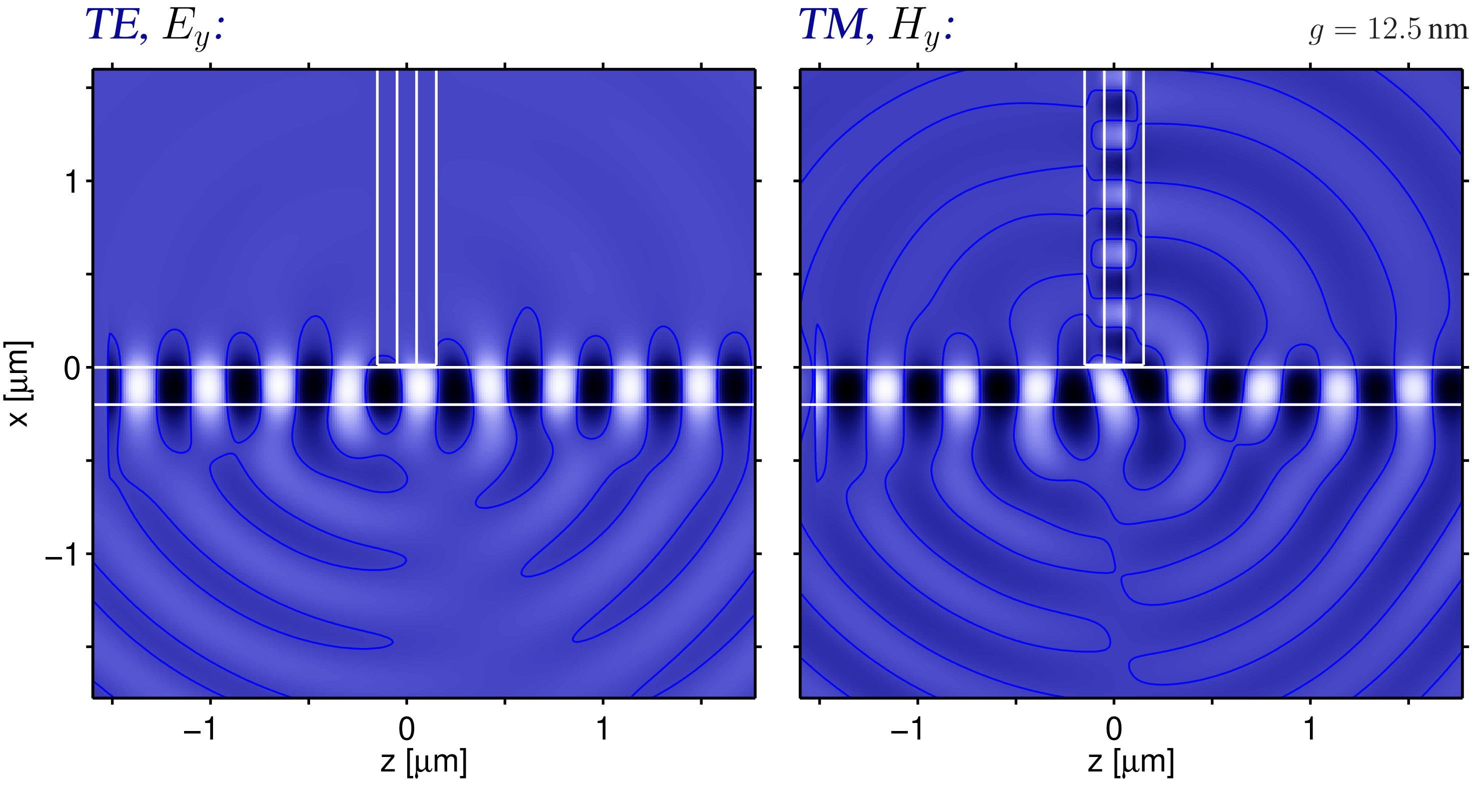


Probe: dielectric slab with metal coating;
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2\,\mu$m,
$n_p = 1.5$, $w = 100\,$nm, $c = 100\,$nm,
$\lambda = 0.633\,\mu$m.

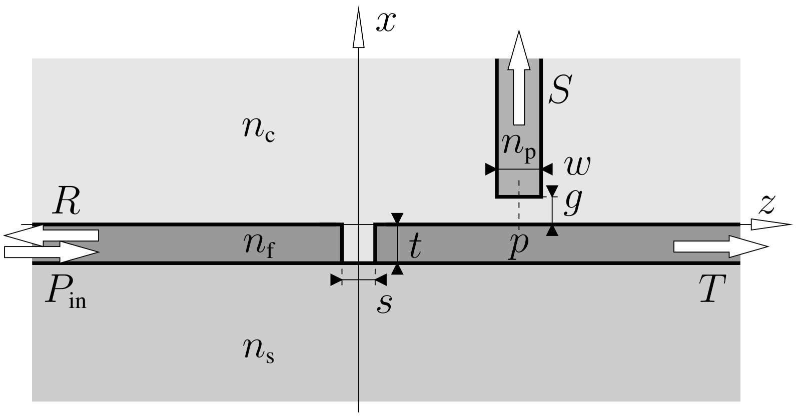
FDTD calculations,
$\Delta x = \Delta z = 12.5\,$nm, $\Delta t = 2.5 \cdot 10^{-17}\,$s.

Vertical scan:

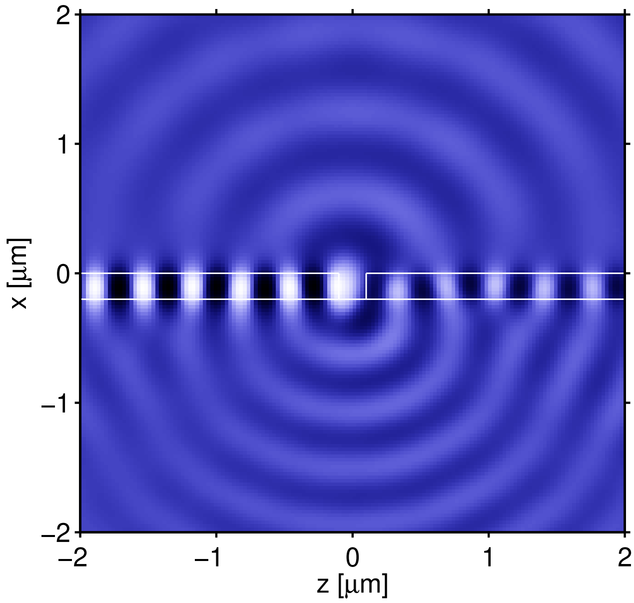


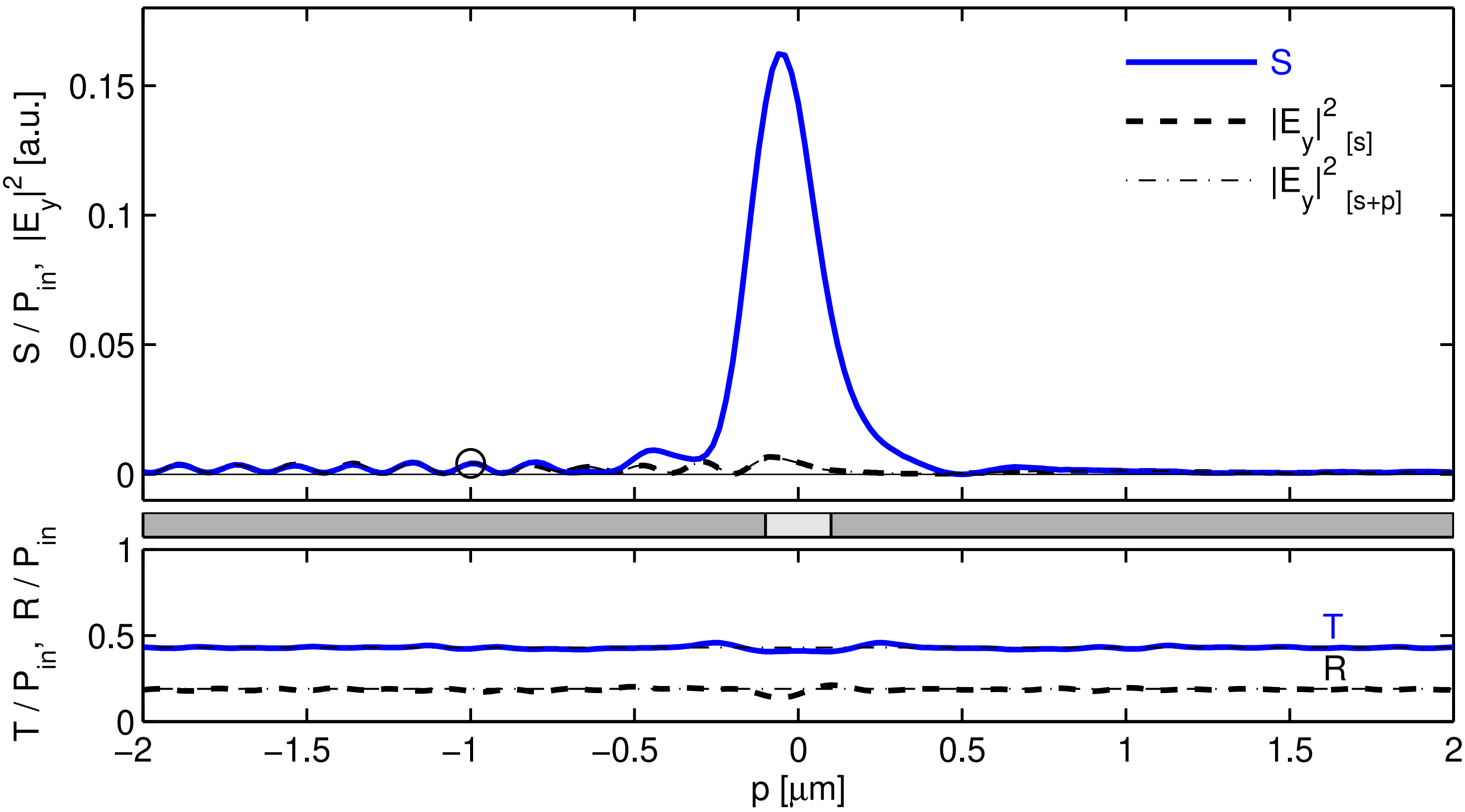


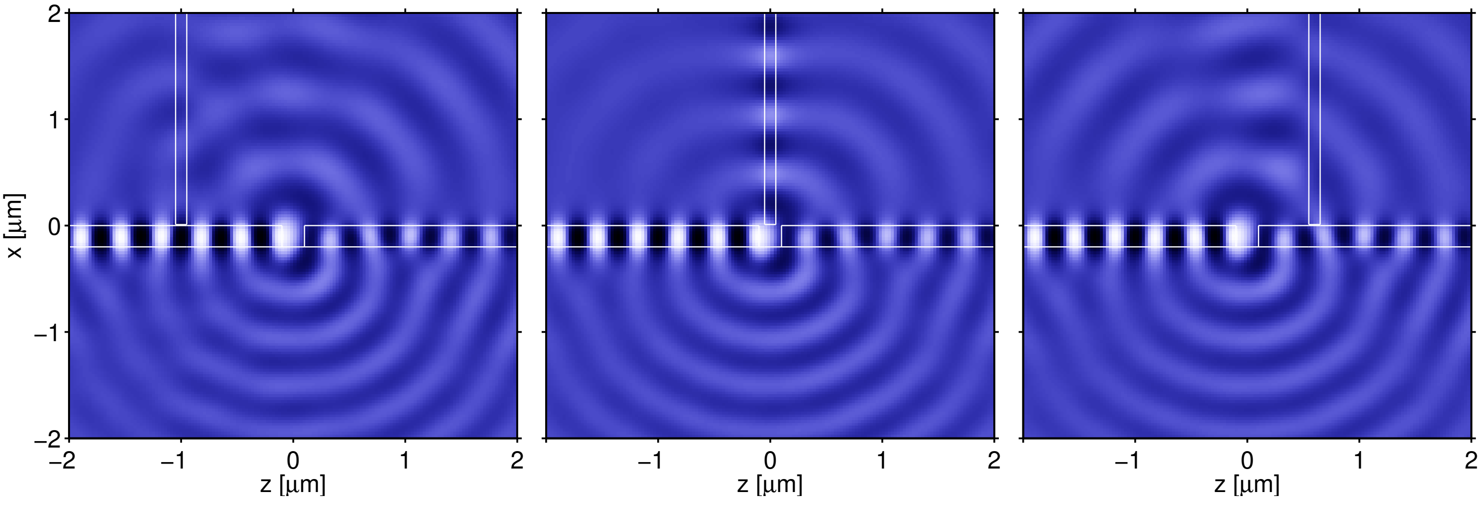
5 A hole defect



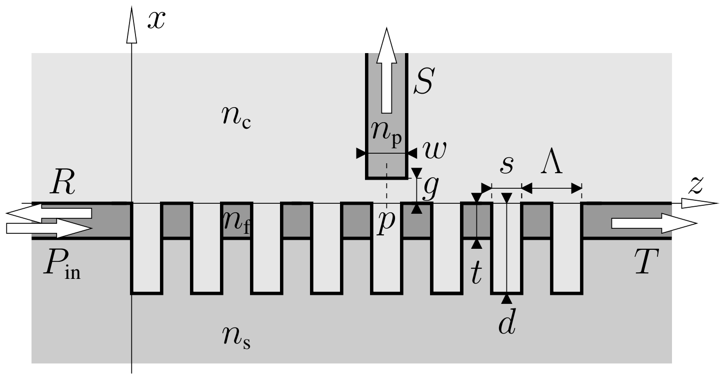
TE, $\lambda = 0.633\,\mu$m, $n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$,
$t = 0.2\,\mu$m, $s = 0.2\,\mu$m, $g = 10\,$nm, $w = 100\,$nm, $n_p = 1.5$.



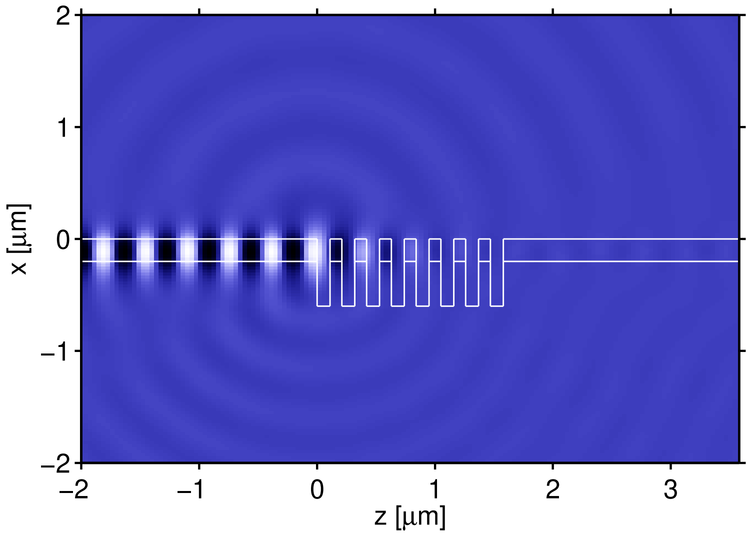


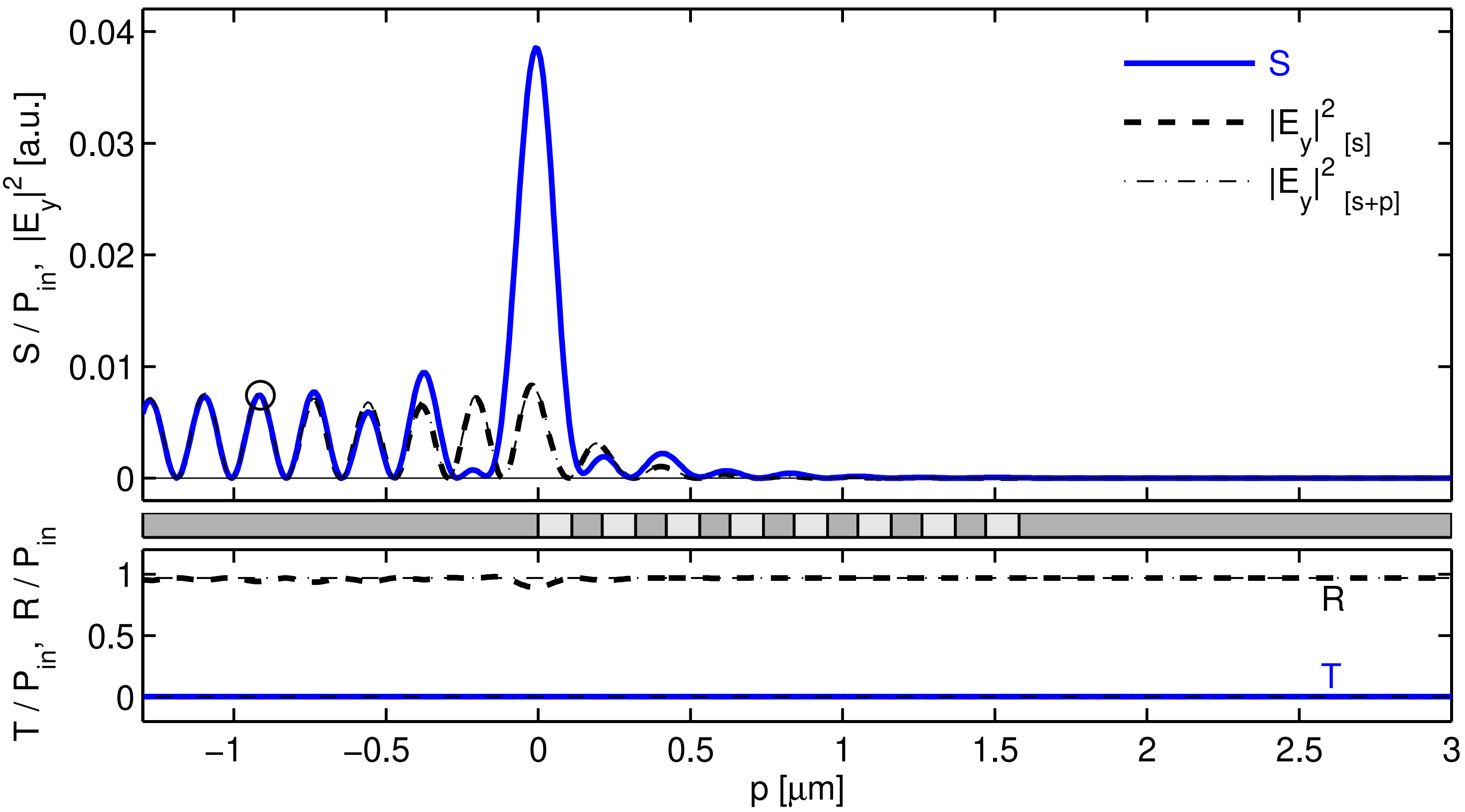


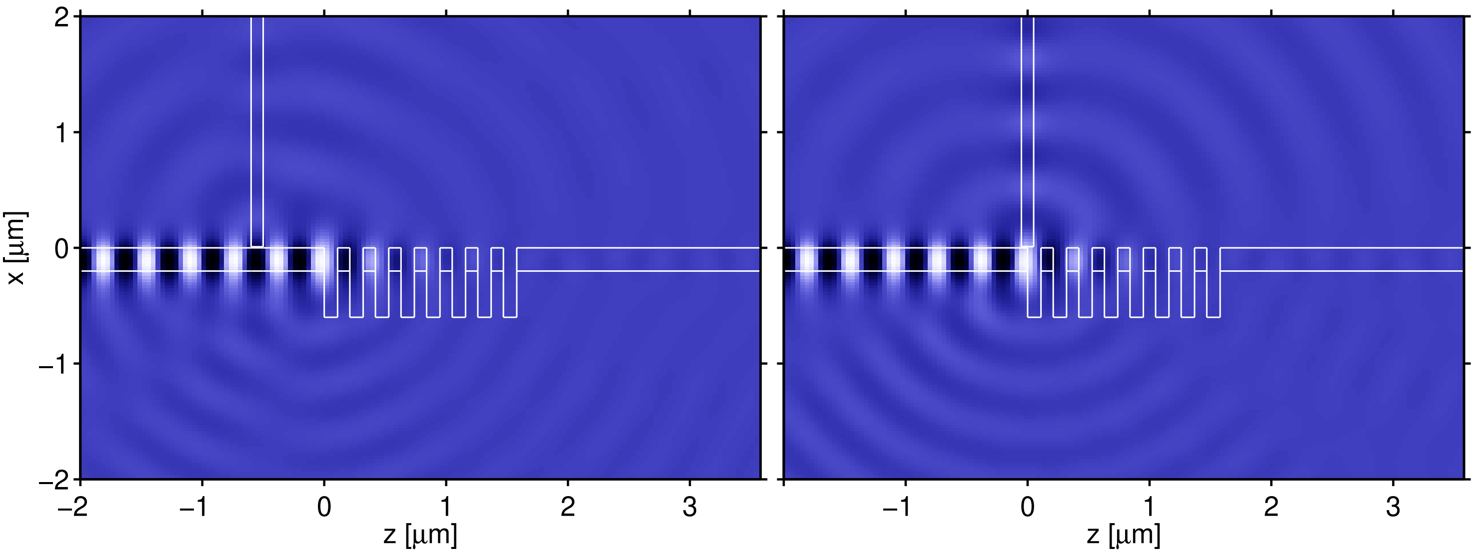
6 Short waveguide Bragg grating



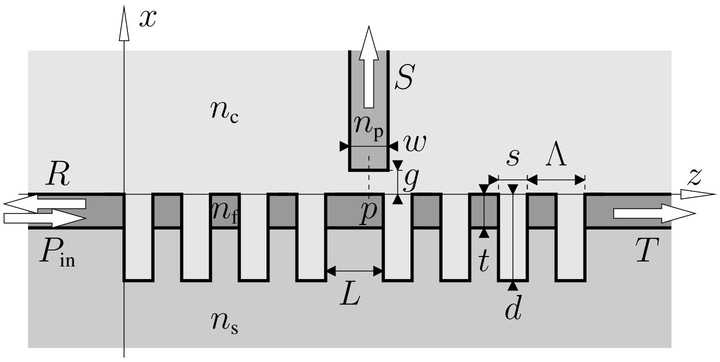
TE, $\lambda = 0.633\,\mu$m, $n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2\,\mu$m, $d = 0.6\,\mu$m, $\Lambda = 0.21\,\mu$m, $s = 0.11\,\mu$m, $g = 10\,$nm, $w = 100\,$nm, $n_p = 1.5$.



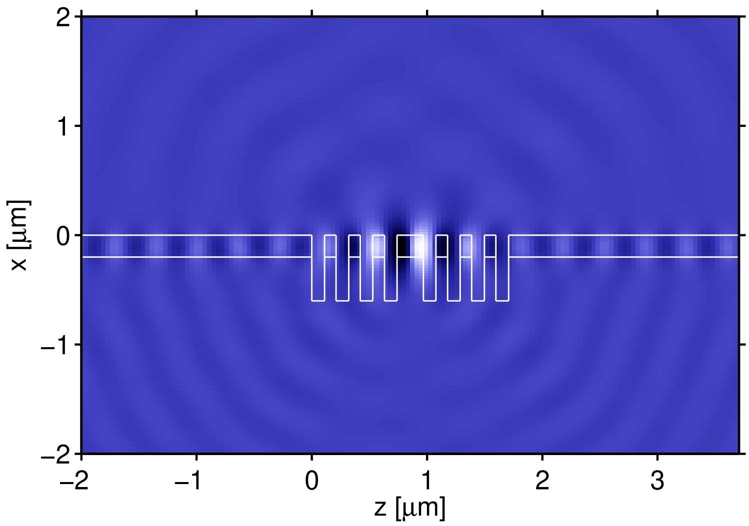


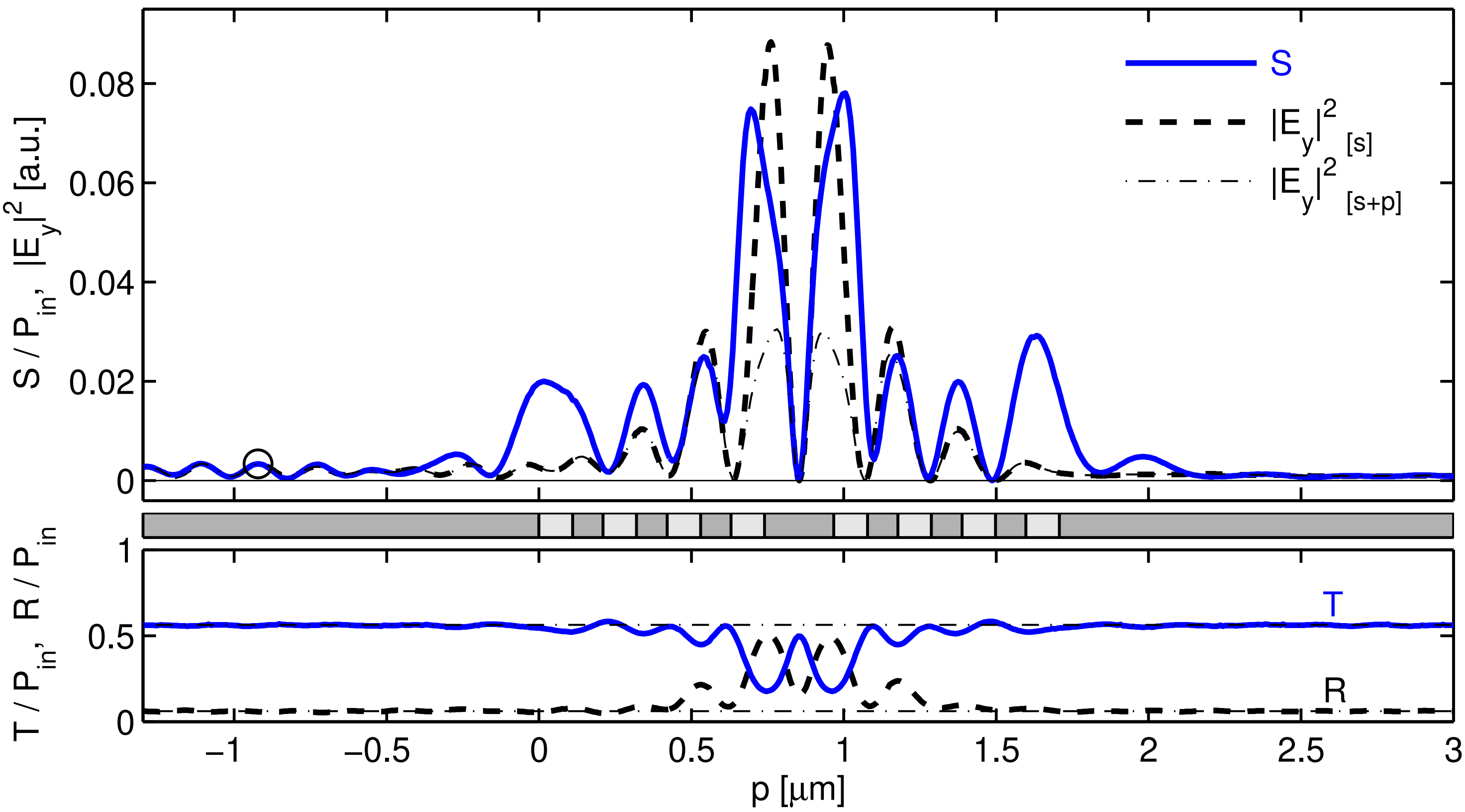


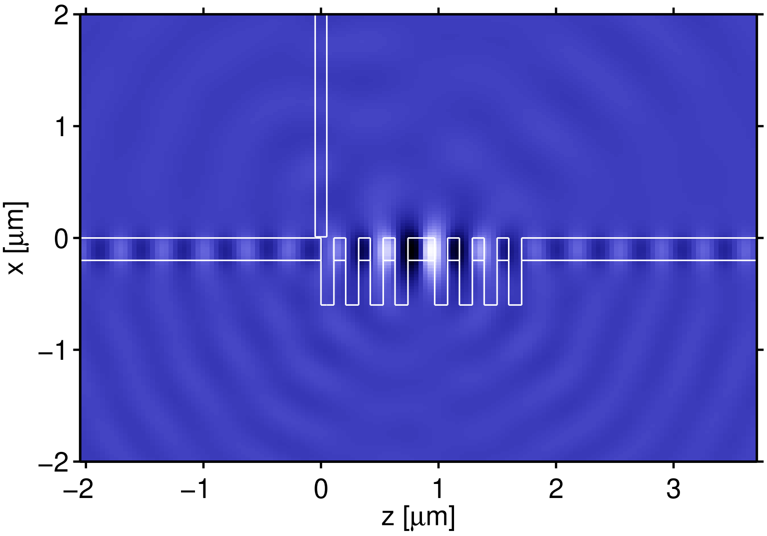
7 *Resonant defect cavity*

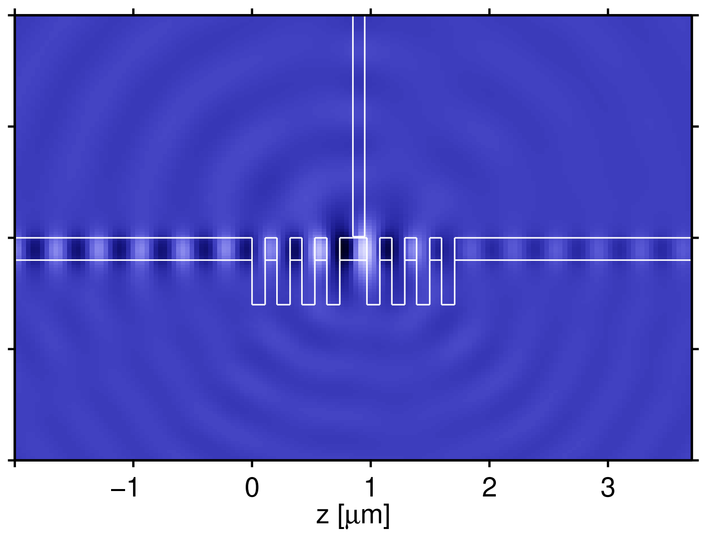


TE, $\lambda = 0.633\,\mu$m, $n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$,
$t = 0.2\,\mu$m, $d = 0.6\,\mu$m, $\Lambda = 0.21\,\mu$m, $s = 0.11\,\mu$m,
$L = 0.2275\,\mu$m, $g = 10\,$nm, $w = 100\,$nm, $n_p = 1.5$.

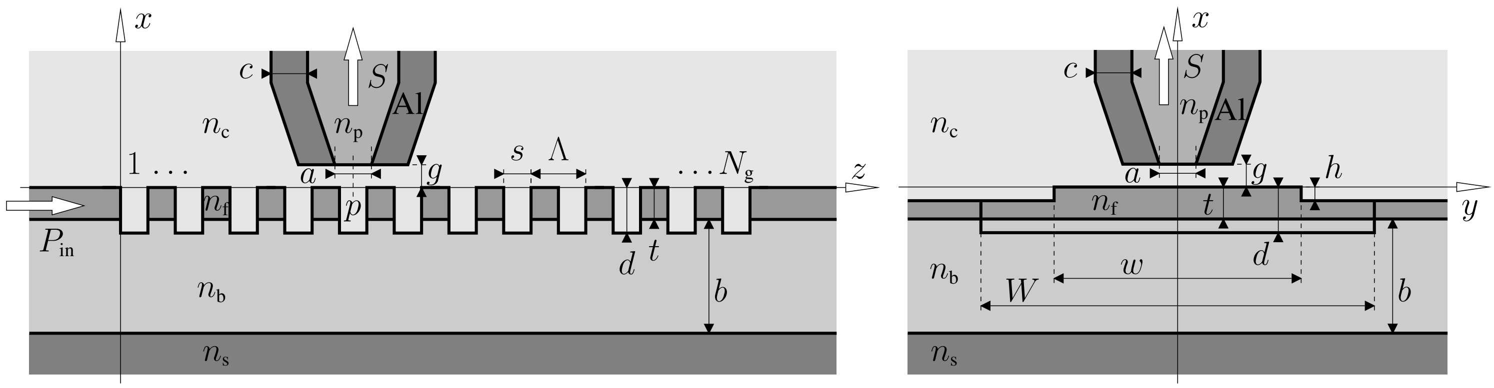






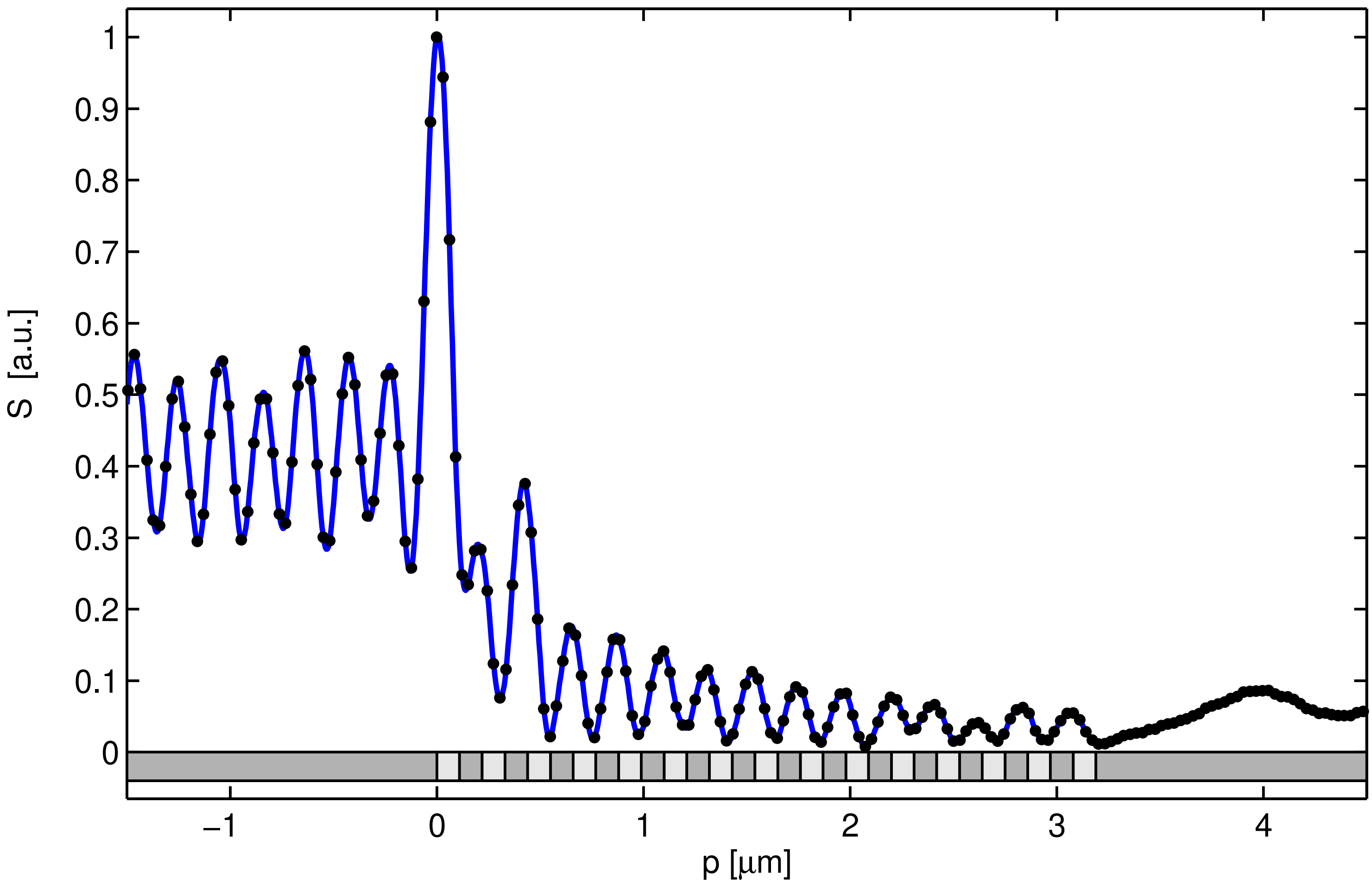


8 Bragg grating: PSTM experiment *



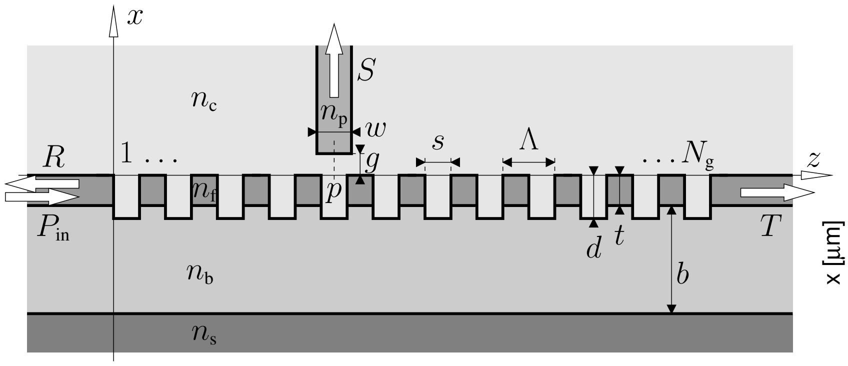
Sample: Rib waveguide with a series of deep, rectangular slits,
$n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $h = 11\,$nm, $w = 1.5\,\mu$m, $W = 2.5\,\mu$m, $t = 55\,$nm, $b = 3.2\,\mu$m, $\Lambda = 220\,$nm, $s = 110\,$nm, $d = 70\,$nm, $N_g = 15$.

Probe: Tapered cylindrical fiber tip with aluminium coating,
$a \approx 80\,$nm, $c \approx 100\,$nm, $g = 10\,$nm, $n_p = 1.5$; TE polarized light, vacuum wavelength $\lambda = 0.6328\,\mu$m.



* E. Flück, M. Hammer, A. M. Otter, J. P. Korterijk, L. Kuipers, N. F. van Hulst,
Amplitude and phase evolution of optical fields inside periodic photonic structures,
Journal of Lightwave Technology **21**(5), 1384-1393 (2003)

9 *Bragg grating: 2-D model*



TE, $\lambda = 0.6328\,\mu$m, $n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $t = 55$ nm, $d = 70$ nm, $b = 3.2\,\mu$m, $\Lambda = 220$ nm, $s = 110$ nm, $N_g = 15$, $g = 10$ nm, $w = 100$ nm, $n_p = 1.5$.