

Computational photonics

— scattering problems in guided wave optics



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AAMP

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Photonics

“**Photonics** is the science and technology of generating, controlling, and detecting photons, particularly in the visible light and near infra-red spectrum.

... quantum optics, ... optoelectronics ...

... the overlap between all these fields and **optics** is unclear, and different definitions are used in different parts of the world and in different industries.

... goal of establishing an electronics of photons instead of electrons.

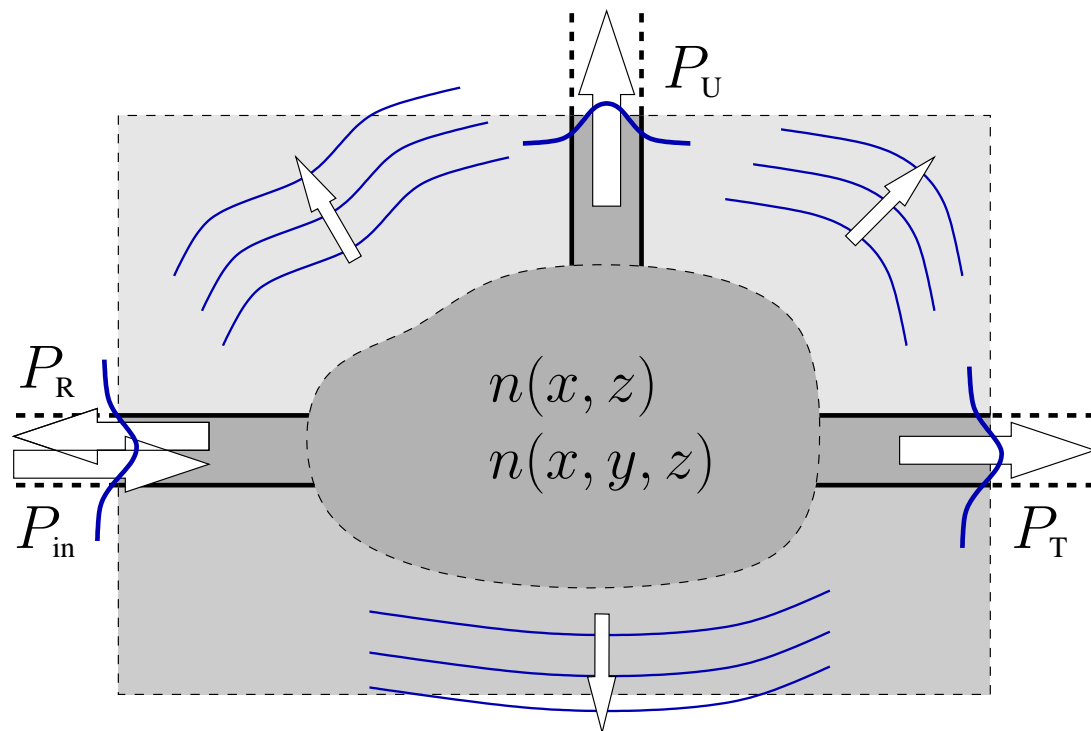
... strong interest in optical communication ... usually based on laser light.”

<http://www.wikipedia.org>

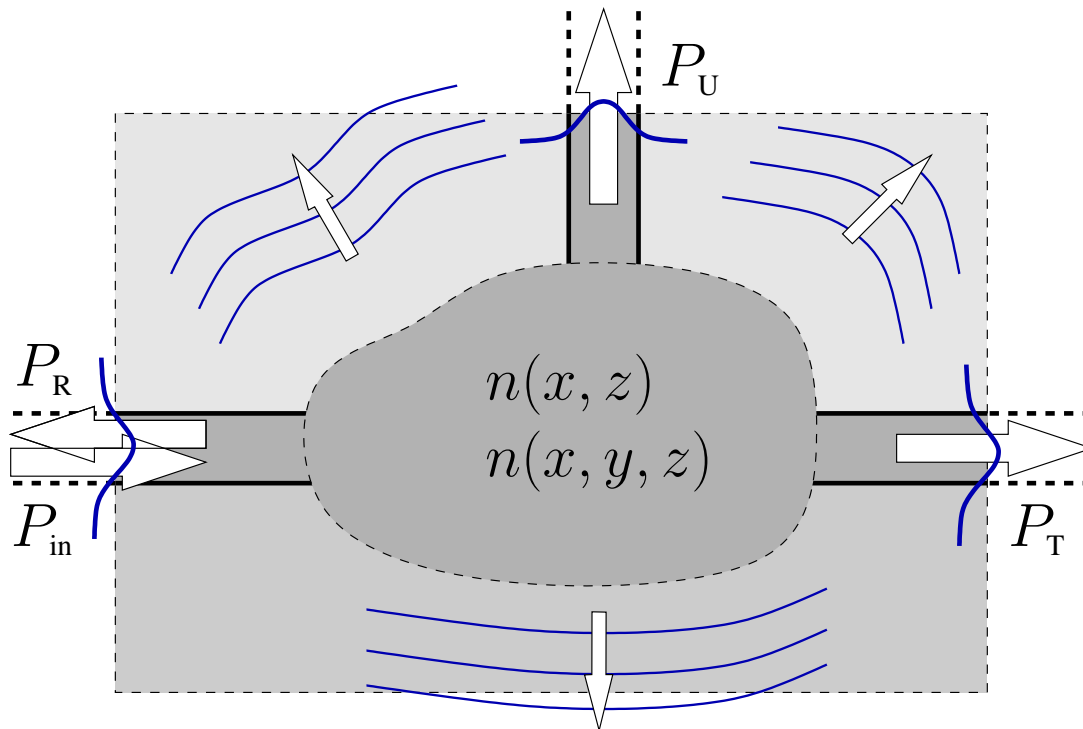
Outline

- Simulations in guided wave optics
 - Macroscopic Maxwell equations
 - Stationary and time-domain problems
 - 2-D problems
 - Modes of dielectric waveguides
- Quadridirectional eigenmode propagation
 - Problem setting
 - Eigenmode expansion
 - Algebraic procedure
- 2-D PSTM model
 - Probing evanescent fields
 - Hole defect in a slab waveguide
 - Waveguide Bragg grating: experiment & 2-D model
 - Resonant defect cavity
- Optical switching by NEMS-actuated resonator arrays

Abstract scattering problem



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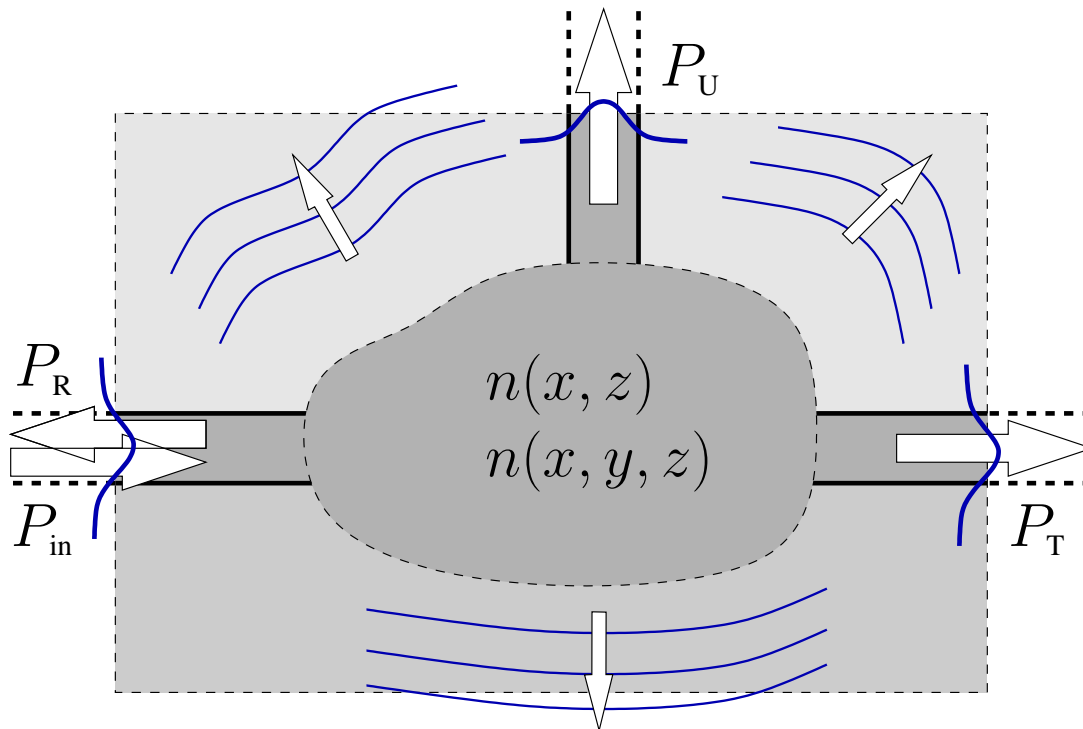


Typical parameters:

- vacuum wavelength
 $\lambda \in [400, 700] \text{ nm}$ (visible light),
 $\lambda \approx 1.3 \mu\text{m}, 1.55 \mu\text{m}$
(optical fibers, attenuation min.),
- refractive indices $n \in [1, 3.4]$,
small attenuation
(transparent dielectrics).

- Interesting domain: $(10 \lambda - 100 \lambda)^d$, $d = 2, 3$ (2-D, 3-D).
- Details: $\approx \lambda/10$, $\approx \lambda/100$.
- Influx and outflux: guided & nonguided waves \leftrightarrow boundary conditions.

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- Details: $\approx \lambda/10$, $\approx \lambda/100$.
- Influx and outflux: guided & nonguided waves \leftrightarrow boundary conditions.
- Emphasis: device concepts, design.

Macroscopic Maxwell equations

... for the electromagnetic fields

$$\mathcal{E}(x, y, z, t) = \frac{1}{2} \left(\mathbf{E}(x, y, z) e^{i\omega t} + \mathbf{E}^*(x, y, z) e^{-i\omega t} \right),$$

$$\hat{=} \mathcal{B}, \mathbf{B}, \mathcal{D}, \mathbf{D}, \mathcal{H}, \mathbf{H}, \mathcal{P}, \mathbf{P}, \mathcal{M}, \mathbf{M}, \omega = kc = 2\pi c/\lambda,$$

in frequency domain form, SI (source-free):

$$\begin{aligned} \text{curl } \mathbf{E} &= -i\omega \mathbf{B}, & \text{curl } \mathbf{H} &= i\omega \mathbf{D}, & \text{div } \mathbf{D} &= 0, & \text{div } \mathbf{B} &= 0, \\ \mathbf{B} &= \mu_0(\mathbf{H} + \mathbf{M}), & \mathbf{D} &= \epsilon_0 \mathbf{E} + \mathbf{P}. \end{aligned}$$

Macroscopic Maxwell equations

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$$\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M}), \quad \mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P}.$$

Typical media:

- uncharged, no free currents and charges,
- nonmagnetic at optical frequencies, $\mathbf{M} = 0$,
- dielectrics, susceptibilities $\hat{\chi}^{(j)}(x, y, z; \omega)$:

$$P_j = \epsilon_0 \left(\sum_k \chi_{j,k}^{(1)} E_k + \sum_{k,l} \chi_{j,k,l}^{(2)} E_k E_l + \sum_{k,l,m} \chi_{j,k,l,m}^{(3)} E_k E_l E_m \dots \right).$$

Convention: eliminate \mathbf{D} and \mathbf{B}  formulation in \mathbf{E} and \mathbf{H} .

Linear problems

$$\mathbf{P} = \epsilon_0 \hat{\chi}^{(1)} \mathbf{E}, \quad \mathbf{D} = \epsilon_0 (1 + \hat{\chi}^{(1)}) \mathbf{E} = \epsilon_0 \hat{\epsilon} \mathbf{E};$$

$\hat{\epsilon} = 1 + \hat{\chi}^{(1)}$: relative permittivity.

Simplest case: isotropic, lossless dielectrics; refractive index n :

$$\hat{\epsilon} = \epsilon \mathbf{1}, \quad \epsilon = n^2, \quad n(x, y, z; \omega) \in \mathbb{R}.$$

Frequently n is piecewise constant \longleftrightarrow interface conditions for \mathbf{E} , \mathbf{H} .

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Frequently n is piecewise constant \longleftrightarrow interface conditions for \mathbf{E} , \mathbf{H} .

Complications:

- anisotropic media, $\hat{\epsilon} \not\approx \mathbf{1}$ (crystals, ordered materials),
- attenuation, $\hat{\epsilon}^\dagger \neq \hat{\epsilon}$, $n \notin \mathbb{R}$,
- nonlinear problems, $\hat{\chi}^{(2)}$, $\hat{\chi}^{(3)}$...

Stationary problems

Continuous wave excitation, ω a given parameter:

$$\operatorname{curl} \mathbf{E} = -i\omega\mu_0\mathbf{H}, \quad \operatorname{curl} \mathbf{H} = i\omega\epsilon_0\hat{\epsilon}\mathbf{E}, \quad \operatorname{div} \hat{\epsilon}\mathbf{E} = 0, \quad \operatorname{div} \mathbf{H} = 0,$$

or

$$\operatorname{curl} \operatorname{curl} \mathbf{E} = k^2\hat{\epsilon}\mathbf{E}, \quad \operatorname{curl} \hat{\epsilon}^{-1}\operatorname{curl} \mathbf{H} = k^2\mathbf{H},$$

$$\mathbf{E}(x, y, z) \in \mathbb{C}^3, \quad \mathbf{H}(x, y, z) \in \mathbb{C}^3.$$

Helmholtz solver:

Given $\hat{\epsilon}$ and an optical “influx”, find \mathbf{E} , \mathbf{H} on a computational domain, subject to suitable boundary conditions.

Scans over ω  Spectral data.

Time dependent modeling

Propagation of time dependent signals, pulsed excitation:

$$\text{curl } \mathcal{E} = -\mu_0 \partial_t \mathcal{H}, \quad \text{curl } \mathcal{H} = \epsilon_0 \hat{\epsilon} \partial_t \mathcal{E}, \quad \text{div } \hat{\epsilon} \mathcal{E} = 0, \quad \text{div } \mathcal{H} = 0,$$

or

$$\text{curl curl } \mathcal{E} = -\frac{1}{c^2} \hat{\epsilon} \partial_t^2 \mathcal{E}, \quad \text{curl } \hat{\epsilon}^{-1} \text{curl } \mathcal{H} = -\frac{1}{c^2} \partial_t^2 \mathcal{H},$$

$$\mathcal{E}(x, y, z, t) \in \mathbb{R}^3, \quad \mathcal{H}(x, y, z, t) \in \mathbb{R}^3.$$

Time domain solver:

Given $\hat{\epsilon}$ and an optical “influx” signal, find \mathcal{E} , \mathcal{H} on a computational domain within a certain time interval, subject to suitable boundary conditions.

Fourier transform with respect to time  spectral data.

2-D problems

$$\partial_y \epsilon = 0, \quad \epsilon(x, z) = n^2(x, z),$$

$$\partial_y \mathbf{E} = 0, \quad \partial_y \mathbf{H} = 0;$$

equations split into two subsets:

TE, E_y , H_x , and H_z , principal component E_y :

$$i\omega\mu_0 H_x = \partial_z E_y, \quad i\omega\mu_0 H_z = -\partial_x E_y, \quad i\omega\epsilon_0 \epsilon E_y = \partial_z H_x - \partial_x H_z,$$

or

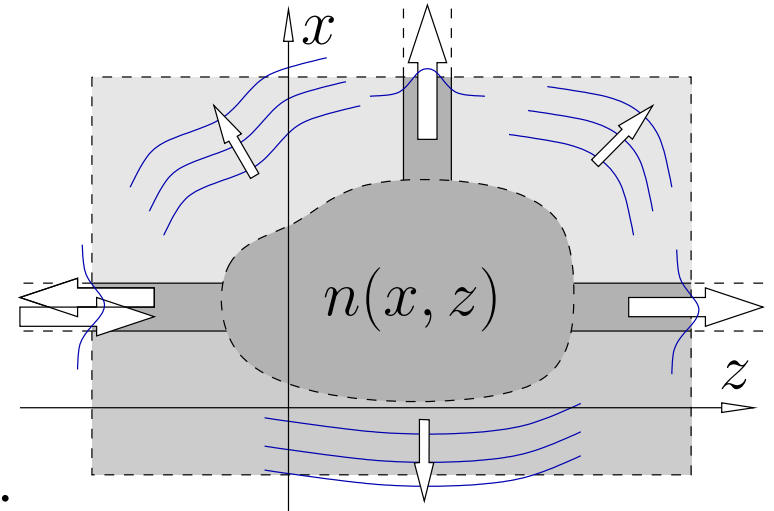
$$\partial_x^2 E_y + \partial_z^2 E_y + k^2 \epsilon E_y = 0.$$

TM, H_y , E_x , and E_z , principal component H_y :

$$i\omega\epsilon_0 \epsilon E_x = -\partial_z H_y, \quad i\omega\epsilon_0 \epsilon E_z = \partial_x H_y, \quad -i\omega\mu_0 H_y = \partial_z E_x - \partial_x E_z,$$

or

$$\partial_x \frac{1}{\epsilon} \partial_x H_y + \partial_z \frac{1}{\epsilon} \partial_z H_y + k^2 H_y = 0.$$

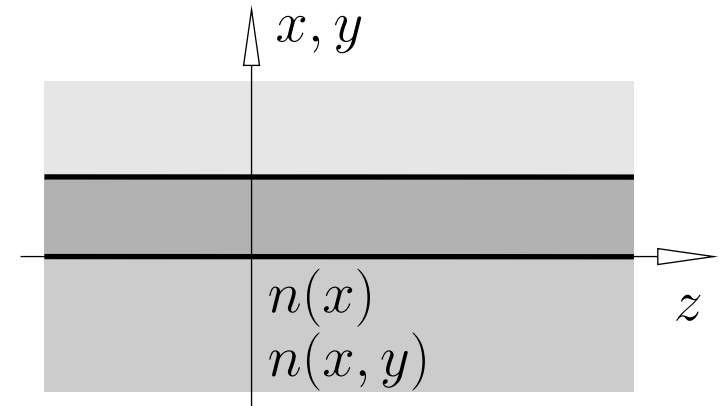


Dielectric waveguides

$\partial_z \epsilon = 0$, $\partial_z n = 0$, modal solutions with profile $\tilde{\mathbf{E}}$, $\tilde{\mathbf{H}}$, and propagation constant β ;

$$\mathbf{E}(x, y, z) = \tilde{\mathbf{E}}(x, y) e^{-i\beta z},$$

$$\mathbf{H}(x, y, z) = \tilde{\mathbf{H}}(x, y) e^{-i\beta z}.$$



$$\mathcal{E}(x, y, z, t) = \text{Re} \tilde{\mathbf{E}}(x, y) e^{i\omega t - i\beta z}, \quad \mathcal{H}(x, y, z, t) = \text{Re} \tilde{\mathbf{H}}(x, y) e^{i\omega t - i\beta z}.$$

Guided modes: $\iint |\tilde{\mathbf{E}}|^2 dx dy < \infty$, $\iint |\tilde{\mathbf{H}}|^2 dx dy < \infty$.

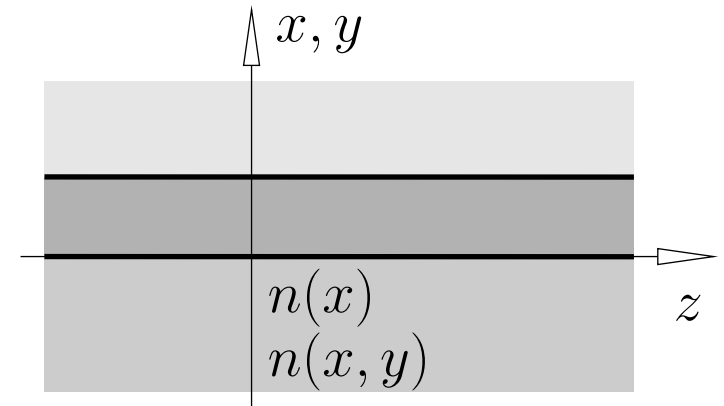
Mode solver: Eigenvalue problem for $\tilde{\mathbf{E}}$, $\tilde{\mathbf{H}}$, and β .

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Mode solver: Eigenvalue problem for $\tilde{\mathbf{E}}$, $\tilde{\mathbf{H}}$, and β .

- Basis for all kinds of design considerations,
- basis fields for various types of perturbational simulations,
- input / output fields for Helmholtz & time domain solvers.

Guided modes, 2-D, TE

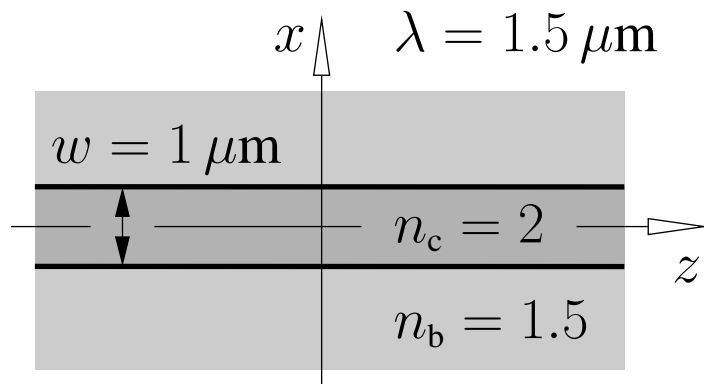
$$(\partial_x^2 + k^2 n^2(x)) \tilde{E}_y = \beta^2 \tilde{E}_y, \quad \int |\tilde{E}_y|^2 dx < \infty, \quad \tilde{H}_x = \frac{-\beta}{\omega \mu_0} \tilde{E}_y, \quad \tilde{H}_z = \frac{i}{\omega \mu_0} \partial_x \tilde{E}_y,$$

$$\mathcal{E}(x, z, t) = \operatorname{Re} \begin{pmatrix} 0 \\ \tilde{E}_y \\ 0 \end{pmatrix} (x) e^{i\omega t - i\beta z}, \quad \mathcal{H}(x, z, t) = \operatorname{Re} \begin{pmatrix} \tilde{H}_x \\ 0 \\ \tilde{H}_z \end{pmatrix} (x) e^{i\omega t - i\beta z},$$

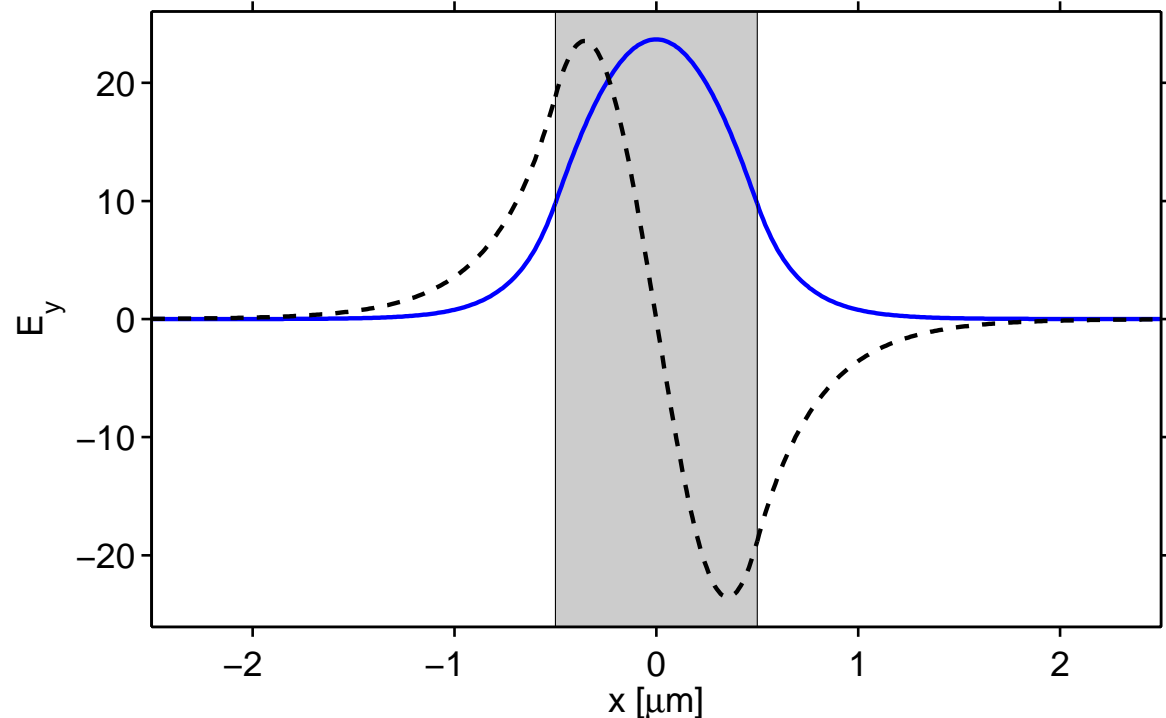
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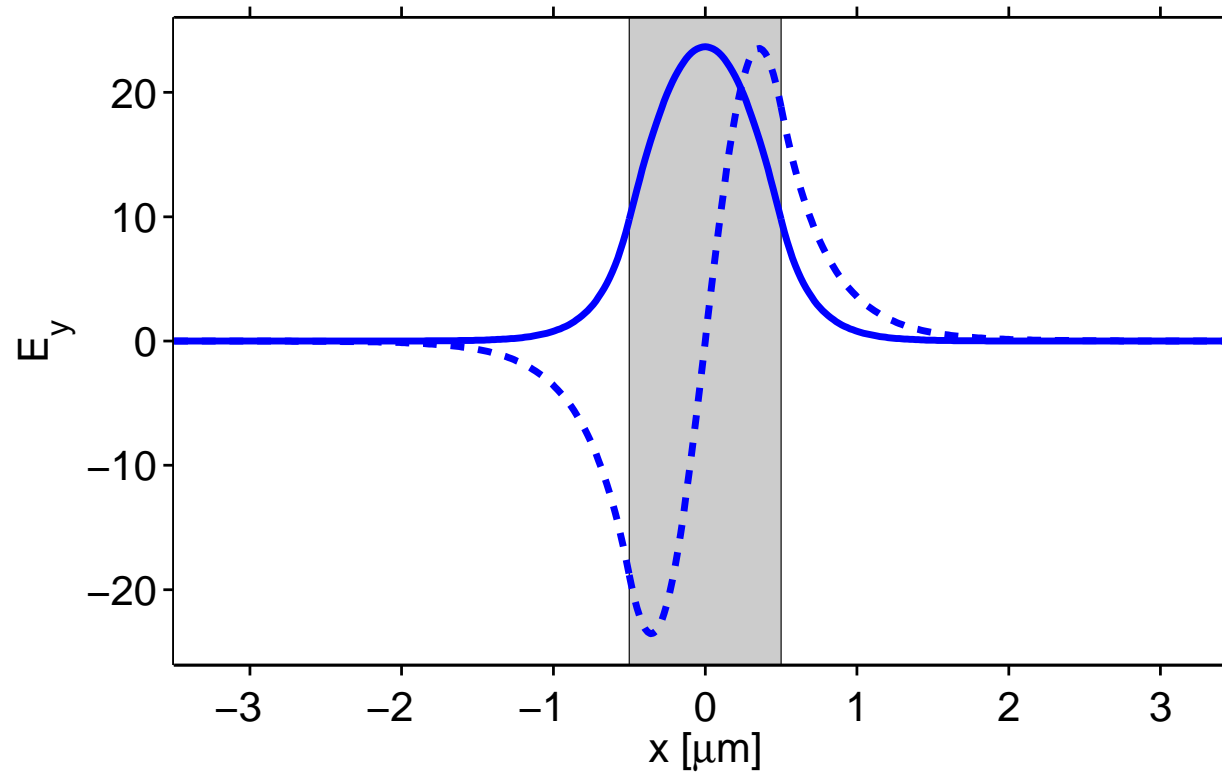


$$\beta_0/k = 1.923, \quad \beta_1/k = 1.697.$$



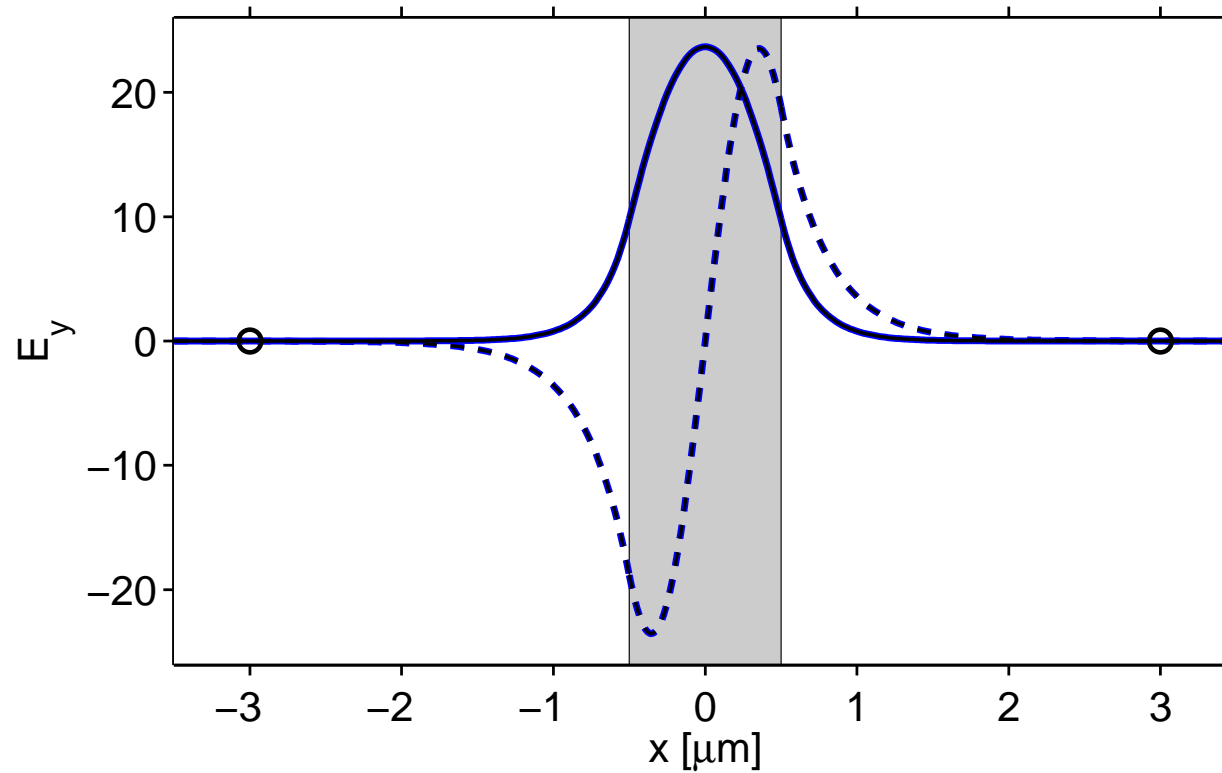
- Mode propagation
- “Coupling” of modes

Modal basis sets



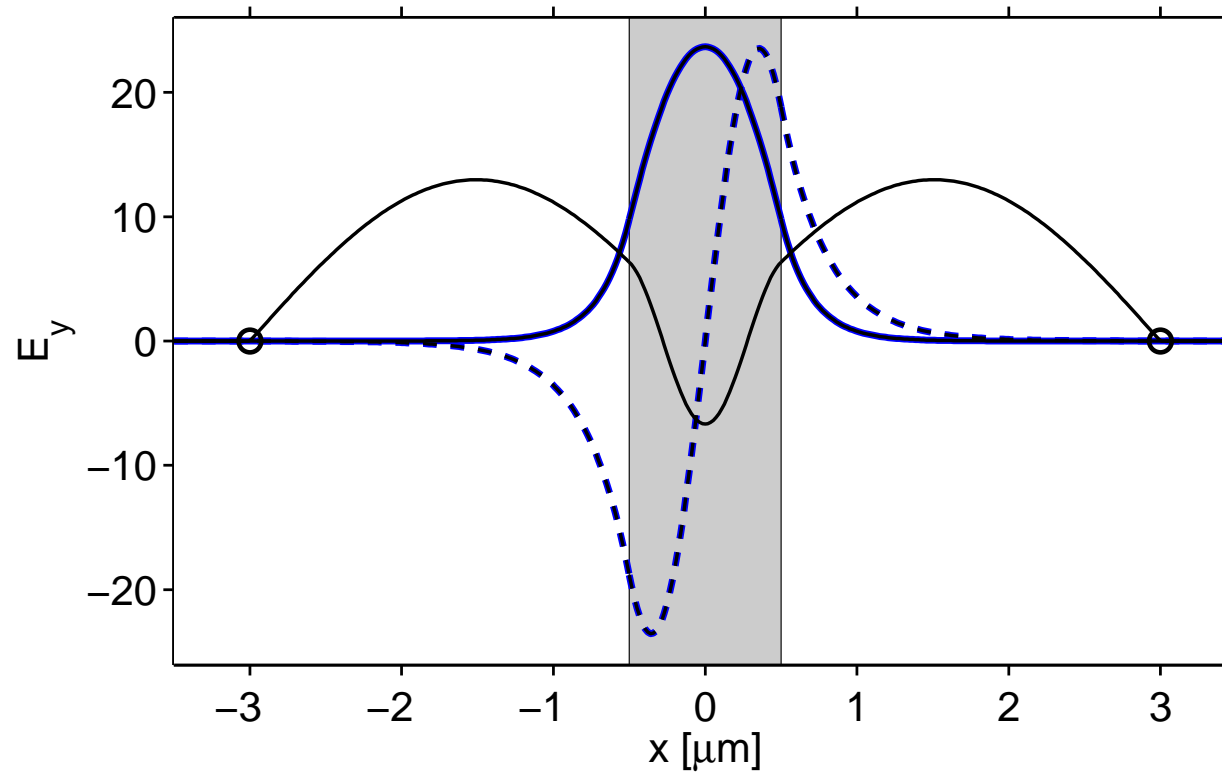
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Modal basis sets



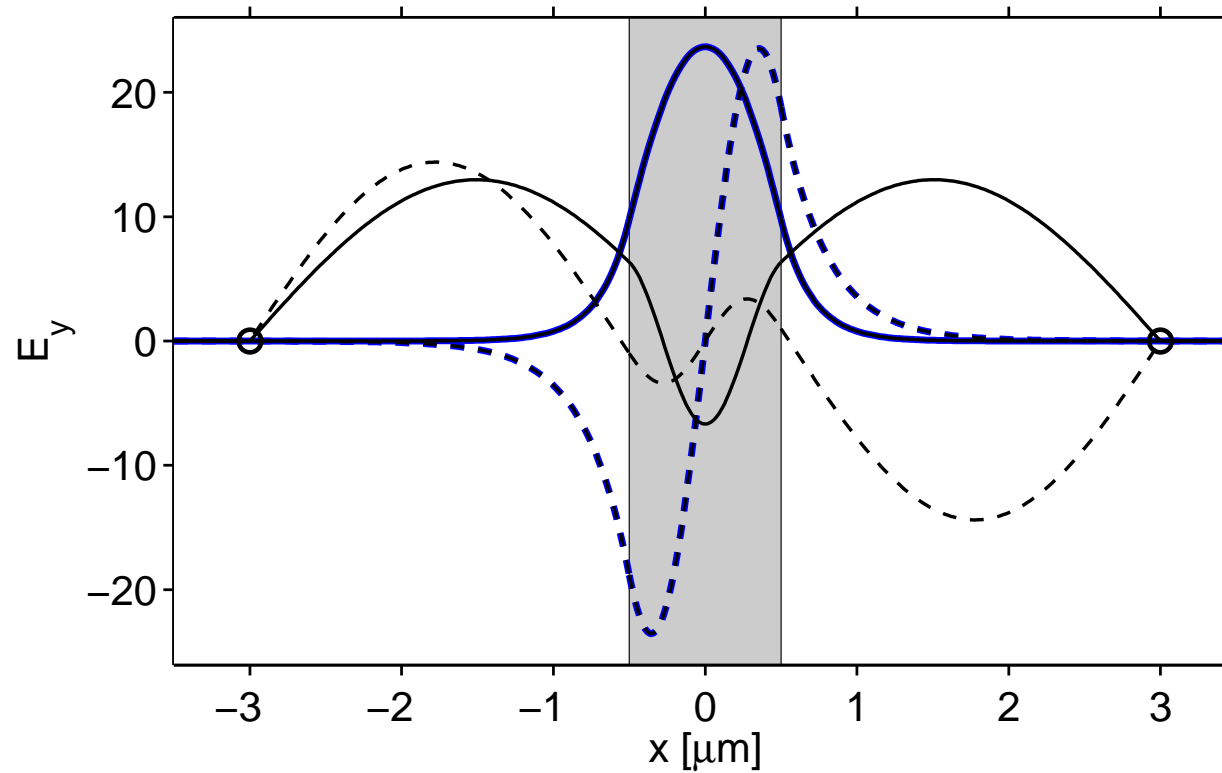
$$(\partial_x^2 + k^2 n^2(x)) \tilde{E}_y = \beta^2 \tilde{E}_y, \quad \int_{x_0}^{x_1} |\tilde{E}_y|^2 dx = 1, \quad \tilde{E}_y(x_0) = \tilde{E}_y(x_1) = 0.$$

Modal basis sets



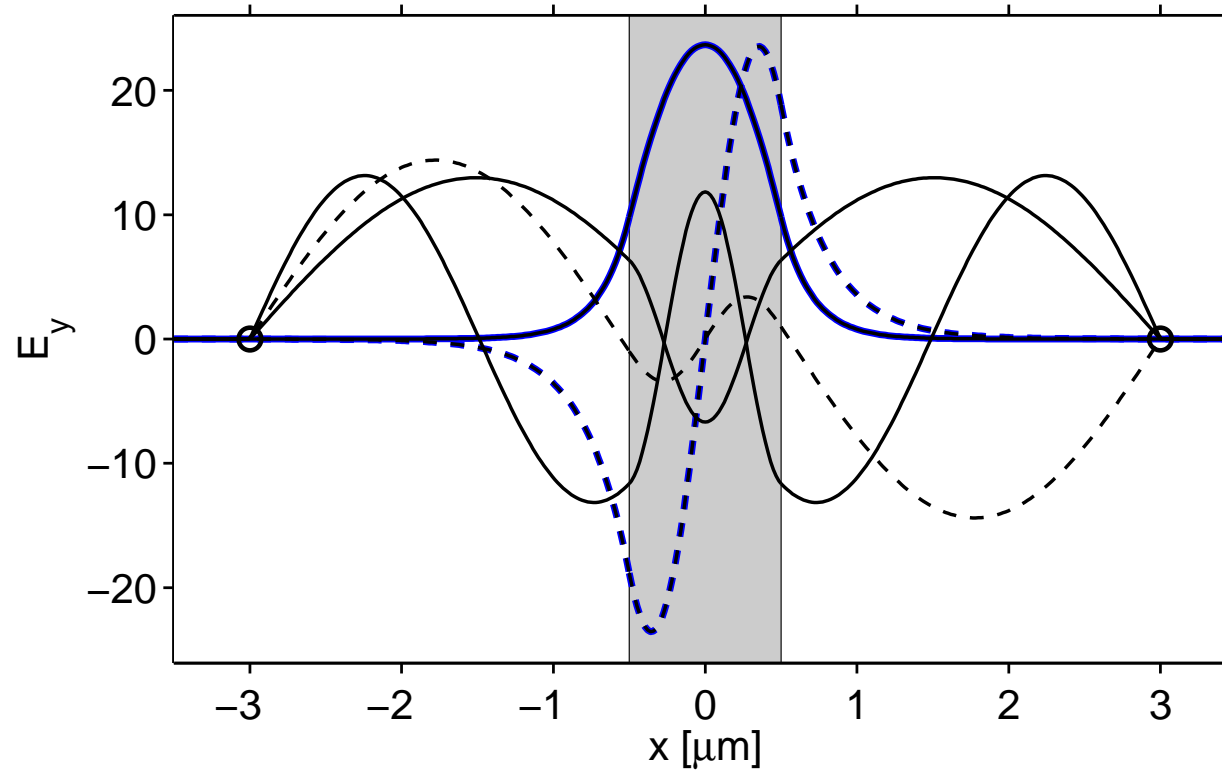
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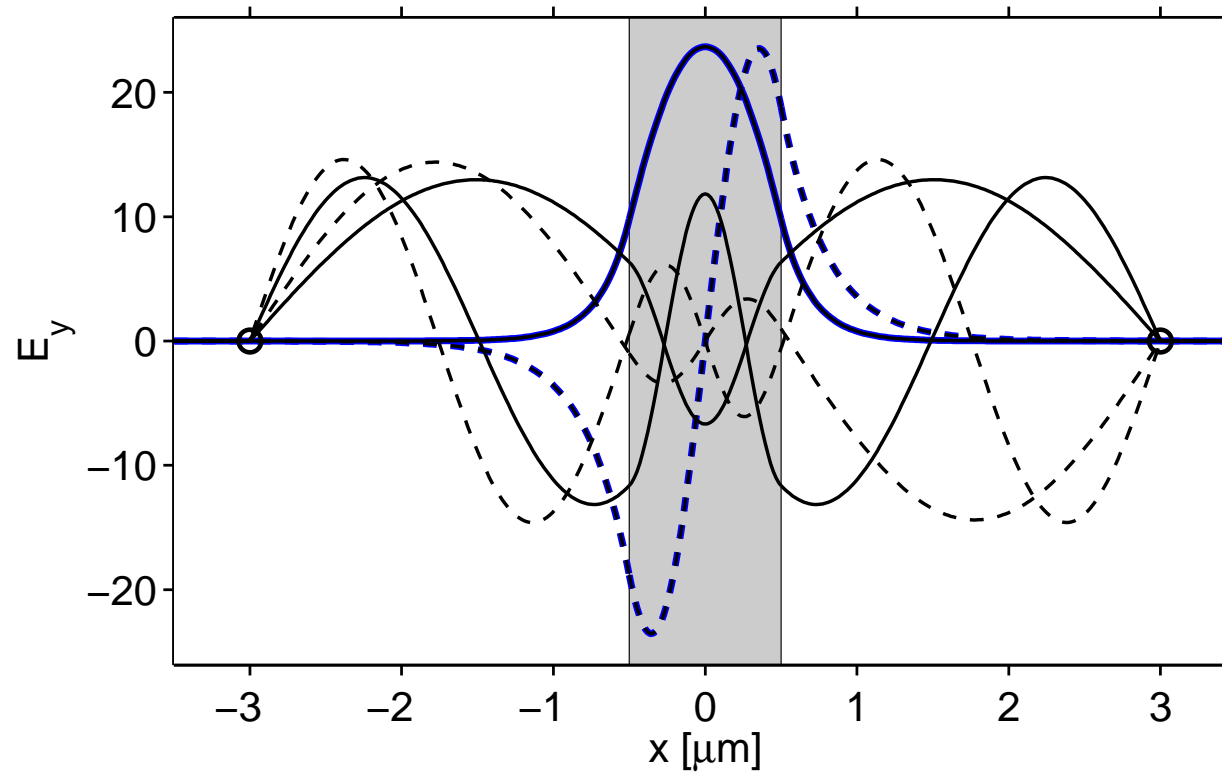
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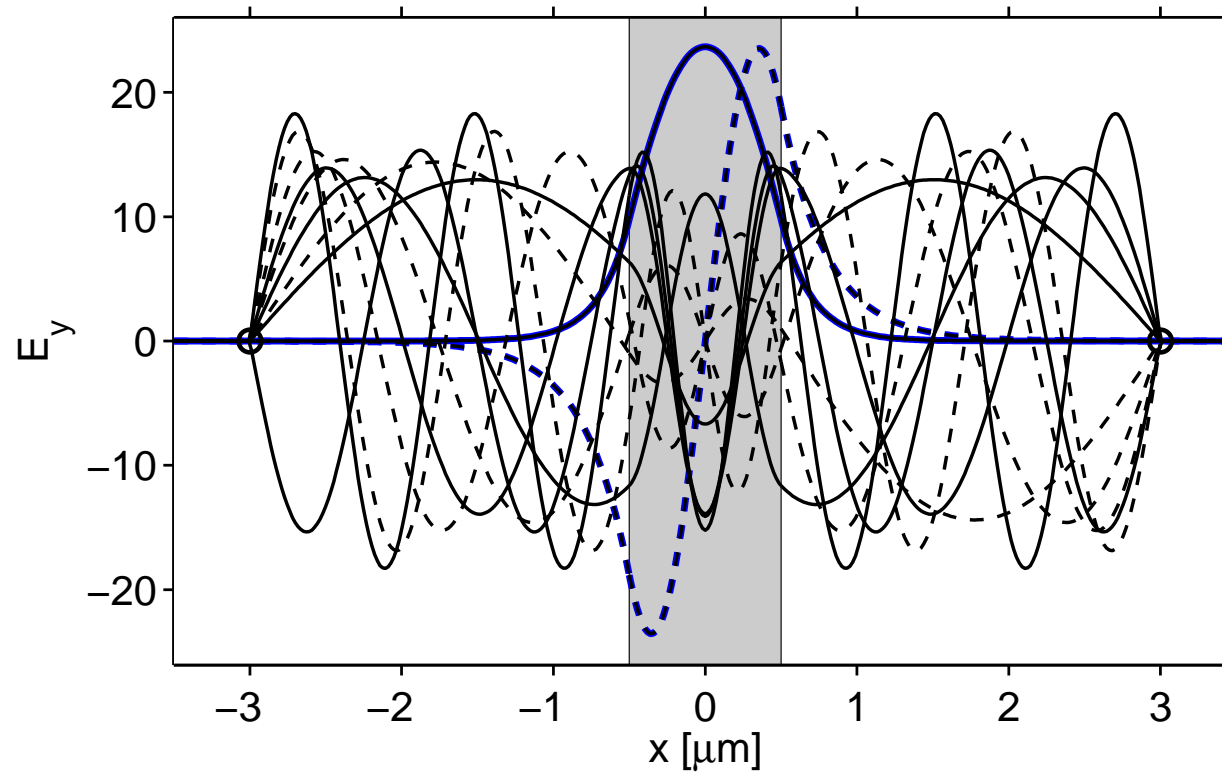
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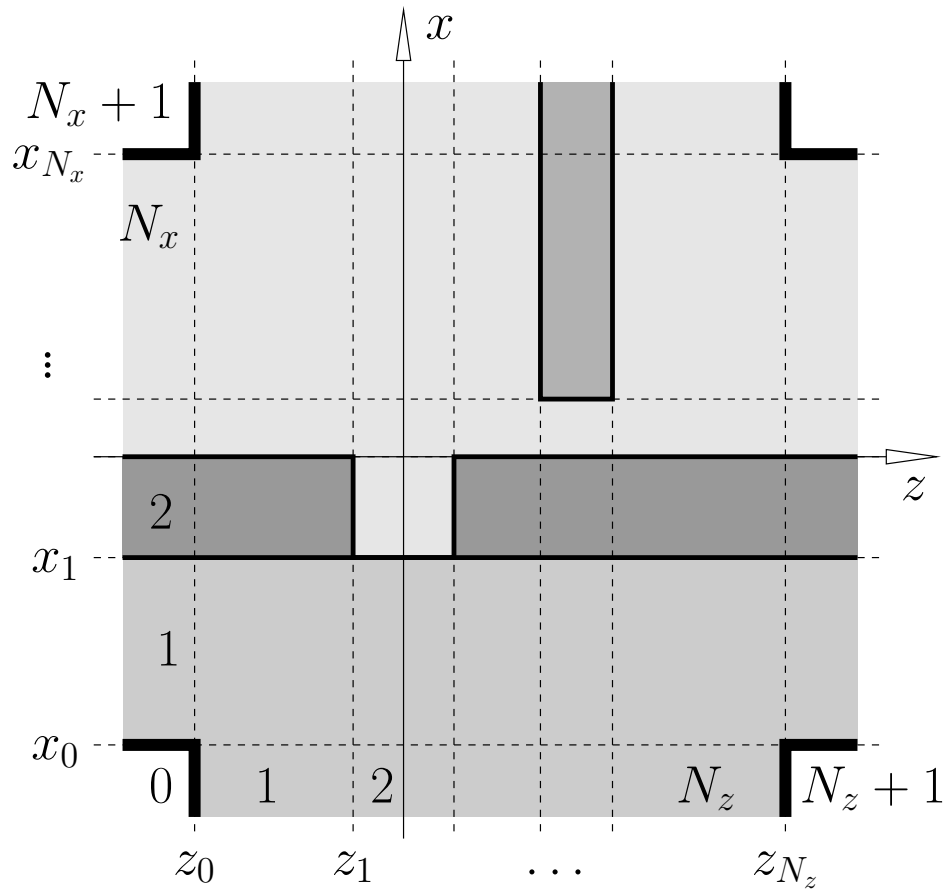
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$\{\beta_j, E_{y,j}\}$: complete discrete set of eigenmodes, expansion basis.

Outline

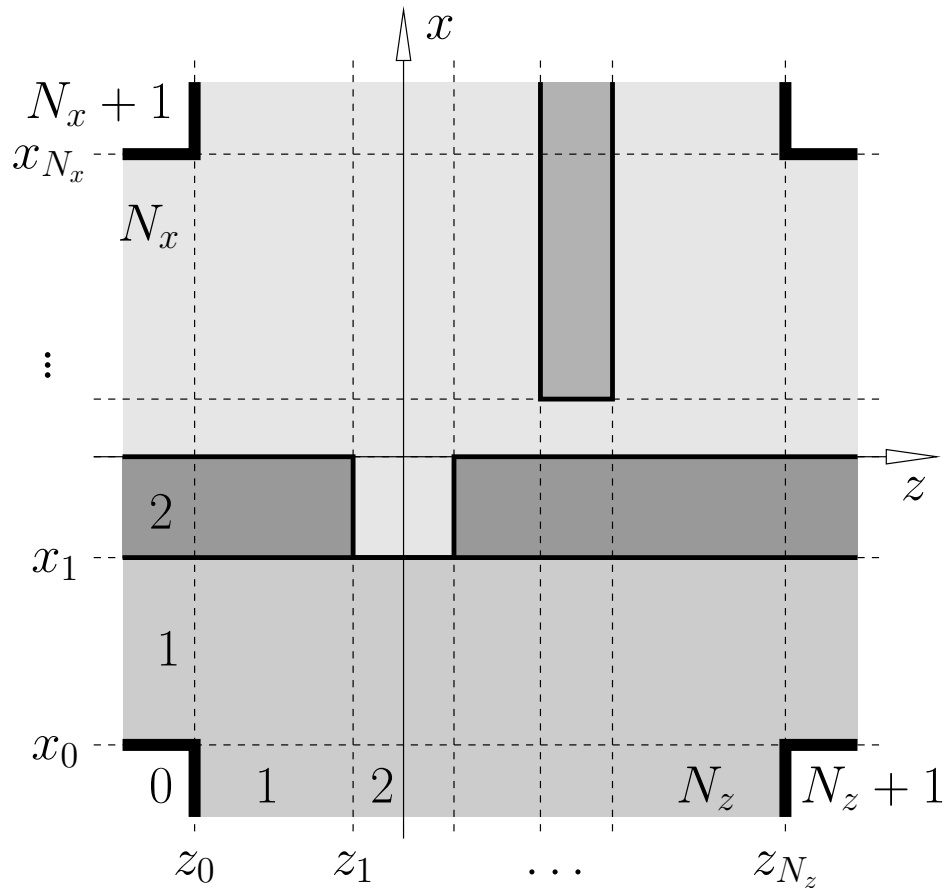
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QUEP simulations, problem setting



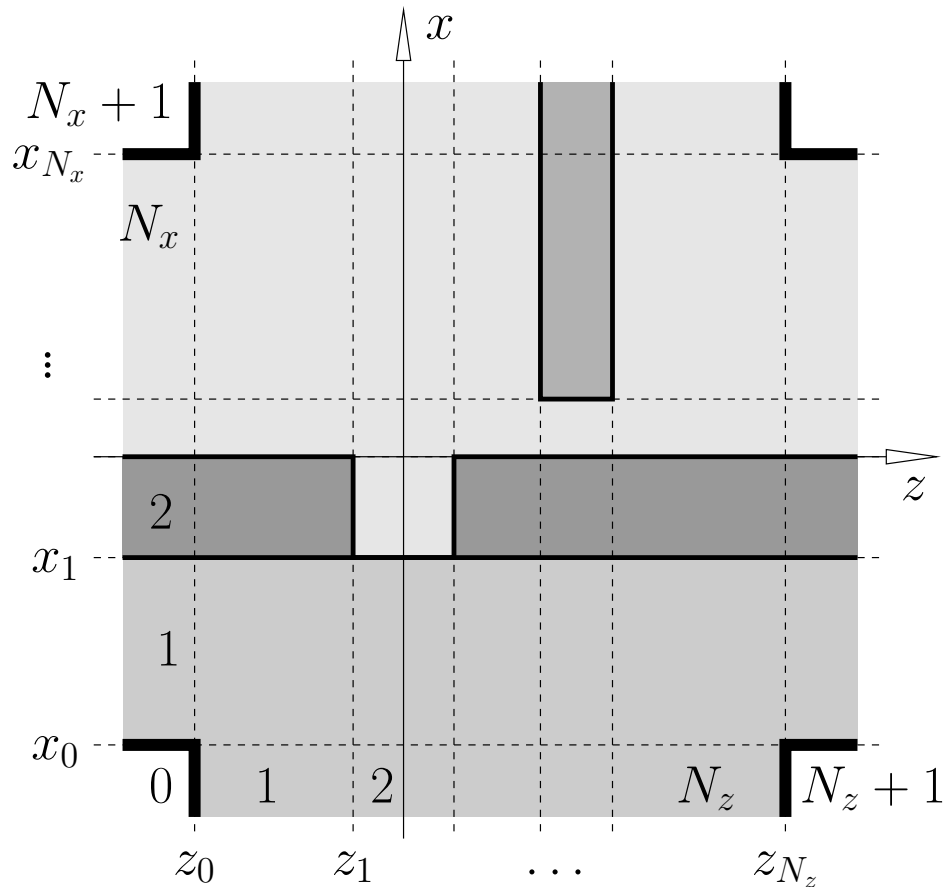
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QUEP simulations, problem setting



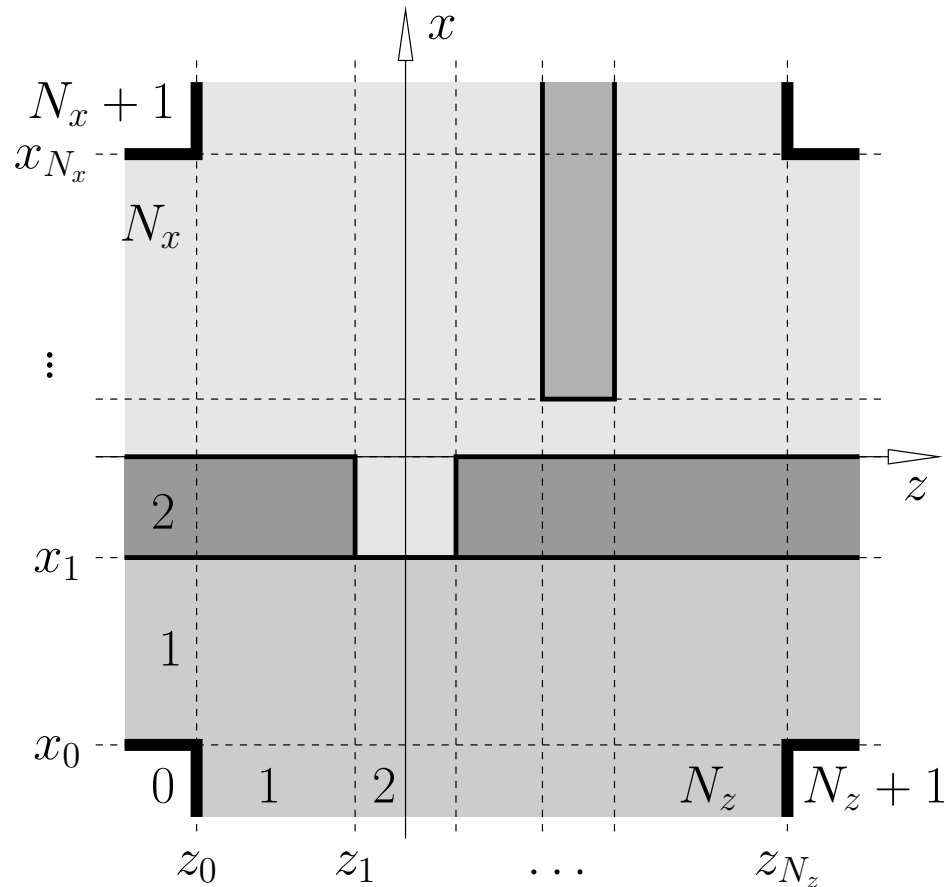
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QUEP simulations, problem setting



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- Piecewise constant, rectangular refractive index distribution; linear, lossless materials.
- Rectangular interior computational domain, influx & outflux across all four boundaries, outwards homogeneous external regions.

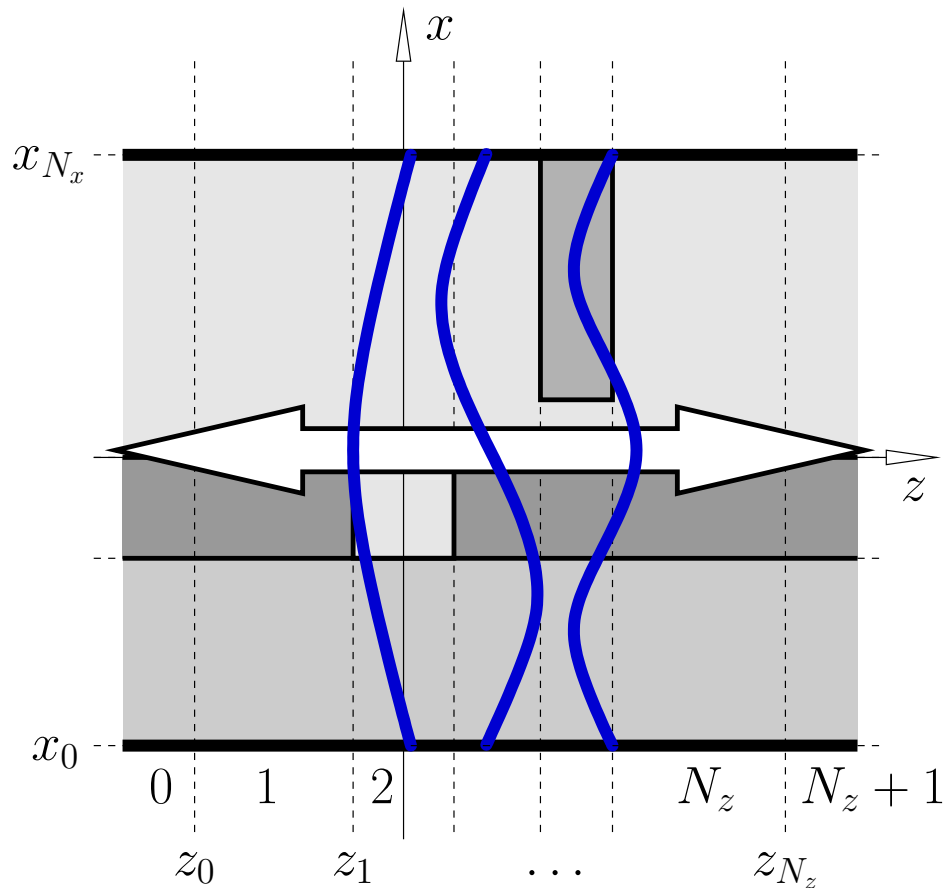
QUEP simulations, problem setting



- 2-D TE/TM Helmholtz problem, vacuum wavelength $\lambda = 2\pi/k$.
- Piecewise constant, rectangular refractive index distribution; linear, lossless materials.
- Rectangular interior computational domain, influx & outflux across all four boundaries, outwards homogeneous external regions.
- Assumption $E_y = 0$, $H_y = 0$ on the corner points and on the external border lines is reasonable for the problems under investigation.

Ingredients: “horizontal” modes

Basis fields,
defined by Dirichlet boundary conditions $E_y = 0$ (TE) or $H_y = 0$ (TM):



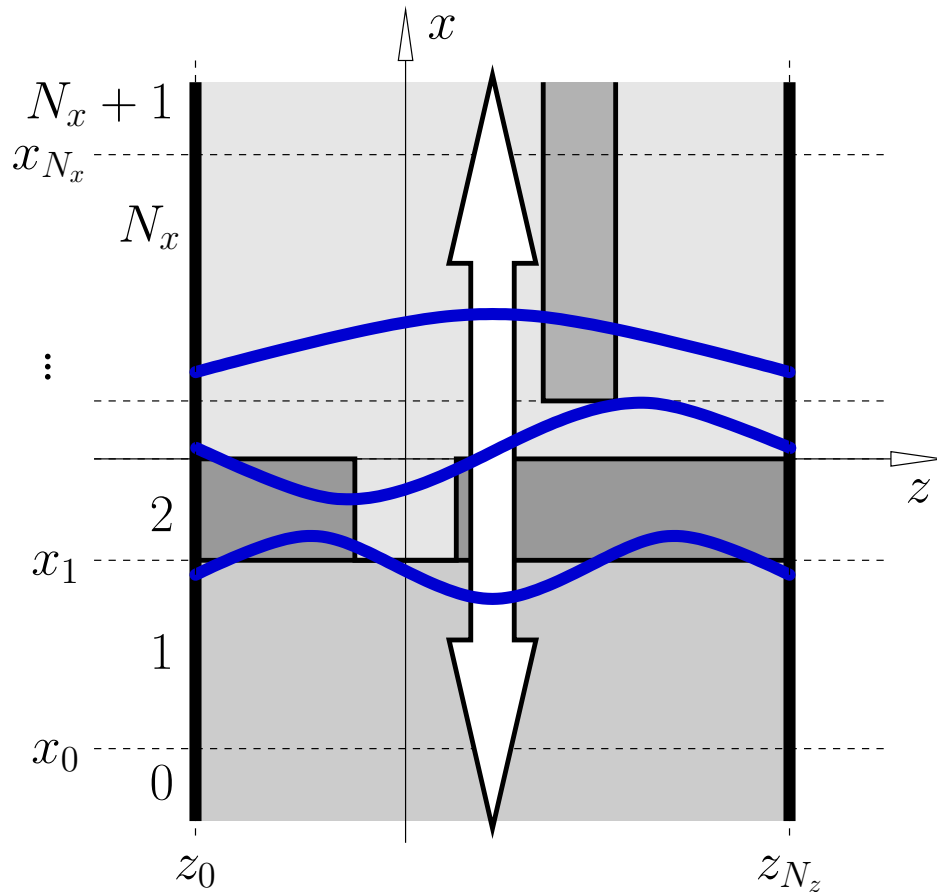
Horizontally traveling eigenmodes:

M_x profiles	$\psi_{s,m}^d(x)$
and propagation constants	$\pm\beta_{s,m}$

of order m , on slice s ,
for propagation directions $d = \text{f, b}$,

Ingredients: “vertical” modes

Basis fields,
defined by Dirichlet boundary conditions $E_y = 0$ (TE) or $H_y = 0$ (TM):



... and vertically traveling fields:

M_z profiles	$\hat{\psi}_{l,m}^d(z)$
and propagation constants	$\pm \hat{\beta}_{l,m}$

of order m , on layer l ,
for propagation directions $d = u, d$.

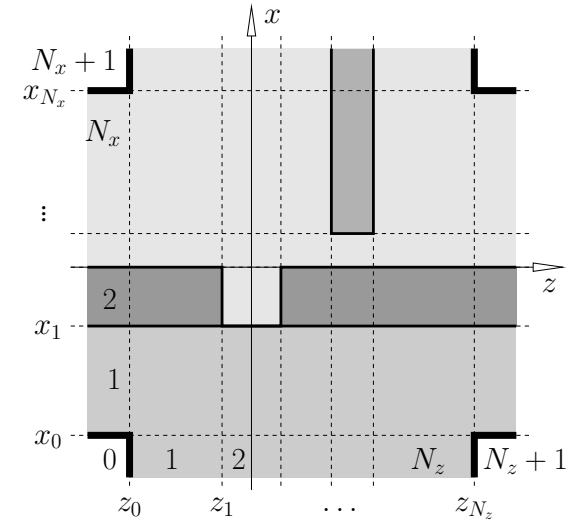
Eigenmode expansion

Ansatz for the optical field,

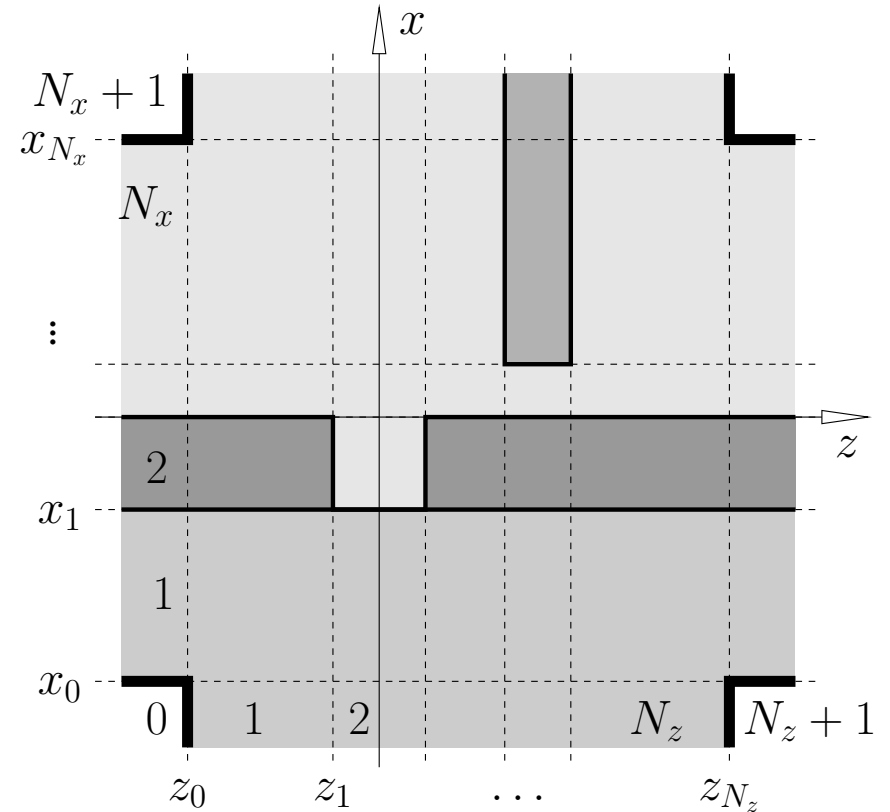
for $z_{s-1} \leq z \leq z_s$, $s = 1, \dots, N_z$,

and $x_{l-1} \leq x \leq x_l$, $l = 1, \dots, N_x$:

$$\begin{aligned}
 \begin{pmatrix} \mathcal{E} \\ \mathcal{H} \end{pmatrix} (x, z, t) = \text{Re} \left\{ \sum_{m=0}^{M_x-1} F_{s,m} \psi_{s,m}^f(x) e^{-i\beta_{s,m}(z - z_{s-1})} \right. \\
 + \sum_{m=0}^{M_x-1} B_{s,m} \psi_{s,m}^b(x) e^{+i\beta_{s,m}(z - z_s)} \\
 + \sum_{m=0}^{M_z-1} U_{l,m} \hat{\psi}_{l,m}^u(z) e^{-i\hat{\beta}_{l,m}(x - x_{l-1})} \\
 \left. + \sum_{m=0}^{M_z-1} D_{l,m} \hat{\psi}_{l,m}^d(z) e^{+i\hat{\beta}_{l,m}(x - x_l)} \right\} e^{i\omega t}.
 \end{aligned}$$



Eigenmode expansion

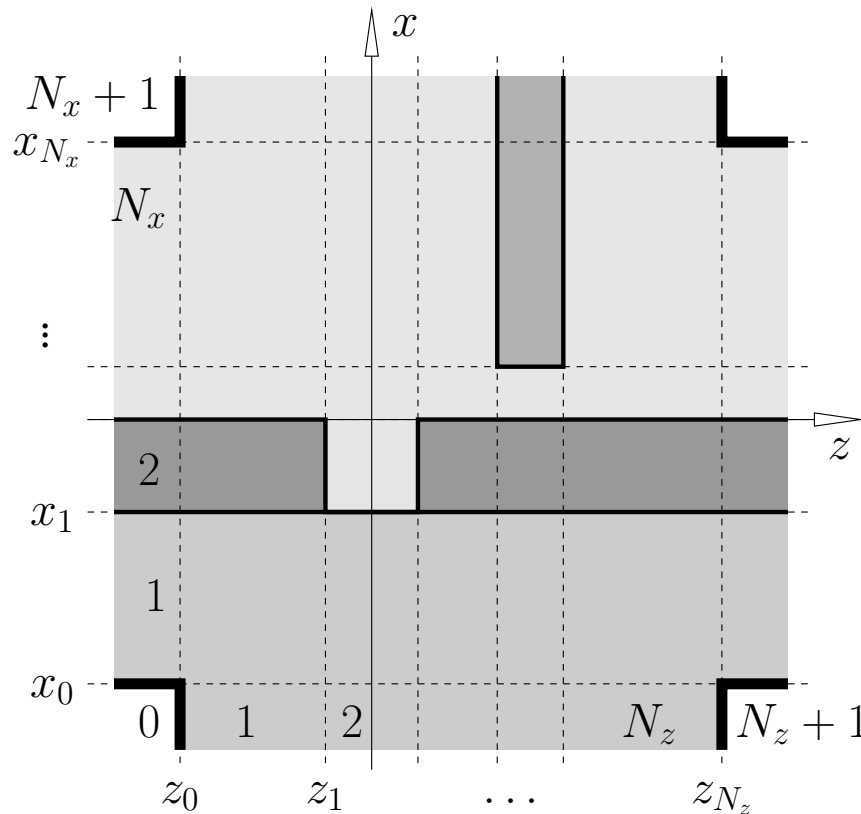


Mode products \leftrightarrow normalization, projection:

$$(\mathbf{E}_1, \mathbf{H}_1; \mathbf{E}_2, \mathbf{H}_2) = \frac{1}{4} \int (E_{1,x}^* H_{2,y} - E_{1,y}^* H_{2,x} + H_{1,y}^* E_{2,x} - H_{1,x}^* E_{2,y}) dx ,$$

$$\langle \mathbf{E}_1, \mathbf{H}_1; \mathbf{E}_2, \mathbf{H}_2 \rangle = \frac{1}{4} \int (E_{1,y}^* H_{2,z} - E_{1,z}^* H_{2,y} + H_{1,z}^* E_{2,y} - H_{1,y}^* E_{2,z}) dz .$$

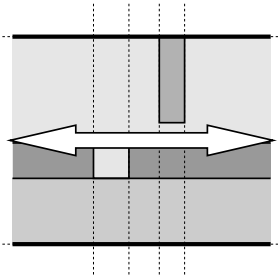
Algebraic procedure



- Consistent bidirectional projection at all interfaces
 \longrightarrow linear system of equations in $\{F_{s,m}, B_{s,m}, U_{l,m}, D_{l,m}\}$.
- Influx: $F_0, B_{N_x+1}, U_0, D_{N_z+1} \longrightarrow$ RHS, given.
- Outflux: $B_0, F_{N_x+1}, D_0, U_{N_z+1} \longrightarrow$ primary unknowns.

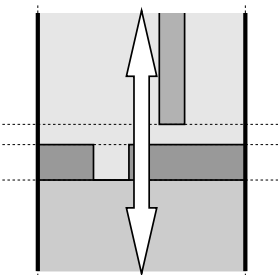
Algebraic procedure

- “Exact” mode profiles \longrightarrow interior problems decouple:



Solve for F_2, \dots, F_{N_z} and B_1, \dots, B_{N_z-1}
in terms of F_1 and B_{N_z}

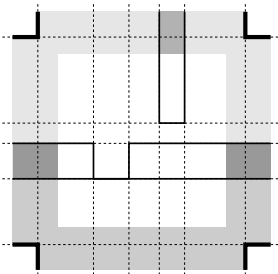
\longrightarrow BEP I.



Solve for U_2, \dots, U_{N_x} and D_1, \dots, D_{N_x-1}
in terms of U_1 and D_{N_x}

\longrightarrow BEP II.

- Continuity of E and H on outer interfaces:



Interior BEP solutions

+ equations at $z = z_0, z_{N_z}, x = x_0, x_{N_x}$

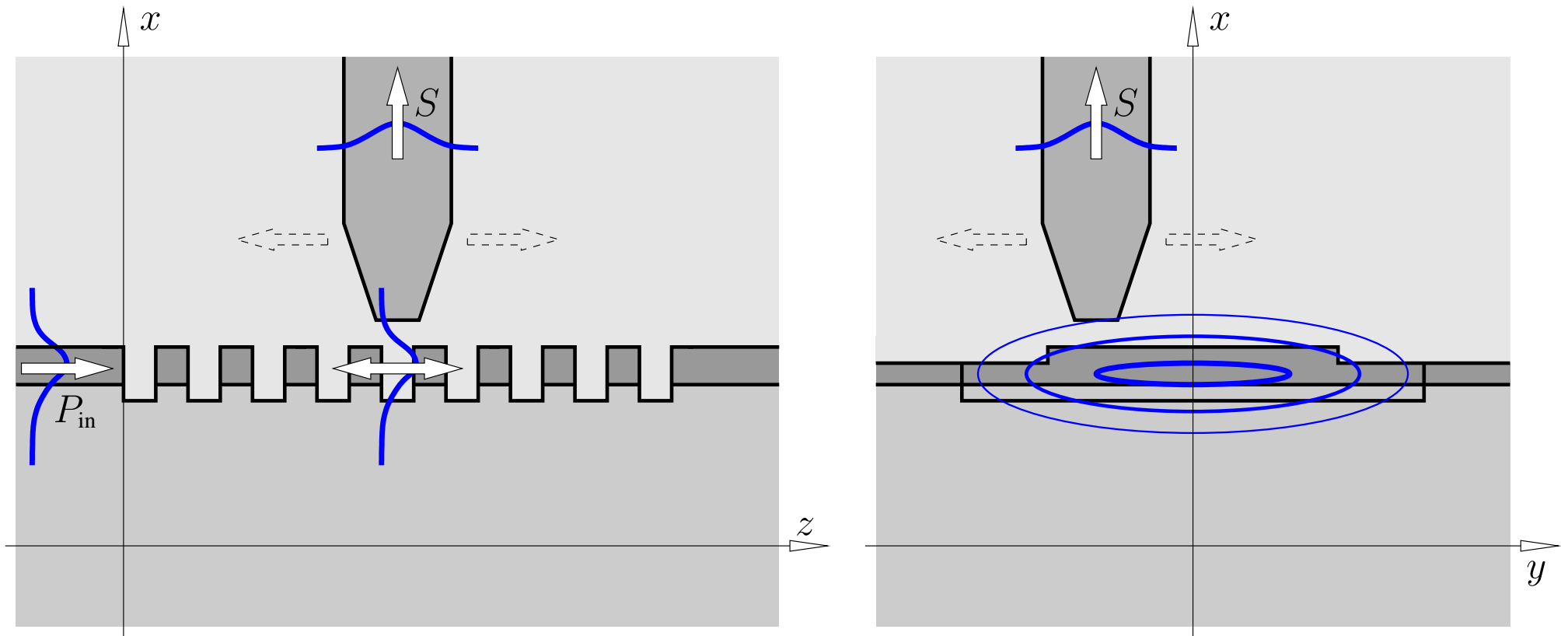
$\longrightarrow B_0, F_{N_x+1}, D_0, U_{N_z+1}$.

“QUadridirectional Eigenmode Propagation method” (QUEP).

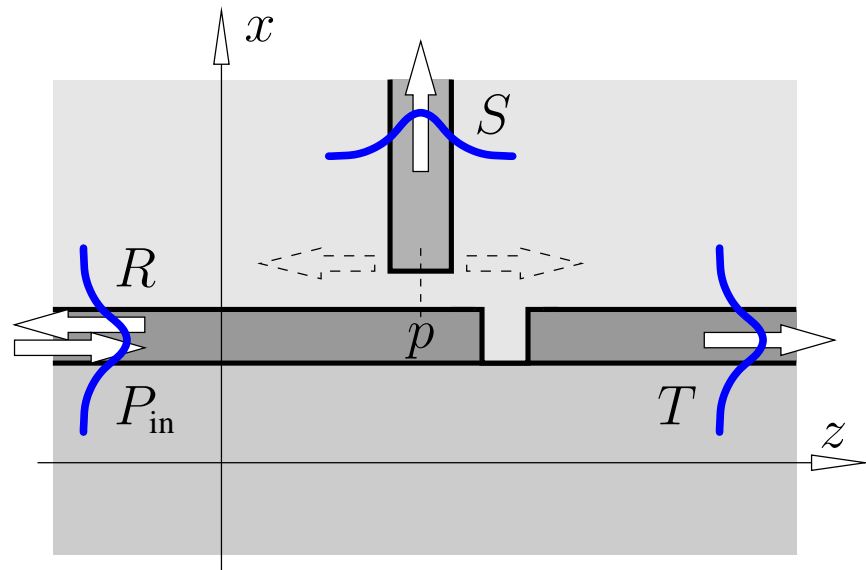
Outline

- Simulations in guided wave optics
 - Macroscopic Maxwell equations
 - Stationary and time-domain problems
 - 2-D problems
 - Modes of dielectric waveguides
- Quadridirectional eigenmode propagation
 - Problem setting
 - Eigenmode expansion
 - Algebraic procedure
- 2-D PSTM model
 - Probing evanescent fields
 - Hole defect in a slab waveguide
 - Waveguide Bragg grating: experiment & 2-D model
 - Resonant defect cavity
- Optical switching by NEMS-actuated resonator arrays

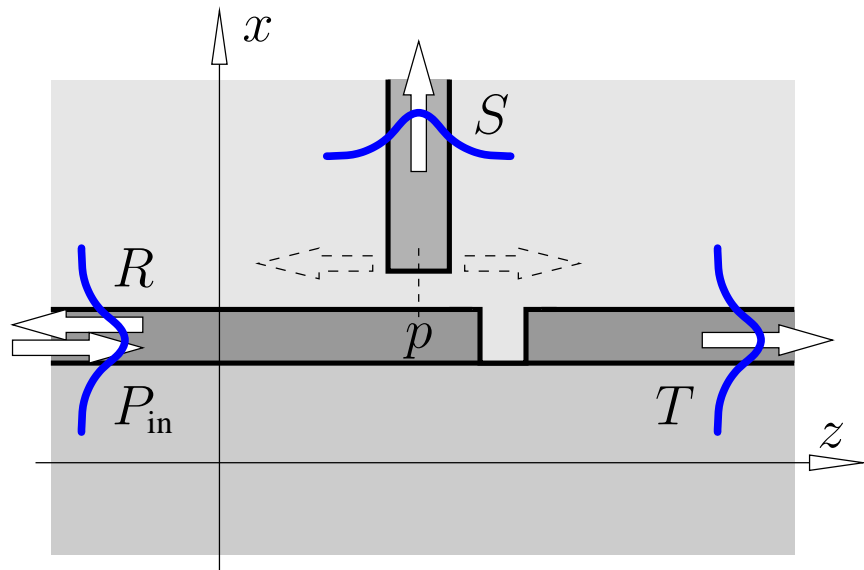
Photon scanning tunneling microscopy (PSTM) of photonic devices



Simplified 2-D model



Simplified 2-D model

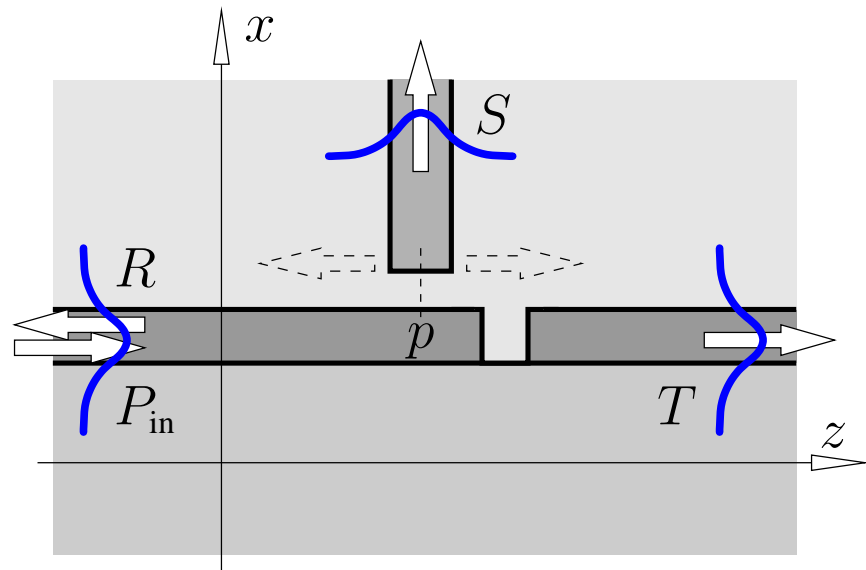


$$P_{\text{in}} = 1. \quad S(p) = ?$$

$$R(p), T(p) = ?$$

$$S(p) \overset{?}{\longleftrightarrow} (\text{optical field})|_p$$

Simplified 2-D model



$$P_{\text{in}} = 1. \quad S(p) = ?$$

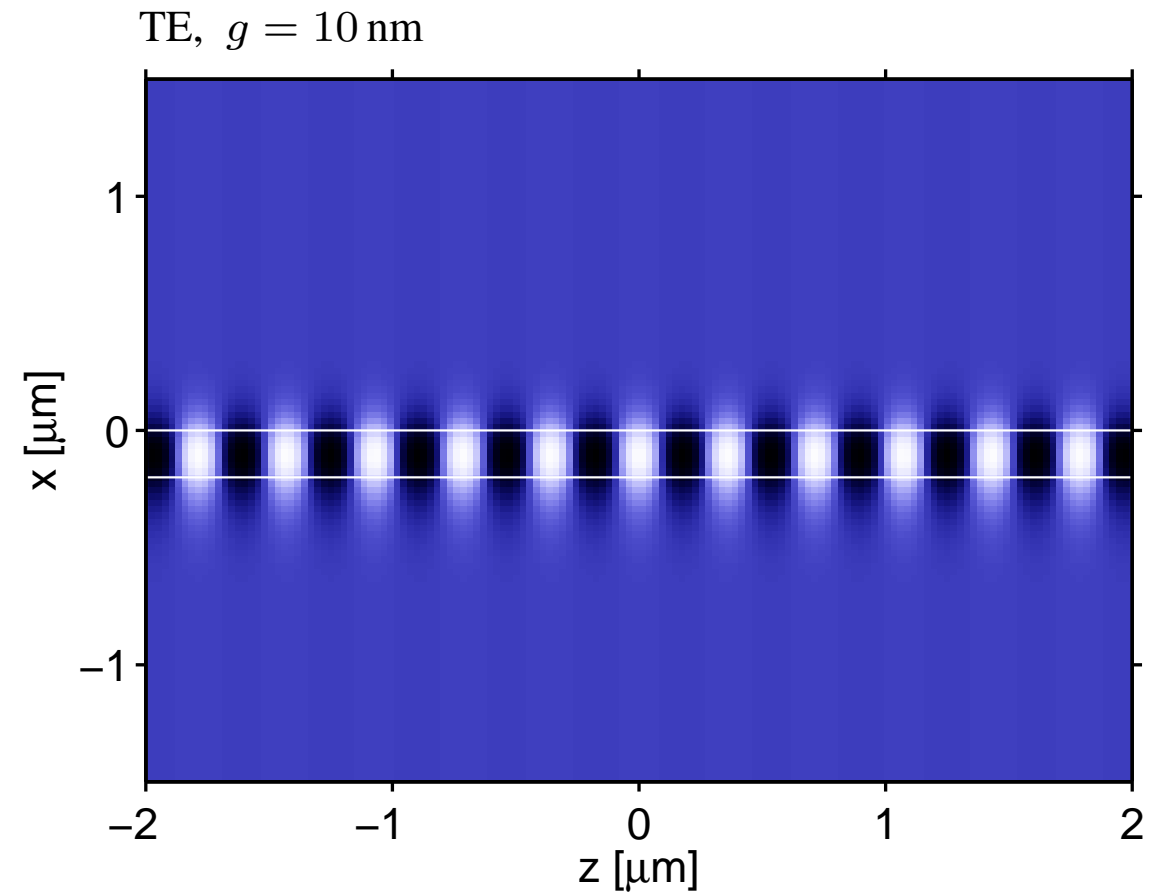
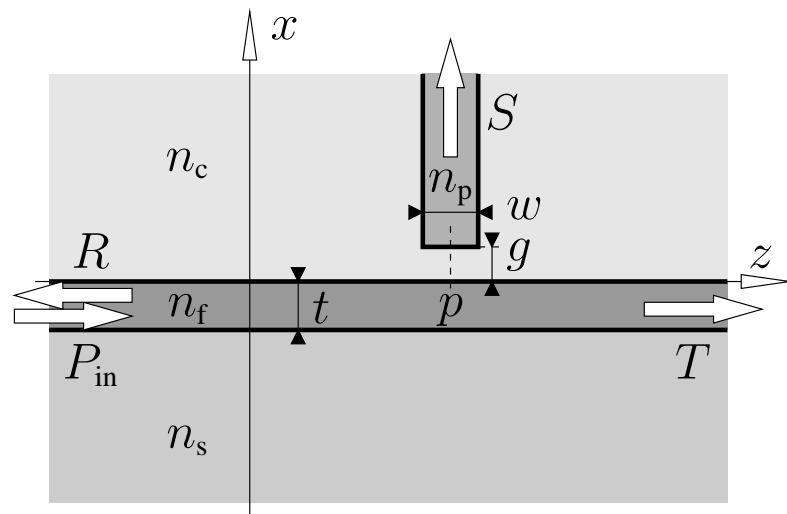
$$R(p), T(p) = ?$$

$$S(p) \overset{?}{\longleftrightarrow} (\text{optical field})|_p$$

Fixed optical frequency, rectangular piecewise constant refractive index,
horizontal & vertical guided wave in- and outflux

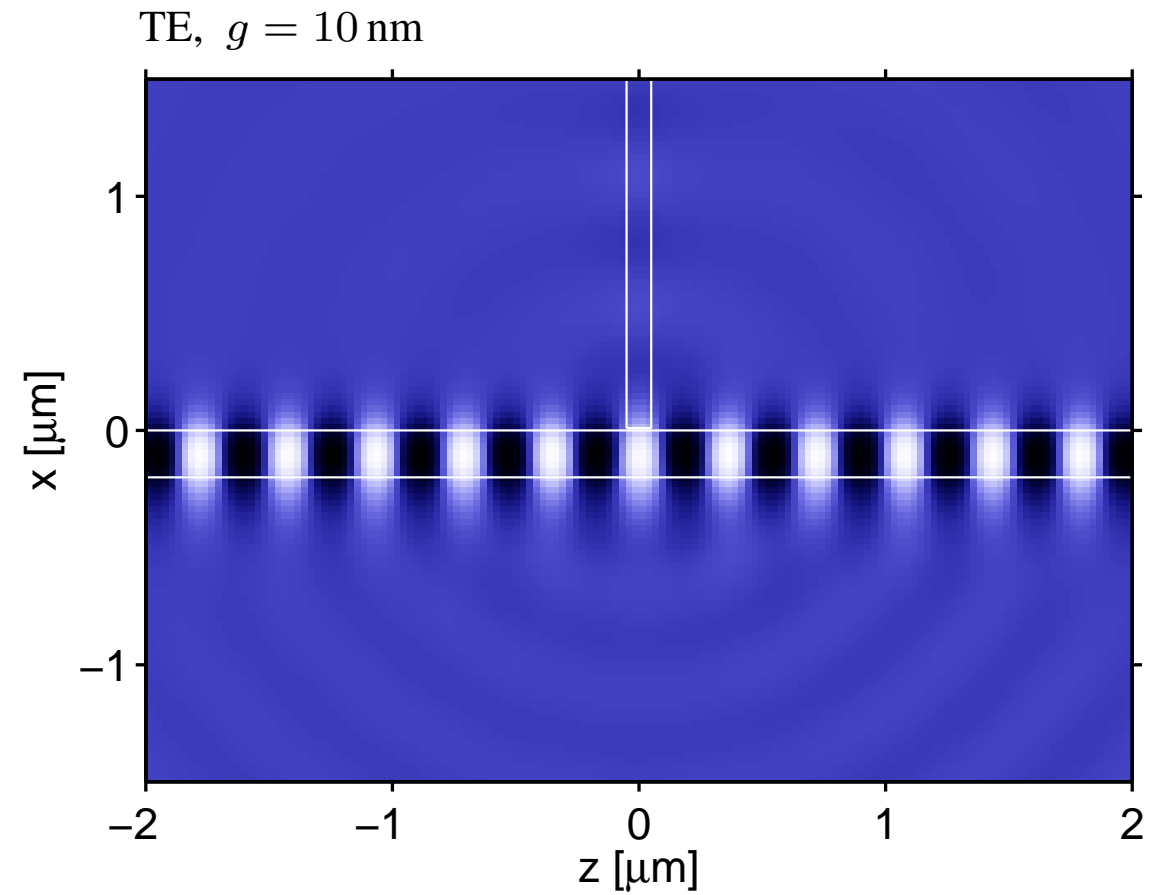
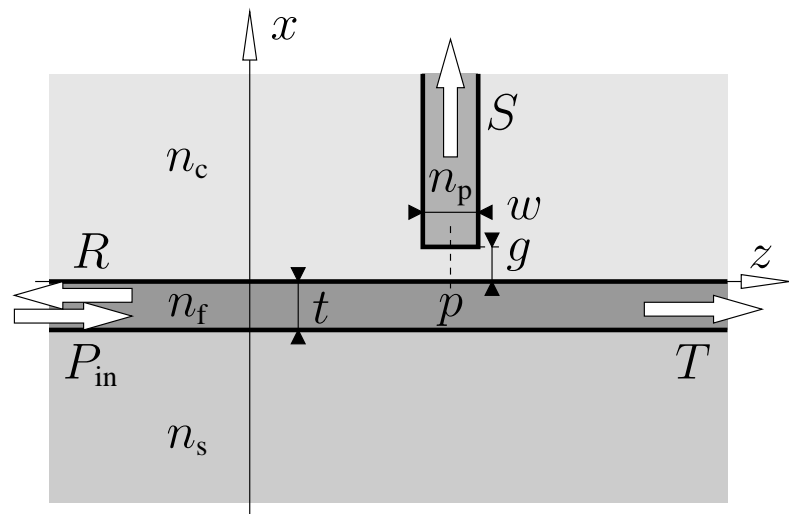
→ *QUEP simulations*

Probing evanescent fields



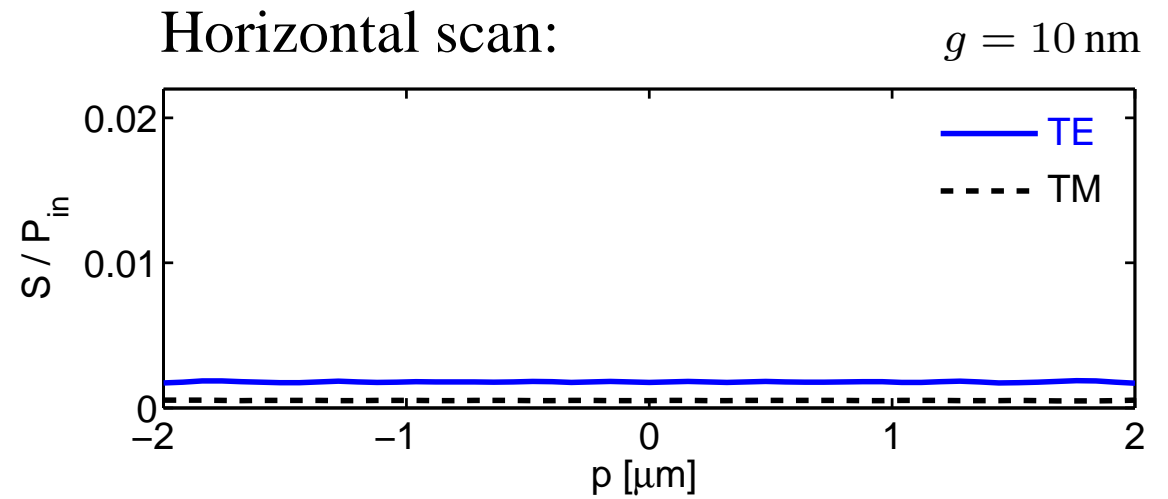
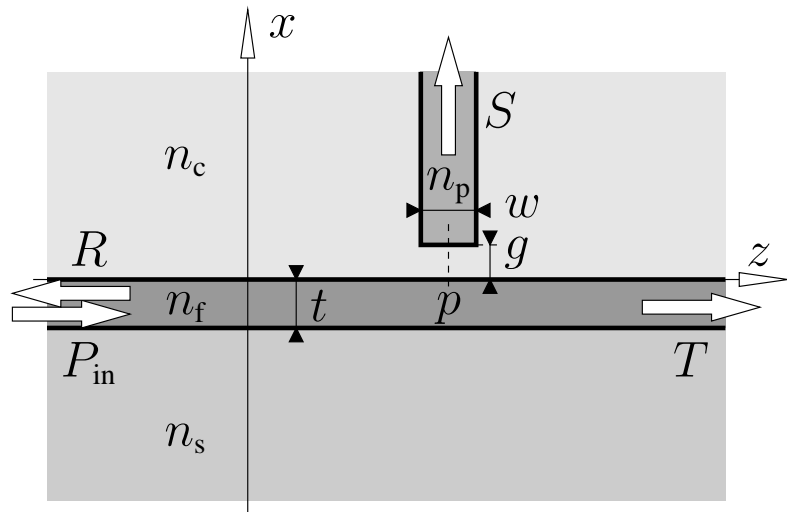
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $w = 100$ nm, $n_p = 1.5$,
 $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.0, 3.0] \mu\text{m}^2$, $M_x = M_z = 80$.

Probing evanescent fields



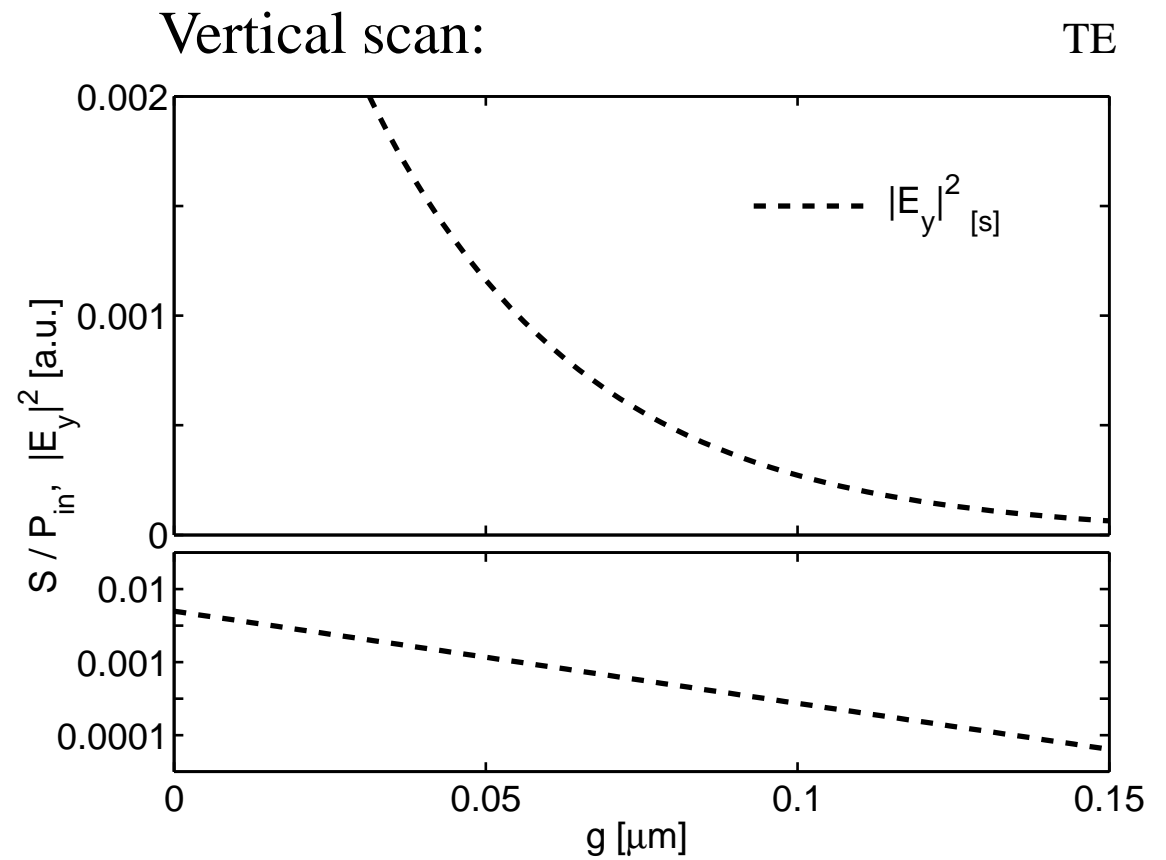
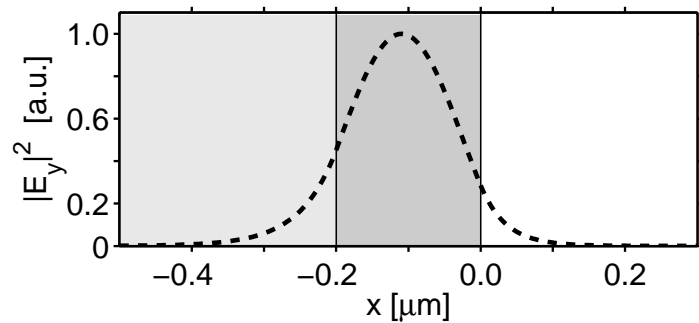
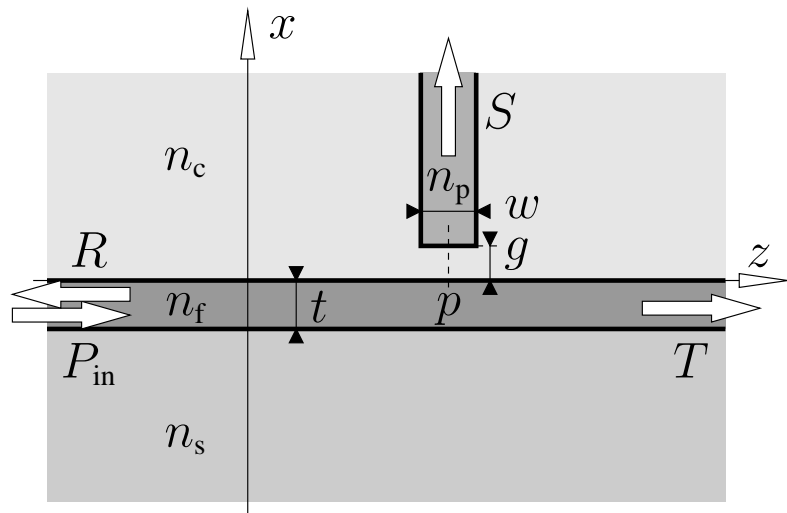
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $w = 100$ nm, $n_p = 1.5$,
 $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.0, 3.0] \mu\text{m}^2$, $M_x = M_z = 80$.

Probing evanescent fields

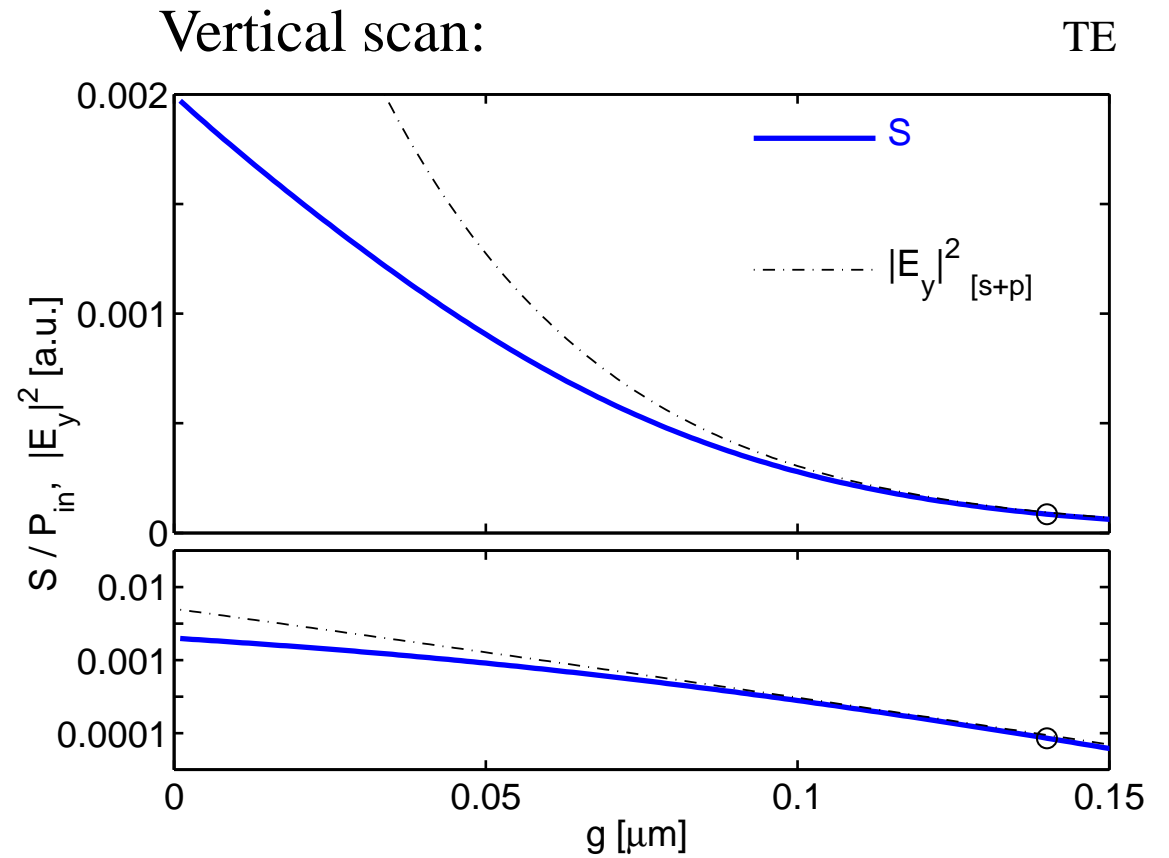
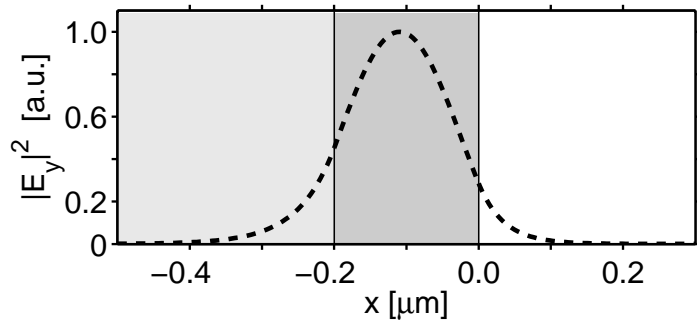
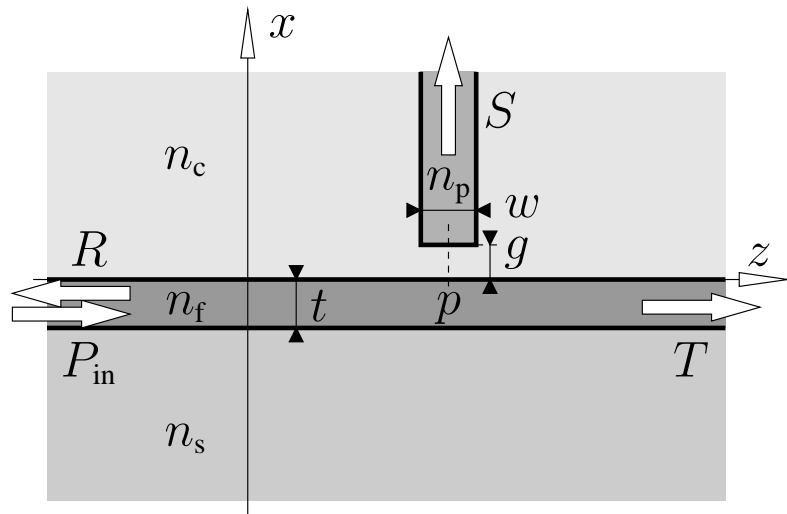


$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $w = 100 \text{ nm}$, $n_p = 1.5$,
 $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.0, 3.0] \mu\text{m}^2$, $M_x = M_z = 80$.

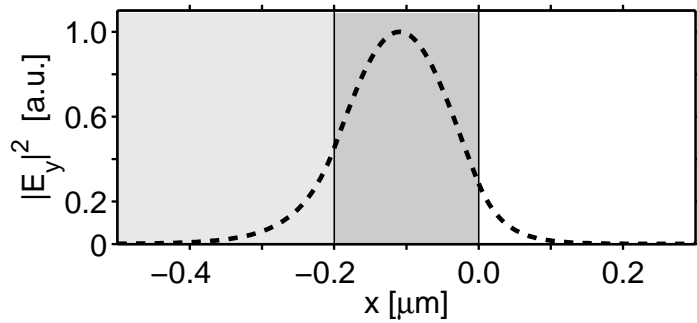
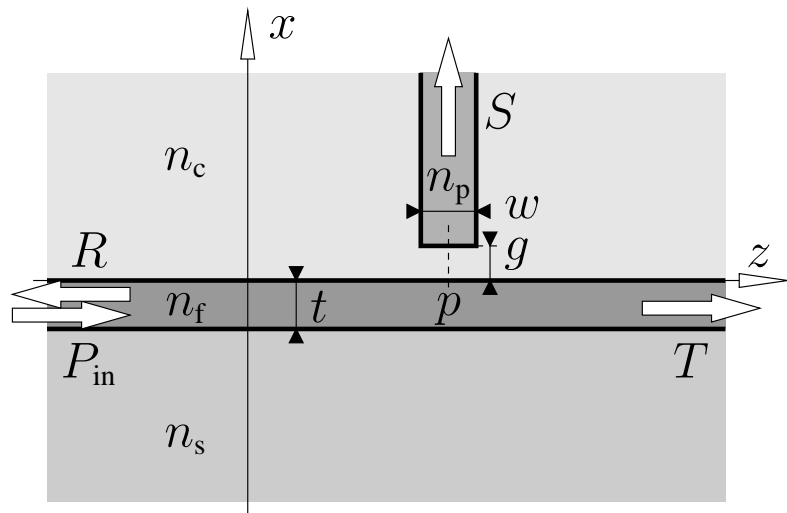
Probing evanescent fields



Probing evanescent fields

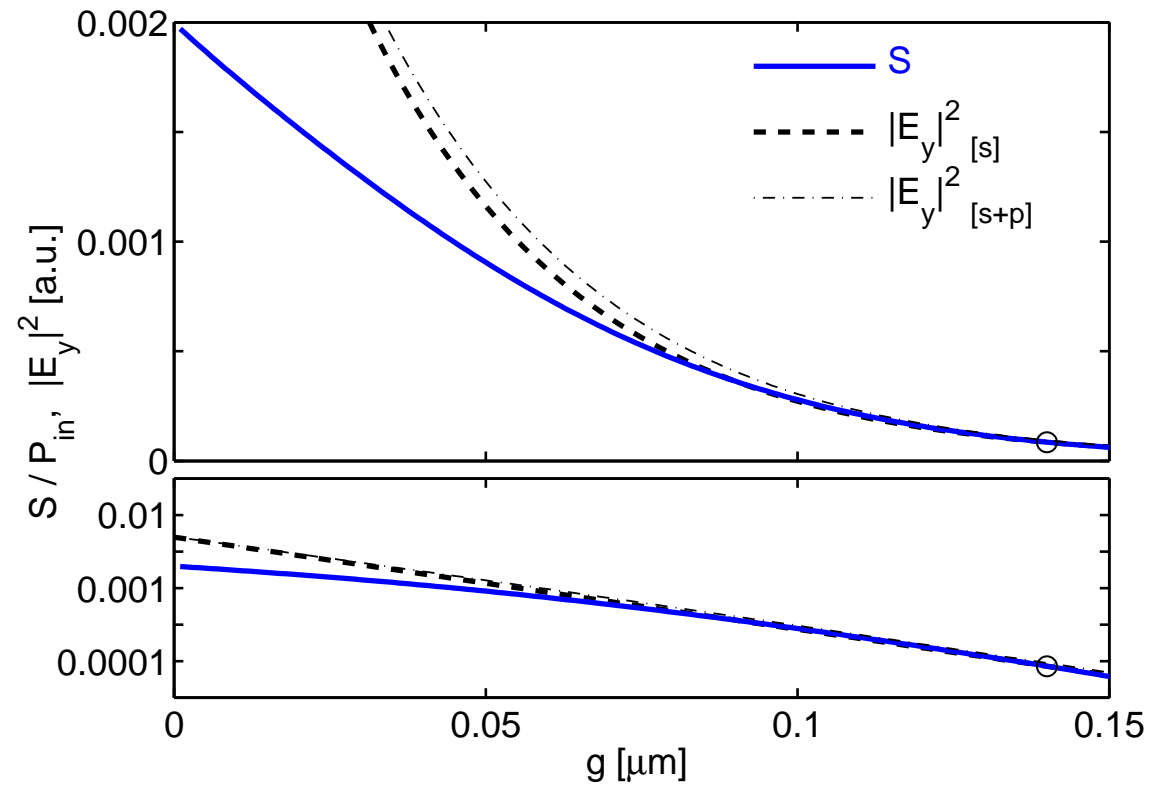


Probing evanescent fields

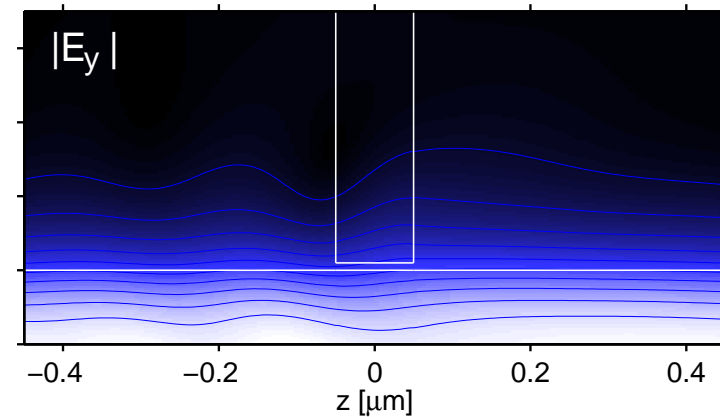
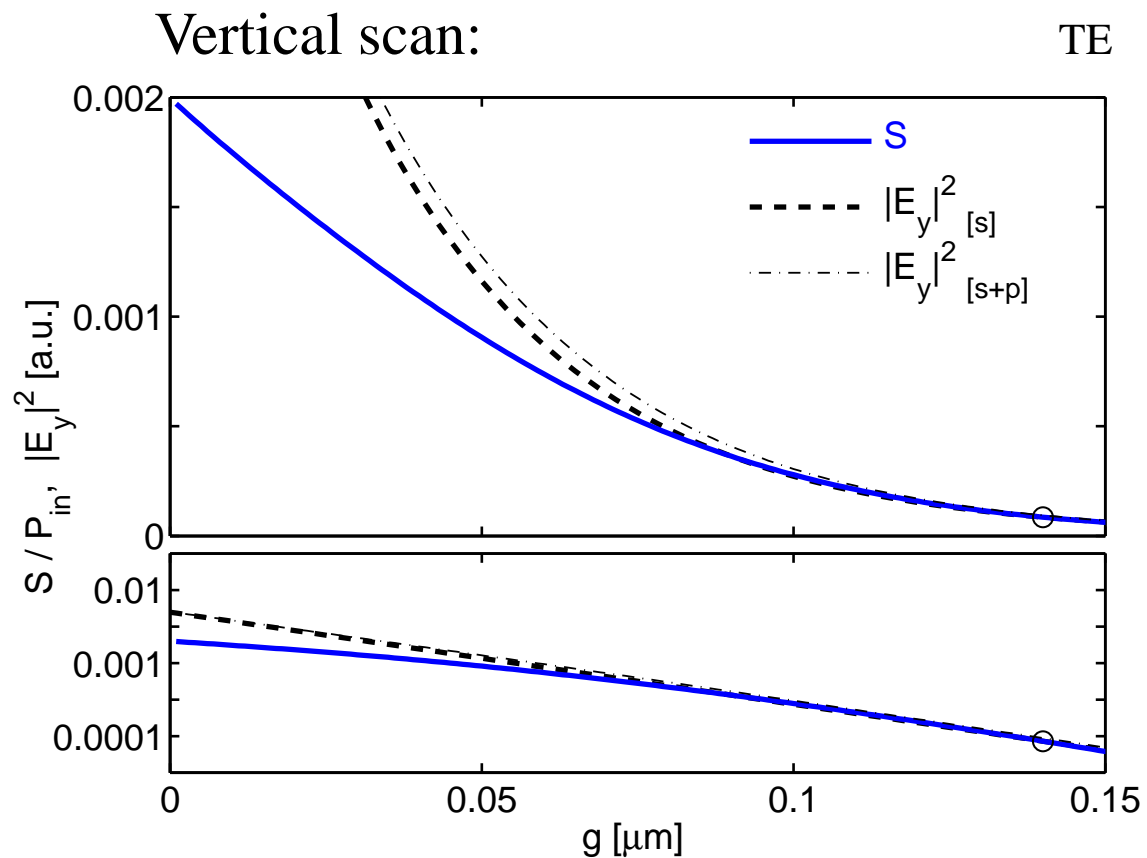
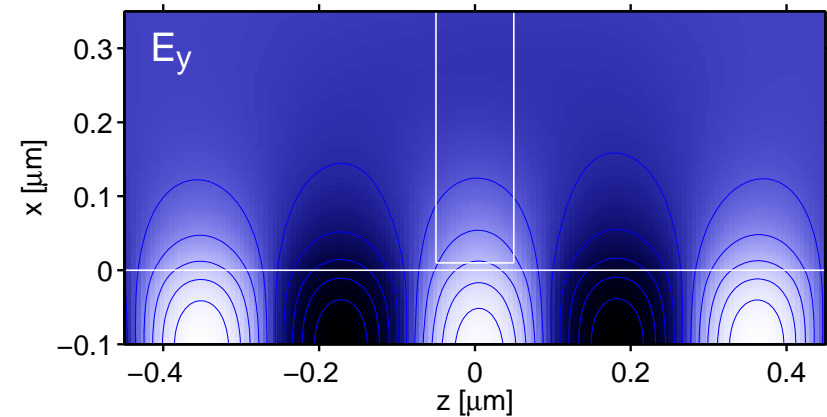
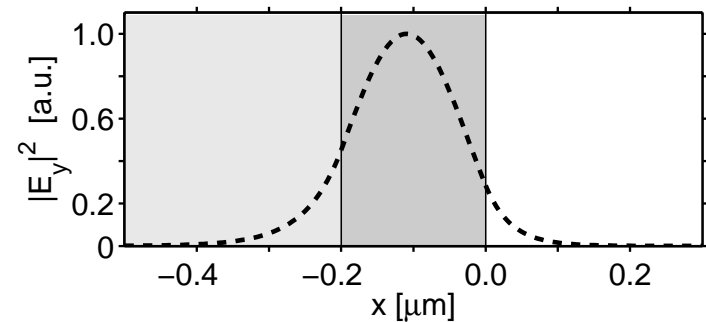
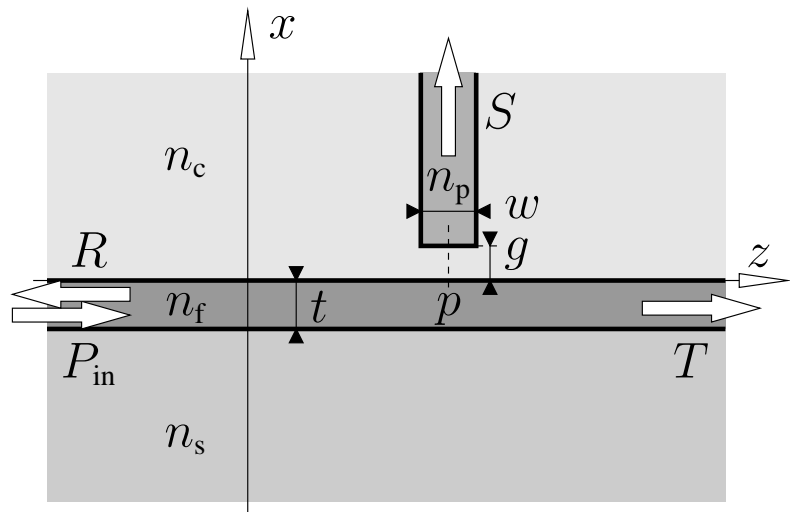


Vertical scan:

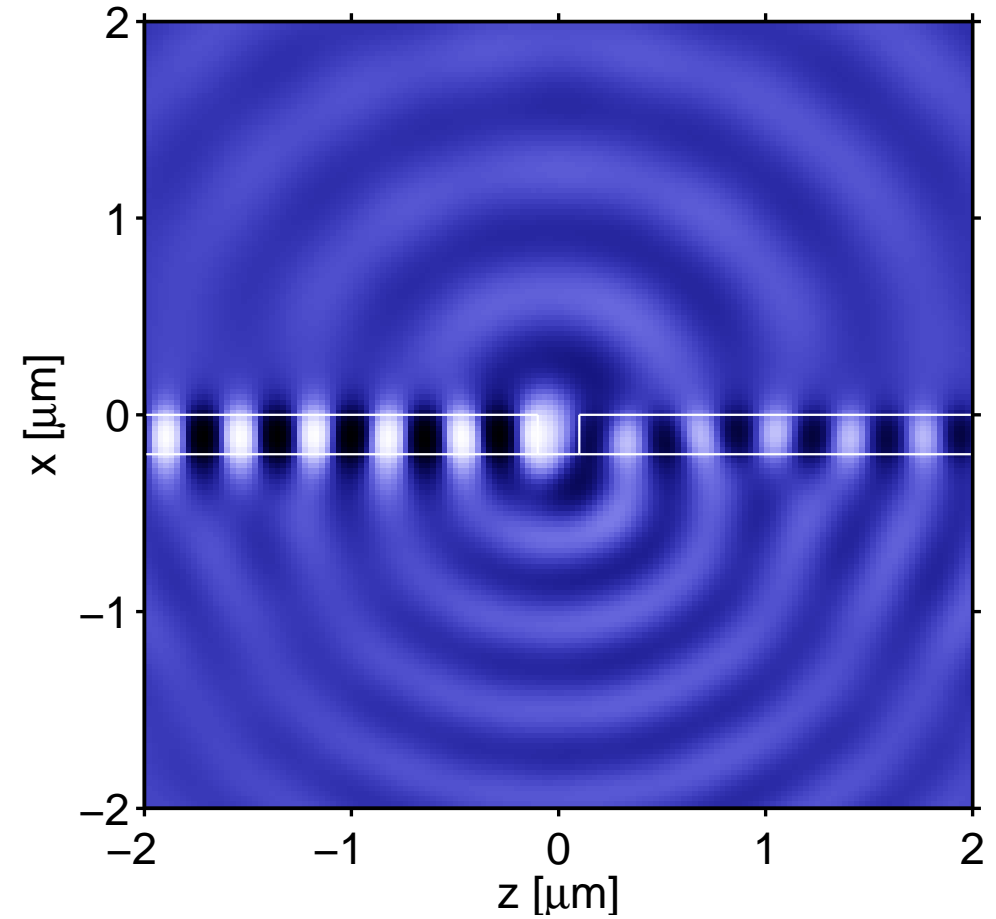
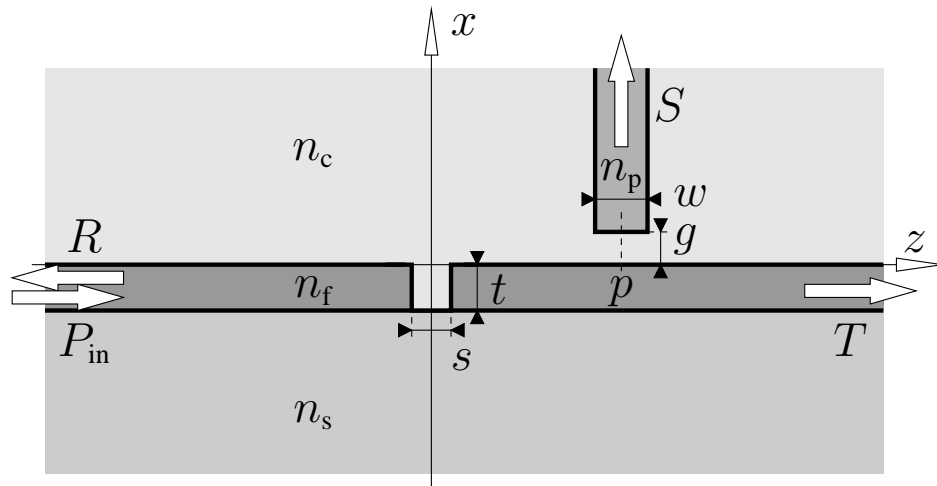
TE



Probing evanescent fields

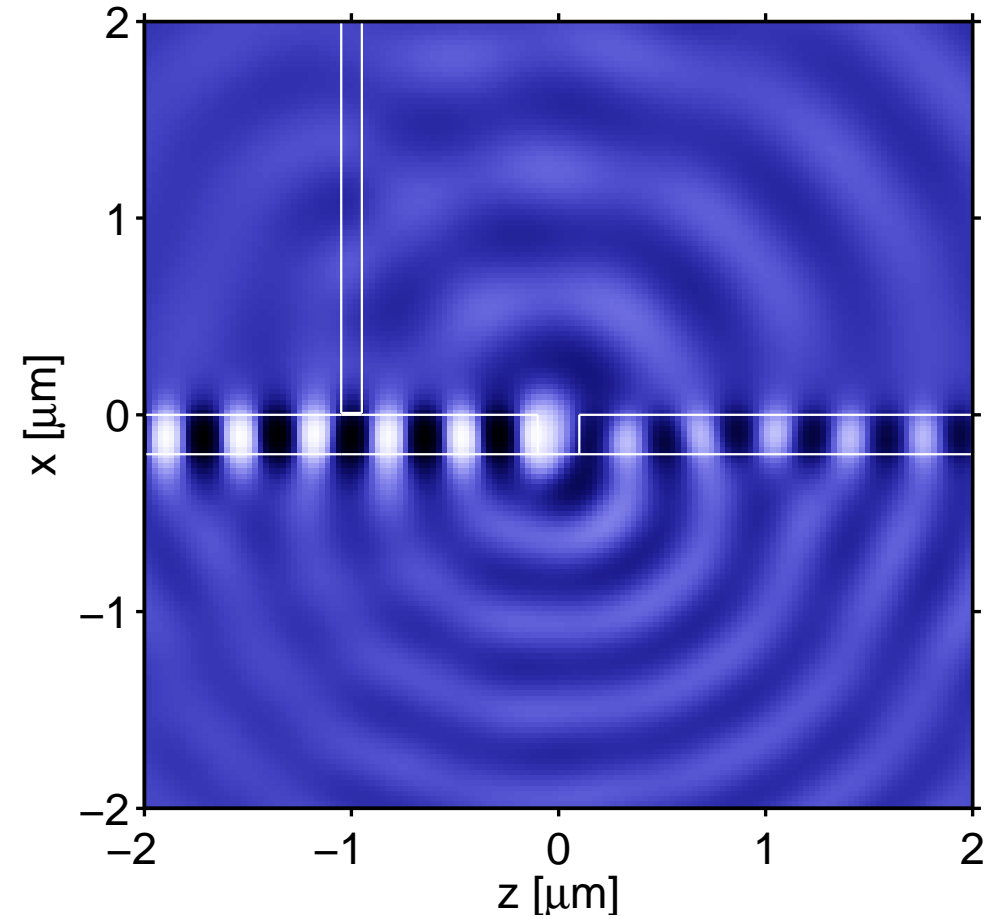
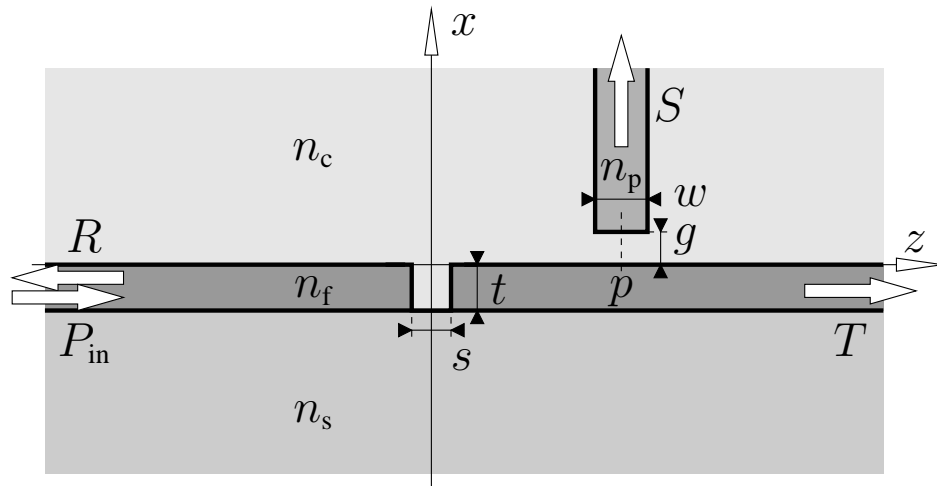


Hole defect in a slab waveguide



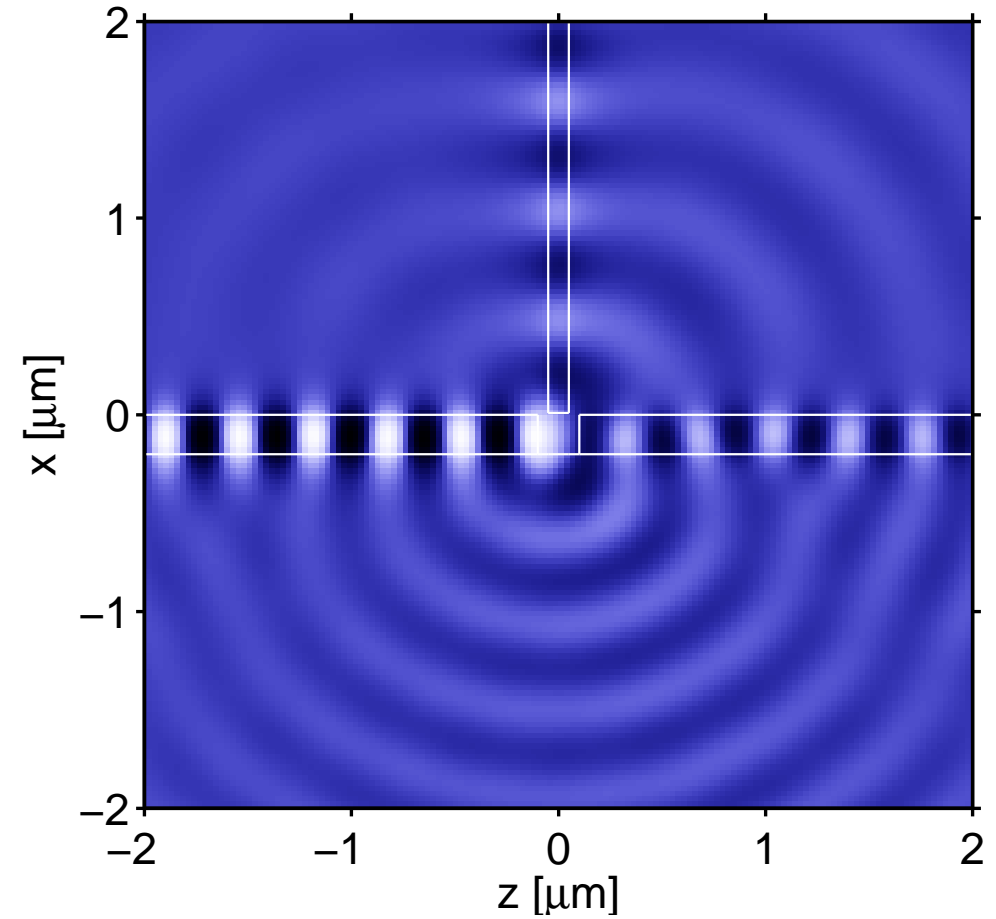
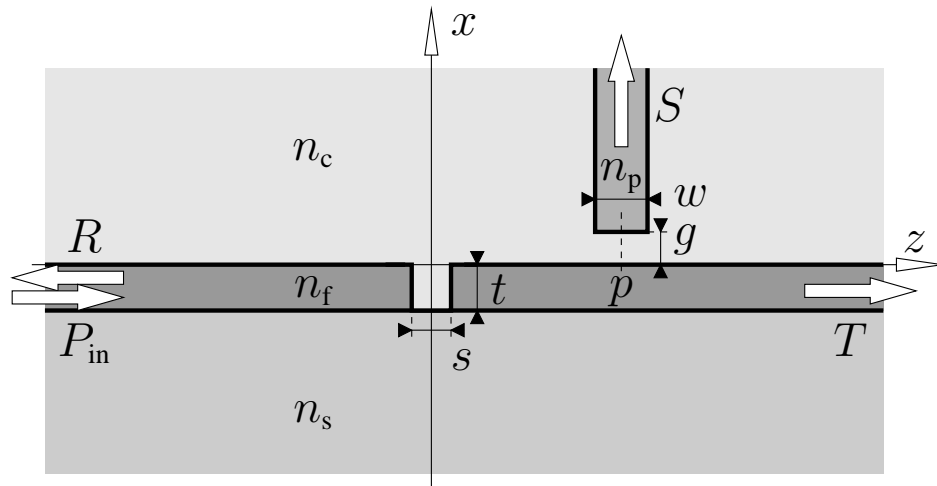
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $s = 0.2 \mu\text{m}$, $g = 10 \text{ nm}$, $w = 100 \text{ nm}$, $n_p = 1.5$,
 TE, $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.1, 3.1] \mu\text{m}^2$, $M_x = M_z = 80$.

Hole defect in a slab waveguide



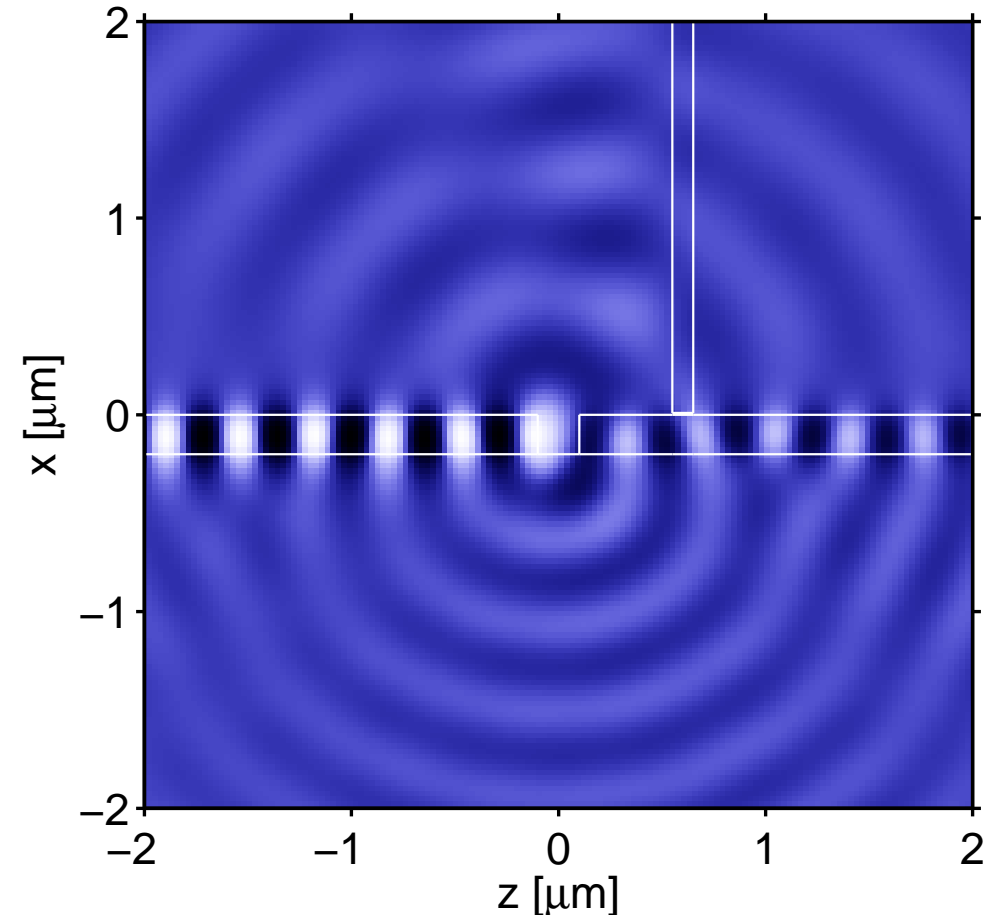
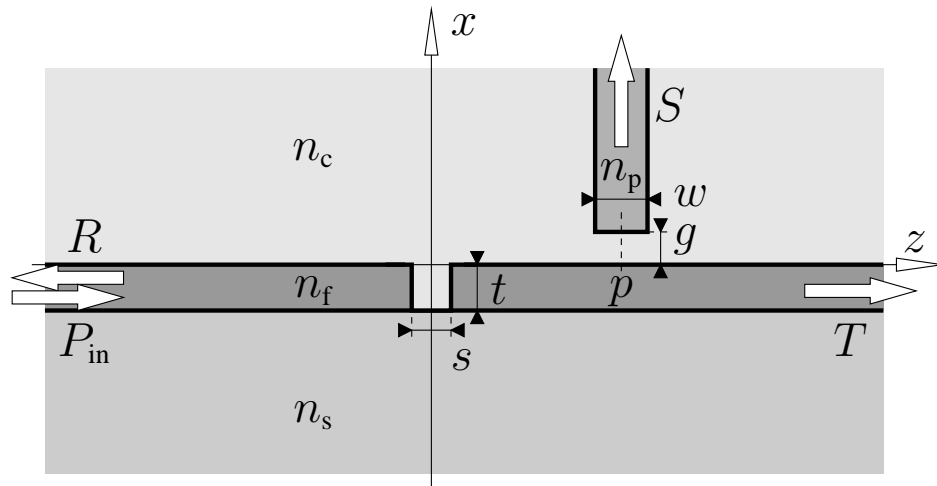
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $s = 0.2 \mu\text{m}$, $g = 10 \text{ nm}$, $w = 100 \text{ nm}$, $n_p = 1.5$,
 TE, $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.1, 3.1] \mu\text{m}^2$, $M_x = M_z = 80$.

Hole defect in a slab waveguide



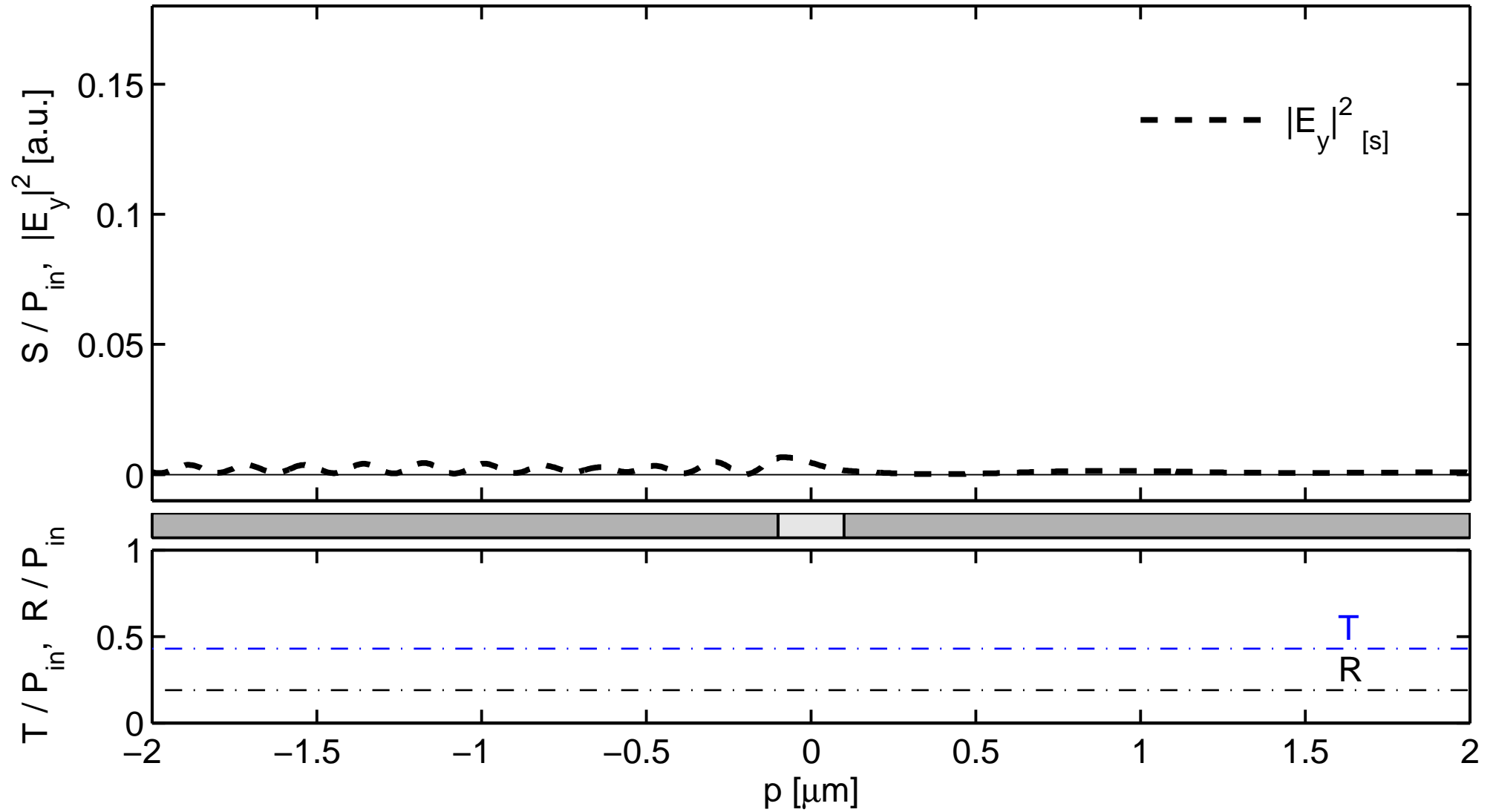
$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $s = 0.2 \mu\text{m}$, $g = 10 \text{ nm}$, $w = 100 \text{ nm}$, $n_p = 1.5$,
 TE, $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.1, 3.1] \mu\text{m}^2$, $M_x = M_z = 80$.

Hole defect in a slab waveguide

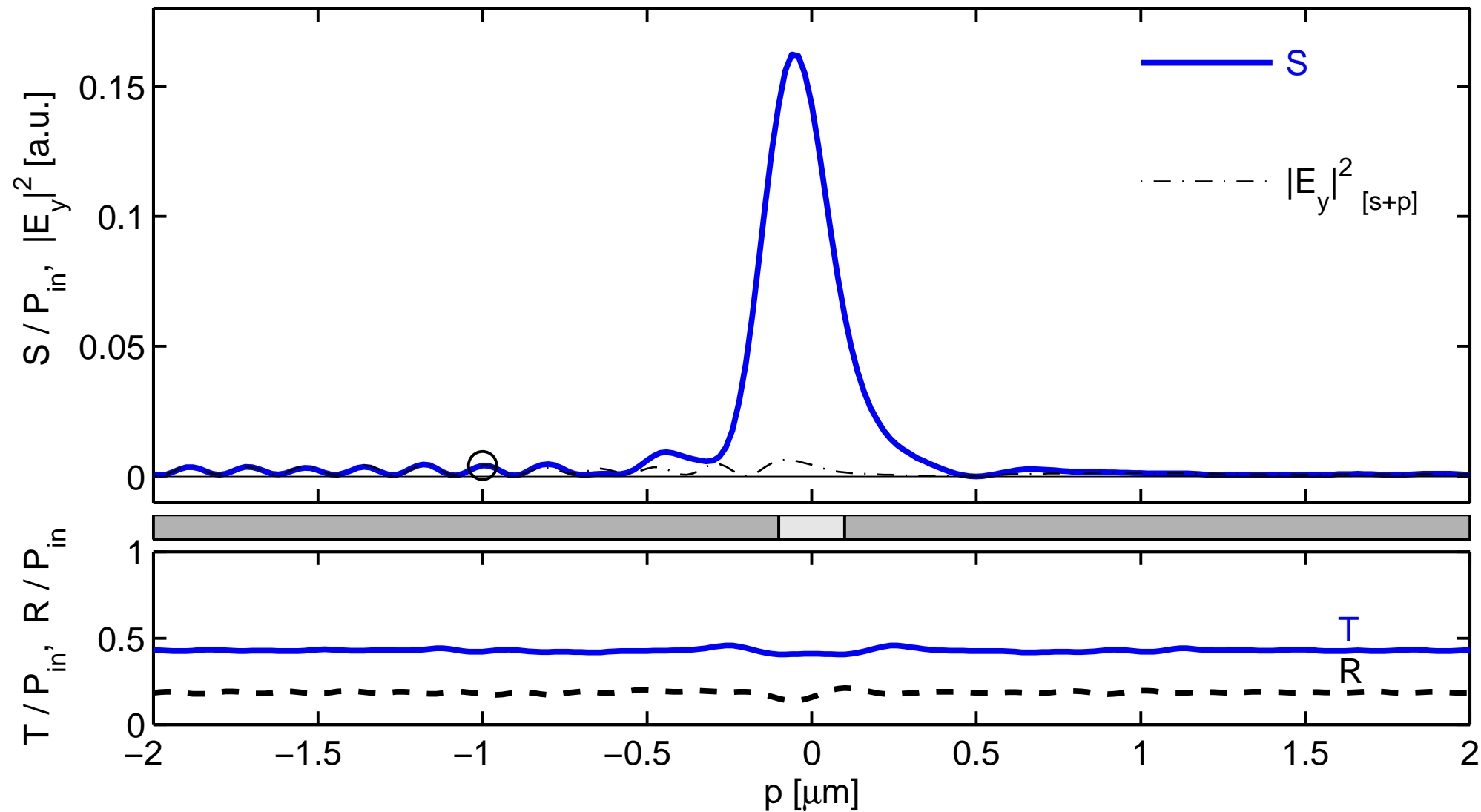


$n_s = 1.45$, $n_f = 2.0$, $n_c = 1.0$, $t = 0.2 \mu\text{m}$, $s = 0.2 \mu\text{m}$, $g = 10 \text{ nm}$, $w = 100 \text{ nm}$, $n_p = 1.5$,
 TE, $\lambda = 0.633 \mu\text{m}$, $(x, z) \in [-3.0, 3.0] \times [-3.1, 3.1] \mu\text{m}^2$, $M_x = M_z = 80$.

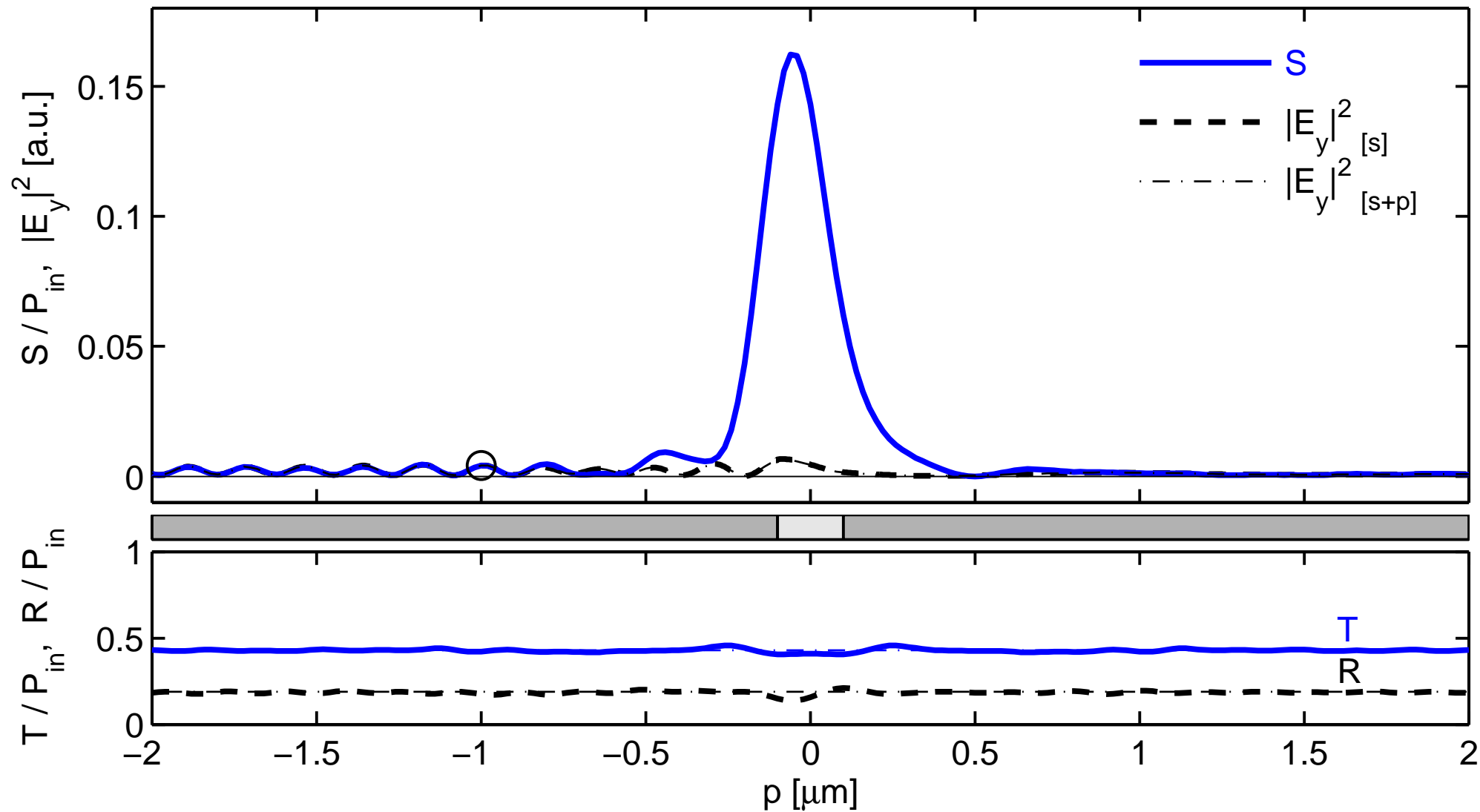
Hole defect in a slab waveguide



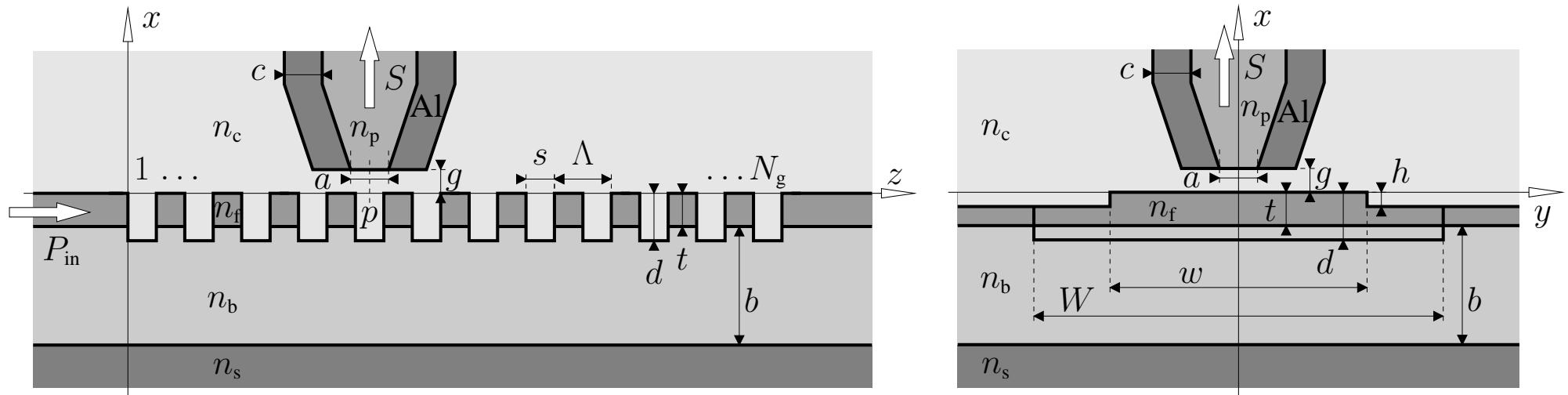
Hole defect in a slab waveguide



Hole defect in a slab waveguide



Bragg grating: PSTM experiment *

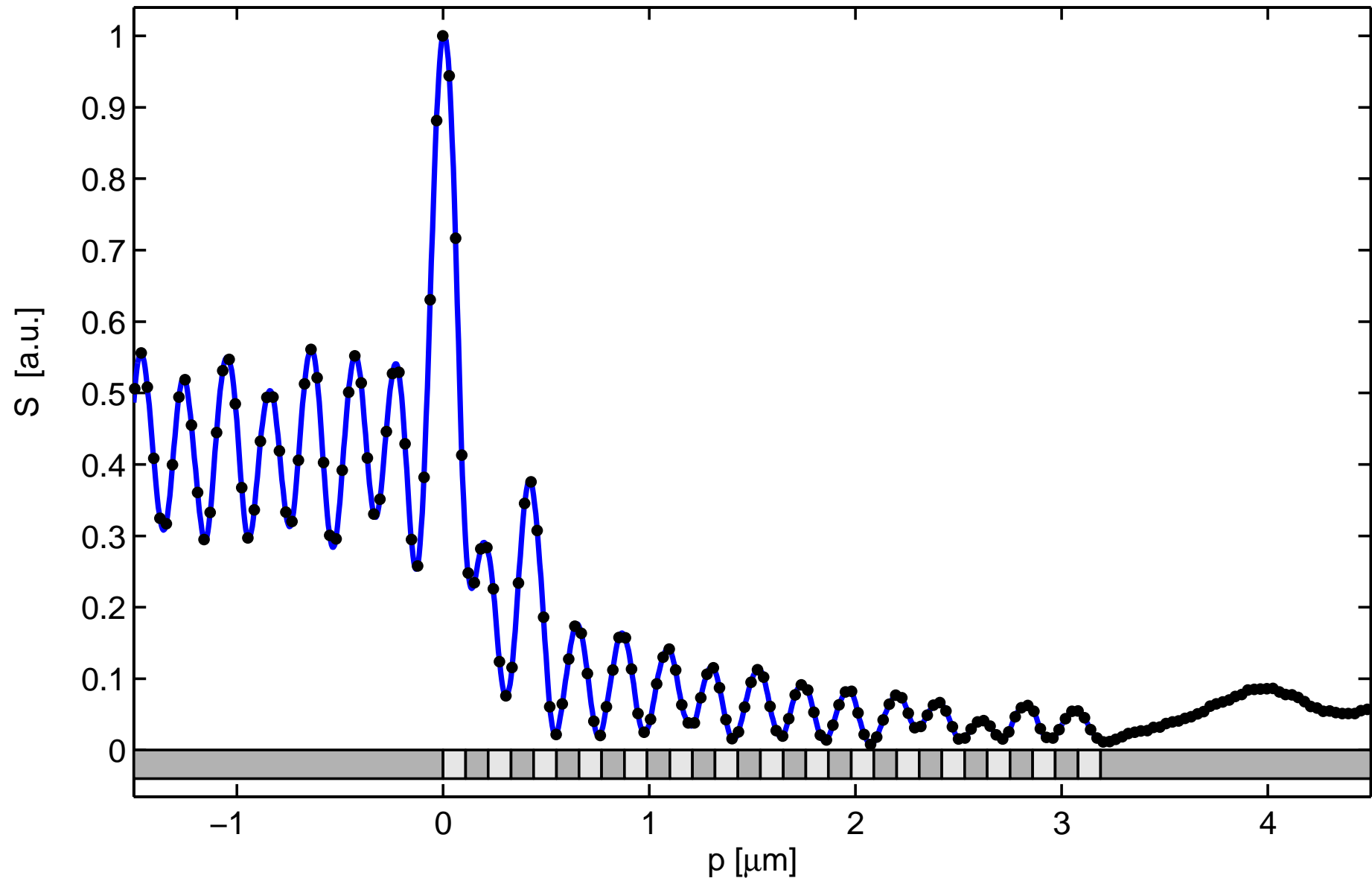


Sample: Rib waveguide with a series of deep, rectangular slits,
 $n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $t = 55$ nm, $h = 11$ nm, $w = 1.5$ μm ,
 $W = 2.5$ μm , $b = 3.2$ μm , $\Lambda = 220$ nm, $s = 110$ nm, $d = 70$ nm, $N_g = 15$.

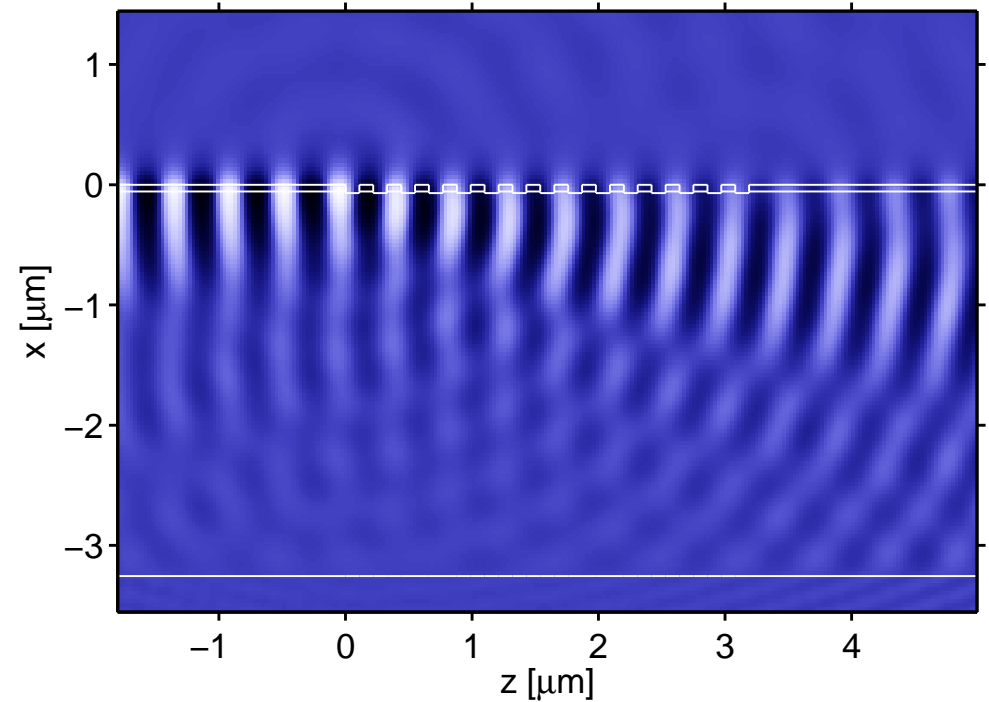
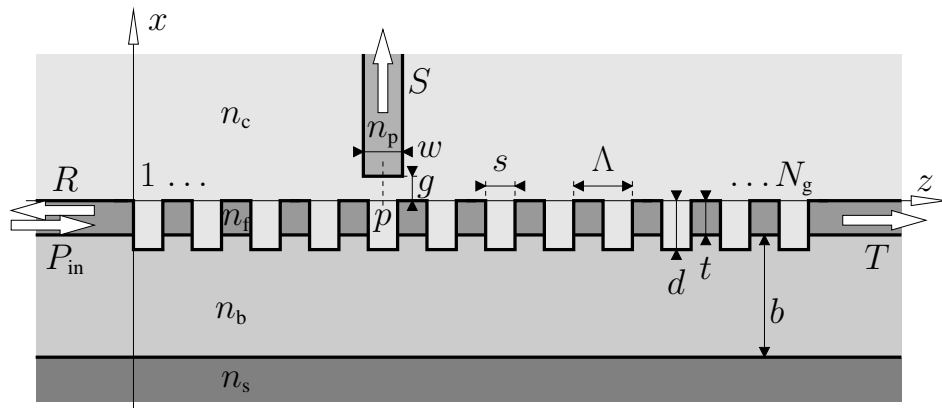
Probe: Tapered cylindrical fiber tip with aluminium coating,
 $a \approx 80$ nm, $c \approx 100$ nm, $g = 10$ nm, $n_p = 1.5$;
 TE polarized light, vacuum wavelength $\lambda = 0.6328$ μm .

* 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)

Bragg grating: PSTM experiment

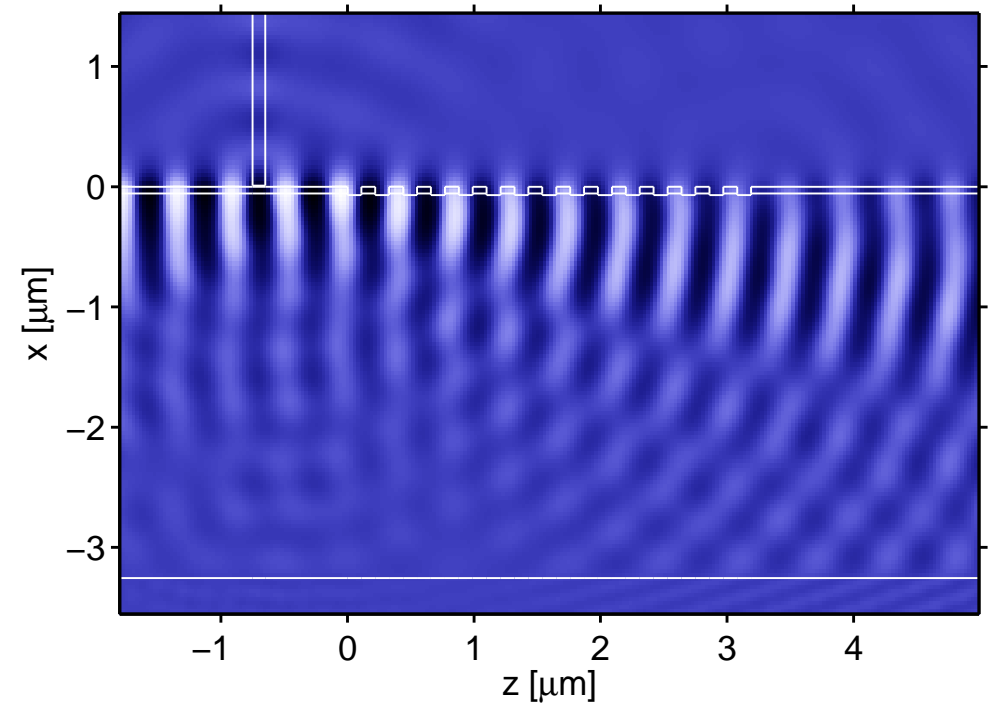
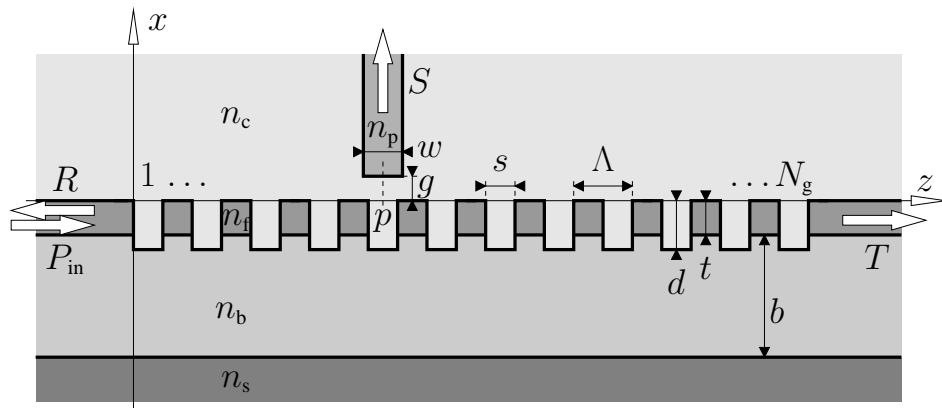


Waveguide Bragg grating



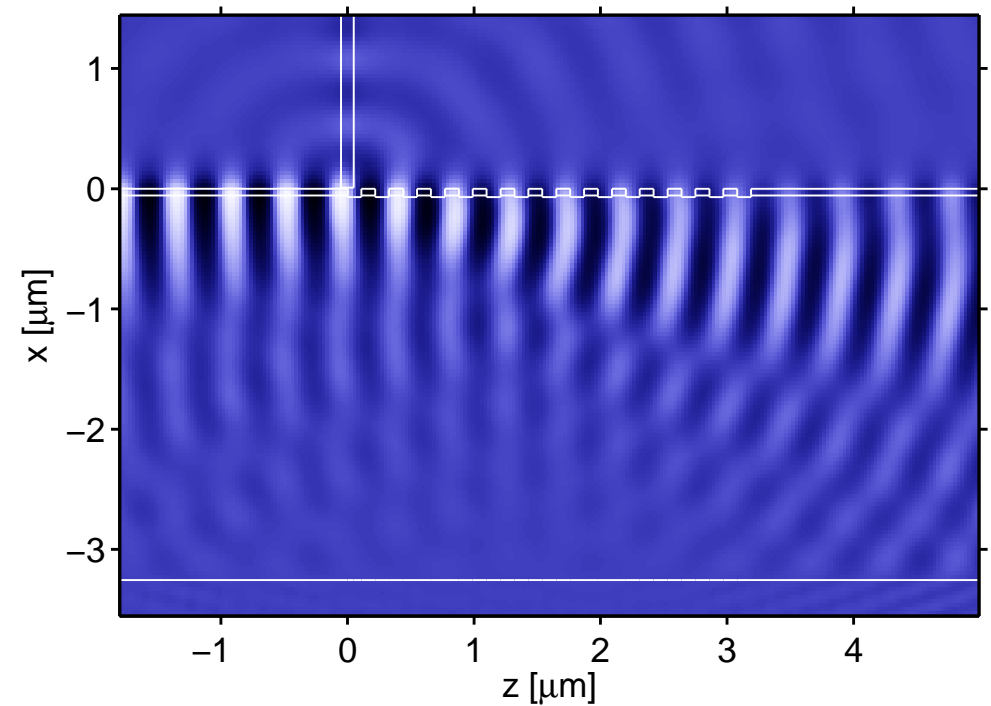
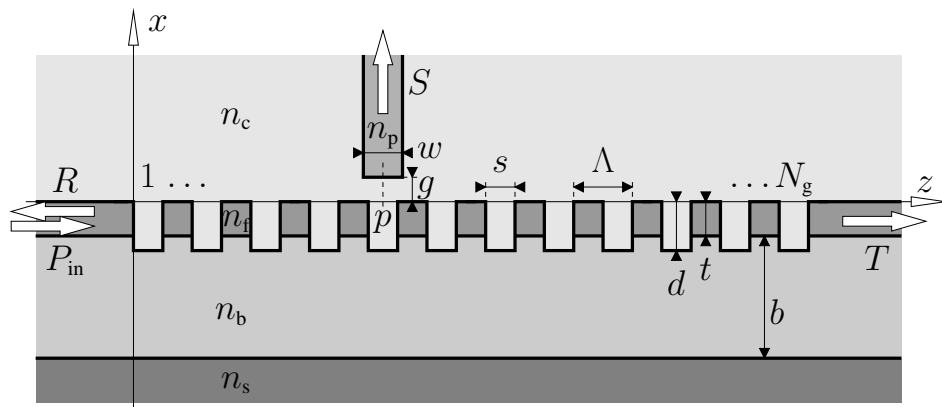
$n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $t = 55$ nm, $b = 3.2$ μm , $d = 70$ nm,
 $\Lambda = 220$ nm, $s = 110$ nm, $N_g = 15$, $g = 10$ nm, $w = 100$ nm, $n_p = 1.5$,
 TE, $\lambda = 0.6328$ μm , $(x, z) \in [-3.5, 1.5] \times [-2.0, 5.2]$ μm^2 , $M_x = 80$, $M_z = 100$.

Waveguide Bragg grating



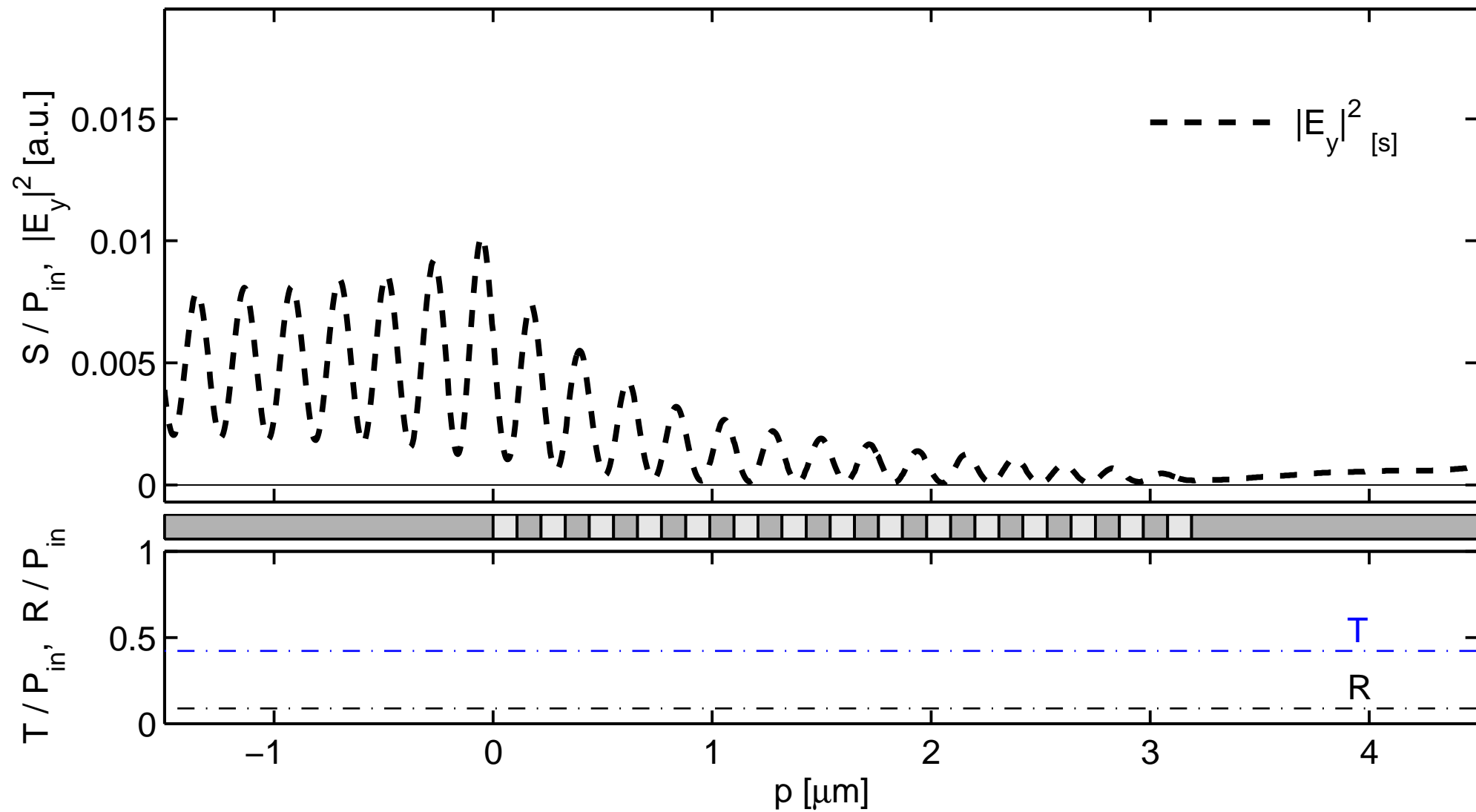
$n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $t = 55$ nm, $b = 3.2$ μm , $d = 70$ nm,
 $\Lambda = 220$ nm, $s = 110$ nm, $N_g = 15$, $g = 10$ nm, $w = 100$ nm, $n_p = 1.5$,
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Waveguide Bragg grating

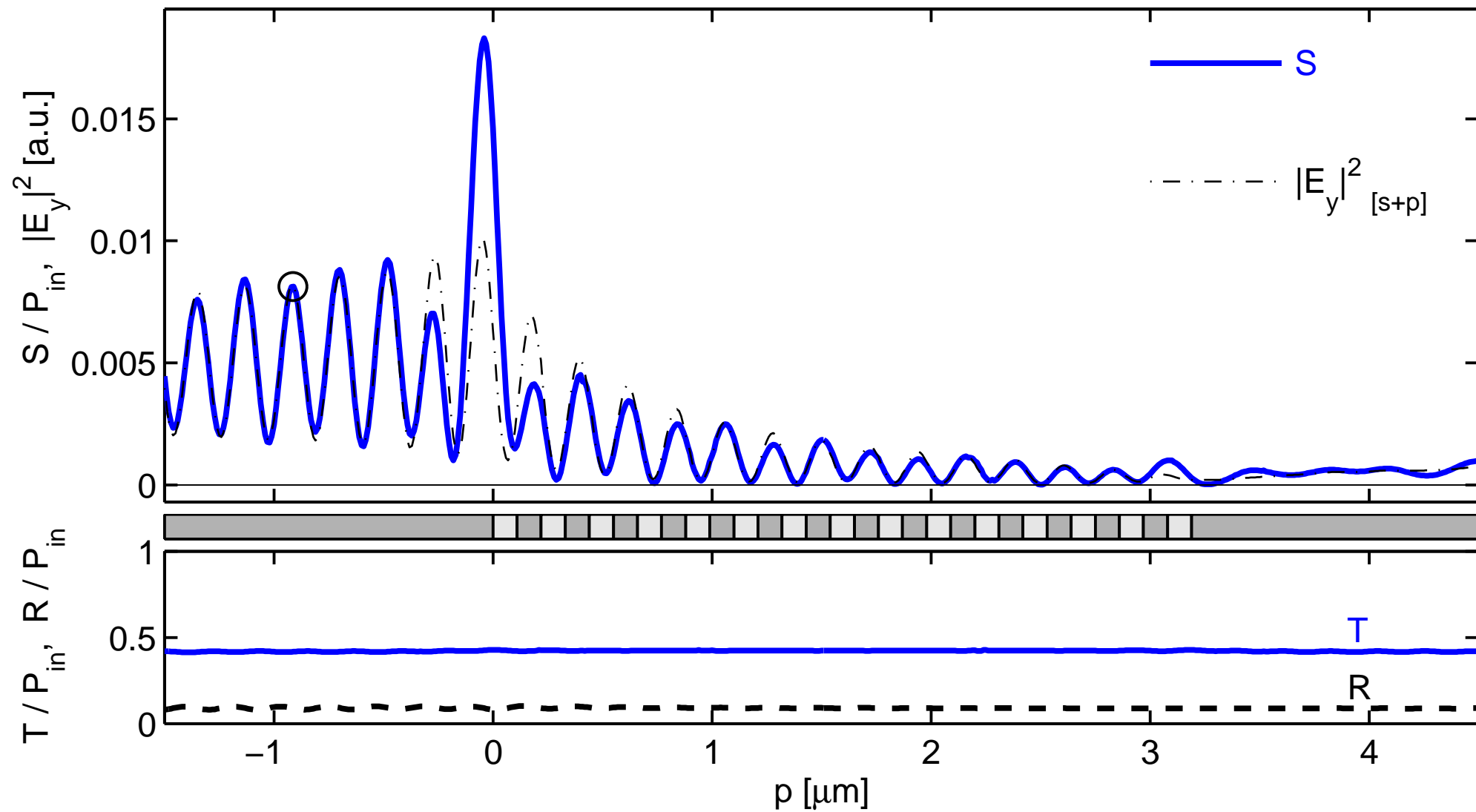


$n_s = 3.4$, $n_b = 1.45$, $n_f = 2.01$, $n_c = 1.0$, $t = 55$ nm, $b = 3.2$ μm , $d = 70$ nm,
 $\Lambda = 220$ nm, $s = 110$ nm, $N_g = 15$, $g = 10$ nm, $w = 100$ nm, $n_p = 1.5$,
 TE, $\lambda = 0.6328$ μm , $(x, z) \in [-3.5, 1.5] \times [-2.0, 5.2]$ μm^2 , $M_x = 80$, $M_z = 100$.

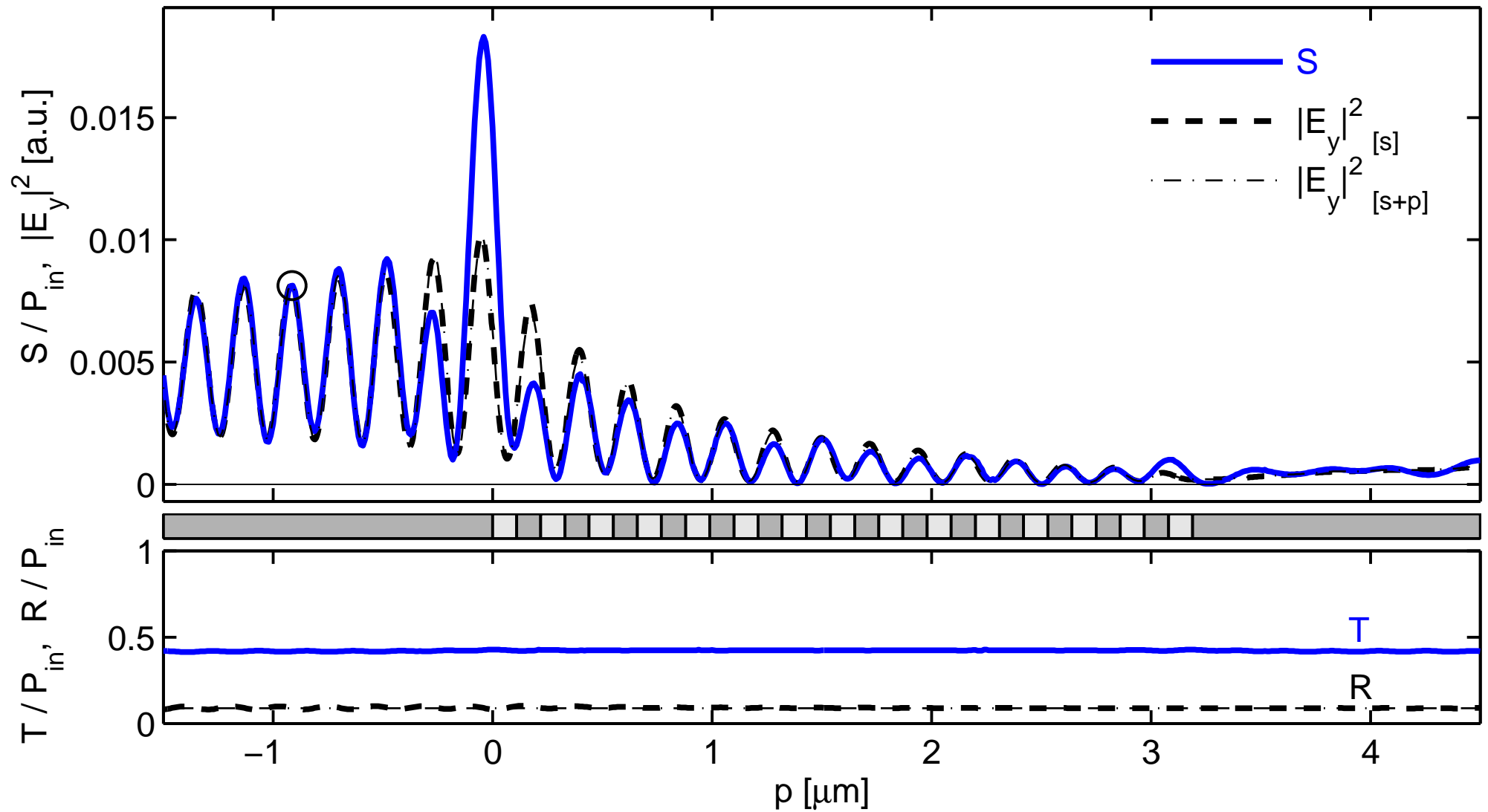
Waveguide Bragg grating



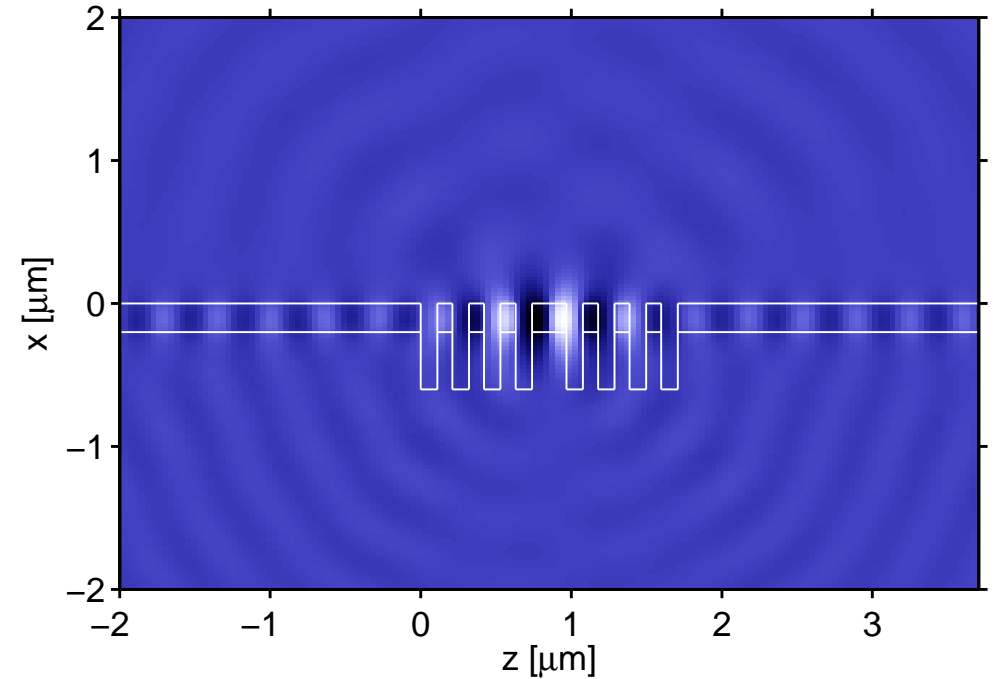
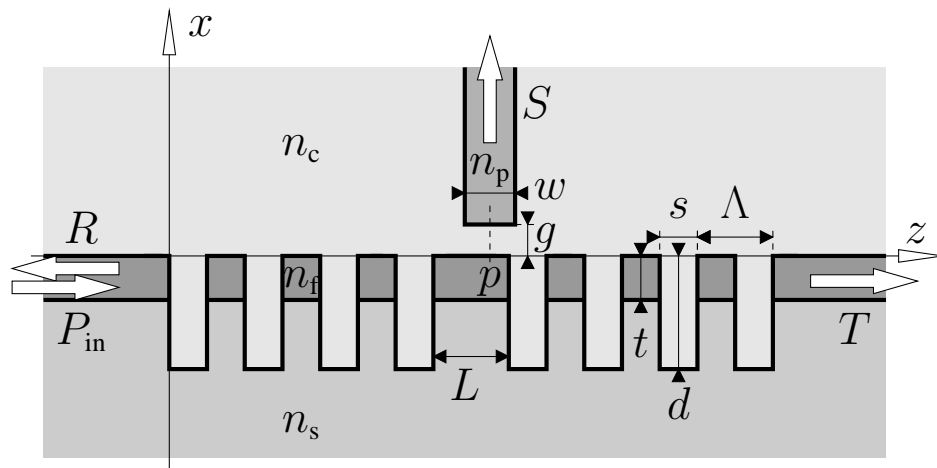
Waveguide Bragg grating



Waveguide Bragg grating

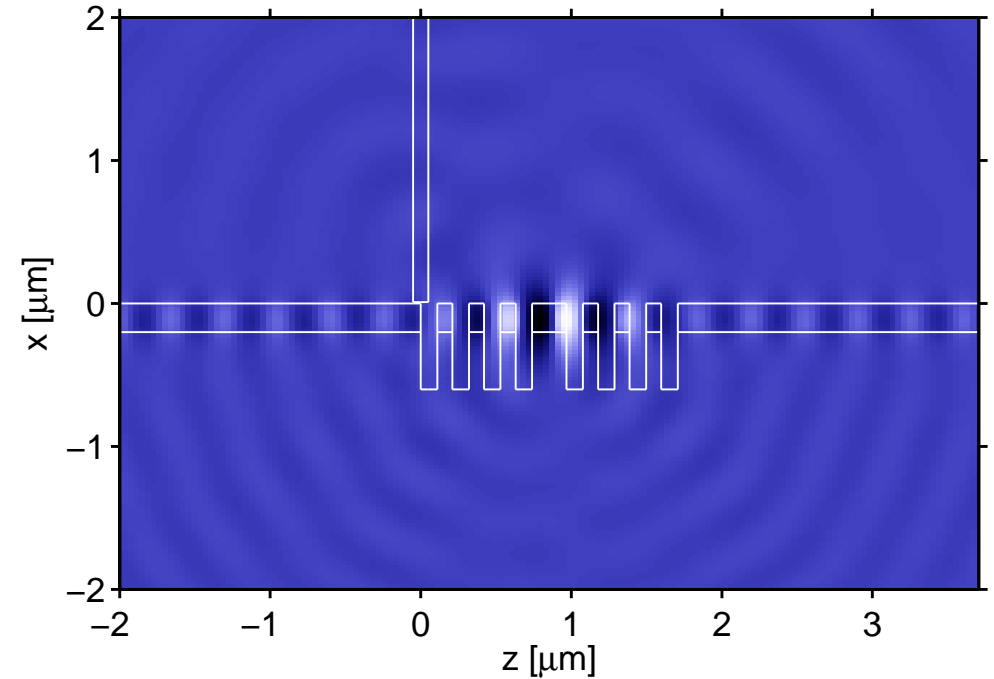
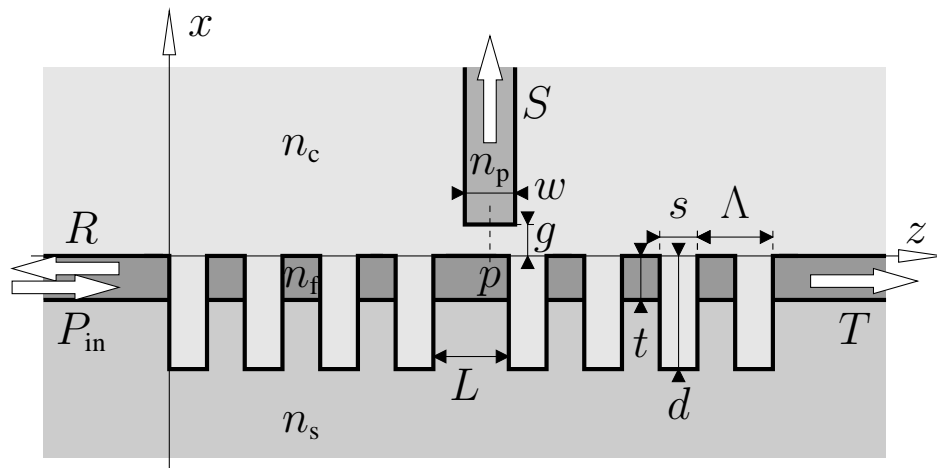


Resonant defect cavity



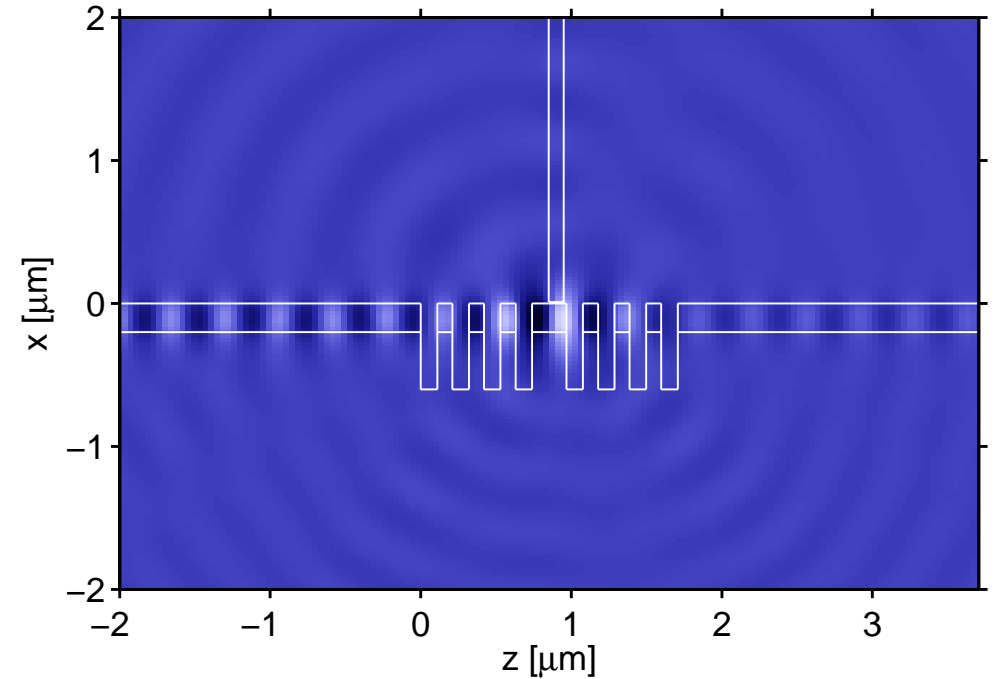
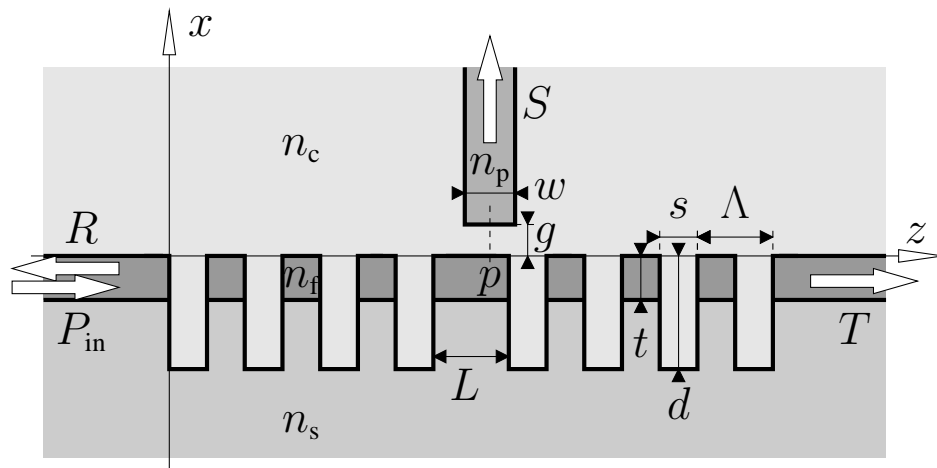
$n_s = 1.45, n_f = 2.0, n_c = 1.0, t = 0.2 \mu\text{m}, d = 0.6 \mu\text{m},$
 $\Lambda = 0.21 \mu\text{m}, s = 0.11 \mu\text{m}, L = 0.2275 \mu\text{m}, g = 10 \text{ nm}, w = 100 \text{ nm}, n_p = 1.5,$
 TE, $\lambda = 0.633 \mu\text{m}, (x, z) \in [-3.0, 3.0] \times [-3.0, 4.7075] \mu\text{m}^2, M_x = 100, M_z = 120.$

Resonant defect cavity



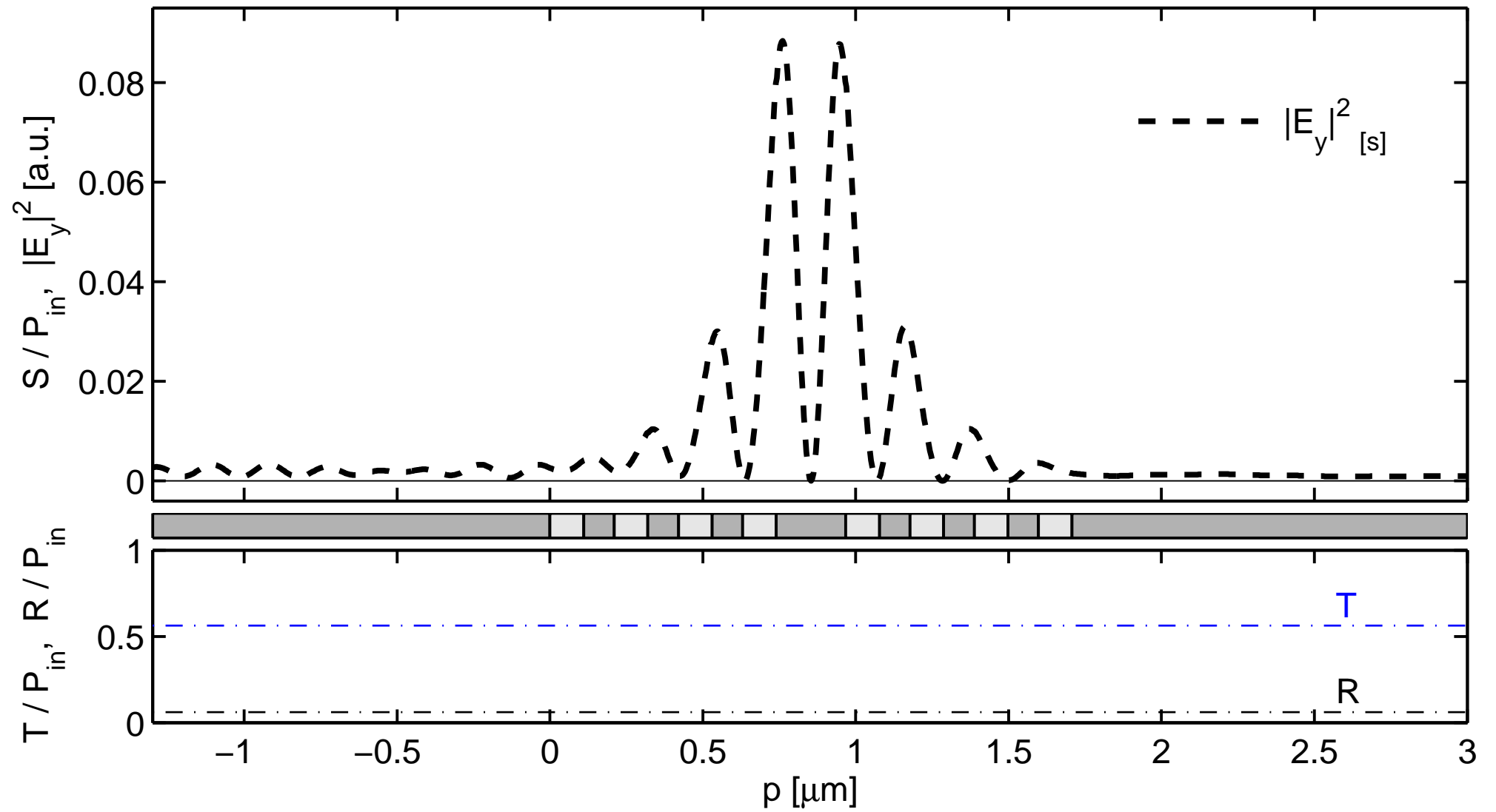
$n_s = 1.45, n_f = 2.0, n_c = 1.0, t = 0.2 \mu\text{m}, d = 0.6 \mu\text{m},$
 $\Lambda = 0.21 \mu\text{m}, s = 0.11 \mu\text{m}, L = 0.2275 \mu\text{m}, g = 10 \text{ nm}, w = 100 \text{ nm}, n_p = 1.5,$
 $\text{TE}, \lambda = 0.633 \mu\text{m}, (x, z) \in [-3.0, 3.0] \times [-3.0, 4.7075] \mu\text{m}^2, M_x = 100, M_z = 120.$

Resonant defect cavity

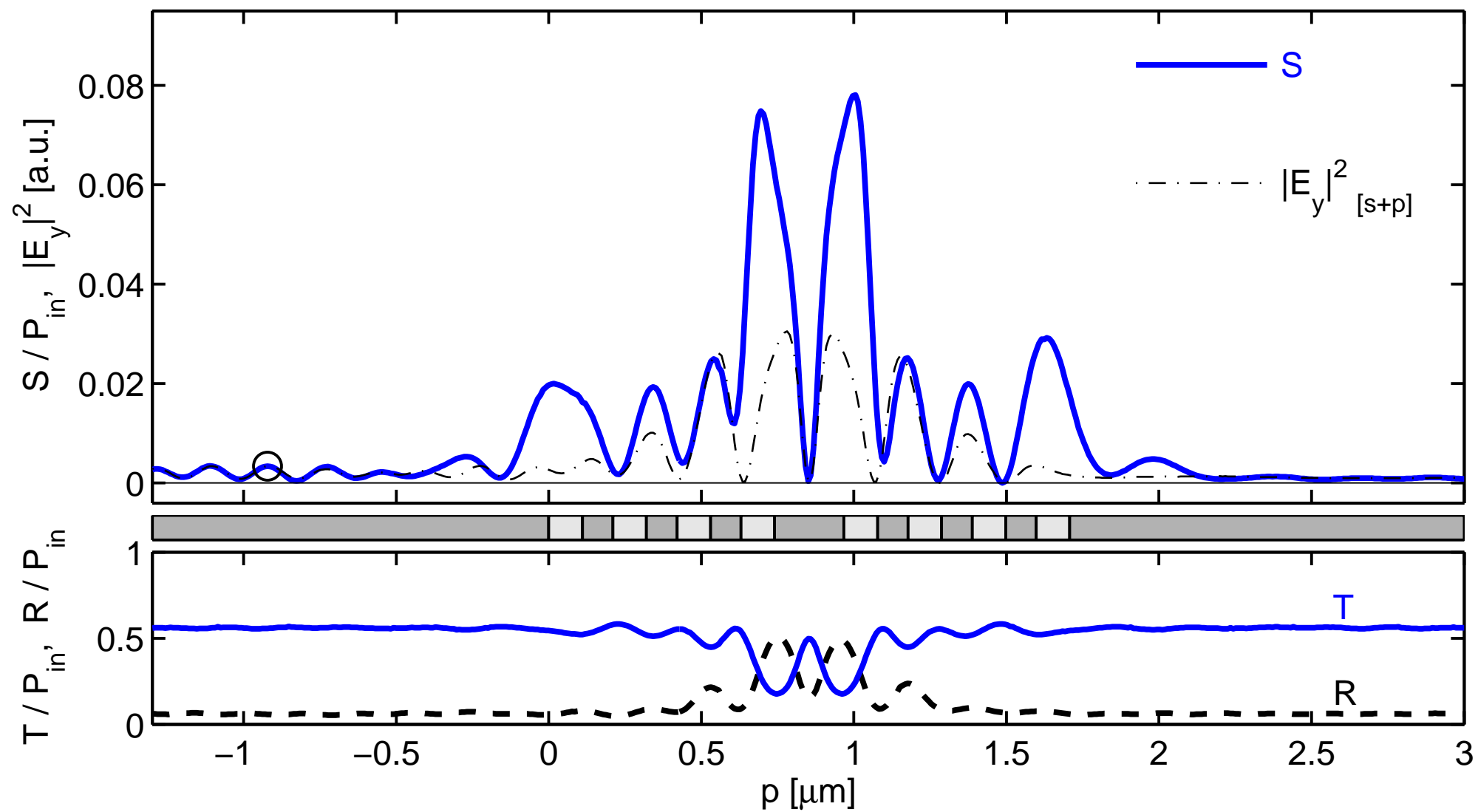


$n_s = 1.45, n_f = 2.0, n_c = 1.0, t = 0.2 \mu\text{m}, d = 0.6 \mu\text{m},$
 $\Lambda = 0.21 \mu\text{m}, s = 0.11 \mu\text{m}, L = 0.2275 \mu\text{m}, g = 10 \text{ nm}, w = 100 \text{ nm}, n_p = 1.5,$
 TE, $\lambda = 0.633 \mu\text{m}, (x, z) \in [-3.0, 3.0] \times [-3.0, 4.7075] \mu\text{m}^2, M_x = 100, M_z = 120.$

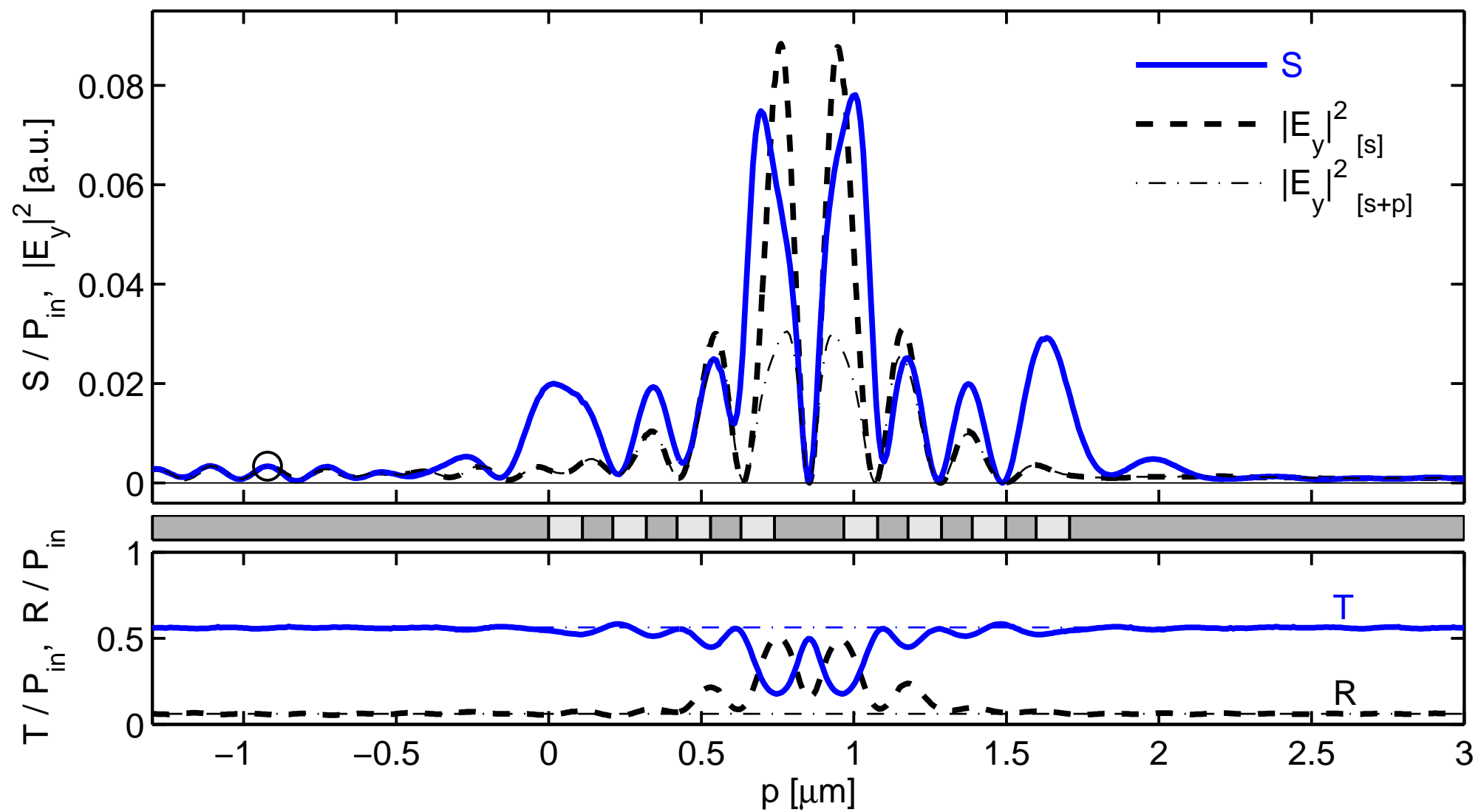
Resonant defect cavity



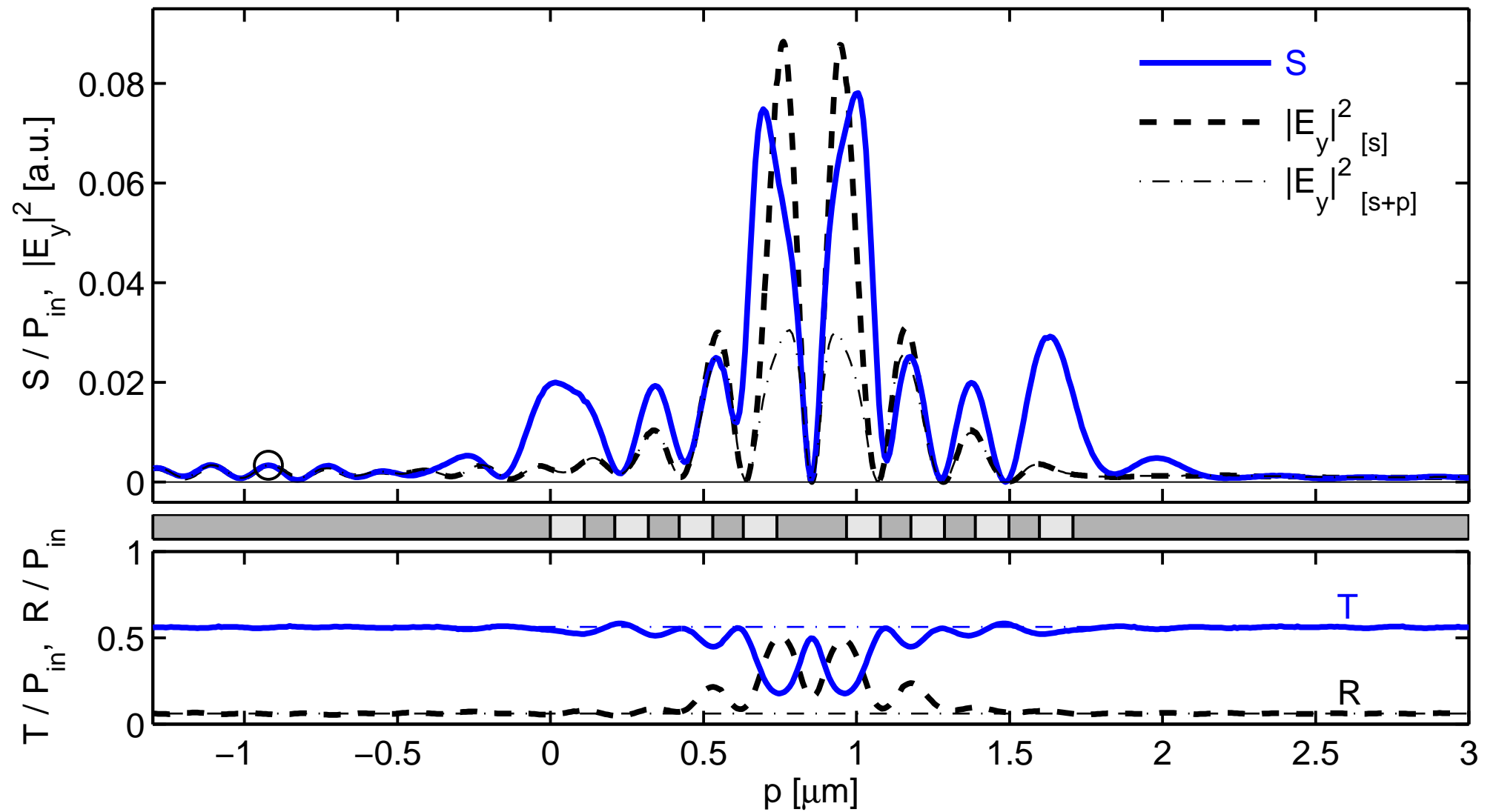
Resonant defect cavity



Resonant defect cavity



Resonant defect cavity

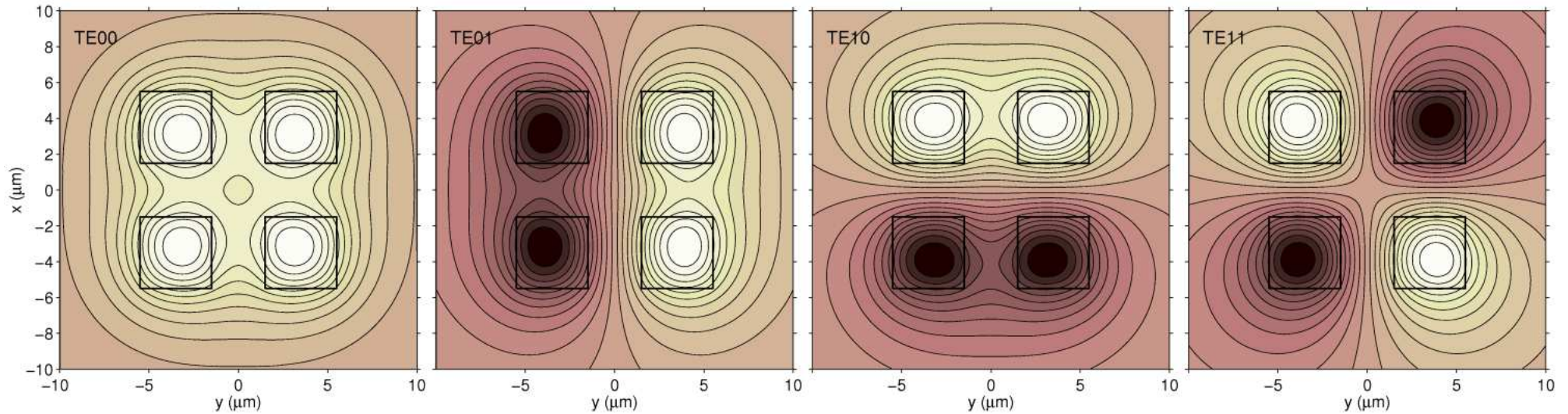


$T(p)$, $R(p)$: the probe switches the transmission.

Outline

- Simulations in guided wave optics
 - Macroscopic Maxwell equations
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 - Modes of dielectric waveguides
- Quadridirectional eigenmode propagation
 - Problem setting
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 - Algebraic procedure
- 2-D PSTM model
 - Probing evanescent fields
 - Hole defect in a slab waveguide
 - Waveguide Bragg grating: experiment & 2-D model
 - Resonant defect cavity
- Optical switching by NEMS-actuated resonator arrays

Ongoing: TOE.7143



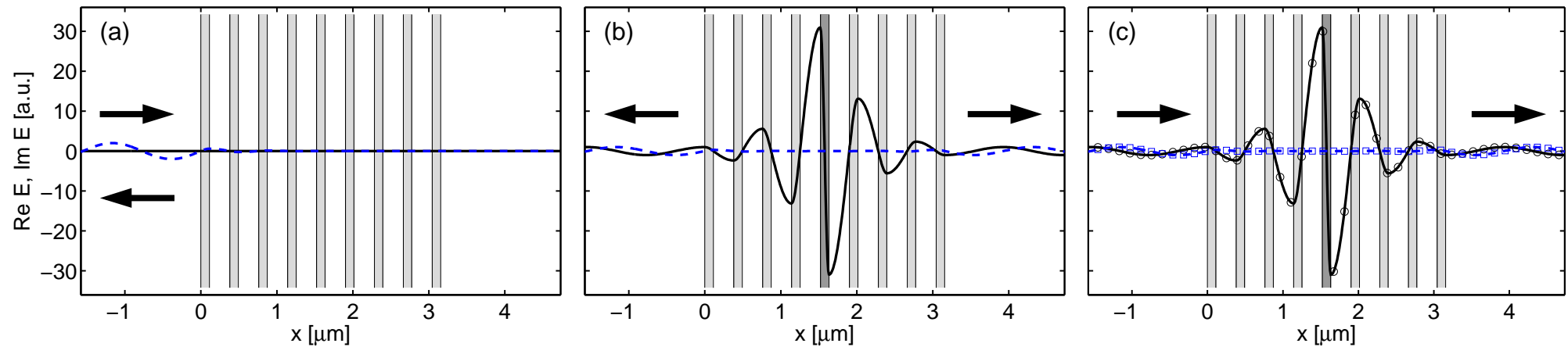
Olena Ivanova

Projection techniques for dimensionality reduction 3-D \rightarrow 2-D



NanoPhotonics Flagship, project TOE.7143

Optical switching by NEMS actuated resonator arrays — modeling & simulation tools



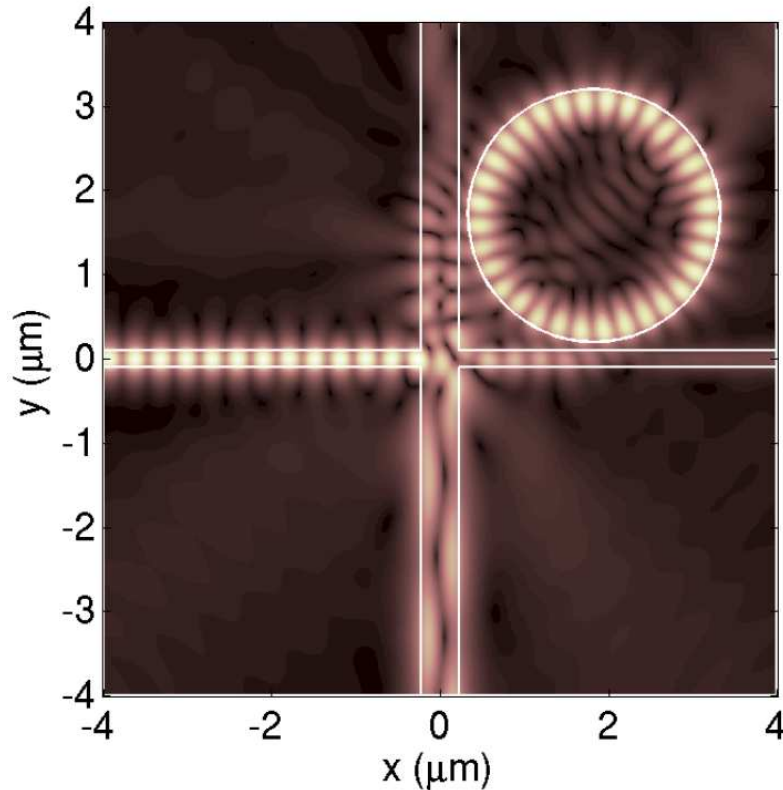
Milan Maksimovic

Time domain characterization of resonances & perturbations



NanoPhotonics Flagship, project TOE.7143

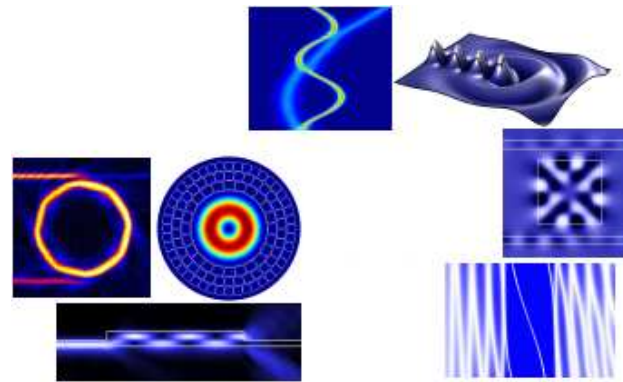
Optical switching by NEMS actuated resonator arrays — modeling & simulation tools



Remco Stoffer

Numerical simulation tools
& interaction with projects

TOE.7144, NEMS, group TST (EEMCS, EL),
TOE.7145, Optics, group IOMS (EEMCS, EL).



<http://www.math.utwente.nl/aamp/>

<http://www.math.utwente.nl/aamp/research.html#MATHOPT>