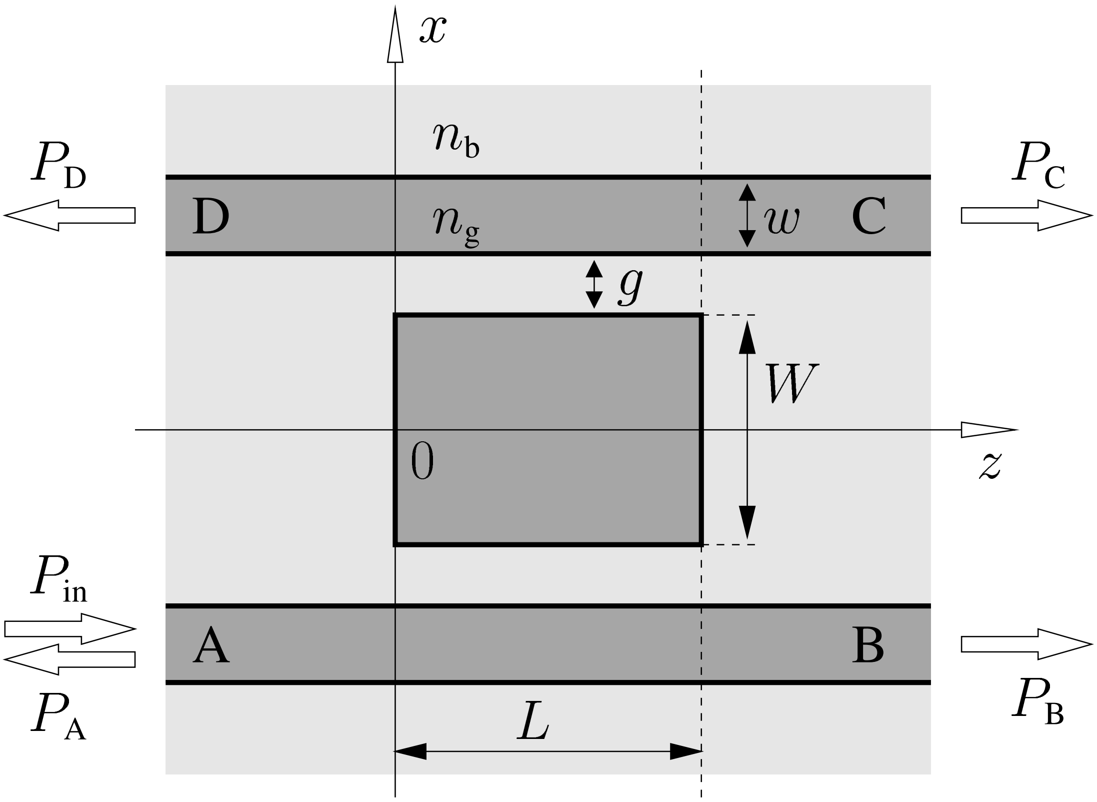

$$P_{in}(\lambda) = 1. \quad P_A,\, P_B,\, P_C,\, P_D \;=\; ?$$

Mode expansion modeling of rectangular integrated optical microresonators

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MESA$^+$ Research Institute, University of Twente, The Netherlands

- Rectangular microresonators
- Mode expansion modeling
- Single resonators:
  - Spectral response
  - Parameter influences
  - Convergence issues
- Wavelength filter:
  - Spectral response
  - Parameter influences

International Workshop on Optical Waveguide Theory and Numerical Modelling
Paderborn, Germany *6 – 7 April 2001*

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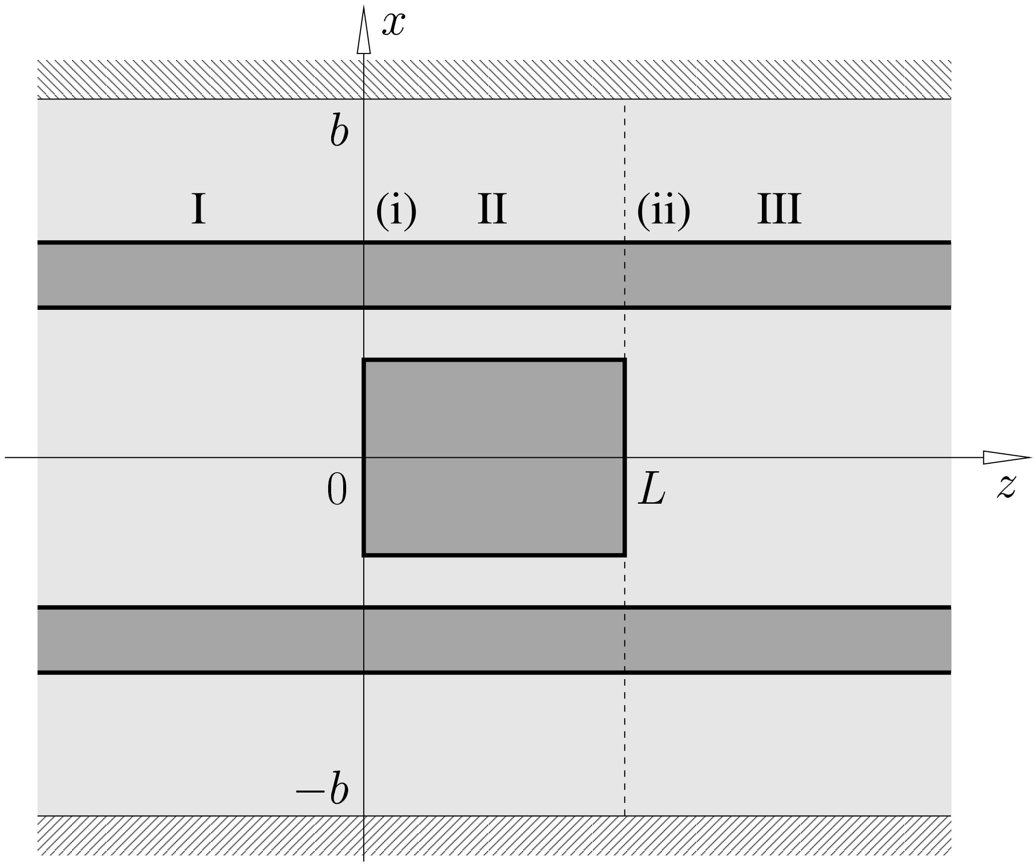
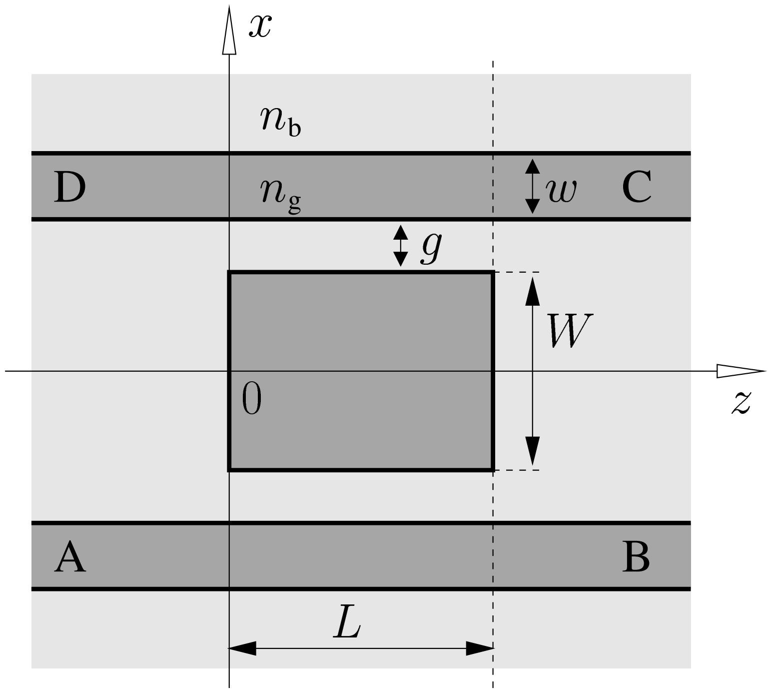


- Spatial 2D setting, fixed angular frequency ω / vacuum wavelength λ.
- Division into z-homogeneous segments I, II, III.
- Artificial boundaries $\rightarrow$ discretization of the mode spectrum.
- Mode expansion ansatz, $s = \mathrm{I}, \mathrm{II}, \mathrm{III}$:

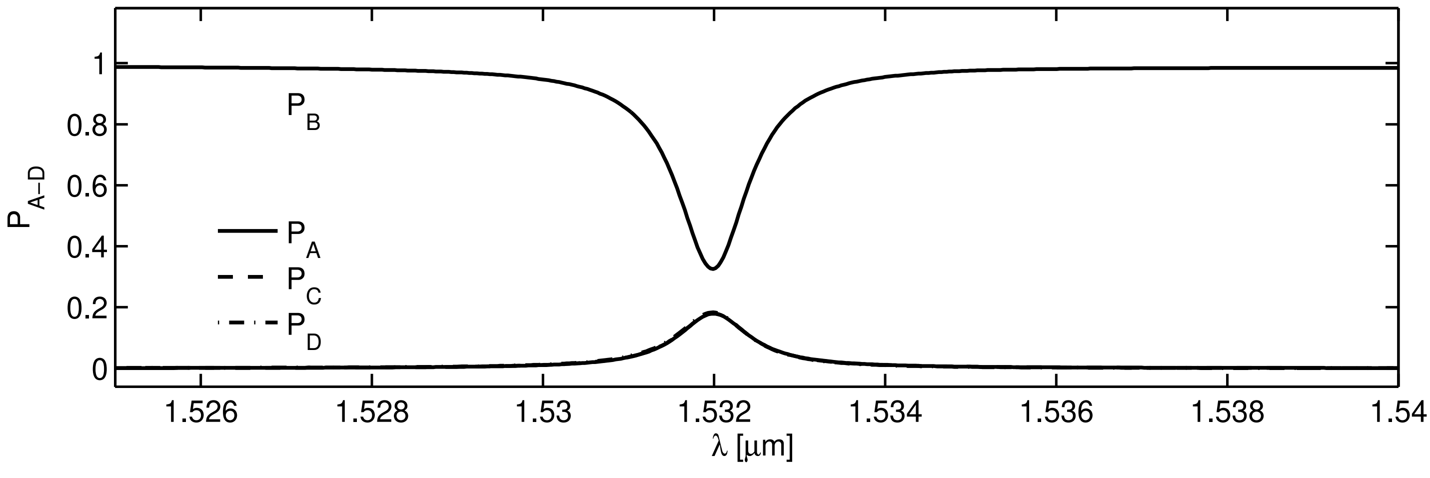
$$\begin{pmatrix} \boldsymbol{\mathcal{E}} \\ \boldsymbol{\mathcal{H}} \end{pmatrix}^{s}(x,z,t) = \sum_m F_m^s \boldsymbol{\psi}_m^{s,\mathrm{f}}(x)\, \mathrm{e}^{\mathrm{i}\omega t - \mathrm{i}\beta_m^s z} + \sum_m B_m^s \boldsymbol{\psi}_m^{s,\mathrm{b}}(x)\, \mathrm{e}^{\mathrm{i}\omega t + \mathrm{i}\beta_m^s z}.$$

  $\{\boldsymbol{\psi}_m^{s,\mathrm{f}}, \boldsymbol{\psi}_m^{s,\mathrm{b}}\}$: forward + backward, propagating + evanescent terms.

- Inner product for overlap computations + orthogonality relations
  $\rightarrow$ bidirectional field expansions at the junctions (i), (ii),
  $\rightarrow$ linear set of equations for $\{F_m^s, B_m^s\}$.
- $F_0^{\mathrm{I}} = 1, \quad F_j^{\mathrm{I}} = 0, j \neq 0, \quad B_m^{\mathrm{III}} = 0; \quad B_m^{\mathrm{I}}, F_m^{\mathrm{II}}, B_m^{\mathrm{II}}, F_m^{\mathrm{III}} = \ ?$



* $n_g = 3.2$, $n_b = 1.0$,
$w = 0.20\,\mu$m, $g = 0.29\,\mu$m,
$W = 1.54\,\mu$m, $L = 1.54\,\mu$m,
$\lambda \in [1.3\,\mu\text{m}, 1.7\,\mu\text{m}]$,
TE fields, $\boldsymbol{\mathcal{E}} = (0, E_y, 0)$.



$\lambda = 1.532\,\mu$m: $P_A = 0.18$, $P_B = 0.33$, $P_C = 0.18$, $P_D = 0.18$.

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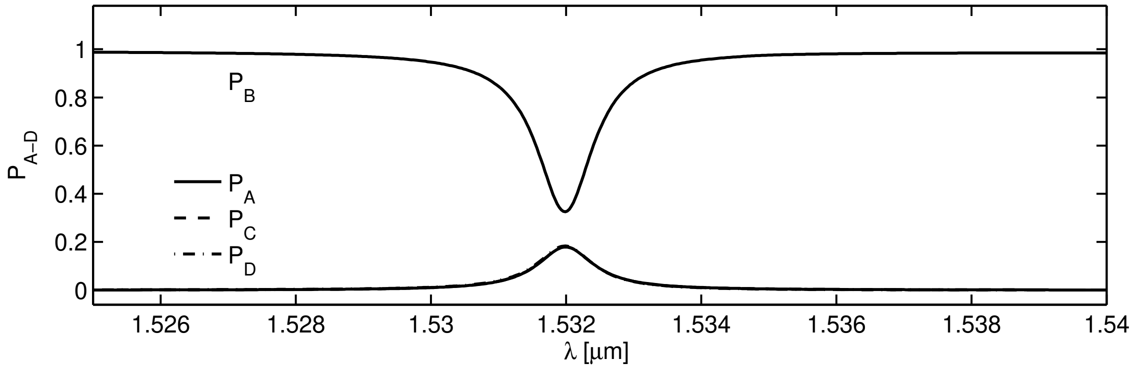
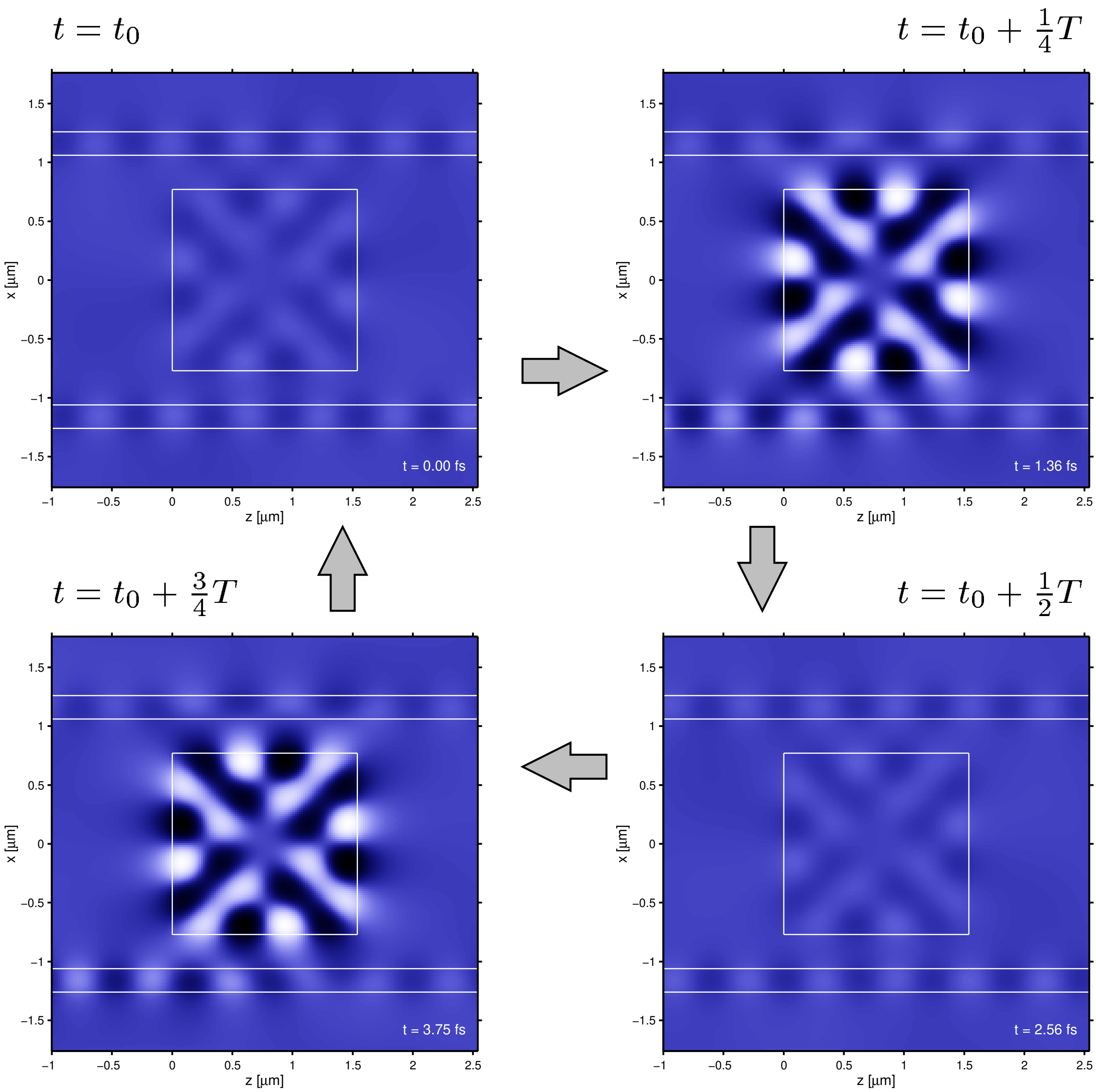
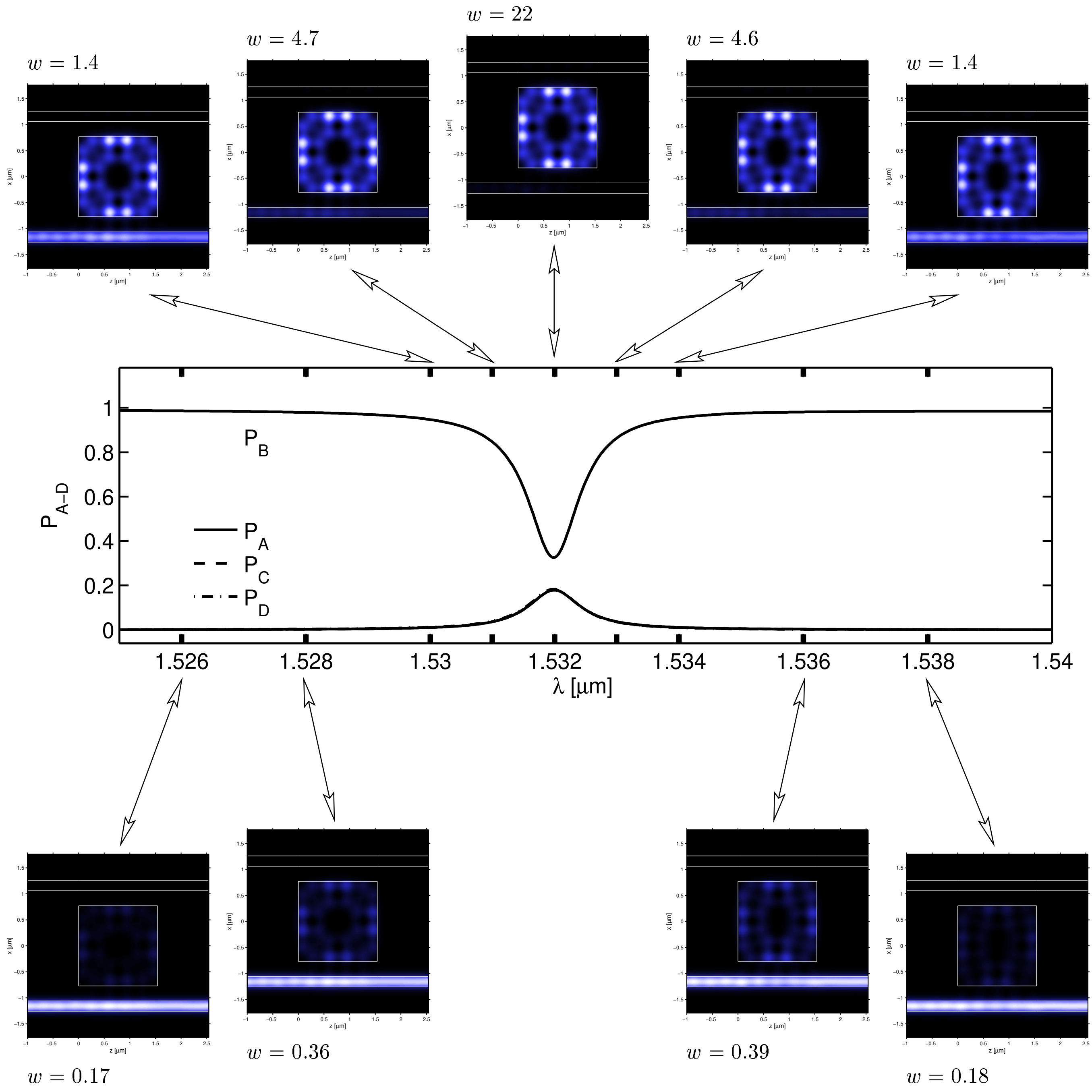
* *C. Manolatou, M. J. Khan, S. Fan, P. R. Villeneuve, H. A. Haus, J. D. Joannopoulos, Coupling of Modes Analysis of Resonant Channel Add-Drop Filters, IEEE Journal of Quantum Electronics 35(9), 1322–1331, 1999*

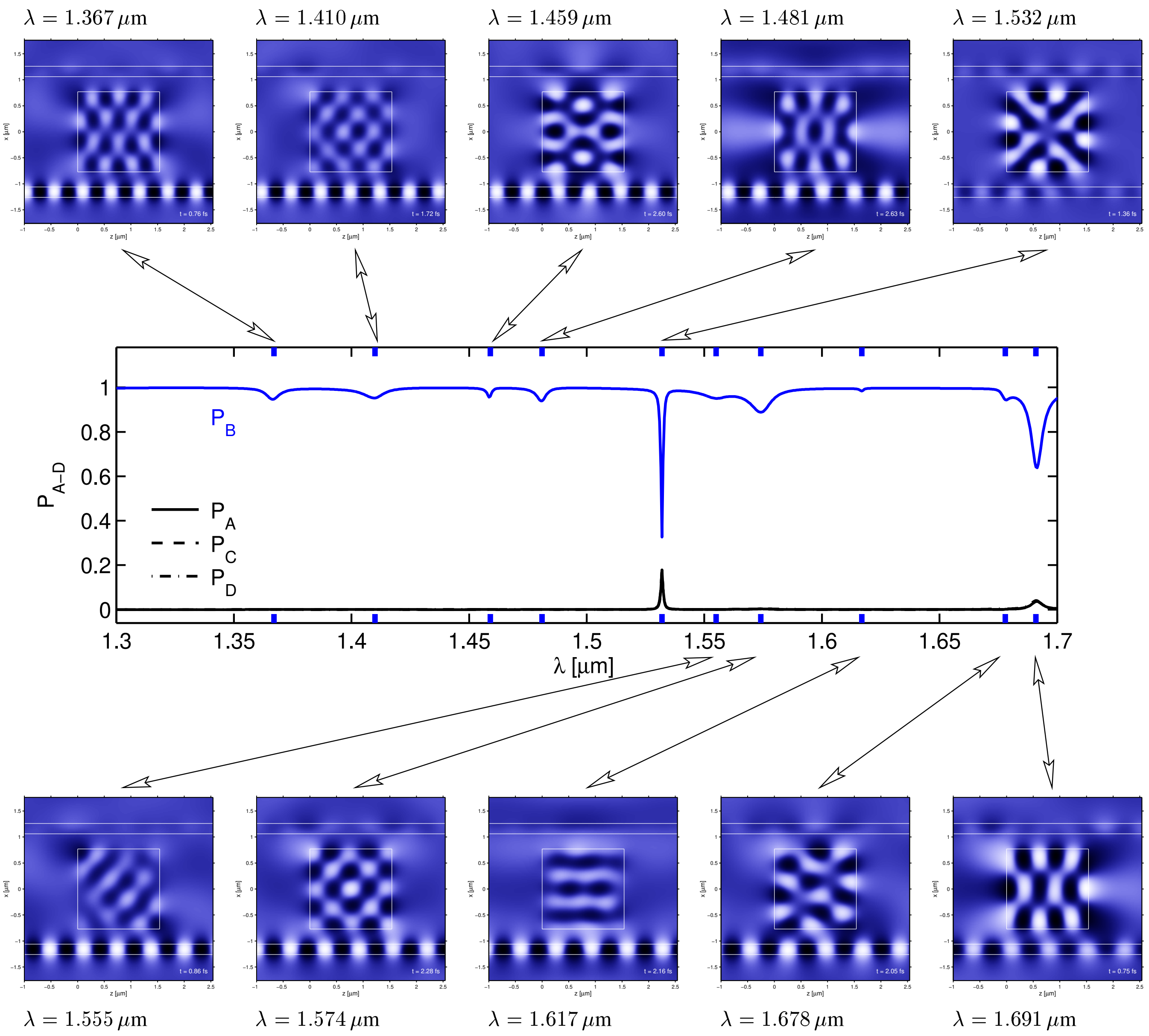


$\lambda = 1.532\,\mu\text{m},\;\; f = 196\,\text{THz},\;\; T = 5.11\,\text{fs},\;\; E_y(x, z, t)$:

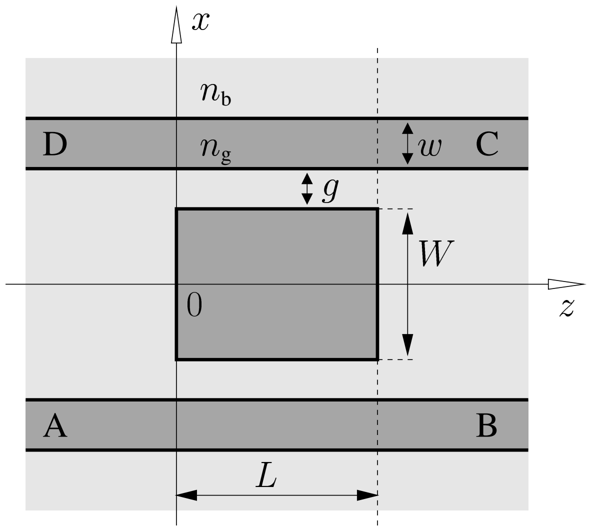


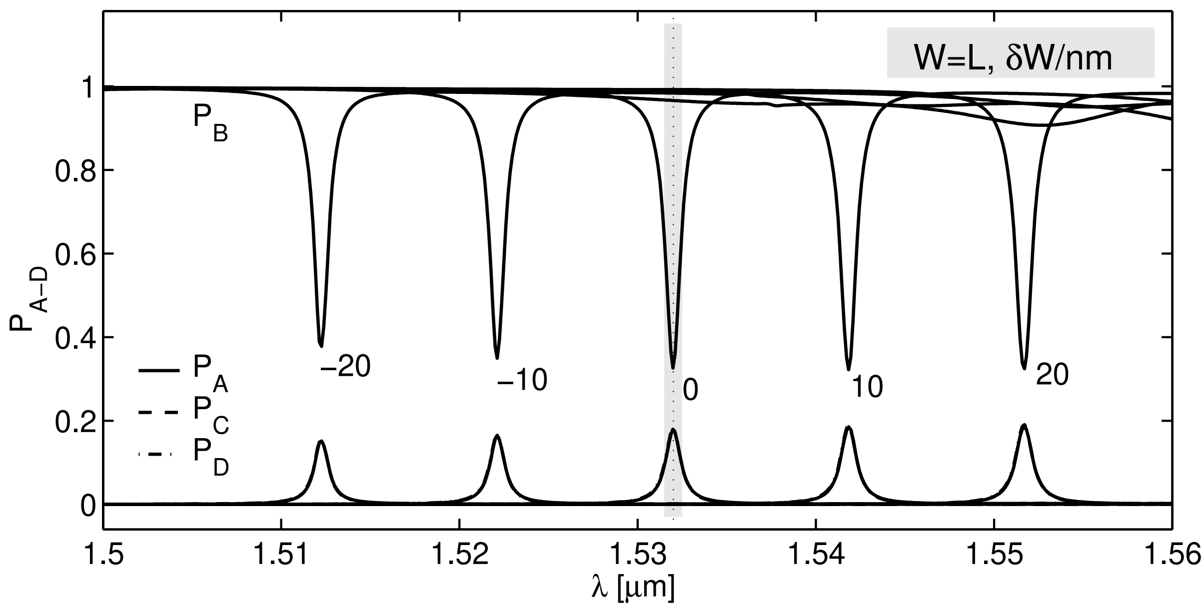


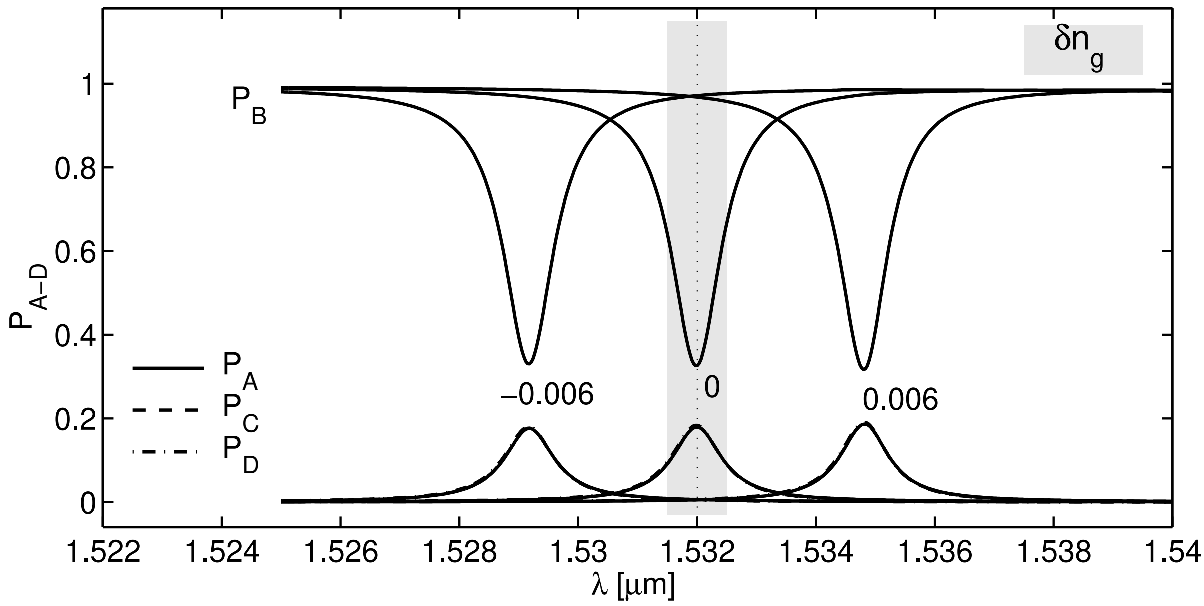
w: maximum electromagnetic energy density in the cavity region, relative to an isolated, equally excited waveguide.

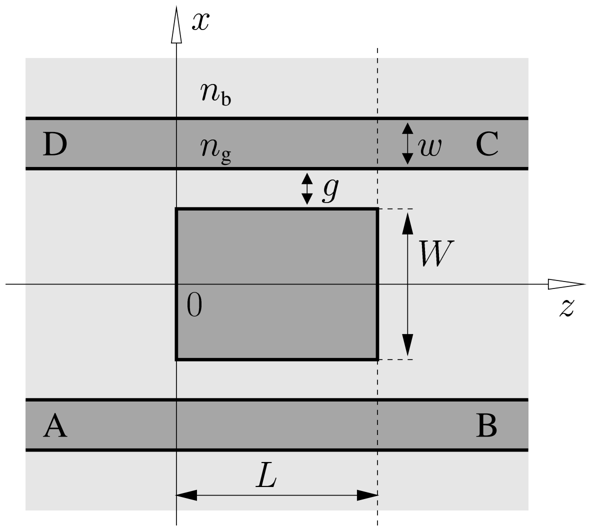


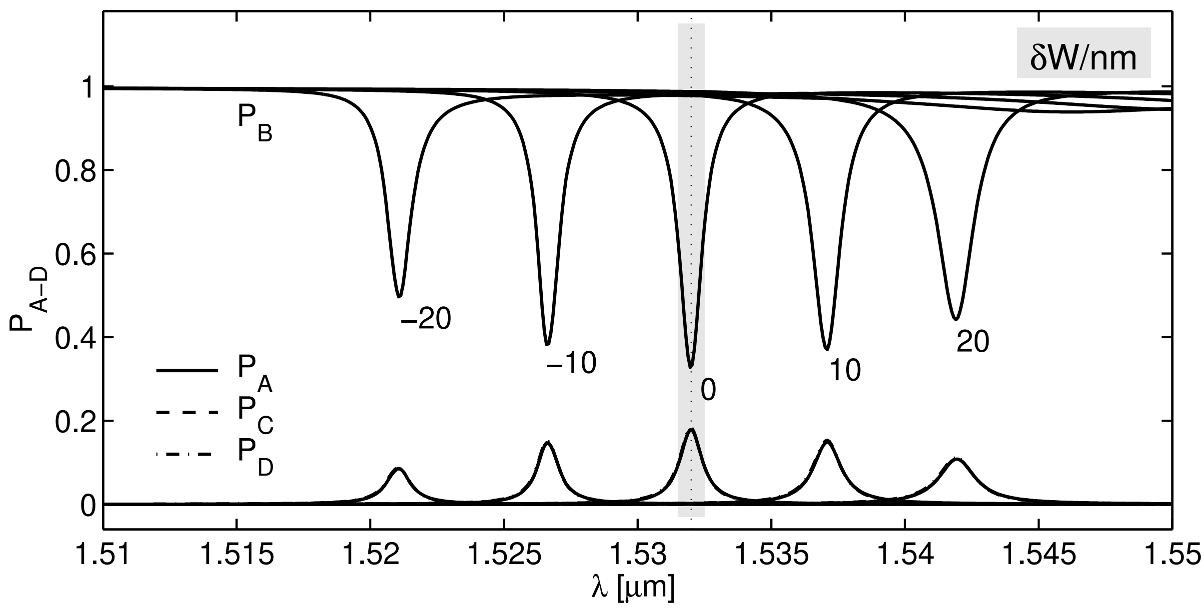
$\lambda = 1.367\,\mu$m
$\lambda = 1.410\,\mu$m
$\lambda = 1.459\,\mu$m
$\lambda = 1.481\,\mu$m
$\lambda = 1.532\,\mu$m
P_B
P_{A-D}
P_A
P_C
P_D
1
0.8
0.6
0.4
0.2
0
1.3
1.35
1.4
1.45
1.5
1.55
1.6
1.65
1.7
λ [μm]
$\lambda = 1.555\,\mu$m
$\lambda = 1.574\,\mu$m
$\lambda = 1.617\,\mu$m
$\lambda = 1.678\,\mu$m
$\lambda = 1.691\,\mu$m

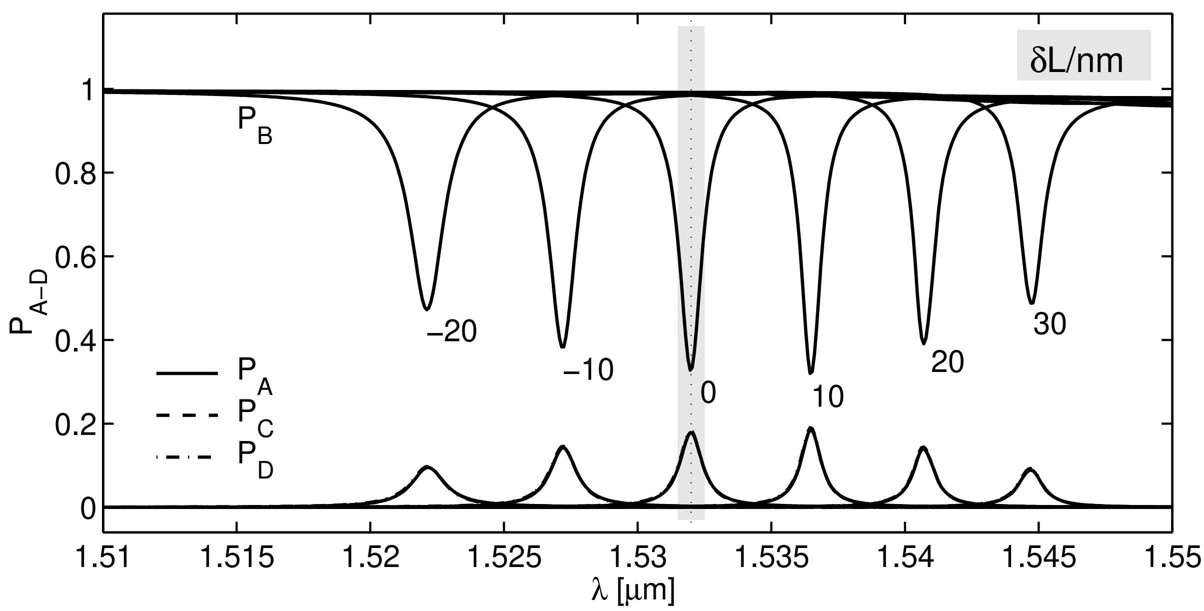

x
n_b
D
n_g
w
C
g
W
0
z
A
B
L

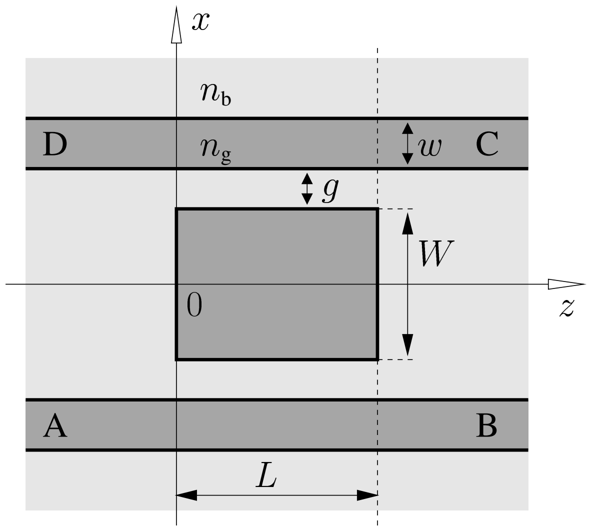

W=L, δW/nm
P_B
P_A–D
P_A
P_C
P_D
−20
−10
0
10
20
λ [μm]

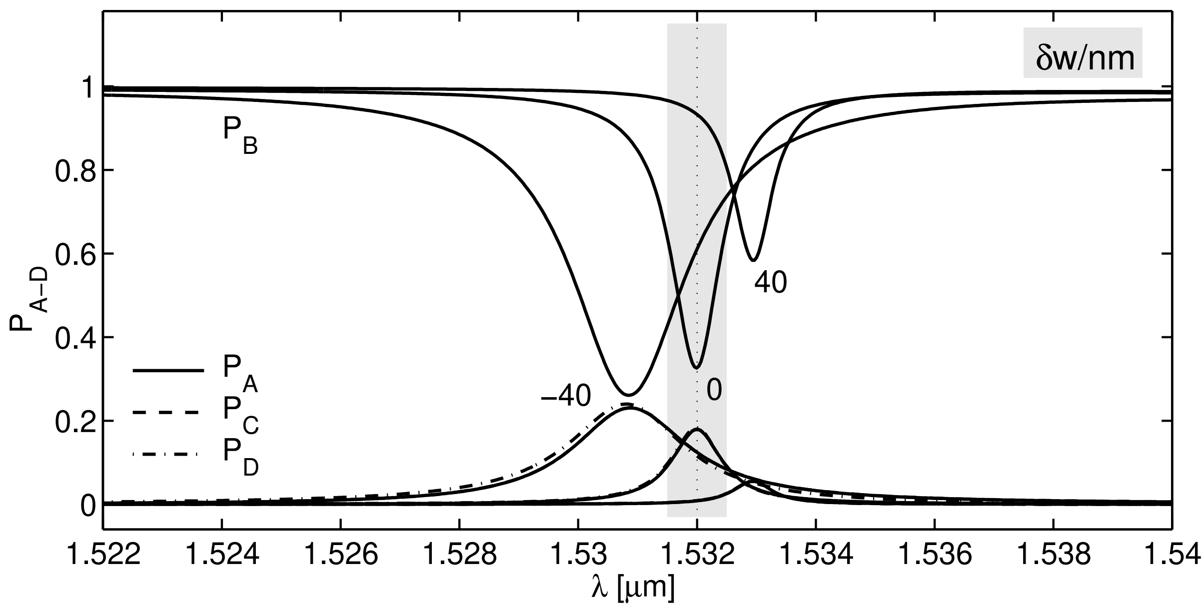

δn_g
P_B
P_A–D
P_A
P_C
P_D
−0.006
0
0.006
λ [μm]

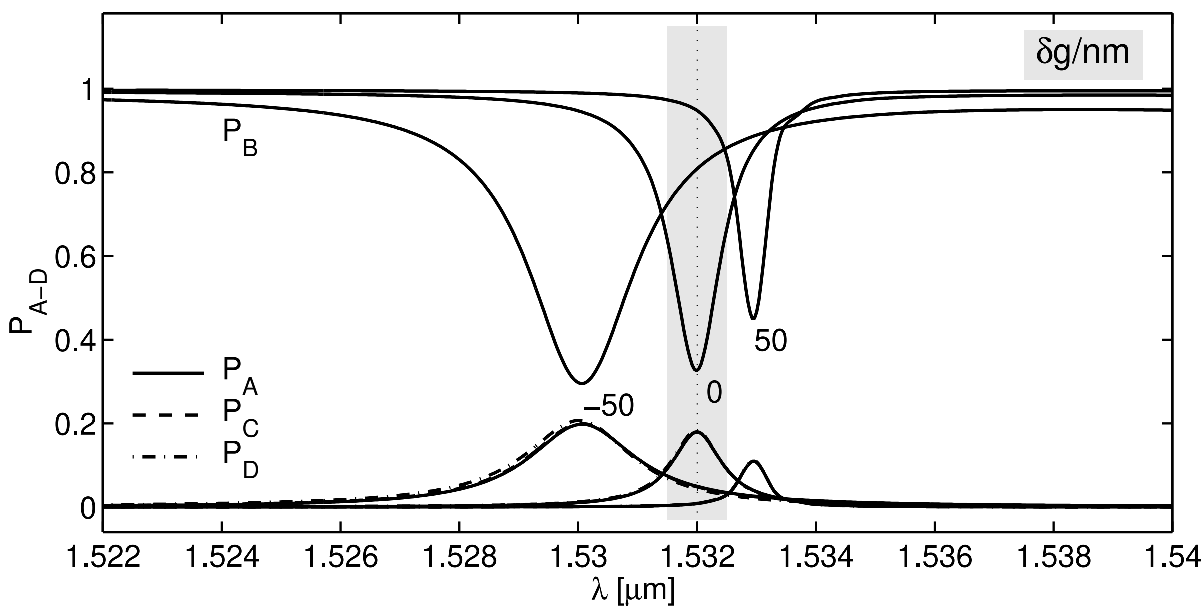

x
n_b
D
n_g
w
C
g
W
0
z
A
B
L

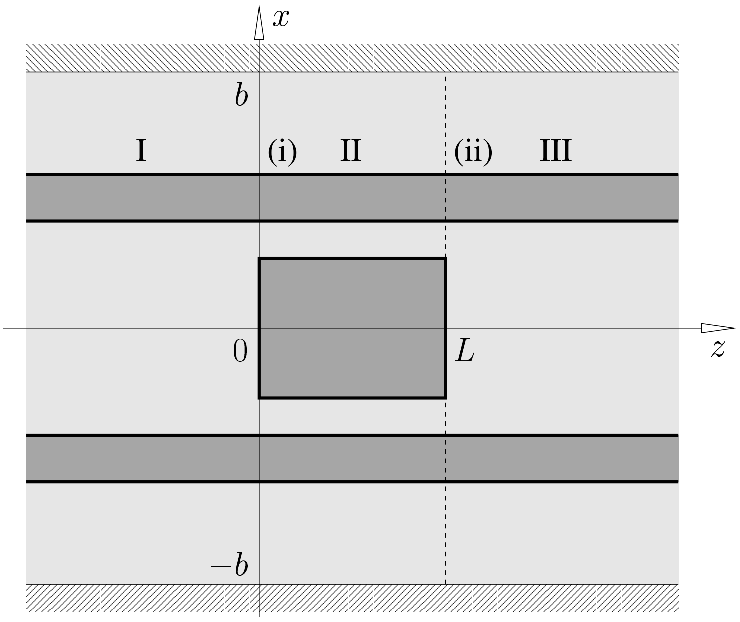

δW/nm
P_B
P_{A-D}
−20
−10
0
10
20
P_A
P_C
P_D
λ [μm]


δL/nm
P_B
P_{A-D}
−20
−10
0
10
20
30
P_A
P_C
P_D
λ [μm]


x
n_b
D
n_g
w
C
g
W
0
z
A
B
L


δw/nm
P_B
P_{A-D}
40
0
−40
P_A
P_C
P_D
λ [μm]

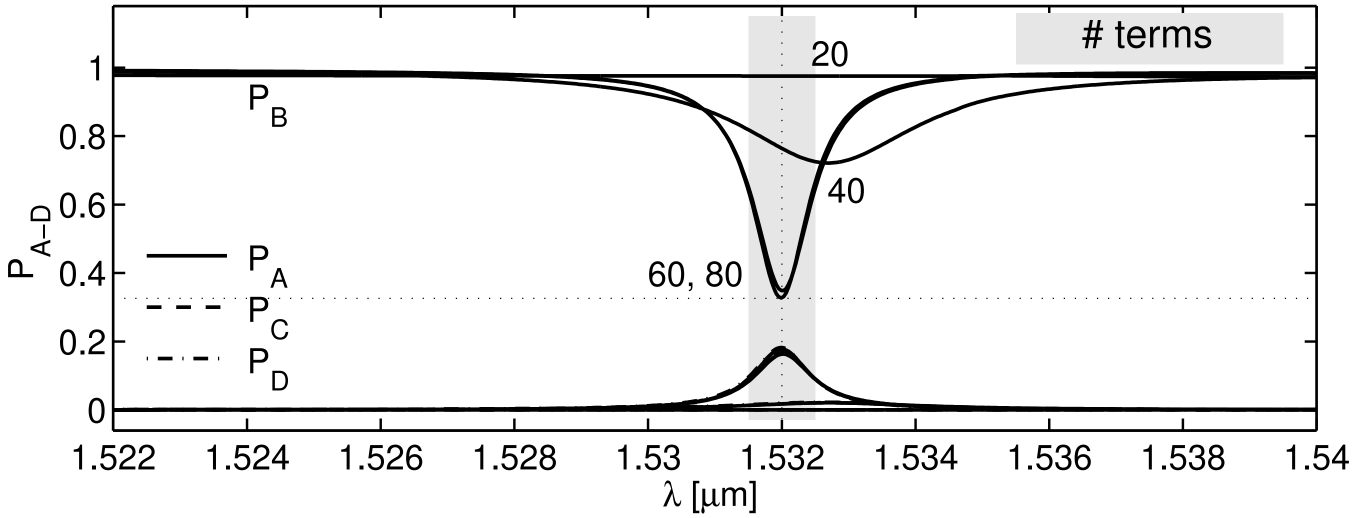

δg/nm
P_B
P_{A-D}
50
0
−50
P_A
P_C
P_D
λ [μm]

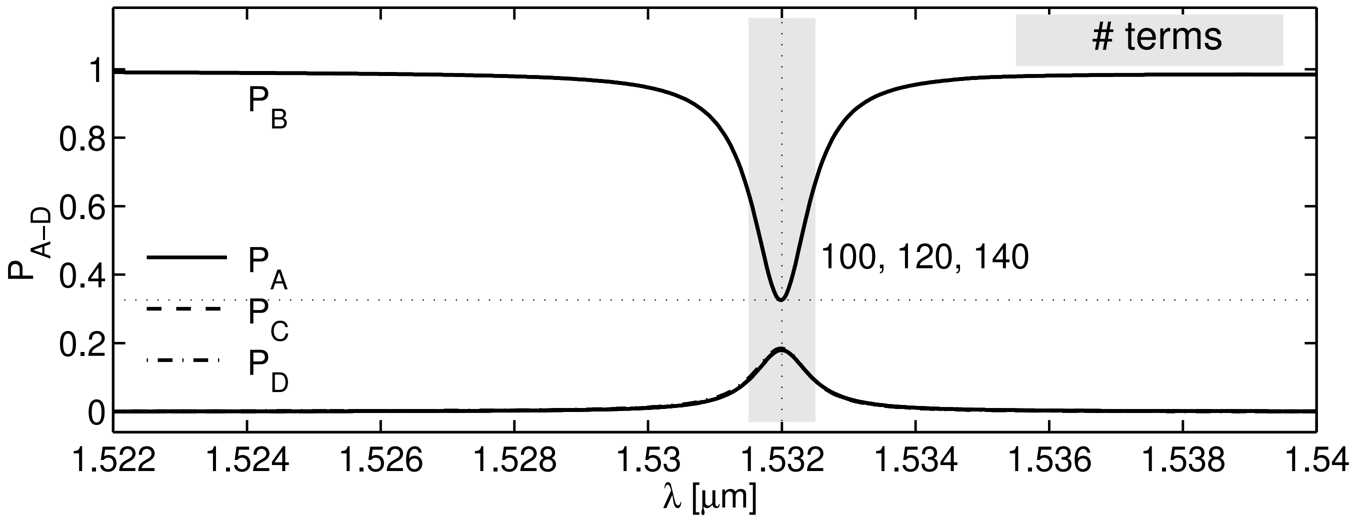


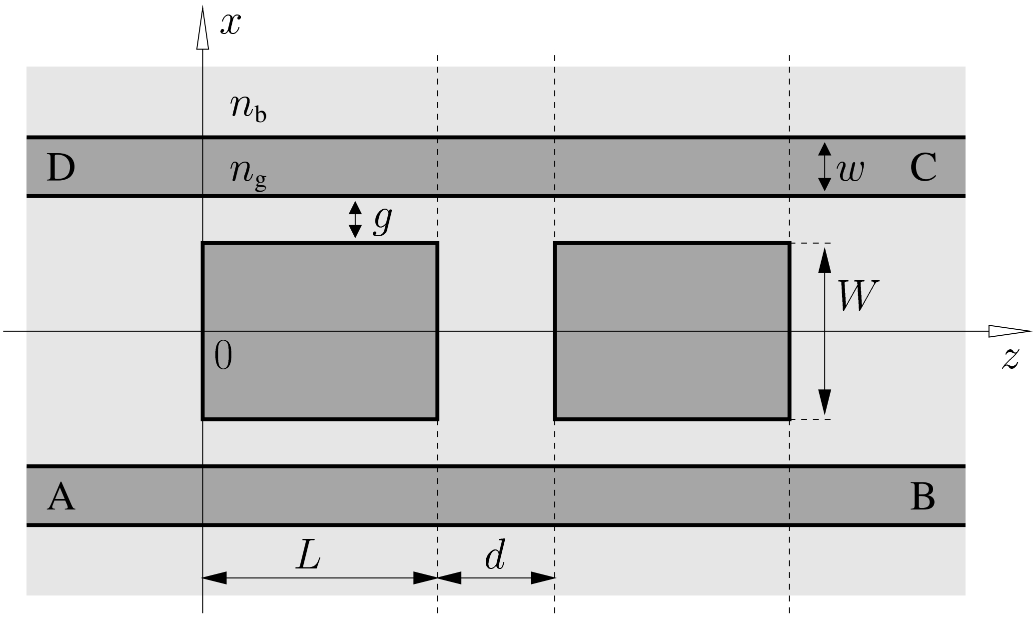
$W + 2g + 2w = 2.52\,\mu$m,
$b = 5.0\,\mu$m.

12 (I, III) and 18 (II) propagating modes at $\lambda = 1.532\,\mu$m.

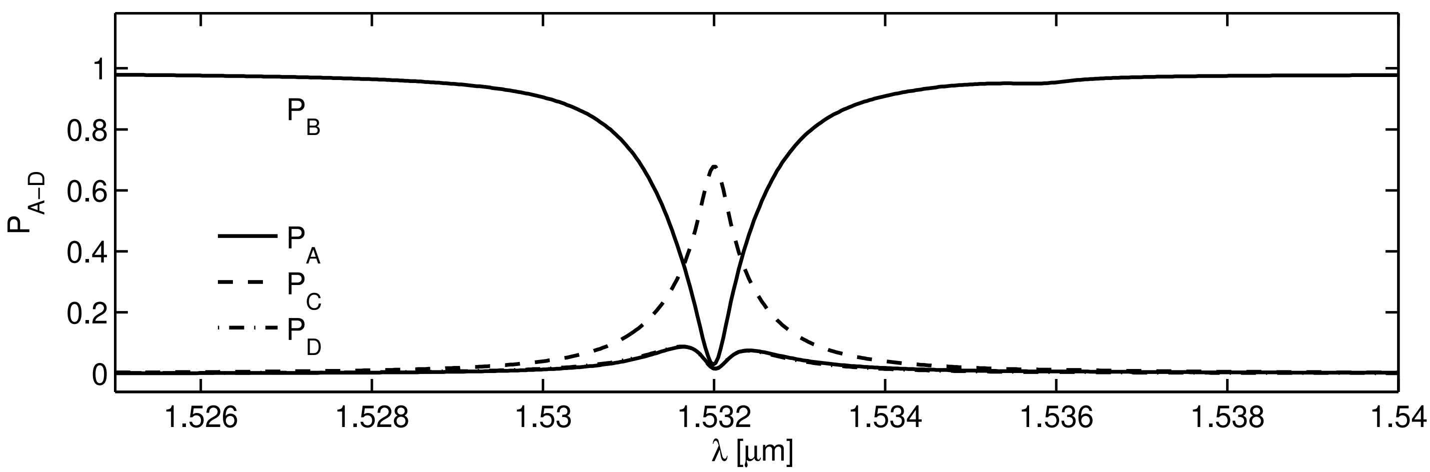
Simulations with different numbers of expansion terms:





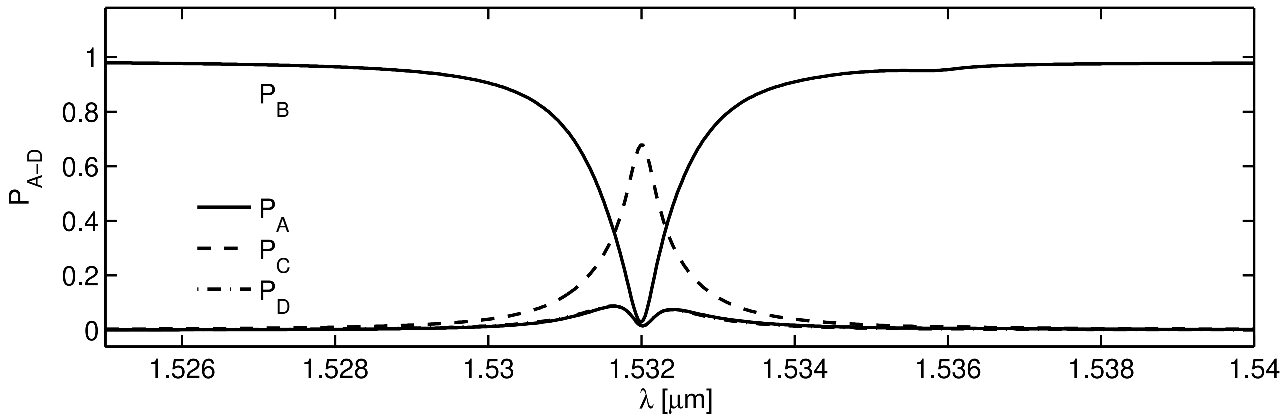


$n_g = 3.2$, $n_b = 1.0$, $w = 0.20\,\mu$m, $g = 0.29\,\mu$m, $d = 0.72\,\mu$m,
$W = 1.54\,\mu$m, $L = 1.54\,\mu$m, $\lambda \in [1.3\,\mu\text{m}, 1.7\,\mu\text{m}]$, TE fields, $\boldsymbol{\mathcal{E}} = (0, E_y, 0)$.

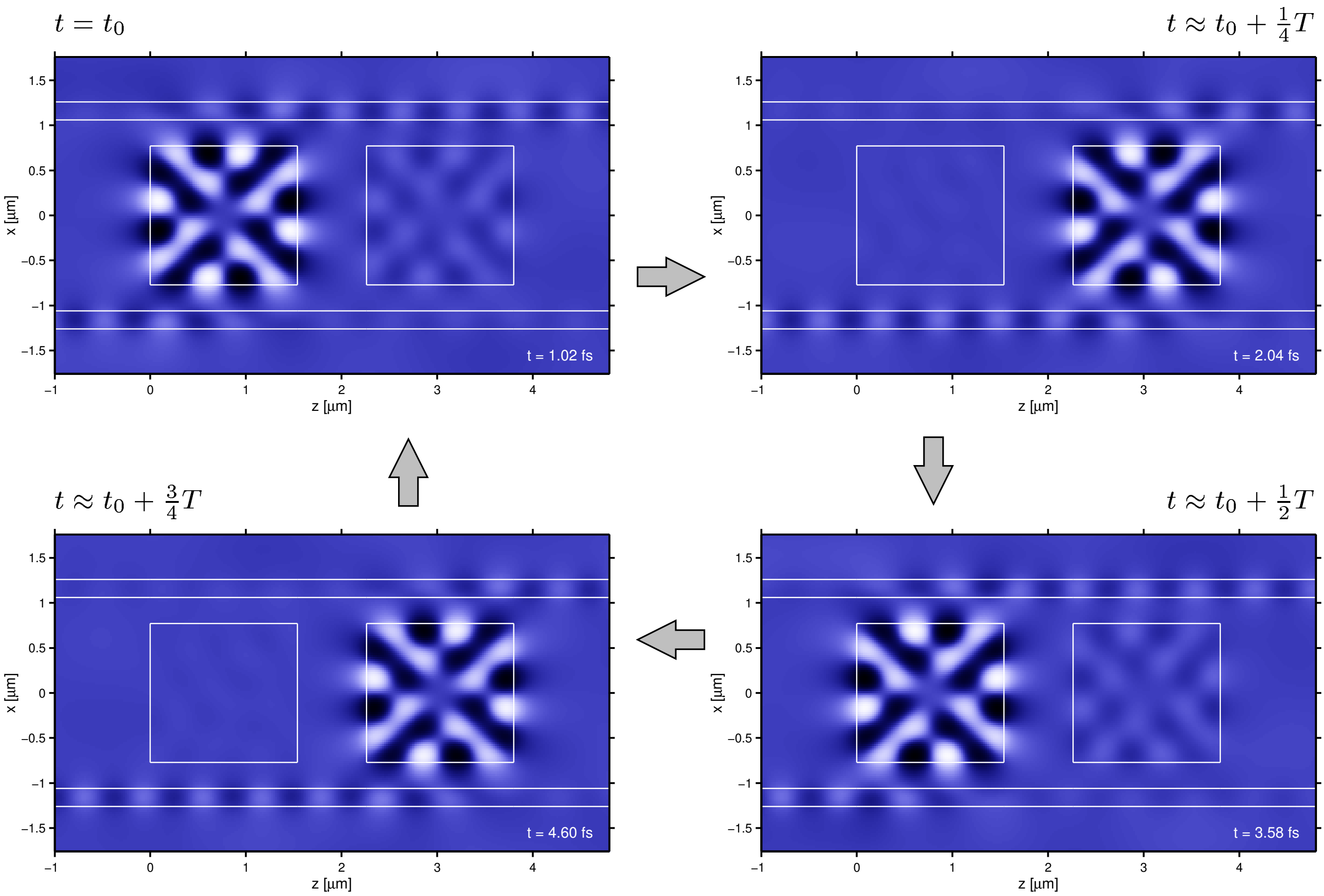


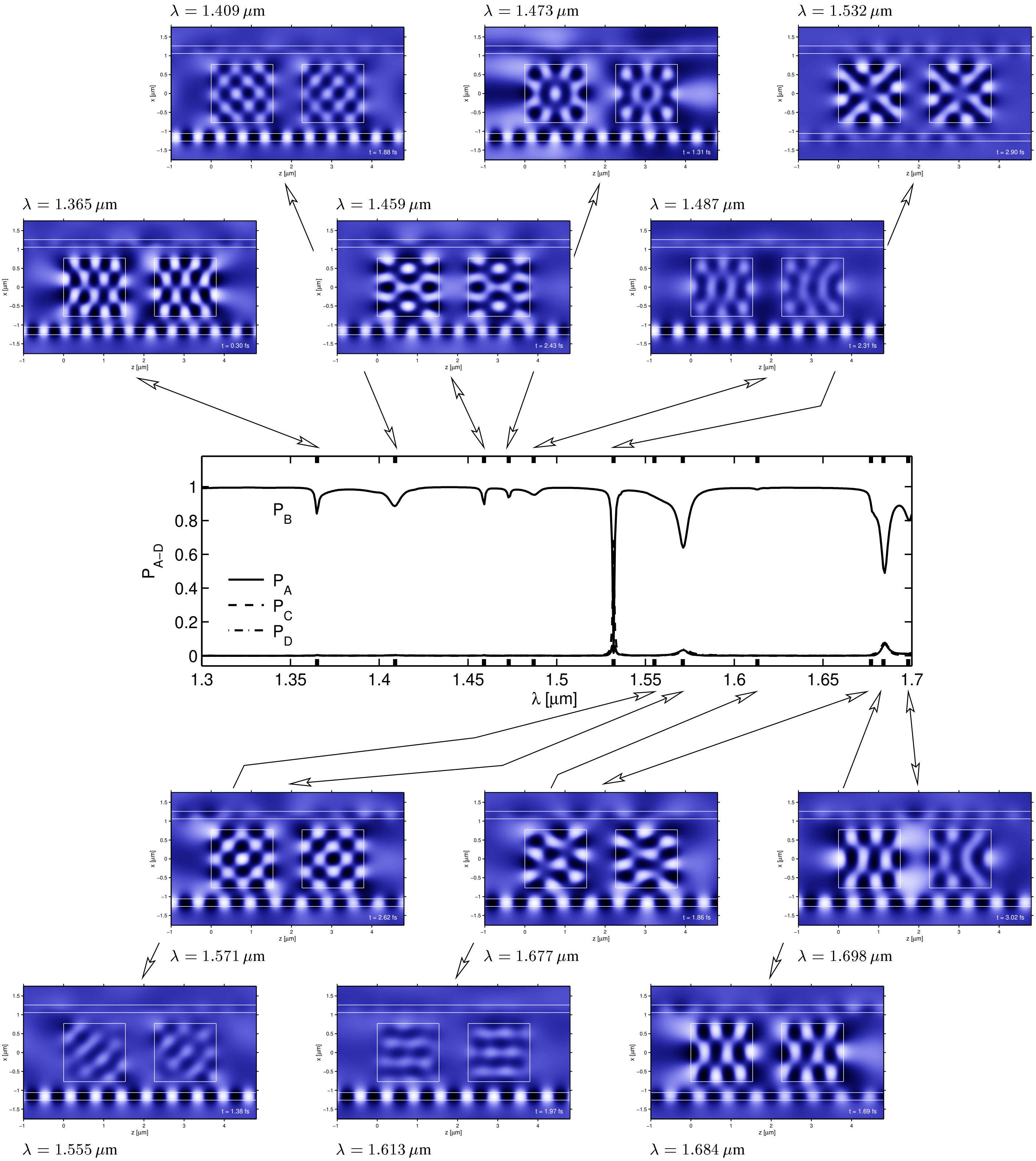
$\lambda = 1.532\,\mu$m: $P_A = 0.02$, $P_B = 0.03$, $P_C = 0.68$, $P_D = 0.02$.

FWHM $\approx 1\,$nm.

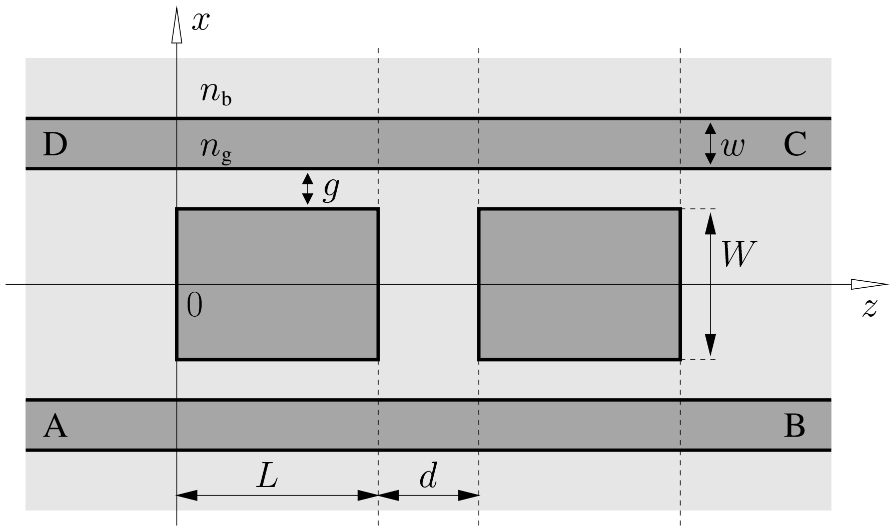


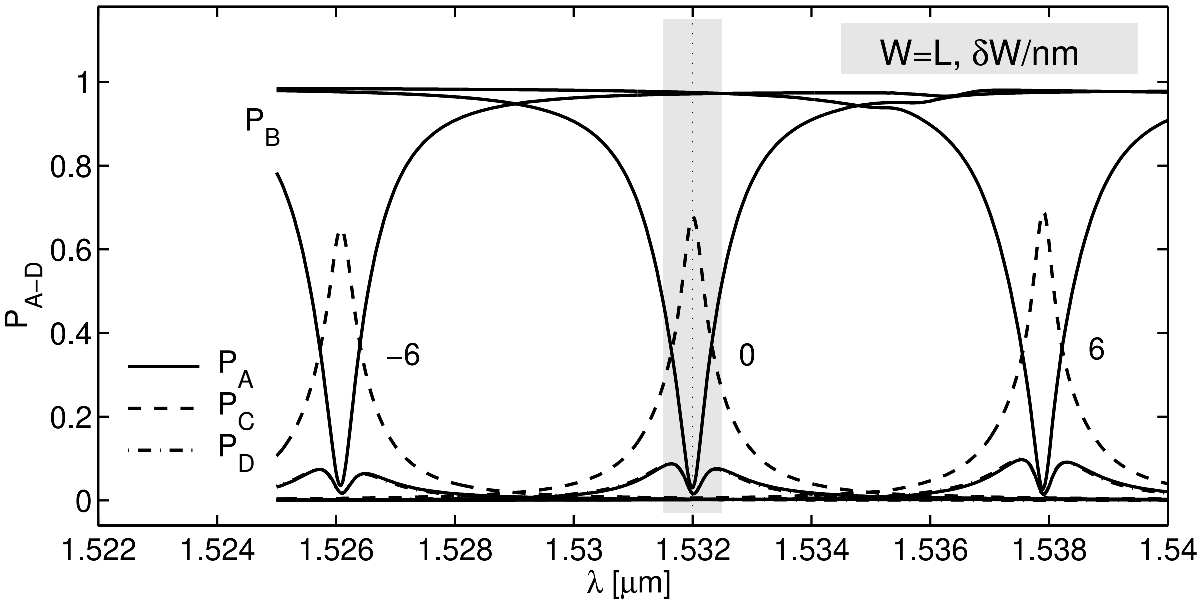
$\lambda = 1.532\,\mu$m, $f = 196\,$THz, $T = 5.11\,$fs, $E_y(x,z,t)$:

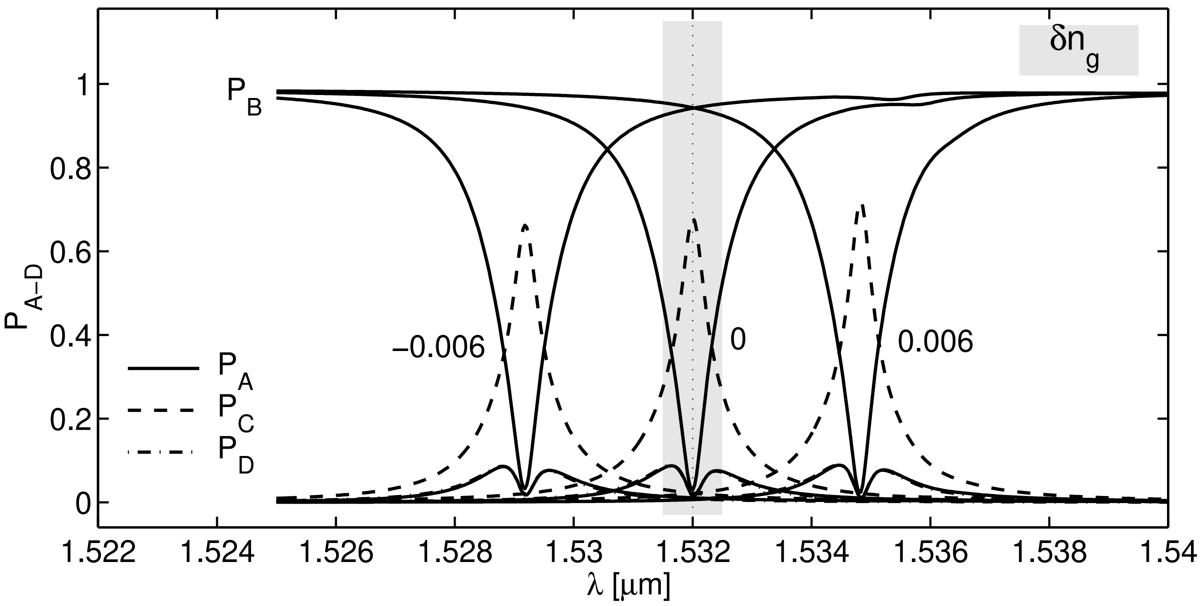


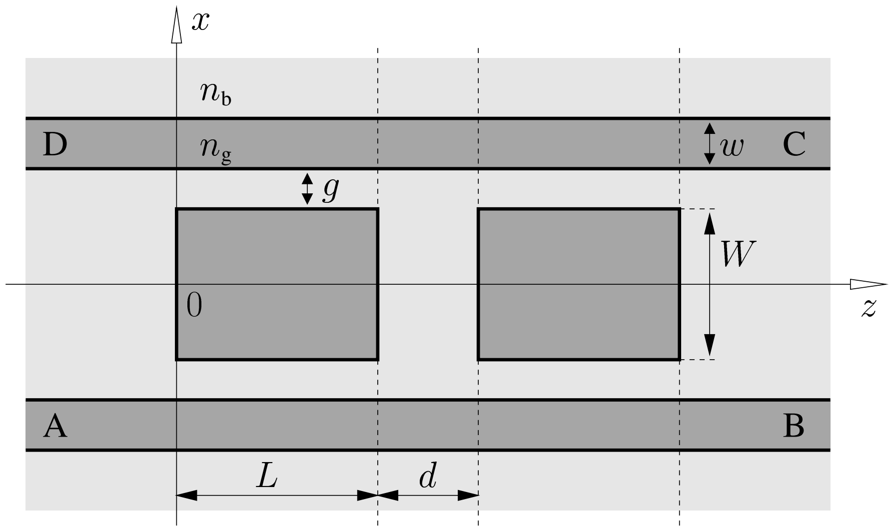


FWHM $\approx 1\,\mathrm{nm}$, FSR $\approx 40\,\mathrm{nm}\ (150\,\mathrm{nm})$.

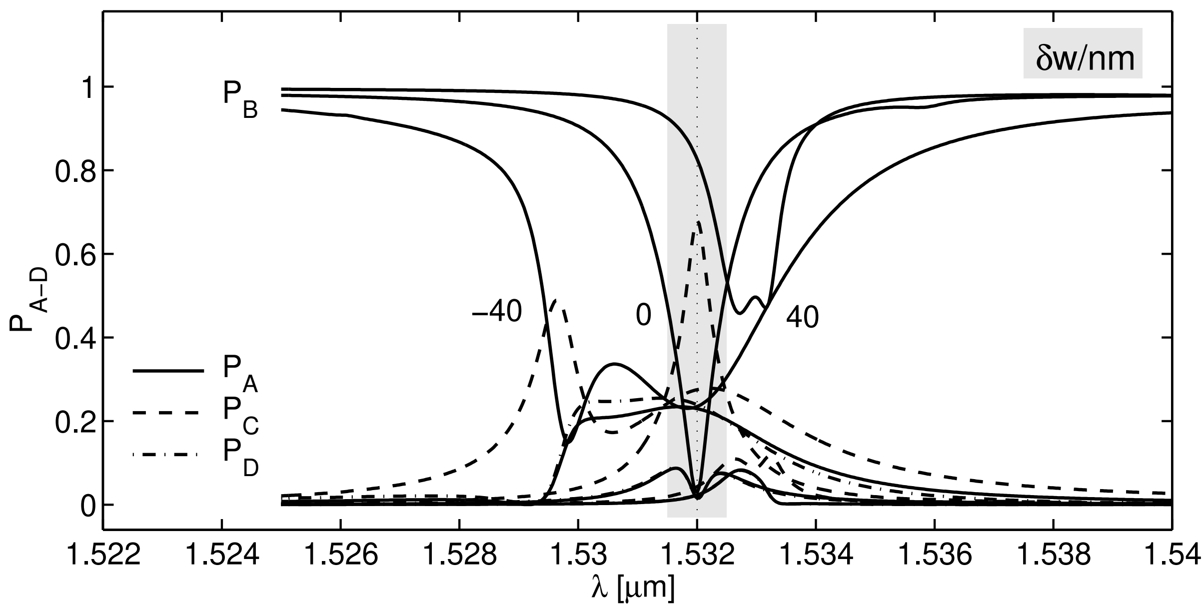

x
n_b
D
n_g
w
C
g
W
0
z
A
B
L
d


W=L, δW/nm
P_B
P_{A-D}
−6
0
6
P_A
P_C
P_D
λ [μm]

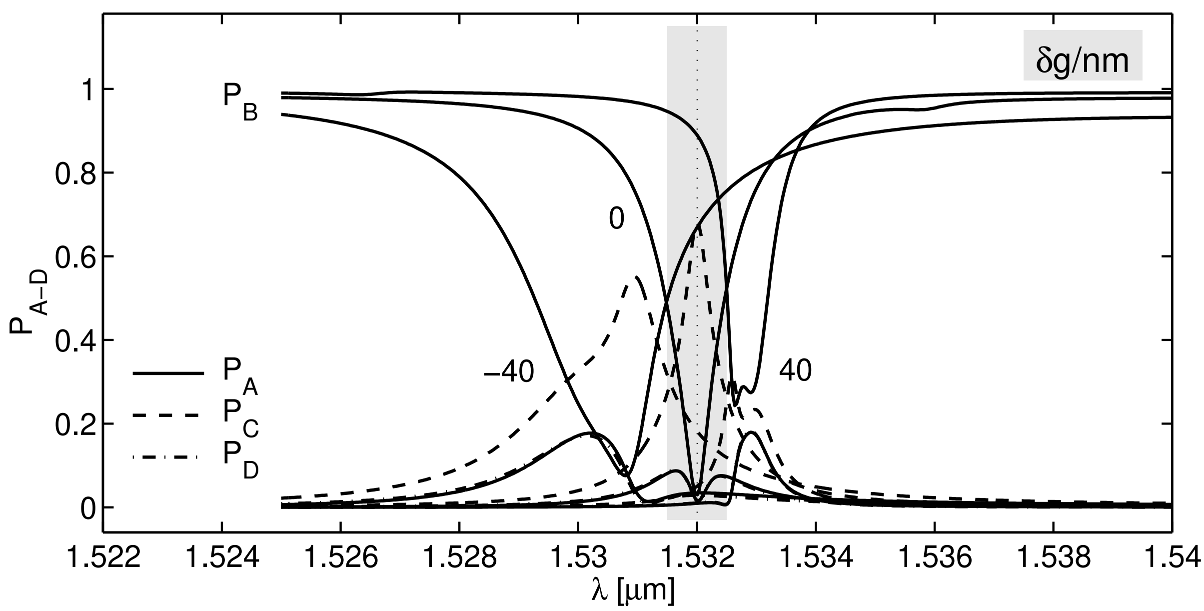

δn_g
P_B
P_{A-D}
−0.006
0
0.006
P_A
P_C
P_D
λ [μm]



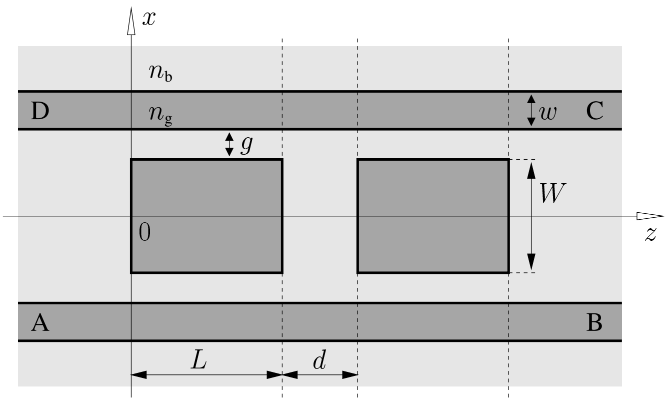
x
n_b
D
n_g
w
C
g
W
0
z
A
B
L
d

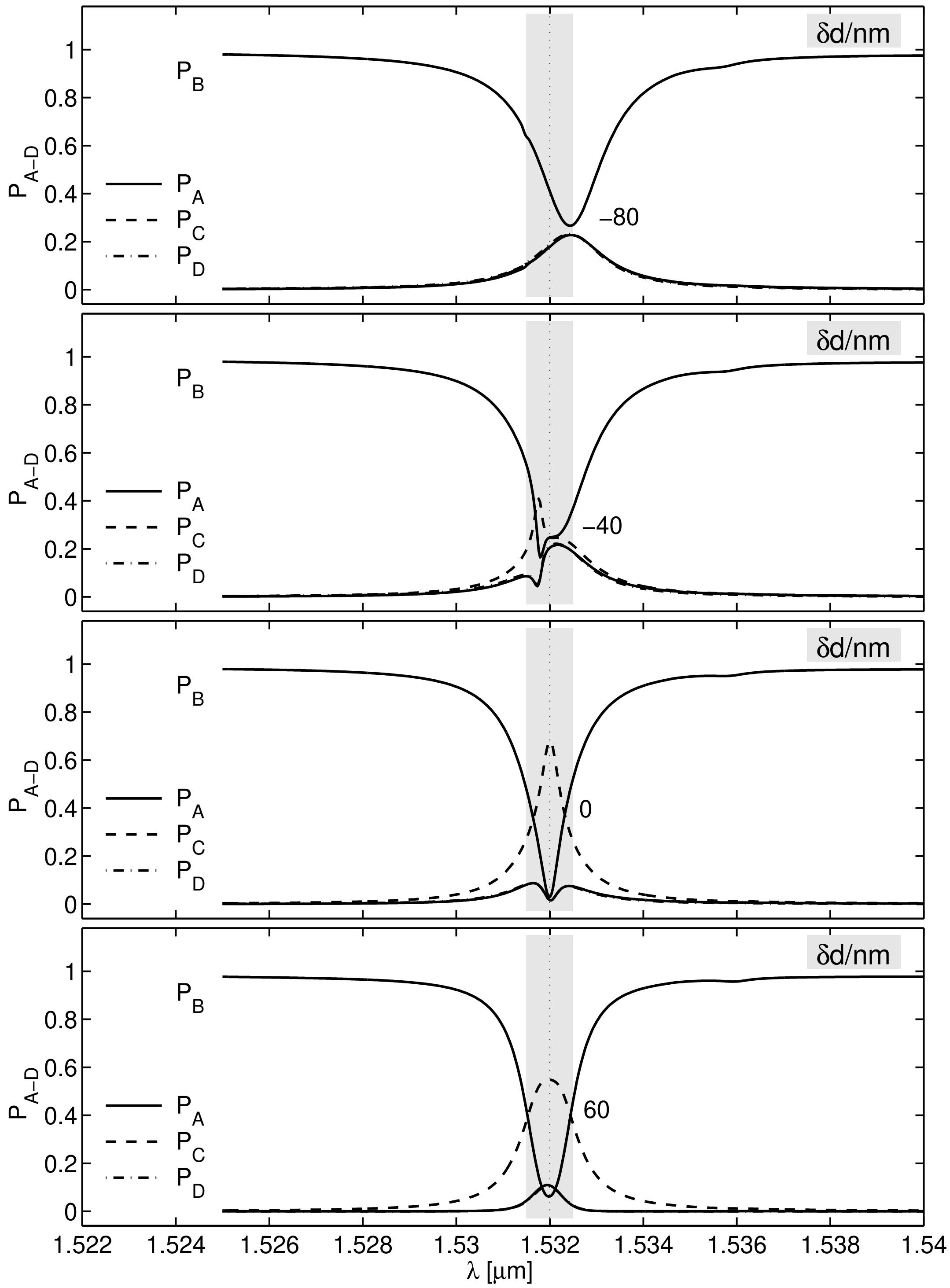


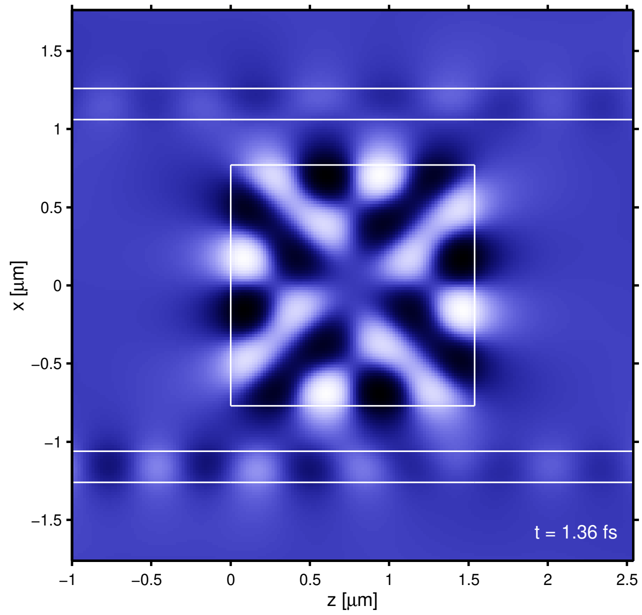
δw/nm
P_B
−40
0
40
P_A
P_C
P_D
P_{A-D}
λ [μm]



δg/nm
P_B
0
−40
40
P_A
P_C
P_D
P_{A-D}
λ [μm]


x
n_b
D
n_g
w
C
g
W
0
z
A
B
L
d


δd/nm
P_B
P_A–D
P_A
P_C
P_D
–80
–40
0
60
1.522
1.524
1.526
1.528
1.53
1.532
1.534
1.536
1.538
1.54
λ [μm]



- Apparently reliable simulations of microresonator systems with rectangular cavities.
- Allow for convenient numerical experiments on these structures, e.g. with respect to the various geometrical and material parameters.
- Suitable model system for investigations on more fundamental issues related to a theory of localized states in integrated optics . . .