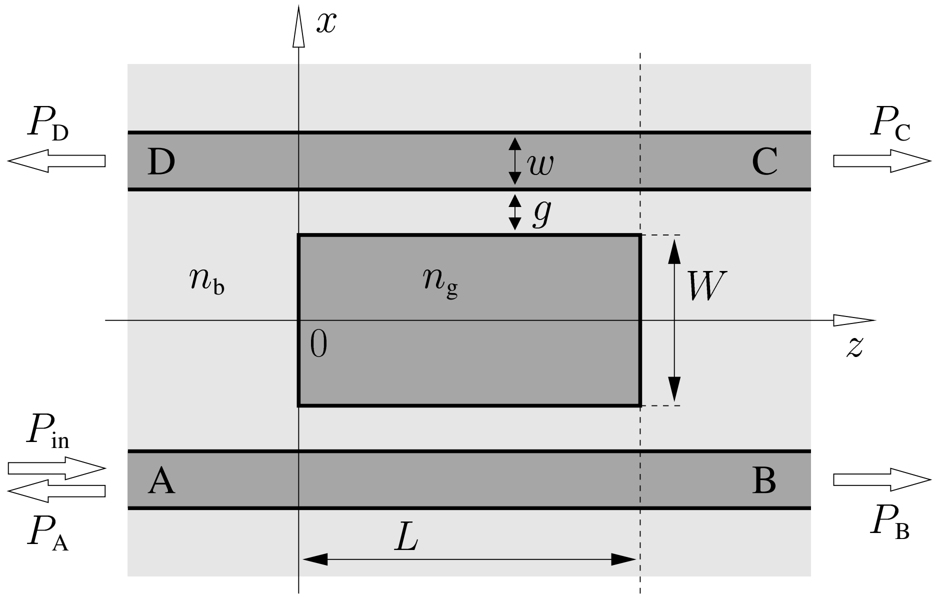
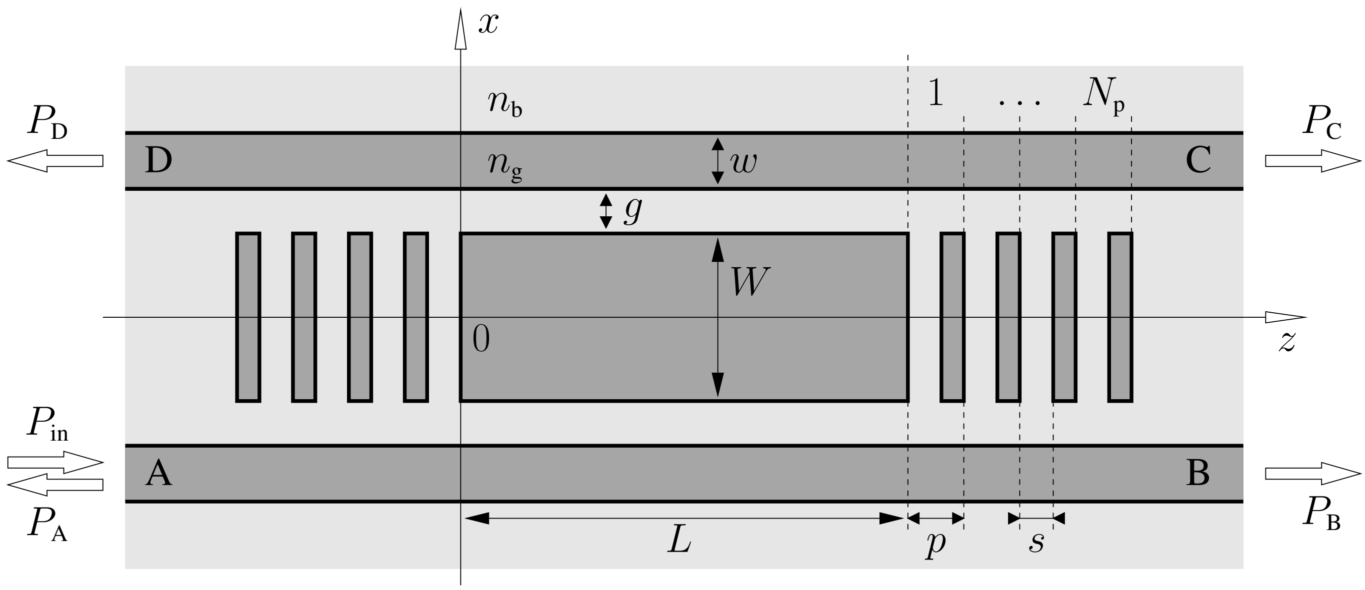
Multimode standing wave resonators:




Constraint (2D):
$n_g \gg \sqrt{2}\, n_b$.

Grating assisted, laterally coupled cavities:




$n_g \not\gg \sqrt{2}\, n_b$. ?

# *Grating assisted rectangular integrated optical microresonators*

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- Rectangular standing wave microresonators
- Design strategy
  - Setting
  - Port waveguides
  - Bragg reflectors
  - Cavity
- Numerical results:
  - Single cavity resonator
  - Nonsymmetric reflectors
  - Filter device

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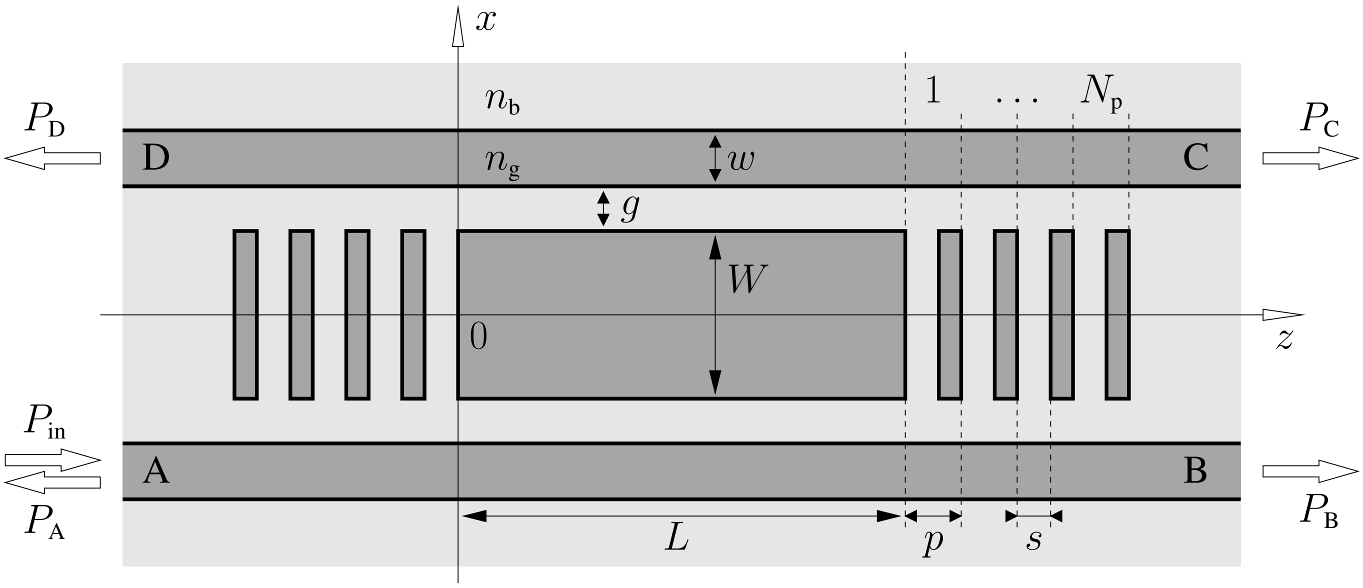
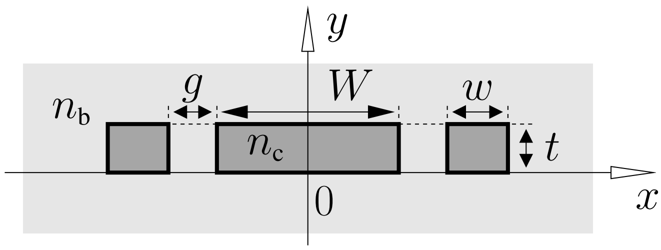



$P_{in}(\lambda) = 1. \quad P_A, P_B, P_C, P_D \;=\; ?$

- Spatial 2D modeling, TE polarization.

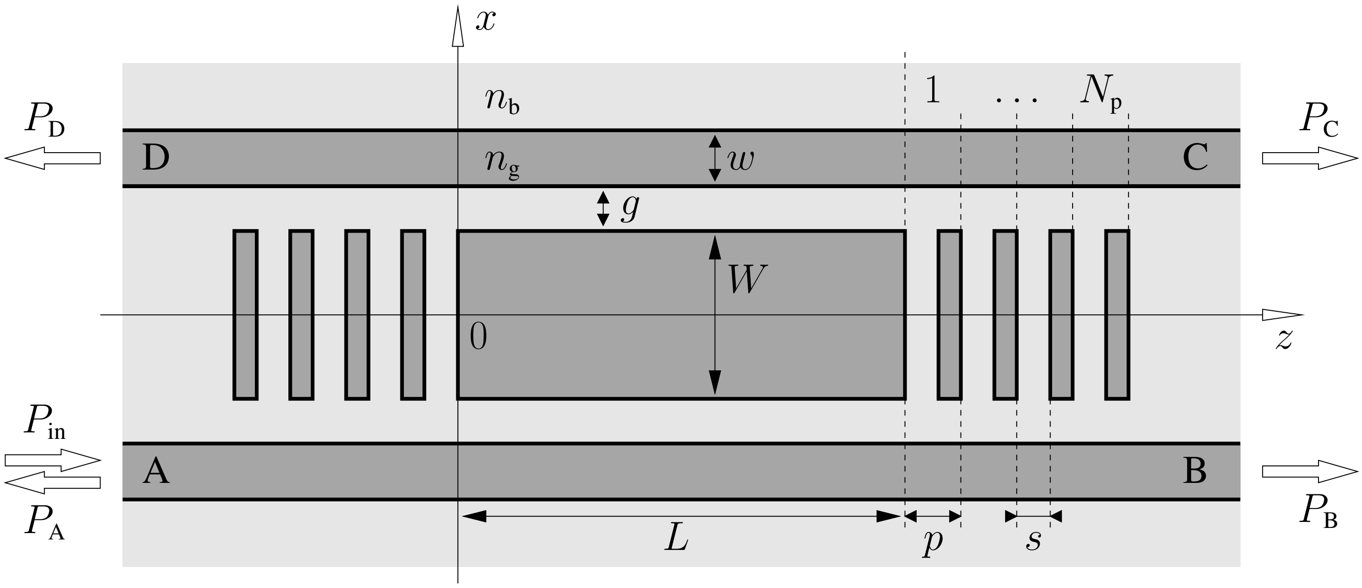
- | $n_g$ | $n_b$ | $\lambda/\,\mu$m |
  |---|---|---|
  | 1.60 | 1.45 | $\in [1.5, 1.6]$ |

  $n_g < \sqrt{2}\, n_b$.




$n_c = 1.98$, $n_b = 1.45$: $Si_3N_4$ cores embedded in $SiO_2$,
$t = 0.223\,\mu$m $\longrightarrow$ vertically single mode cores,
effective mode index $n_g = 1.60$ (TE, $\lambda = 1.55\,\mu$m).

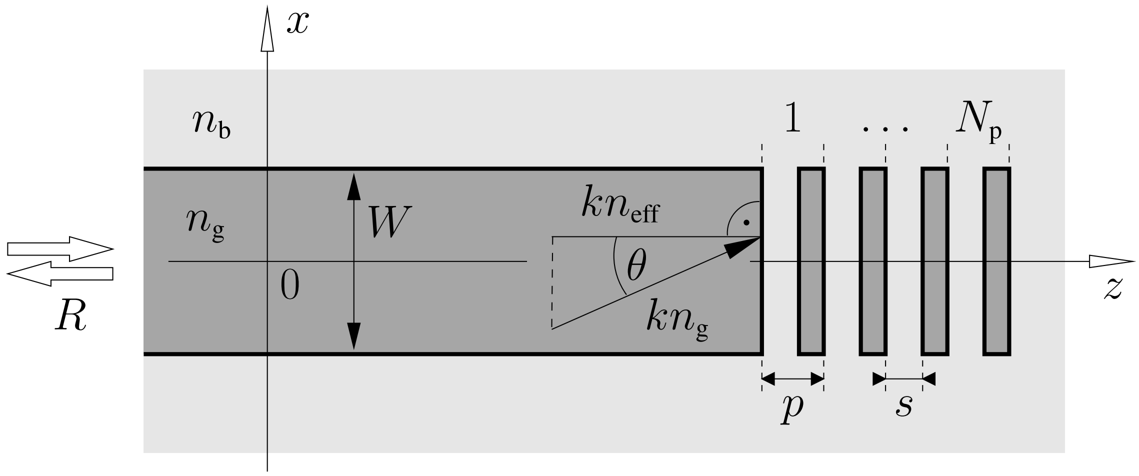
- Computational basis: Bidirectional eigenmode propagation (BEP), 2D, TE, 100 expansion terms, window $x \in [-20, 20]\,\mu$m, Dirichlet b.c.




- *Target wavelength:*
  $\lambda_0 = 1.55\,\mu$m.

- *Port waveguides:*
  Single mode for $\lambda \in [1.5, 1.6]\,\mu$m.
  $\longrightarrow$ $w = 1.0\,\mu$m; $n_{\text{eff}} = 1.540$ at $\lambda_0$.

- *Cavity width:*
  Phase matching with port channels for effective coupling at resonance.
  $\longrightarrow$ $W = (1.0 + m\,1.791)\,\mu$m; integer $m$.



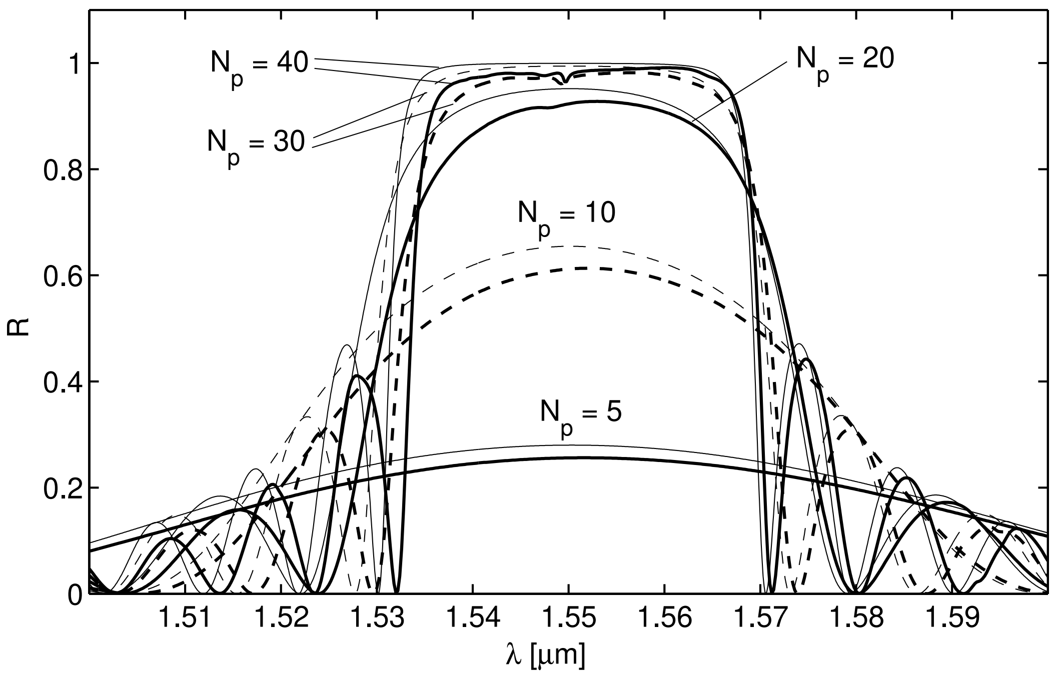

- *Period and spacing:*
  Waves at incidence angle $\theta$ with $\cos\theta = n_{eff}/n_g$ at $\lambda = \lambda_0$, reflectivity optimization within a plane wave model.
  $\longrightarrow$ $p = 1.538\,\mu$m, $s = 0.281\,\mu$m.

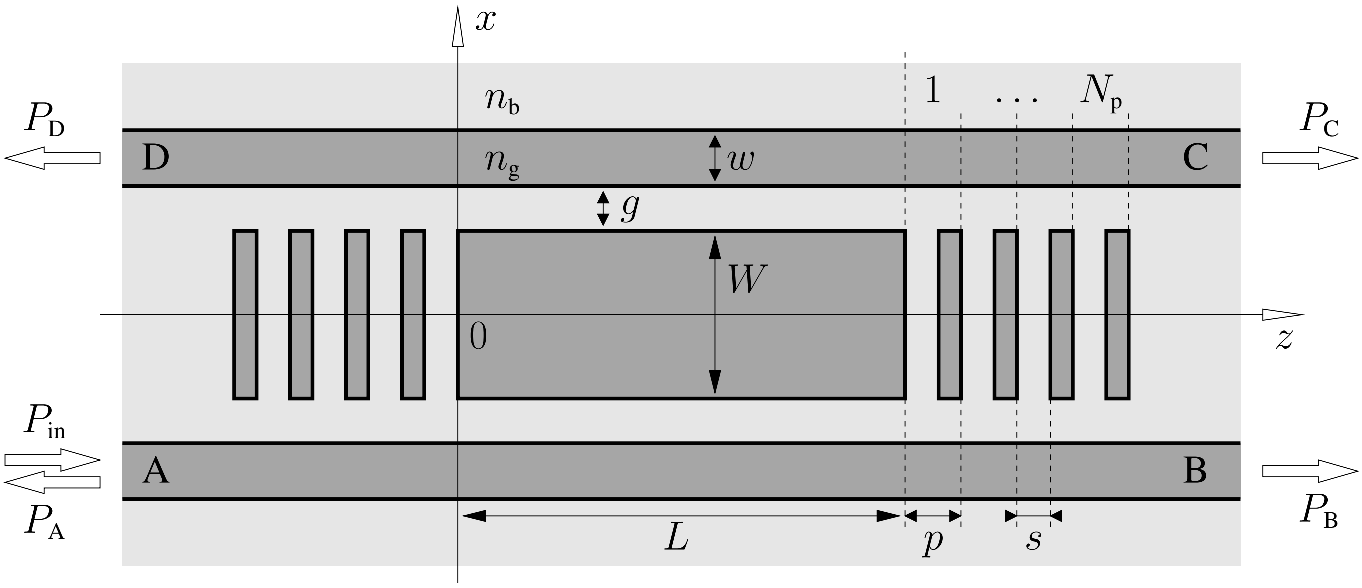
- *Cavity width & mode order:*
  Reflectivity from mode $m$ to mode $m$, for $N_p = 5$ periods:

| $m$ | 0 | 1 | 2 | 3 | 4 | 5 | pw |
|---|---|---|---|---|---|---|---|
| $R$ | 0.17 | 0.21 | 0.23 | 0.24 | 0.25 | 0.26 | 0.28 |

  $\longrightarrow$ $m = 5$, $W = 9.955\,\mu$m.

- *Number of periods:*
  "Quality of the resonances requires a high reflectivity".
  $\longrightarrow$ $N_p = 40$.






- *Cavity length:*
  Total phase gain per propagation cycle = multiple of $\pi$;
  phase shift upon reflection $\varphi_r$;
  $\longrightarrow \quad L = (l\pi + \varphi_r)\lambda_0/(2\pi n_{eff})$, integer $l$.

  Spectral distance of two resonances: $\Delta\lambda \approx \lambda_0/l \approx \lambda_0^2/(2Ln_{eff})$;
  chance for resonances: $\Delta\lambda <$ bandgap region of the reflectors.
  $\longrightarrow \quad l = 159, \;\; L = 79.985\,\mu$m.

- *Gap width:*
  Sufficient power transfer at resonance, but negligible direct coupling.
  $\longrightarrow \quad g = 1.6\,\mu$m.

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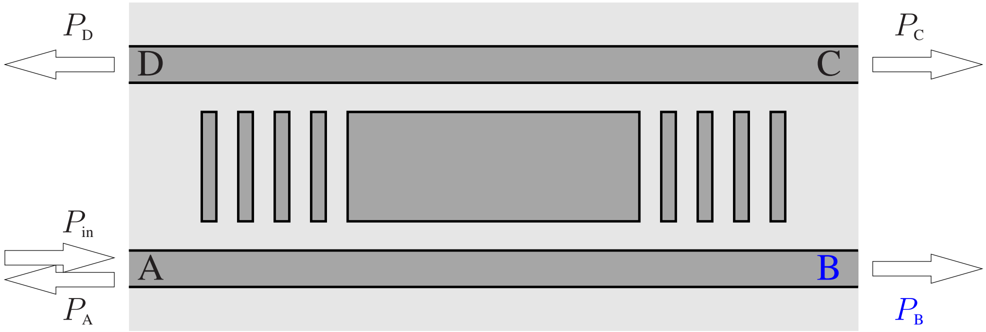
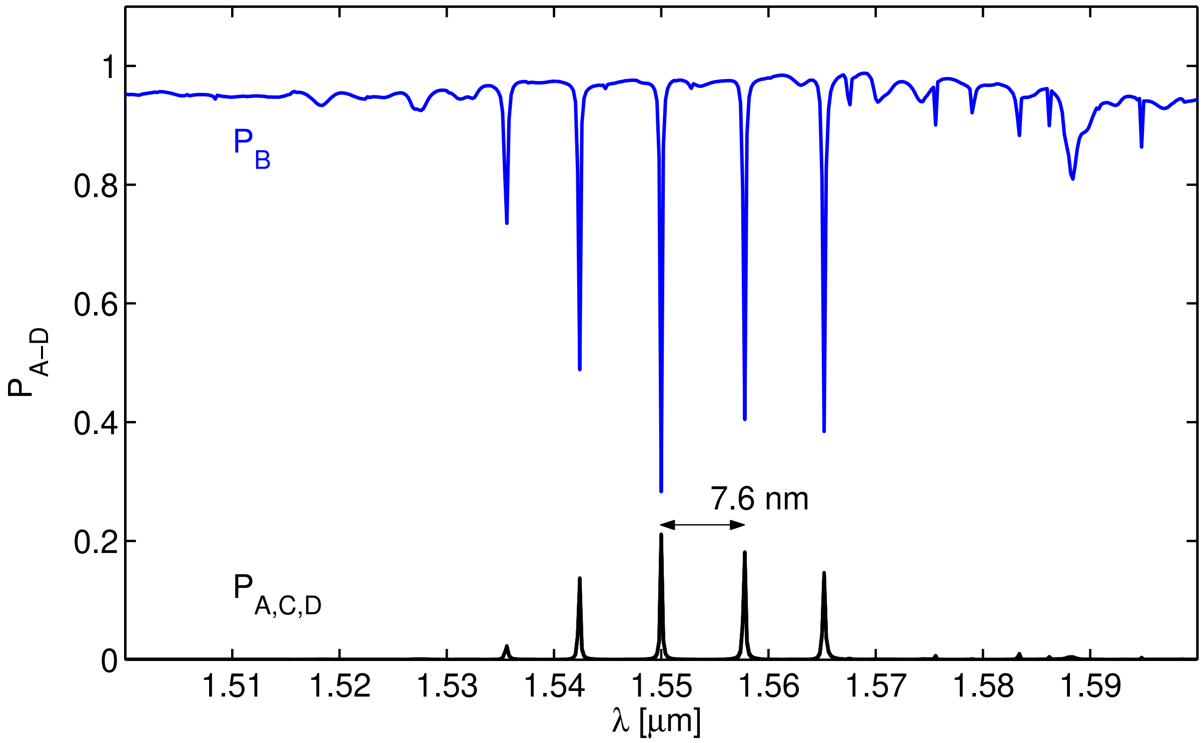
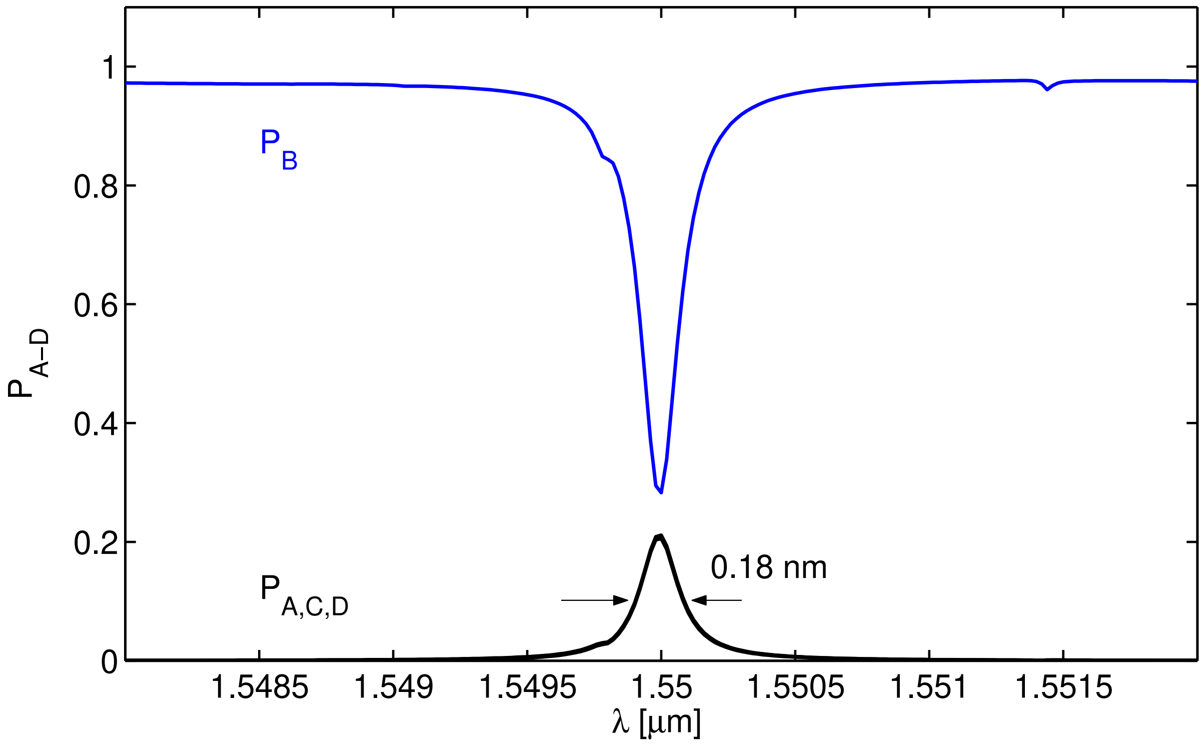
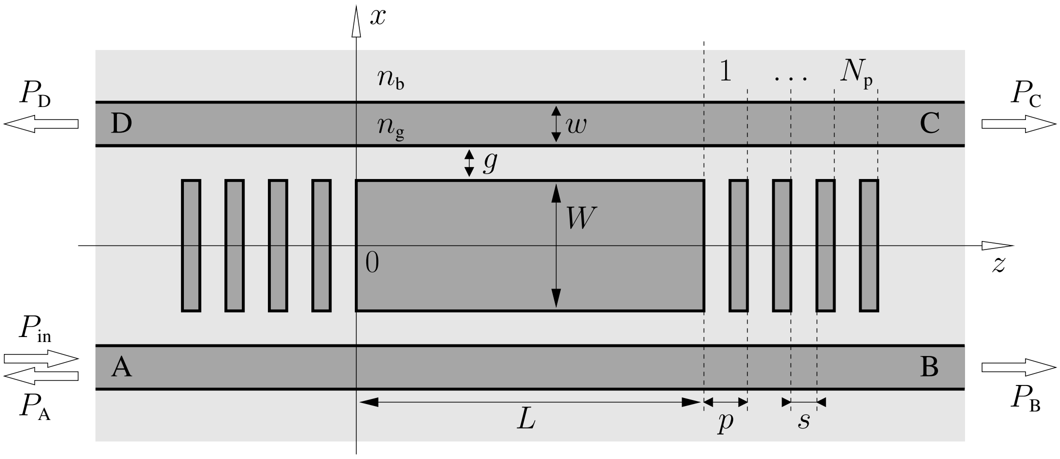
| $n_g$ | $n_b$ | $w/\,\mu$m | $g/\,\mu$m | $W/\,\mu$m | $L/\,\mu$m | $p/\,\mu$m | $s/\,\mu$m | $N_p$ | $\lambda/\,\mu$m |
|---|---|---|---|---|---|---|---|---|---|
| 1.60 | 1.45 | 1.000 | 1.600 | 9.955 | 79.985 | 1.538 | 0.281 | 40 | [1.5, 1.6] |

Overall length: 203 $\mu$m.

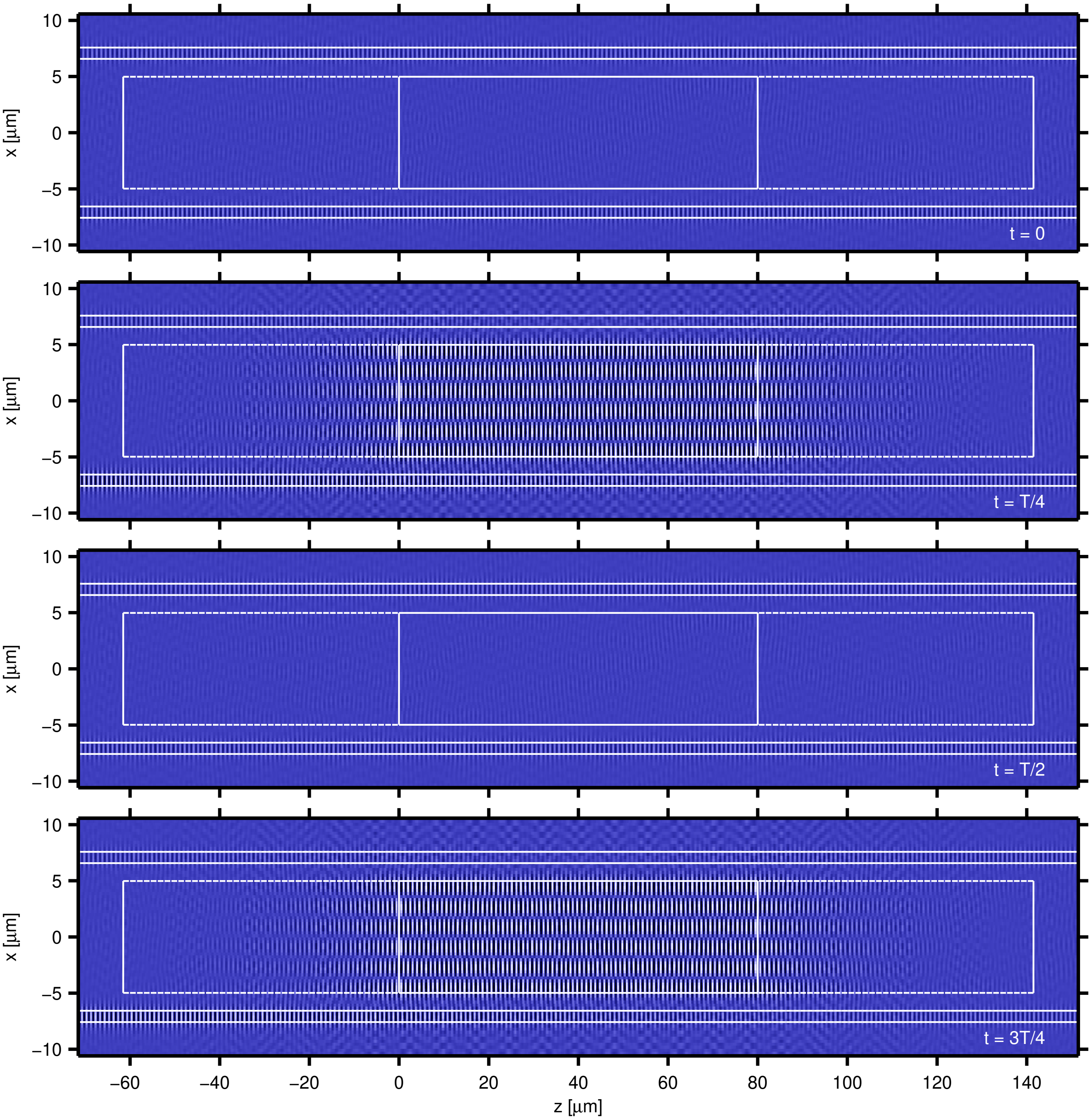

P_D
D
C
P_C
P_in
A
B
P_A
P_B

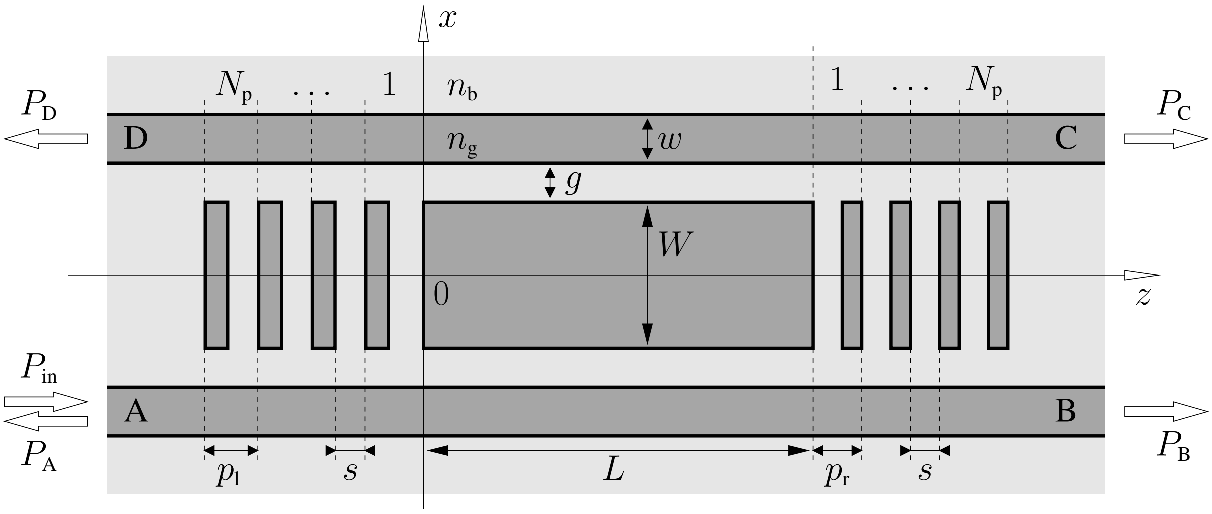

P_B
P_A,C,D
7.6 nm
P_A–D
λ [µm]
1
0.8
0.6
0.4
0.2
0
1.51
1.52
1.53
1.54
1.55
1.56
1.57
1.58
1.59

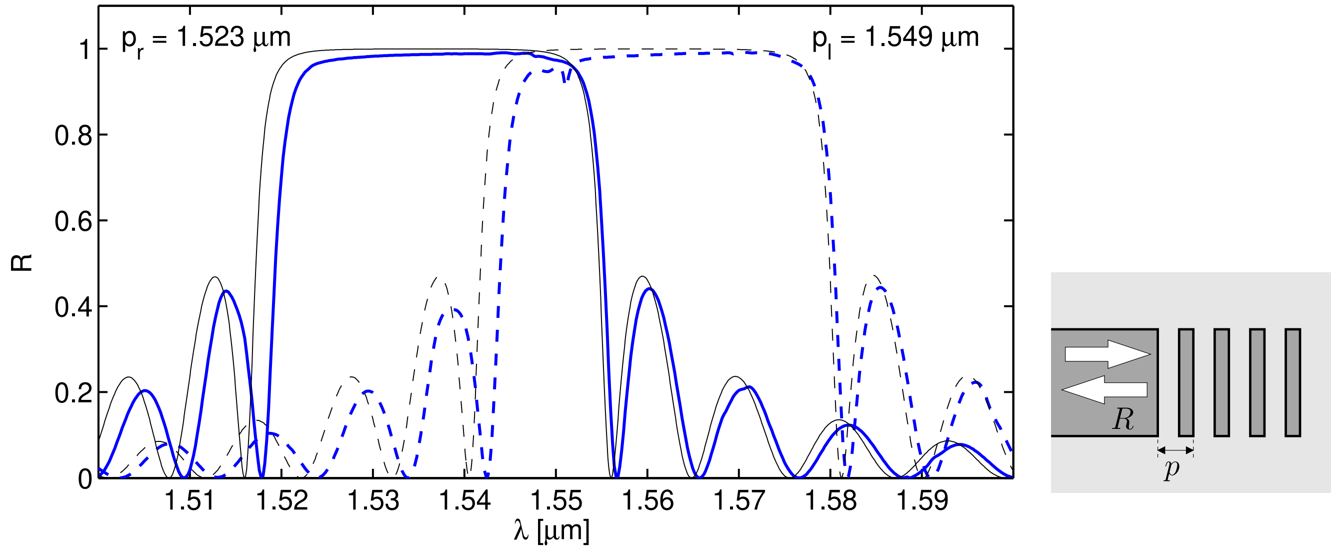

P_B
P_A,C,D
0.18 nm
P_A–D
λ [µm]
1
0.8
0.6
0.4
0.2
0
1.5485
1.549
1.5495
1.55
1.5505
1.551
1.5515

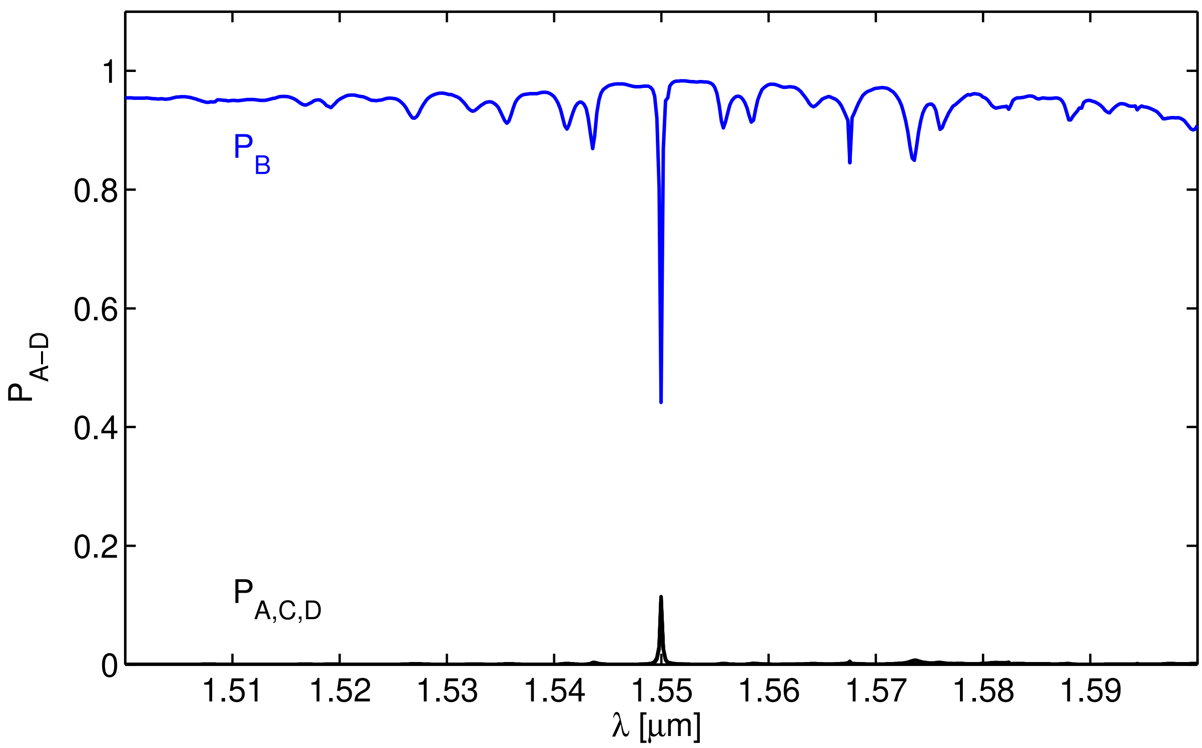


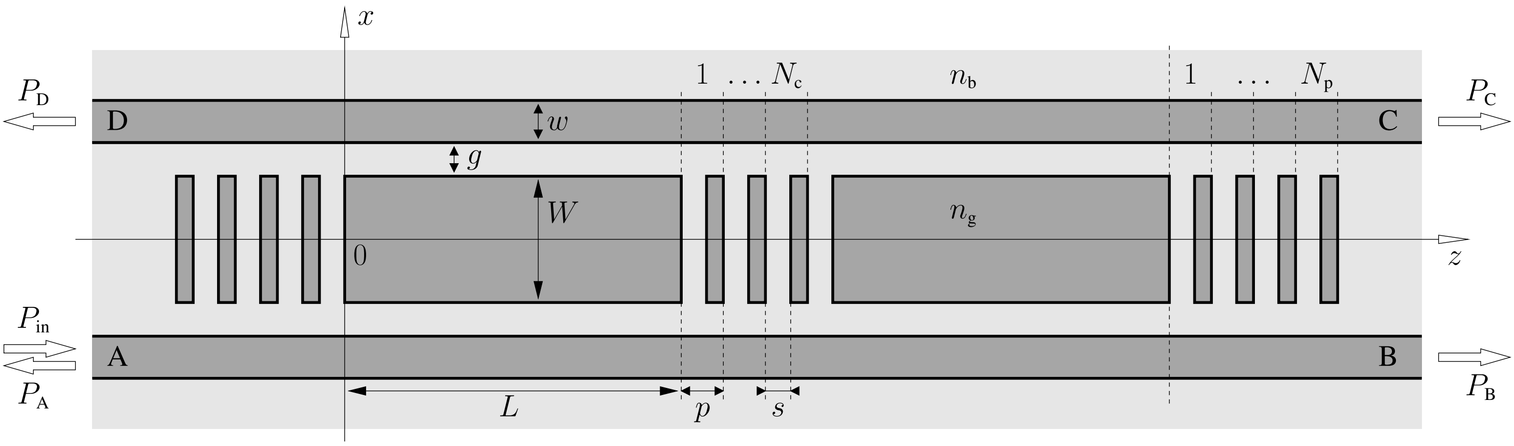

$\lambda = 1.55\,\mu$m,
$T = 5.17$ fs,
$P_A = 0.21$,
$P_B = 0.28$,
$P_C = 0.21$,
$P_D = 0.21$.

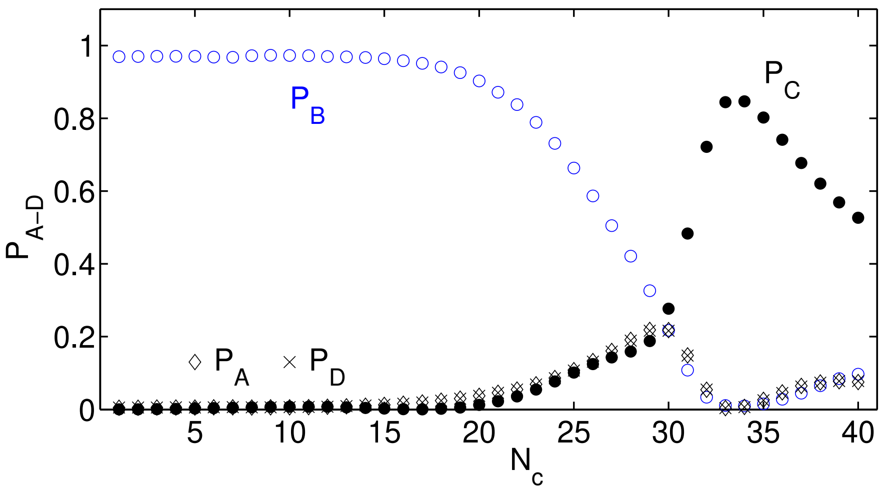



x
$N_p$ . . . 1
$n_b$
1 . . . $N_p$
$P_D$
D
$n_g$
w
C
$P_C$
g
W
0
z
$P_{in}$
A
B
$P_A$
$P_B$
$p_l$
s
L
$p_r$
s


$p_r$ = 1.523 µm
$p_l$ = 1.549 µm
R
λ [µm]
R
p


$P_B$
$P_{A,C,D}$
$P_{A-D}$
λ [µm]

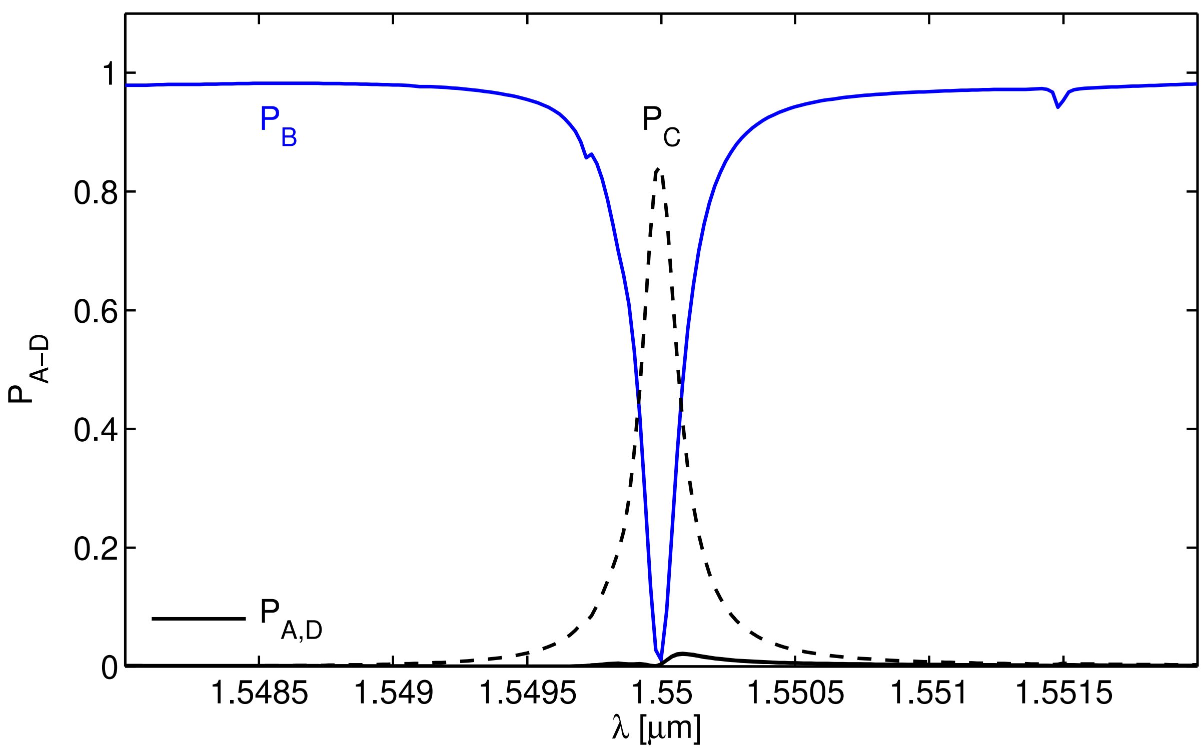


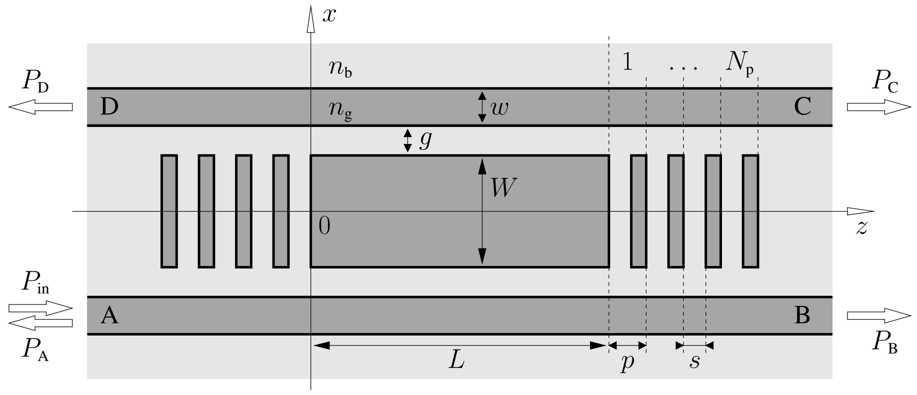

$\lambda = 1.55\,\mu$m, $N_c = 33$:

$P_D = 0.01$, $P_C = 0.84$,
$P_A = 0.01$, $P_B = 0.01$.

Overall length: $334\,\mu$m.




| $n_g$ | $n_b$ | $w/\,\mu$m | $g/\,\mu$m | $W/\,\mu$m | $L/\,\mu$m | $p/\,\mu$m | $s/\,\mu$m | $N_p$ | $N_c$ | $\lambda/\,\mu$m |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.60 | 1.45 | 1.000 | 1.600 | 9.955 | 79.985 | 1.538 | 0.281 | 40 | 33 | [1.5, 1.6] |




- Grating assisted rectangular microresonators:
  Laterally coupled Fabry-Perot cavities.
- 2D model, BEP simulations, moderate numerical effort.
- Relatively simple (heuristic) design rules apply.
- Standing wave resonances are supported just as for
  "conventional" rectangular microcavities;
  a single mode of the cavity waveguide plays a dominant role.
- Only realistic refractive index contrasts are required,
  overall length: A few hundred micrometers.
- Cascading of cavities allows to design devices
  with drop characteristics suitable for filter applications.
- Room for optimization / specialization;
  example: A device that shows a single resonance,
  realized with nonsymmetrically detuned Bragg reflectors.