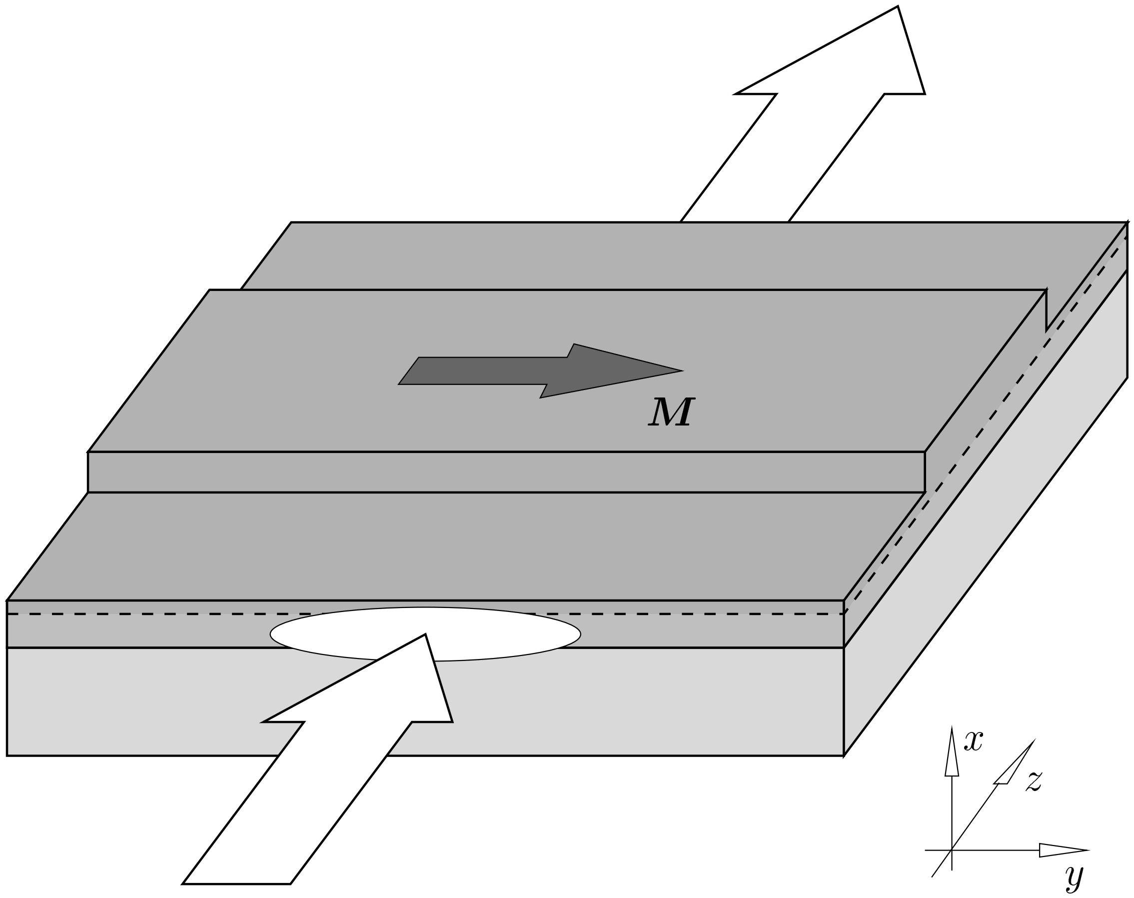
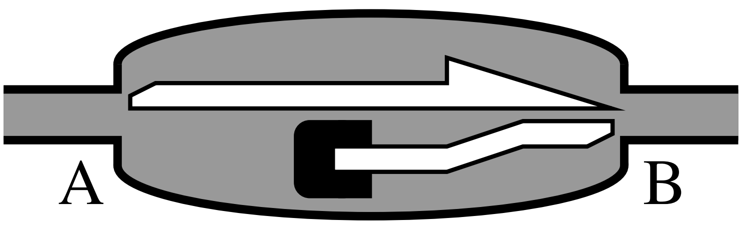
A wide strip, perpendicularly traversed by a beam of light, . . .



. . . can behave like an optical isolator:



Integrated magnetooptic cross strip isolator

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- Cross strip interferometer
  - Overlap model
  - Geometry optimization
  - Interferometer performance
  - Transmission and reflections: BPM vs. mode expansion
- Isolator experiment
  - Nonreciprocal interferometry
  - Tuning
  - Tolerances for the experimental setup
  - Transmission / reflectivity of the entire device
- Summary

International Workshop on Optical Waveguide Theory and Numerical Modelling
Prague, Czech Republic — *26 – 27 May 2000*

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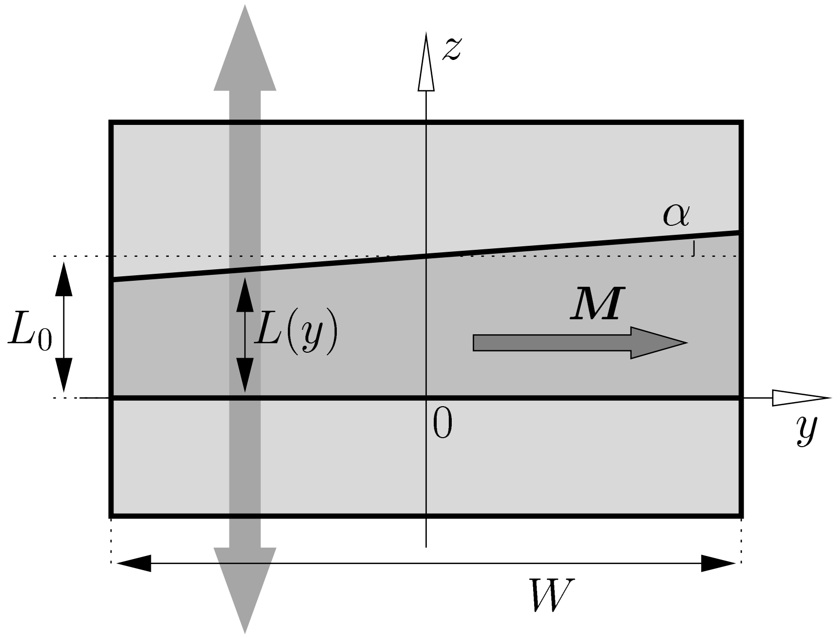
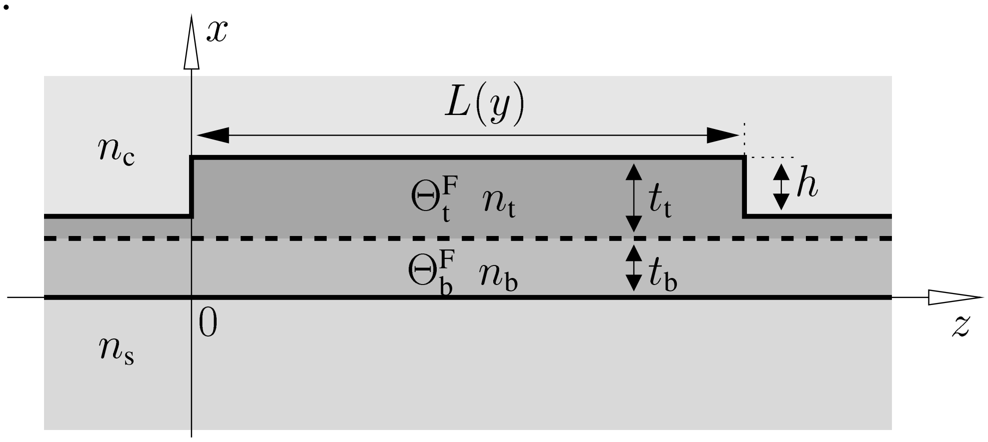
Top view:



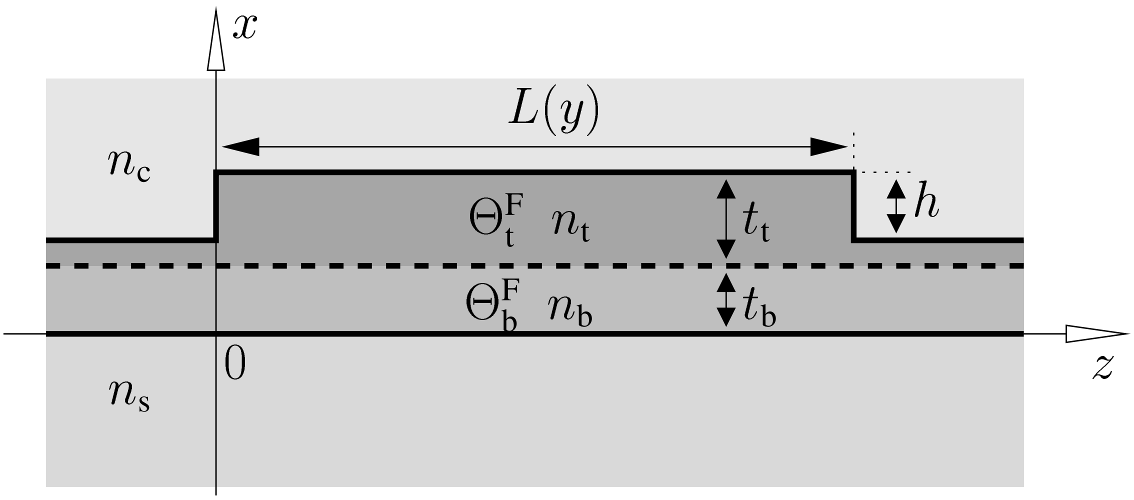
$W = 2\,\mathrm{cm}$, $\quad L_0 = 5\,\mathrm{mm} - 6\,\mathrm{mm}$, $\quad \alpha = 0.02^\circ - 0.1^\circ$; $\quad$ TM polarization.

Side view:



Permittivity of the guiding magnetooptic film:

$$\hat{\epsilon} = \begin{pmatrix} n^2 & 0 & 0 \\ 0 & n^2 & 0 \\ 0 & 0 & n^2 \end{pmatrix} + \begin{pmatrix} 0 & 0 & -\mathrm{i}\xi \\ 0 & 0 & 0 \\ \mathrm{i}\xi & 0 & 0 \end{pmatrix}, \qquad \xi = n\lambda\Theta^\mathrm{F}/\pi\,.$$



Ingredients:

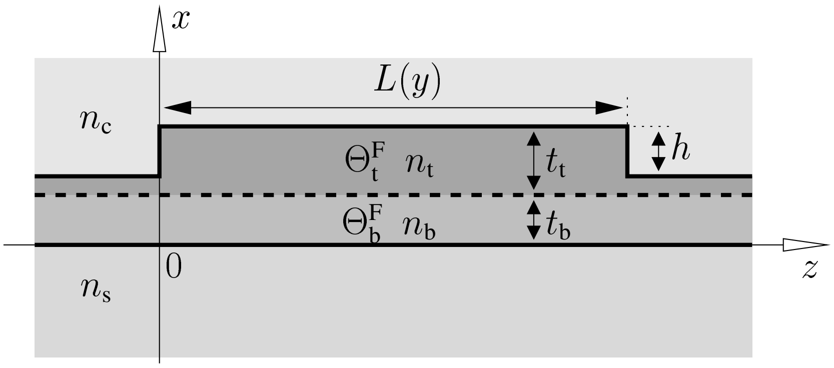
ψ: Input / output mode field,
ϕ_0, ϕ_1: fundamental and first order mode of the coupling segment,
β_0, β_1: the corresponding propagation constants,
$(\, . \, , \, . \,)$: a suitable bilinear product.

$\rightarrow$ Relative power transfer for a coupling segment of length L:

$$P(L) = w_0^2 + w_1^2 + 2w_0 w_1 \cos(\beta_0 - \beta_1)L \, , \qquad w_j = (\psi, \phi_j)^2 \, ;$$

Range for the variation of the transmission:

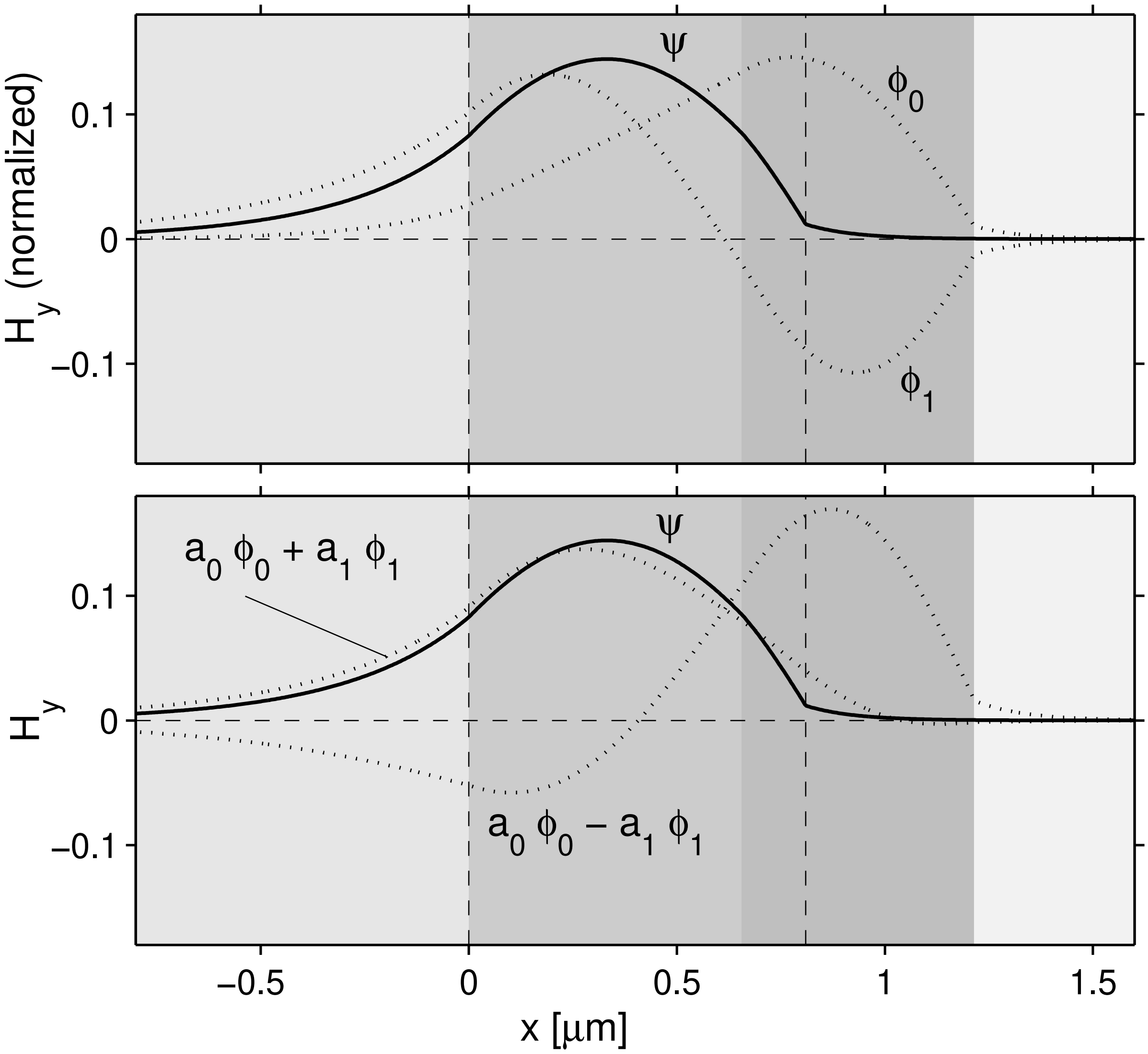
$$(w_0 - w_1)^2 \leq P(L) \leq (w_0 + w_1)^2 \, .$$



$t_b = 0.656\,\mu$m, $t_t = 0.559\,\mu$m,
$h = 0.405\,\mu$m, $\lambda = 1.3\,\mu$m,
$n_s = 1.950$, $n_b = 2.157$,
$n_t = 2.275$, $n_c = 1.0$.

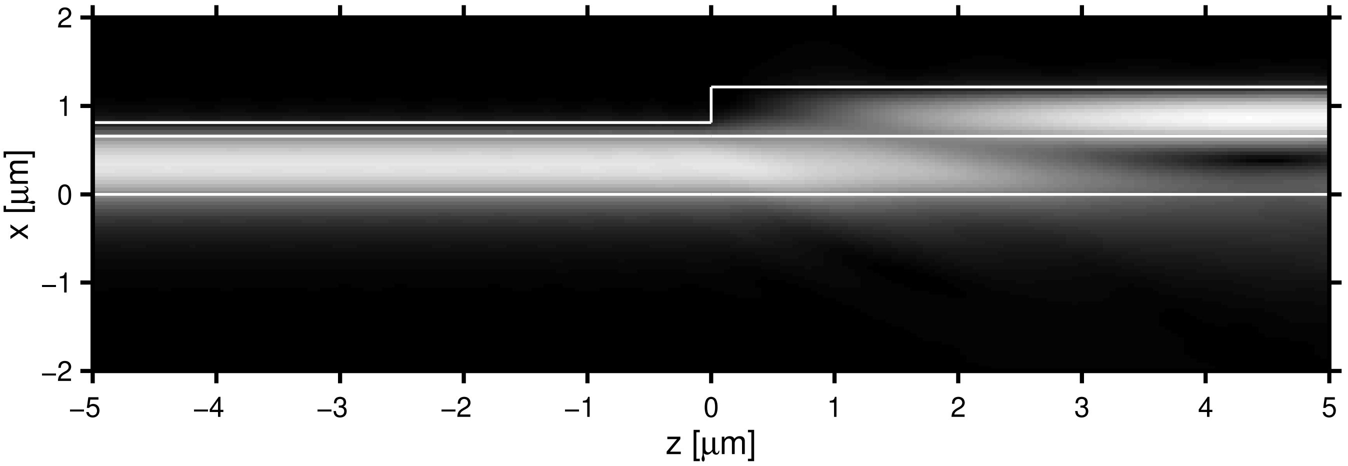
$$(w_0 - w_1)^2 \leq P(L) \leq (w_0 + w_1)^2, \quad w_0 = (\psi, \phi_0)^2, \quad w_1 = (\psi, \phi_1)^2.$$

Adjust $t_b + t_t$ and h for $w_0 = w_1$ and maximum $(w_0 + w_1)^2$:

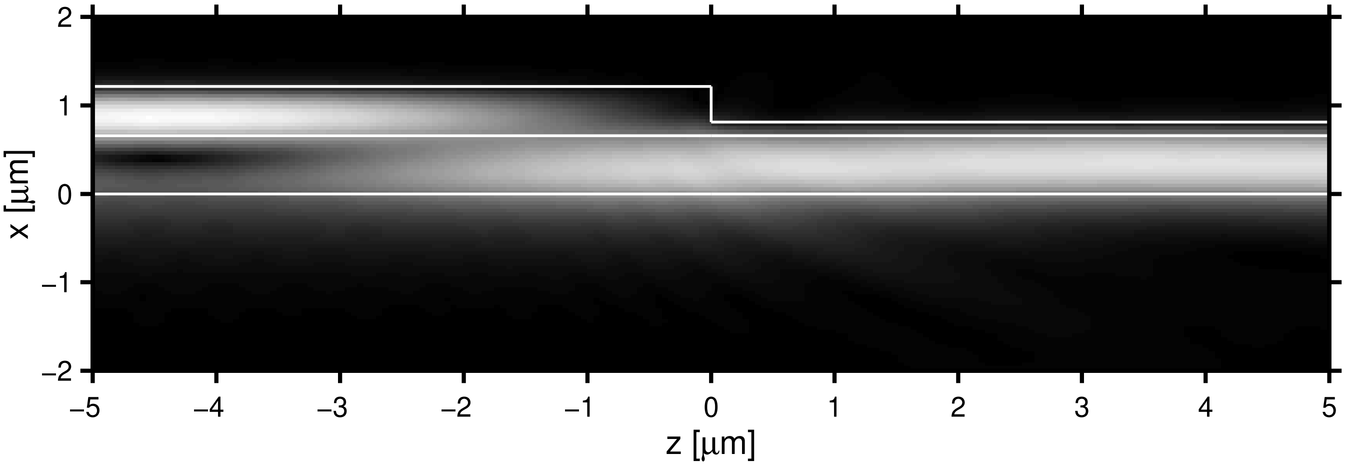


$(\phi_0 + \phi_1)/\sqrt{2} \approx \psi$, $(\phi_0 - \phi_1)/\sqrt{2} \perp \psi$.

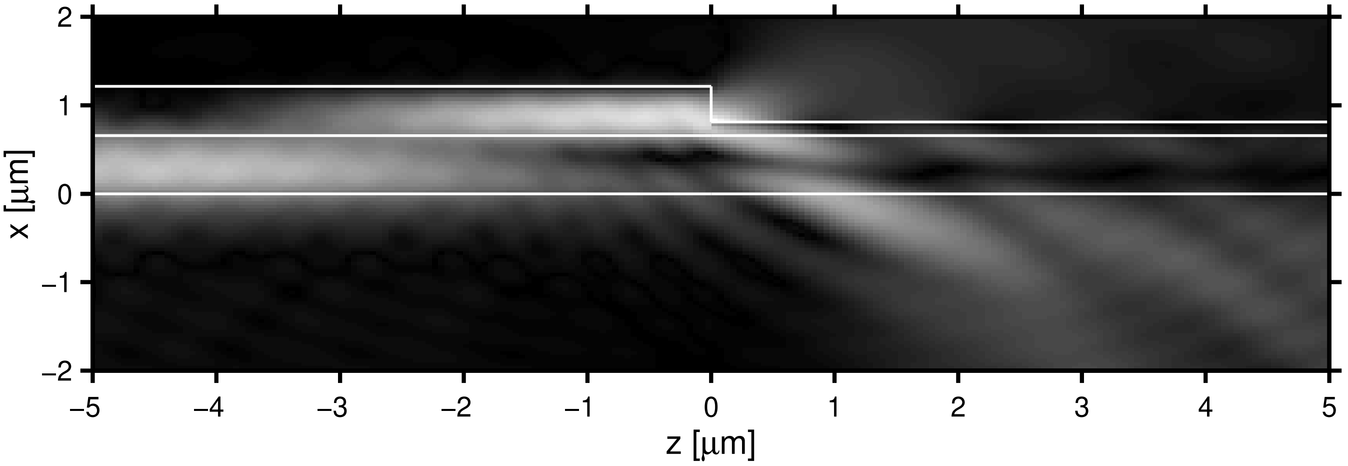
Low losses / reflections at the input junction:

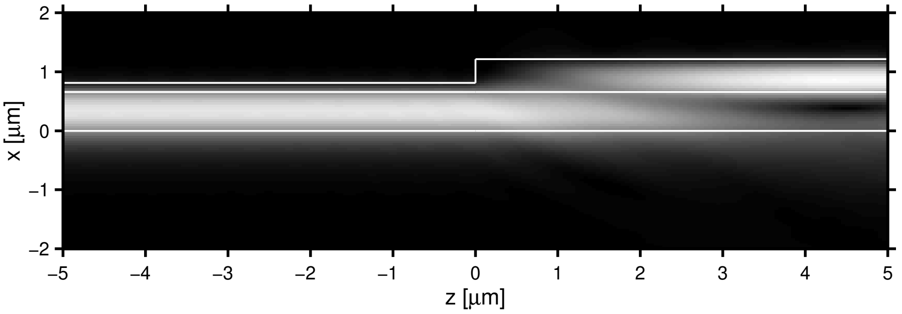


Complete constructive . . .



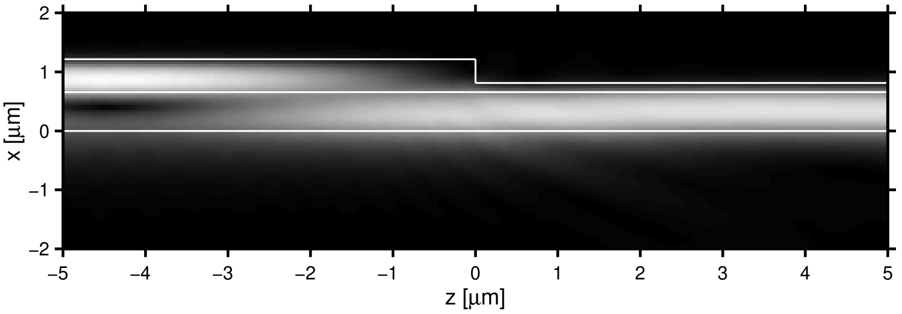
. . . or destructive interference at the output junction:





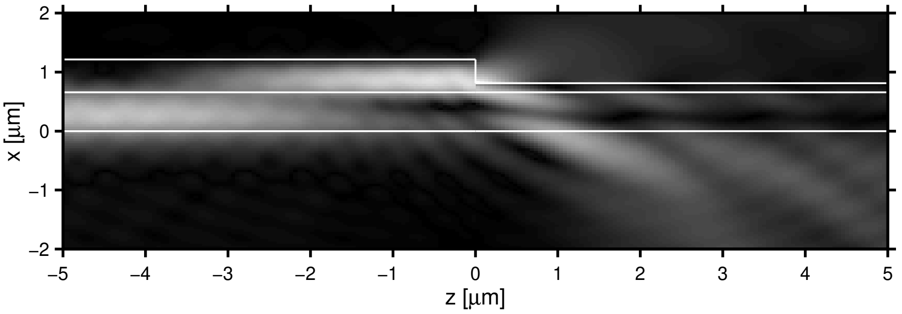
Input: ψ

	$\psi, \rightarrow$	$\psi, \leftarrow$	$\phi_0, \rightarrow$	$\phi_0, \leftarrow$	$\phi_1, \rightarrow$	$\phi_1, \leftarrow$
ME	1	$1.1 \cdot 10^{-6}$	0.49	0	0.50	0
BPM	1	$3.0 \cdot 10^{-5}$	0.48	0	0.51	0



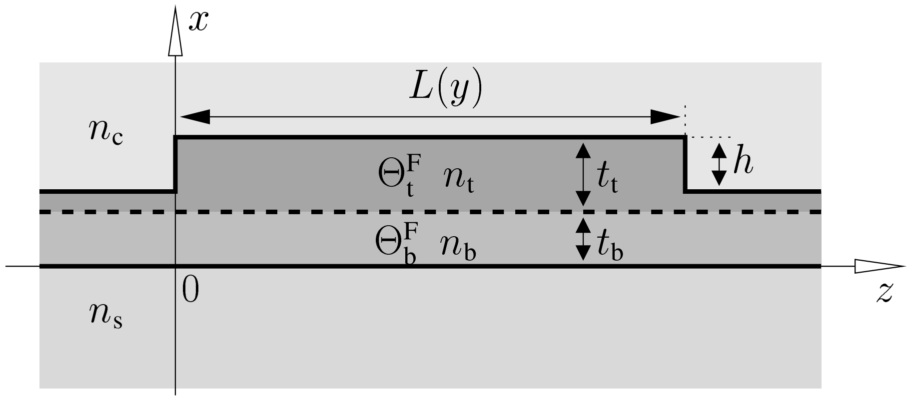
Input: $(\phi_0 + \phi_1)/\sqrt{2}$

	$\phi_0, \rightarrow$	$\phi_0, \leftarrow$	$\phi_1, \rightarrow$	$\phi_1, \leftarrow$	$\psi, \rightarrow$	$\psi, \leftarrow$
ME	$1/2$	$2.1 \cdot 10^{-4}$	$1/2$	$1.1 \cdot 10^{-4}$	0.99	0
BPM	$1/2$	$5.0 \cdot 10^{-4}$	$1/2$	$3.0 \cdot 10^{-4}$	0.99	0



Input: $(\phi_0 - \phi_1)/\sqrt{2}$

	$\phi_0, \rightarrow$	$\phi_0, \leftarrow$	$\phi_1, \rightarrow$	$\phi_1, \leftarrow$	$\psi, \rightarrow$	$\psi, \leftarrow$
ME	$1/2$	$2.0 \cdot 10^{-2}$	$1/2$	$1.3 \cdot 10^{-2}$	$6.5 \cdot 10^{-5}$	0
BPM	$1/2$	$3.6 \cdot 10^{-2}$	$1/2$	$2.8 \cdot 10^{-2}$	$9.0 \cdot 10^{-4}$	0

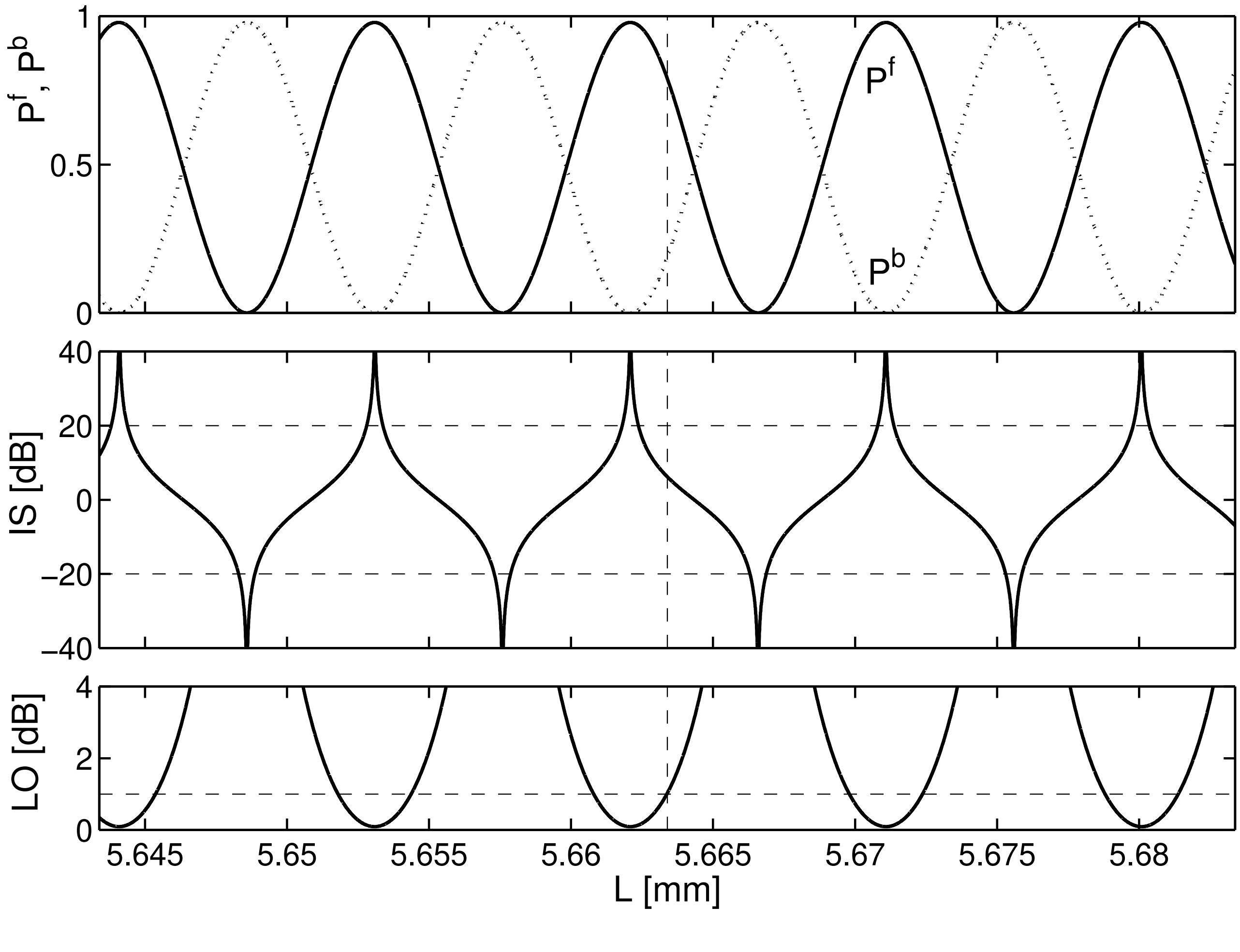


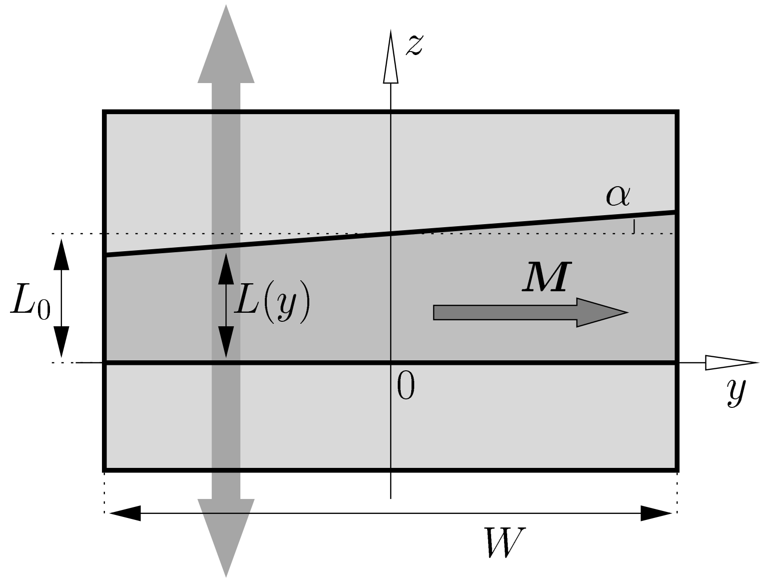
$$L_{\mathrm{c}} = \frac{\pi}{\beta_0 - \beta_1}.$$

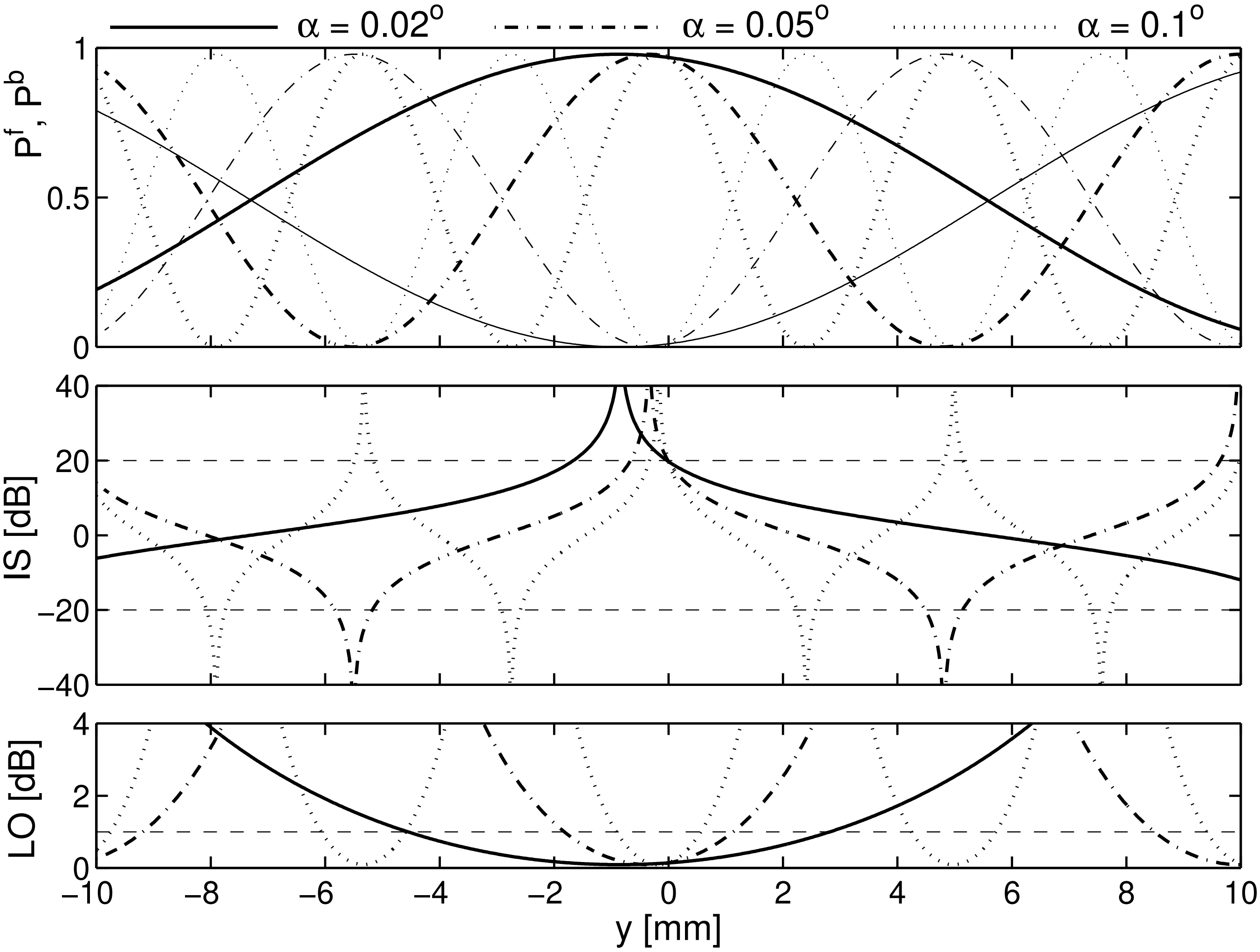
$$\left.\begin{array}{c}\longrightarrow\\ \beta_0^{\mathrm{f}}, \beta_1^{\mathrm{f}}, L_{\mathrm{c}}^{\mathrm{f}}, P^{\mathrm{f}}(L)\end{array}\right\} \neq \left\{\begin{array}{c}\longleftarrow\\ \beta_0^{\mathrm{b}}, \beta_1^{\mathrm{b}}, L_{\mathrm{c}}^{\mathrm{b}}, P^{\mathrm{b}}(L)\end{array}\right.$$

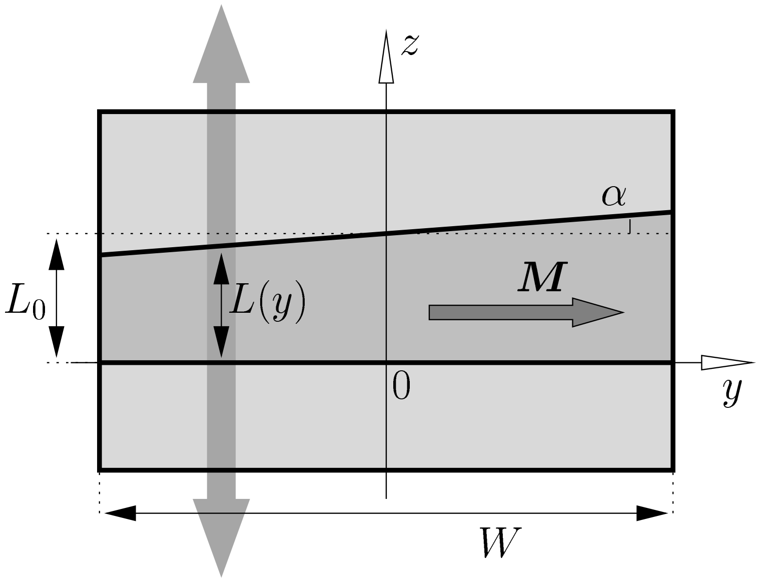
Loss: $\mathrm{LO}(L) = -10 \log_{10} P^{\mathrm{f}}(L)$,
Isolation: $\mathrm{IS}(L) = 10 \log_{10} P^{\mathrm{f}}(L)/P^{\mathrm{b}}(L)$,
Isolator performance for $L = 2mL_{\mathrm{c}}^{\mathrm{f}} = (2m+1)L_{\mathrm{c}}^{\mathrm{b}}$ with natural m:

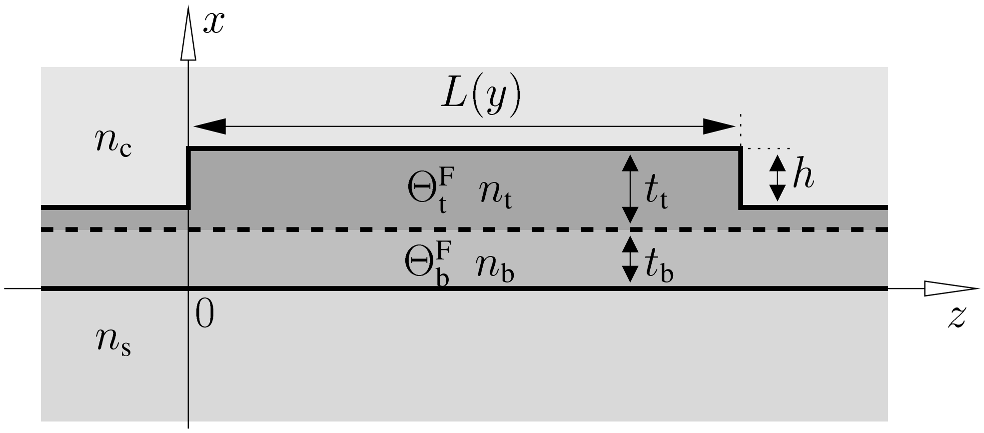
$$L \approx \frac{\pi}{|\beta_0^{\mathrm{f}} - \beta_1^{\mathrm{f}} - \beta_0^{\mathrm{b}} + \beta_1^{\mathrm{b}}|}$$




z
α
M
L_0
$L(y)$
0
y
W


α = 0.02°
α = 0.05°
α = 0.1°
P^f, P^b
IS [dB]
LO [dB]
y [mm]



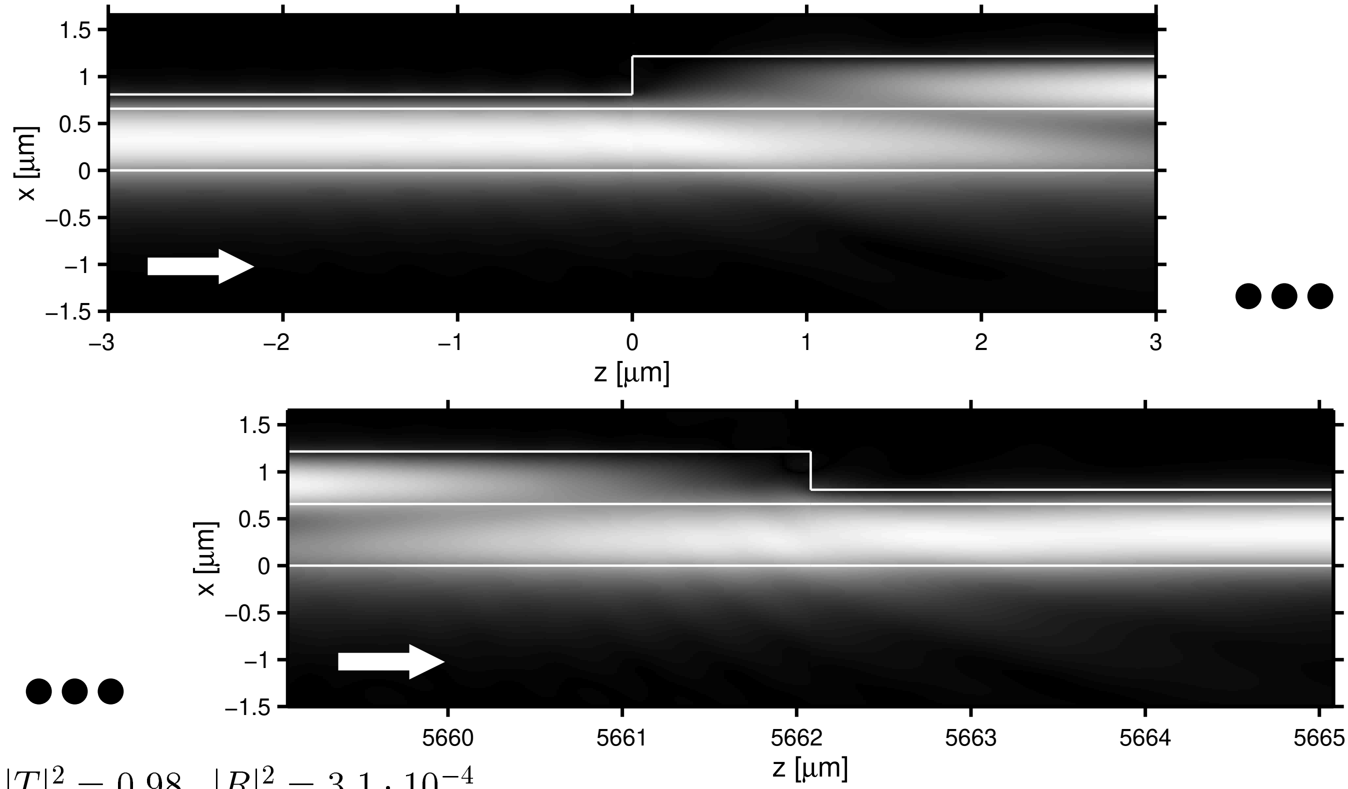


$q_0 - \Delta q \le q \le q_0 + \Delta q$: The experiment can be carried out with IS $\ge 20\,$dB, LO $\le 1\,$dB $\quad (P^\mathrm{f}/P^\mathrm{b} \ge 100,\ P^\mathrm{f} \ge 0.8)$.

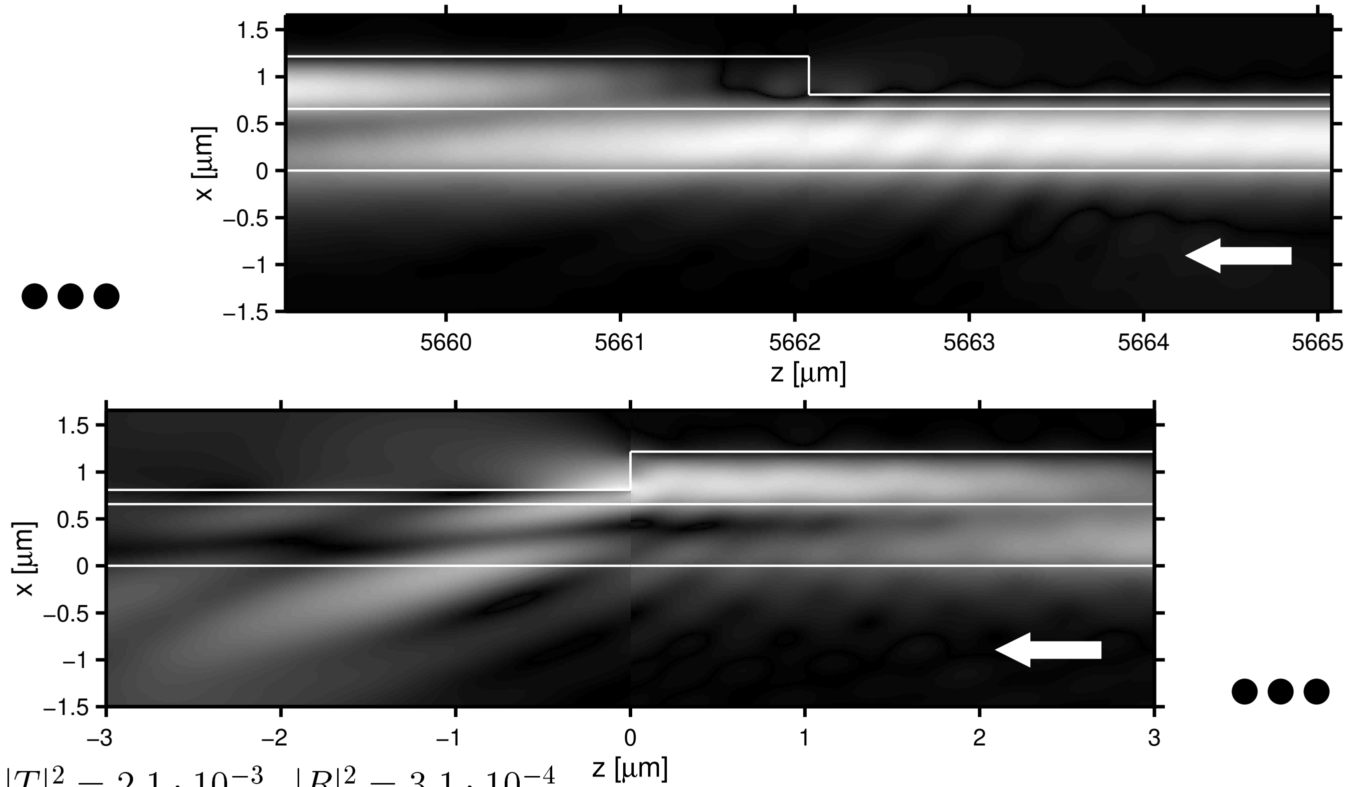
	q_0	Δq
t_b	$0.656\,\mu$m	$\ge 0.2\,\mu$m
t_t	$0.559\,\mu$m	$0.16\,\mu$m
h	$0.405\,\mu$m	$30\,$nm
L_0	$5.663\,$mm	$1.6\,$mm
λ	$1.3\,\mu$m	$\ge 90\,$nm

	q_0	Δq
n_s	1.950	0.1
n_b	2.157	0.02
n_t	2.275	0.02
n_c	1.0	≥ 0.4
$\Theta^\mathrm{F}_\mathrm{b}$	$150°/\,$cm	$202°/\,$cm
$\Theta^\mathrm{F}_\mathrm{t}$	$-1000°/\,$cm	$360°/\,$cm

$L^\mathrm{f}_\mathrm{c} = 4.5008\,\mu$m, $L^\mathrm{b}_\mathrm{c} = 4.4973\,\mu$m, $L_0/L^\mathrm{f}_\mathrm{c} \approx 1258$, $L_0/L^\mathrm{b}_\mathrm{c} \approx 1259$, $\mathrm{IS}_\mathrm{max} \to \infty$, $\mathrm{LO}_\mathrm{min} = 0.09\,$dB.

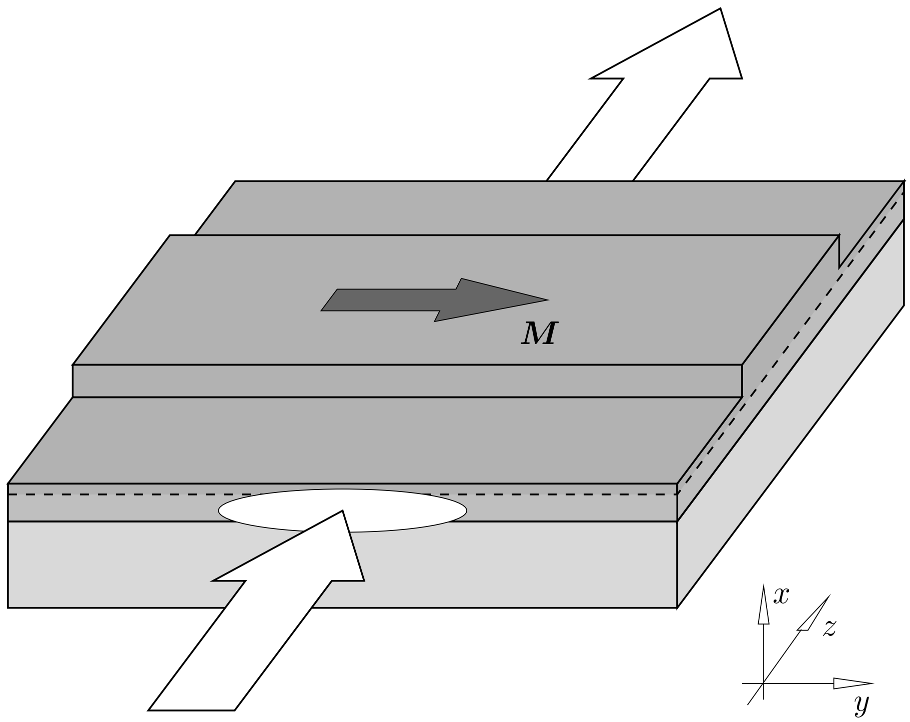


$|T|^2 = 0.98,\ |R|^2 = 3.1 \cdot 10^{-4}$



$|T|^2 = 2.1 \cdot 10^{-3},\ |R|^2 = 3.1 \cdot 10^{-4}$

IS $= 26\,$dB, LO $= 0.09\,$dB.



- Cross strip interferometer: Something between
  - a directional coupler,
  - a multimode interference device, and
  - an interferometer;

  in particular a very *simple* structure.
- Proposal for an isolator experiment:
  - Very promising with respect to isolation ratios and losses, despite the abrupt waveguide junctions, but
  - lacks lateral guiding, and
  - is restricted to TM polarization.
  - Length tuning by shifting the beam incoupling position $\rightarrow$ significantly relaxed tolerances for geometry parameters.

  Should be *feasible* with the present magnetooptic materials.