Integrated Bragg Gratings on SOI Rib Waveguides for Dispersion Compensation

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Fraunhofer Heinrich Hertz Institute

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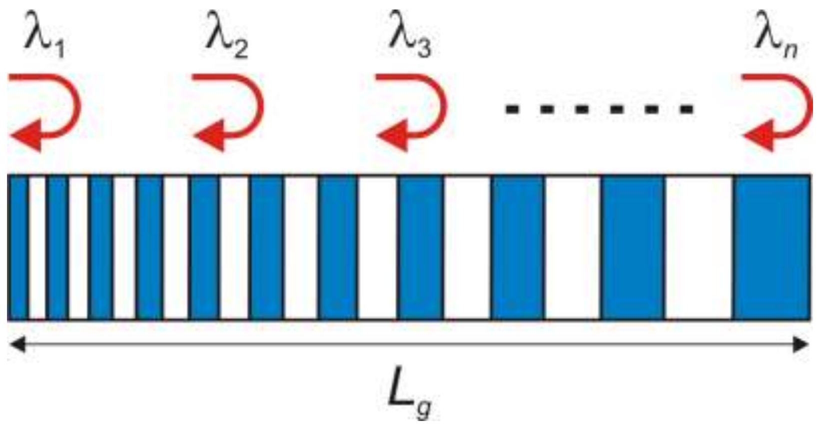
Introduction

Chirped gratings for dispersion compensation

Bragg gratings: key device for optical signal processing:

- Selective reflector for resonators
- Wavelength selection in WDM networks
- Dispersion compensation → chirped gratings

Distribution of the reflected wavelength along the grating → introduction of the desired delay

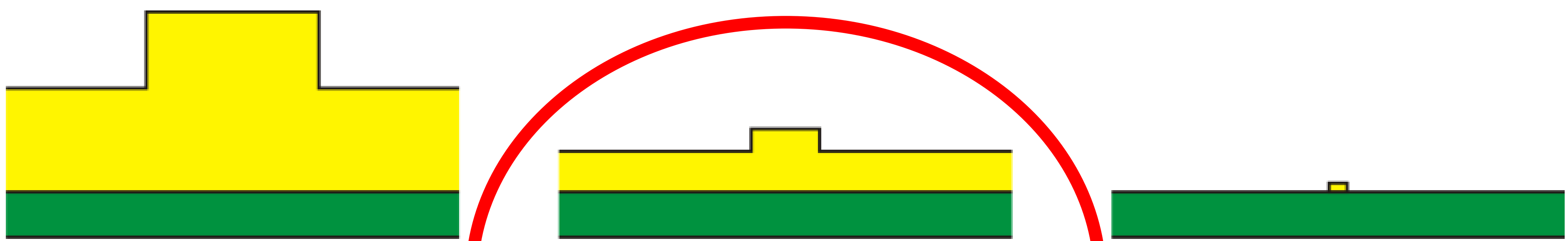


Aim: integration on silicon-on-insulator

Waveguide geometry

- Material: Silicon-on-Insulator
- Silicon photonics: established platform
- Standard silicon technology available from microelectronics

→ enables combination optics/electronics



4 µm rib waveguide

R ~ 5 mm

α ~ 0.1 dB/cm

1.4 µm rib waveguide

R ~ 1 mm

α ~ 0.2 dB/cm

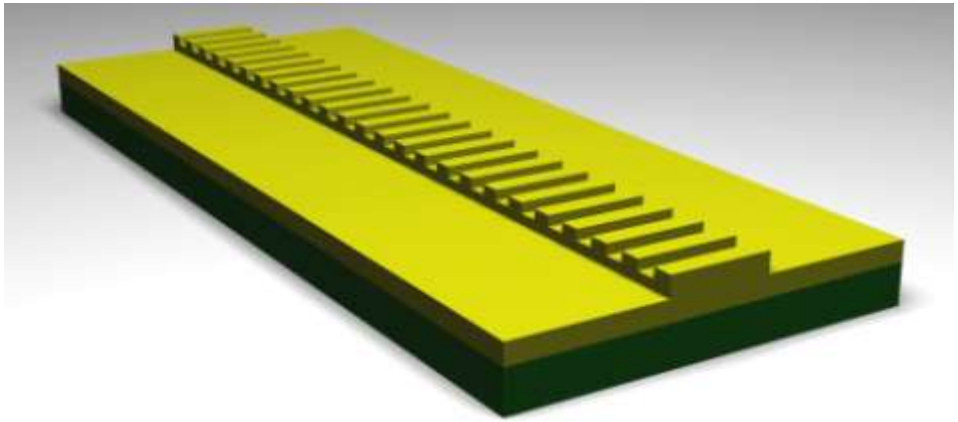
220 nm photonic wires

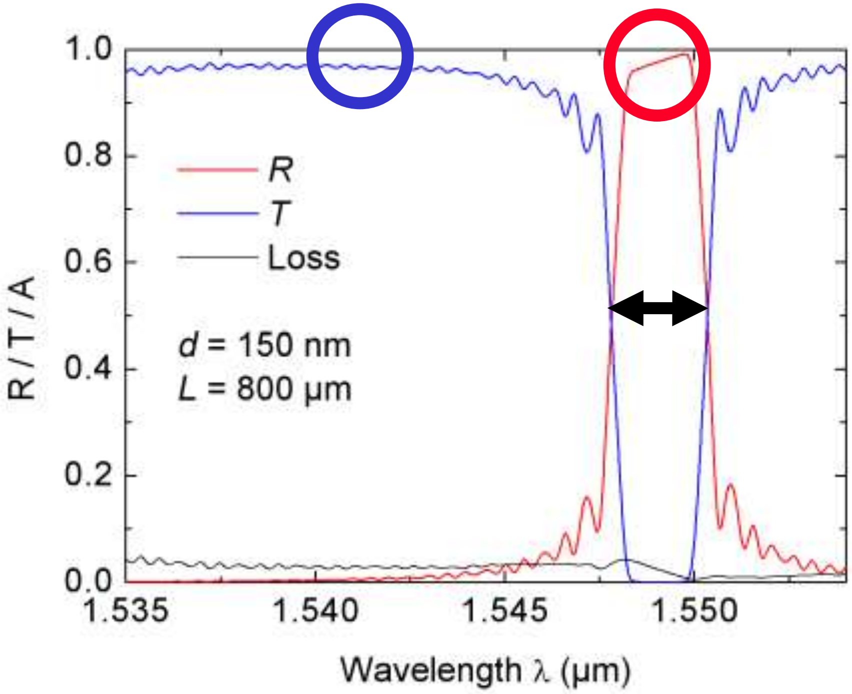
R ~ 5 µm

α ~ 2 dB/cm

Bragg grating integration

Periodic modulation of the refractive index via surface corrugation





Dimensionig required for:

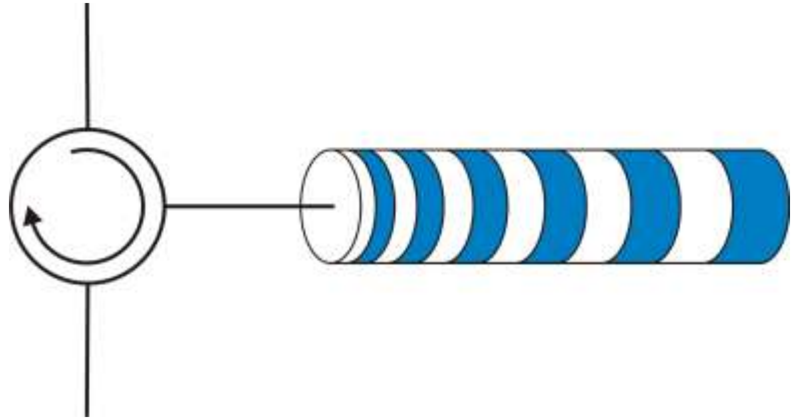
- High reflectivity
- Low insertion loss
- Narrow bandwidth

System integration

Fiber-based solution

Chirped fiber Bragg grating (*L* ~ 10 cm)

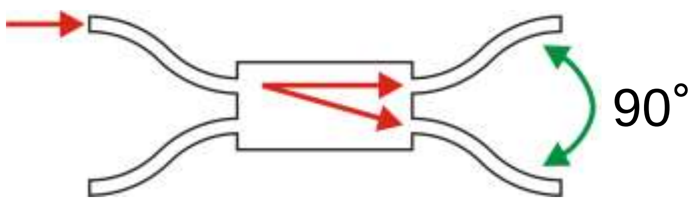
Optical circulator

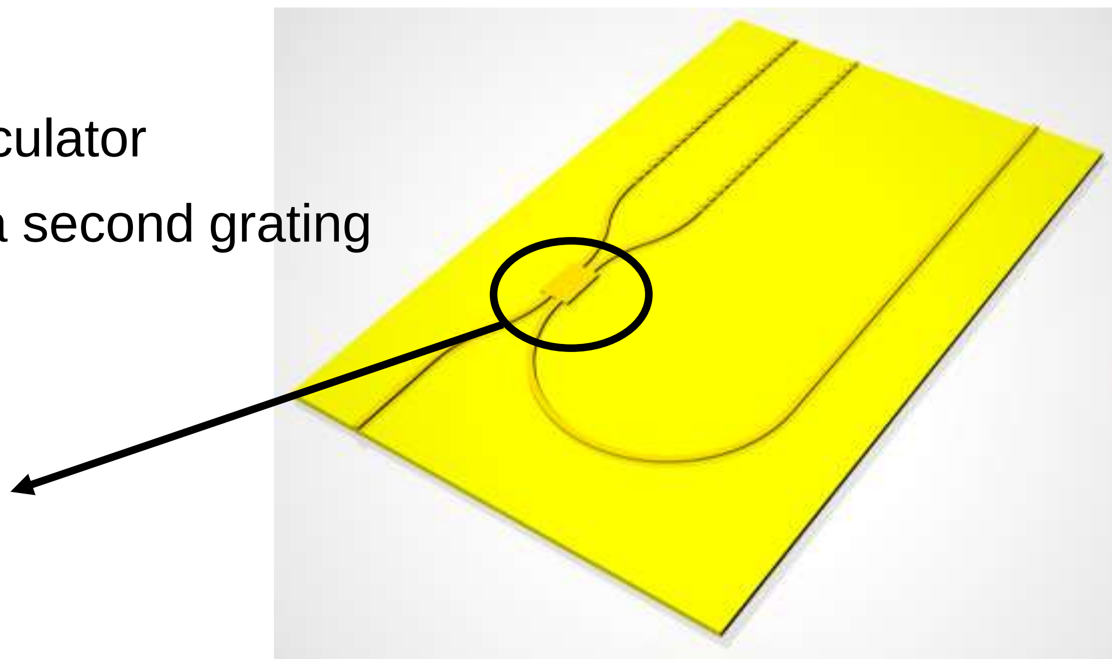


Integrated solution

Difficult integration of the optical circulator

Replacement of the circulator with a second grating and a 3-dB coupler (MMI)





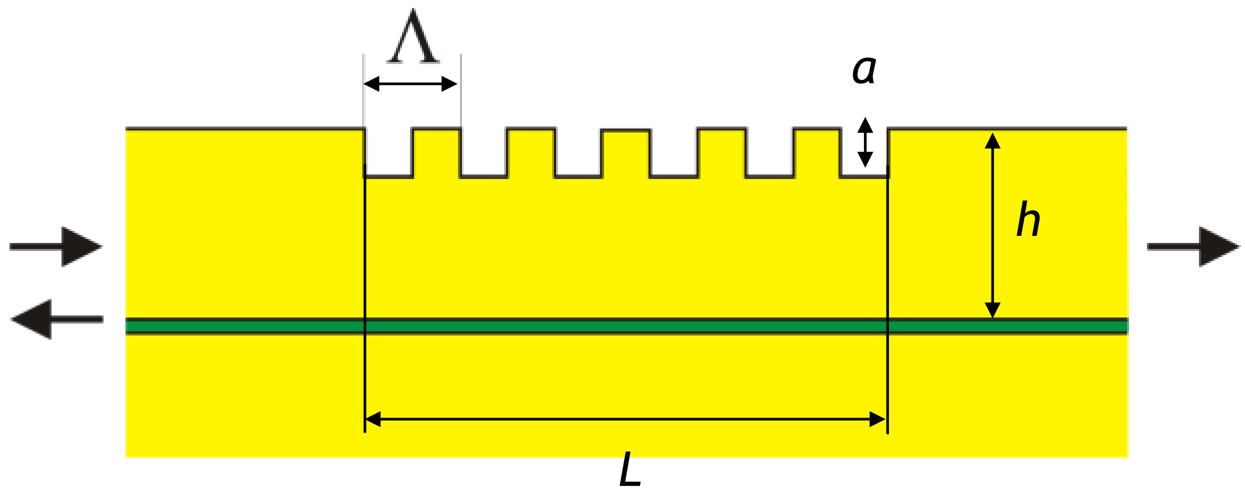
Grating design

Modelling of Bragg Gratings – Coupled Mode Theory

- Grating: periodic variation of the effective index → coupling between the forward and backward modes A and B

$$B(z)E_y(x)\exp\left[j\left(\omega t-\beta z\right)\right]$$

$$A(z)E_y(x)\exp\left[j\left(\omega t+\beta z\right)\right]$$



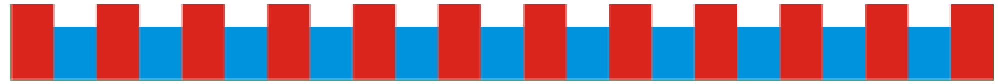
$$\begin{cases} \dfrac{dA}{dz}=\kappa\cdot B\cdot\exp\left[-j2\left(\beta-\beta_0\right)z\right] \\ \dfrac{dB}{dz}=\kappa^{*}\cdot A\cdot\exp\left[+j2\left(\beta-\beta_0\right)z\right] \end{cases}$$

κ coupling constant

- Coupling to higher order/leaky modes is not considered → limitation to weak gratings

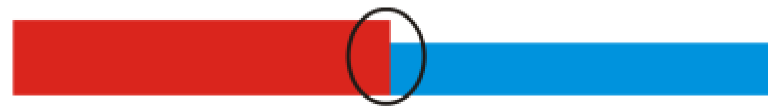
Modelling of Bragg Gratings – BEP

Grating: periodic repetition of waveguide sections with heights h_1 and h_2

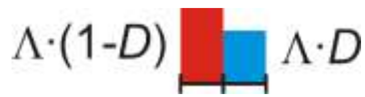


N modes for both waveguides

S-Matrix for a single discontinuity



S-Matrix for a grating period



S-Matrix for *M* grating periods

$$|S_{11}|^2 = R$$

$$|S_{N+1,1}|^2 = T$$

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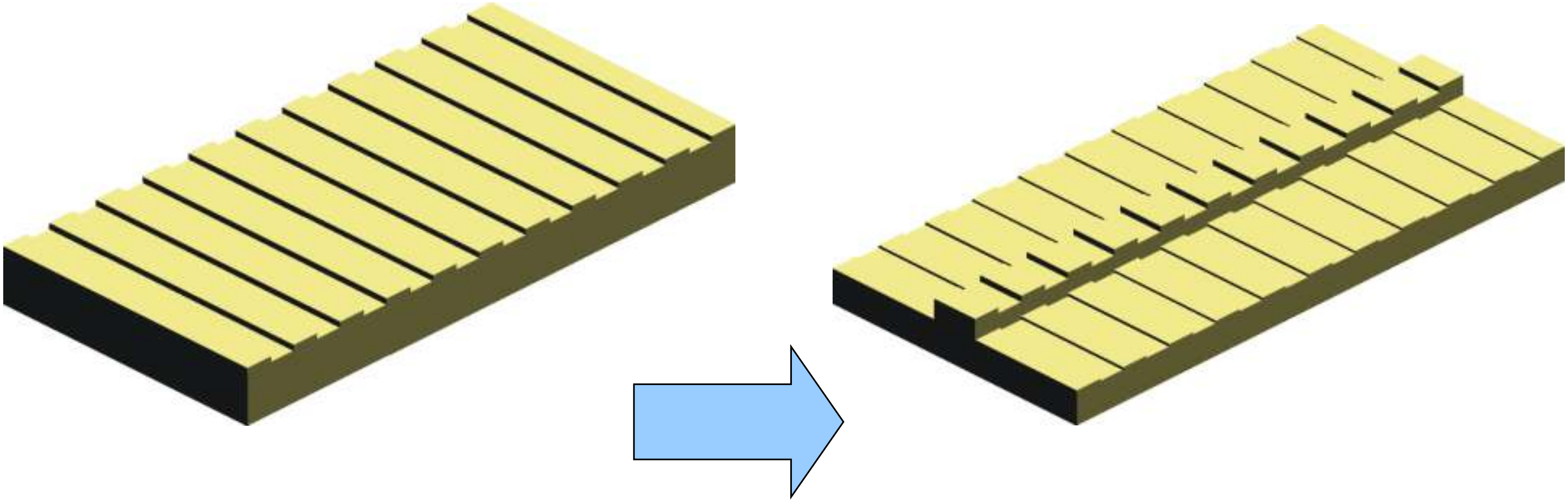
Transition to the third dimension



N guided modes

R and *T* into the fundamental mode

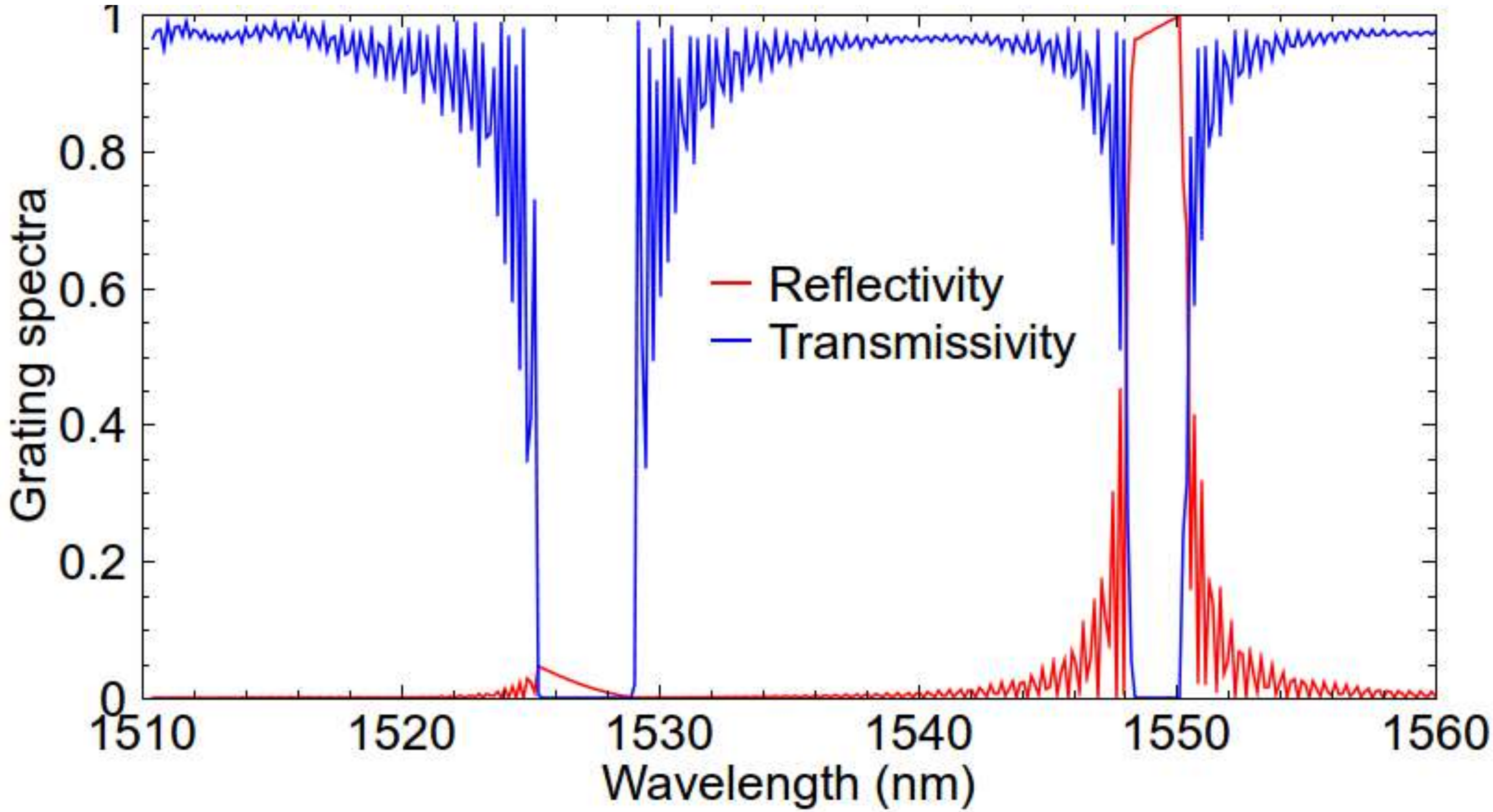
R and *T* into higher order modes

One guided mode

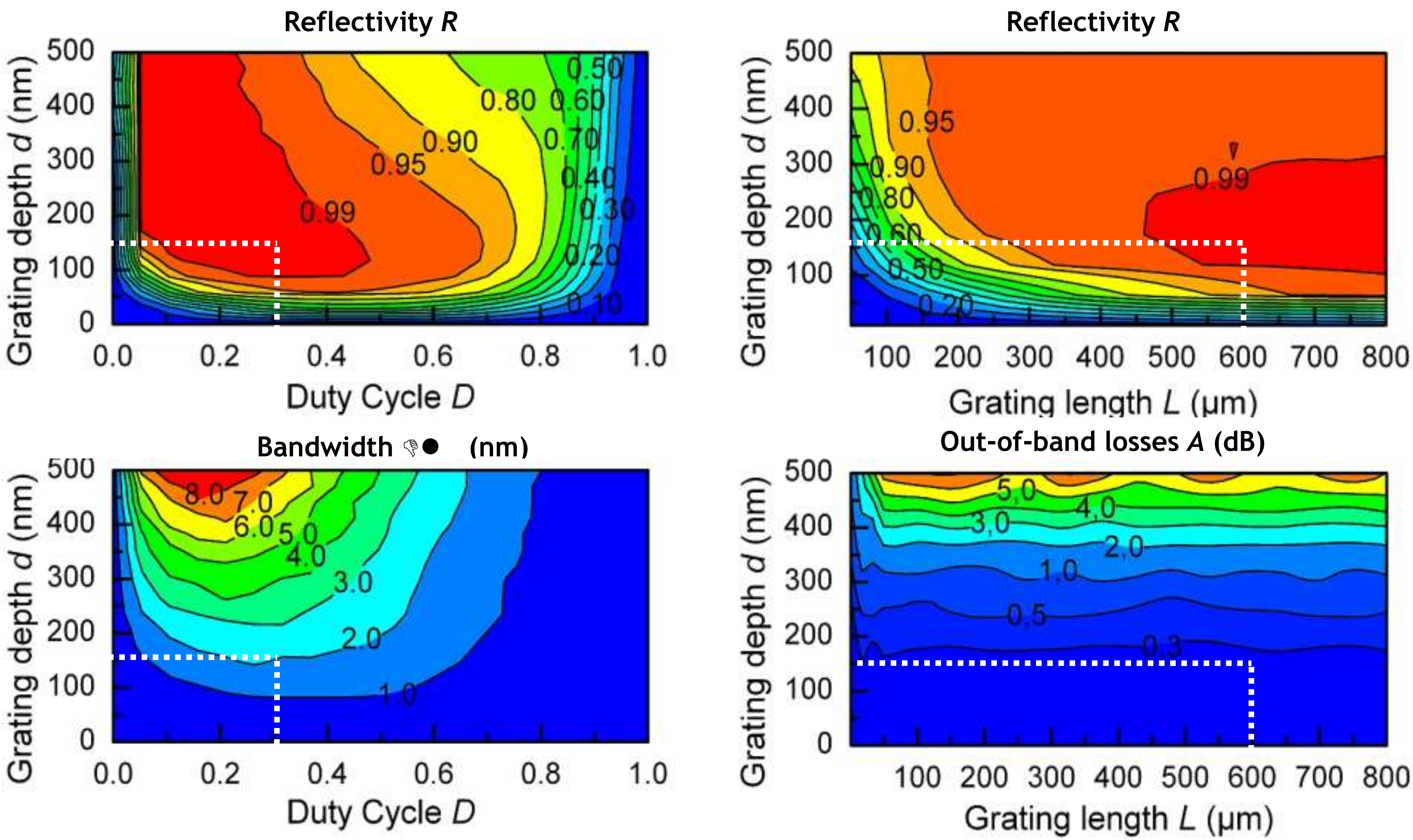
R and *T* of the grating

R and *T* into non guided modes → LOSS

Simulation results

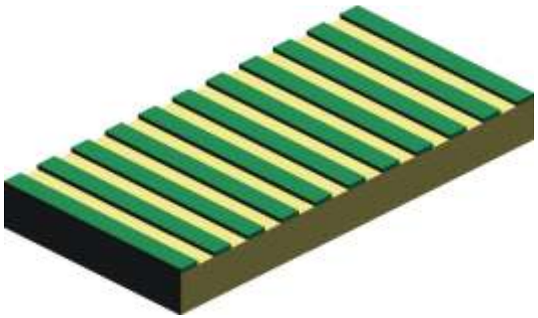


Device design



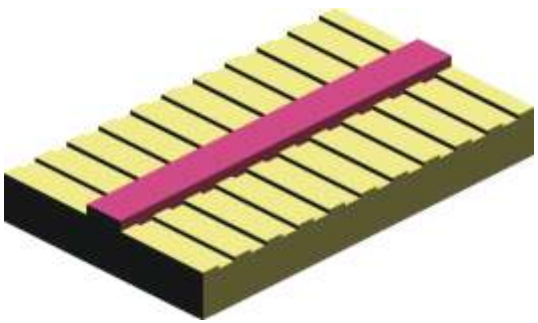
Grating realization

Fabrication



Grating patterning

Grating etching



Waveguide patterning

Waveguide etching

Lithography

	grating	waveguide
1 - TU Berlin + HHI	EBL	i-line lithography
2 - IHP	DUV	DUV

Electron-beam lithography

- High precision
- Flexible
- Slow (serial patterning)
- Stitching errors (*L* < 800 µm)

Deep-UV

- Standard for CMOS
- High throughput
- Stitching-free

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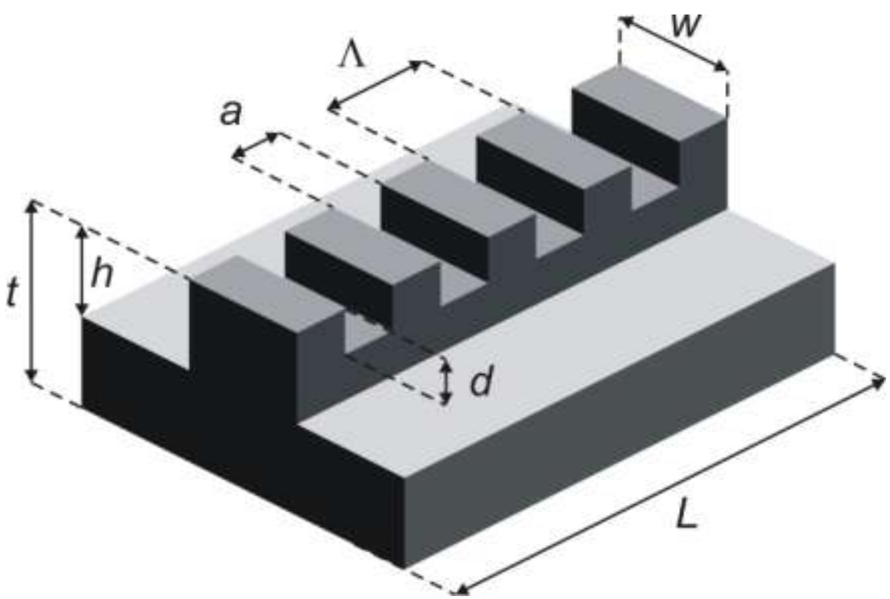
Fabricated gratings

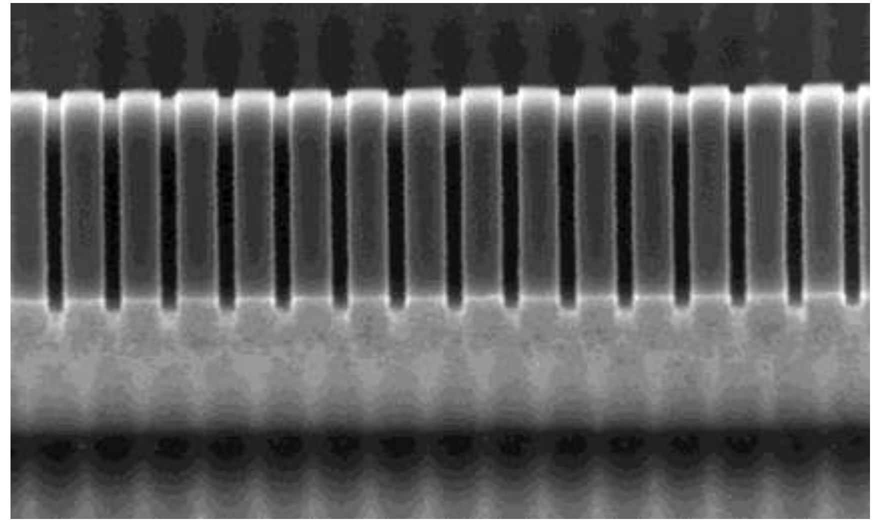
Waveguide parameters:

t = 1.5 µm

h = 0.5 µm

w = 1 – 1.6 µm





Grating parameters:

Λ = 224 - 227 nm

d = 50 – 80 nm

$D = a/\Lambda$ = 0.3 (EBL) 0.5 (DUV)

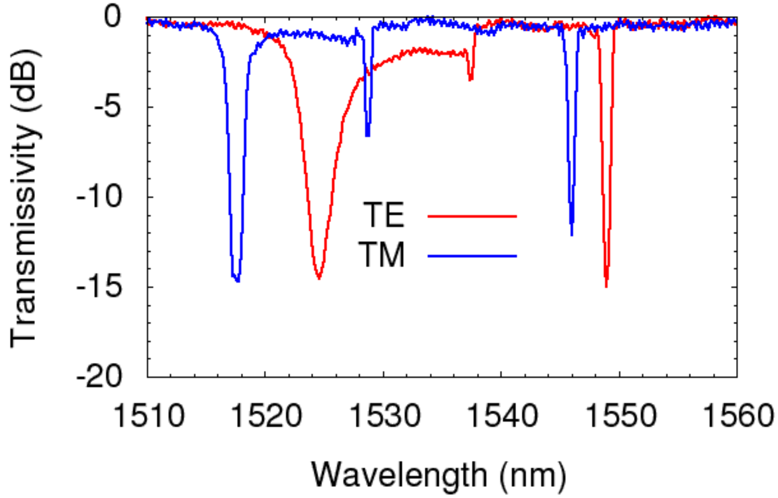
L = 800 µm

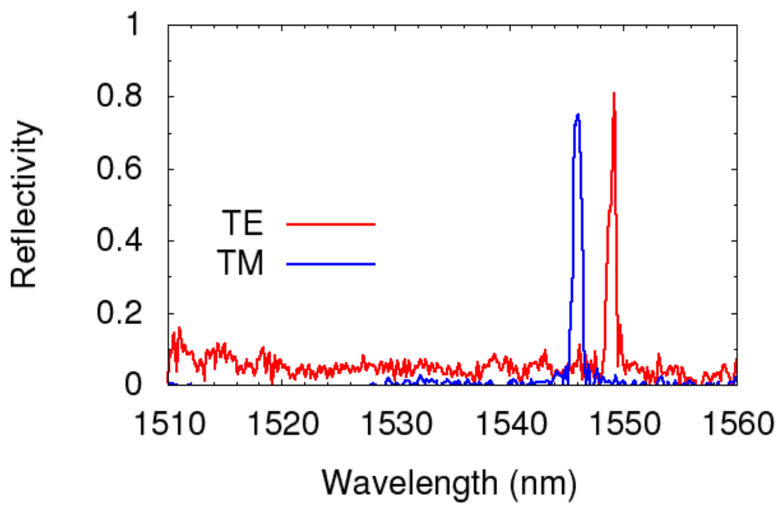
Measurement results

TUB

d = 80 nm Λ = 226 nm D = 0.3

R ~ 80% *Loss* = 0.5 dB $\Delta\lambda$ = 0.8 nm

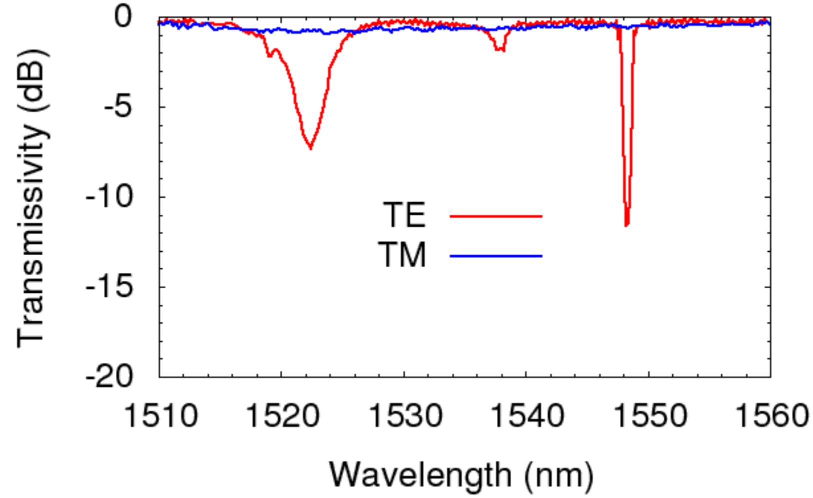


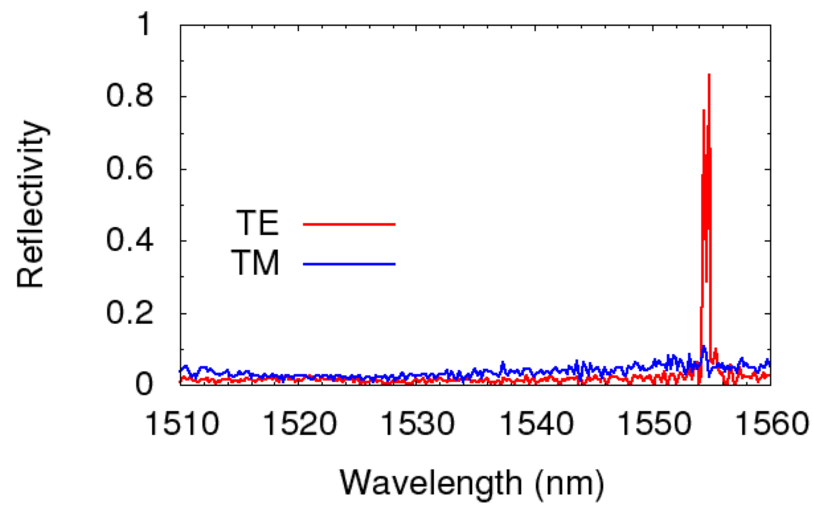


IHP-TUB

d = 50 nm Λ = 227 nm D = 0.5

R ~ 80% *Loss* = 0.3 dB $\Delta\lambda$ = 0.7 nm





Chirped gratings

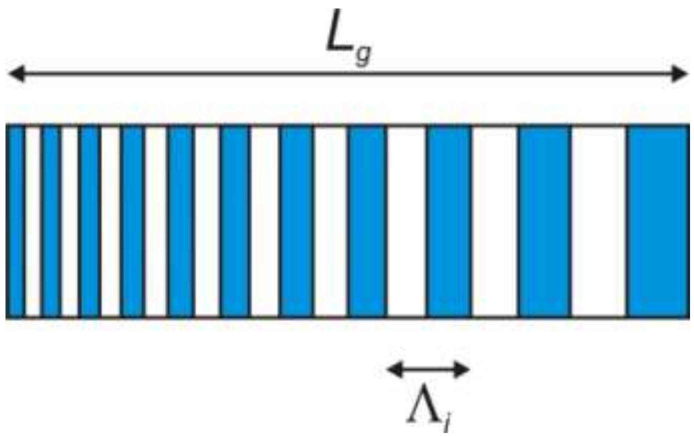
Dispersion specifications

- Target dispersion > 100 ps/nm

$$D = \frac{\Delta \tau}{\Delta \lambda}$$

- Required grating length:

$$\Delta \tau = \frac{2 n_{Si} L_g}{c} = 100 \text{ ps}$$



- With n_{Si} = 3.5

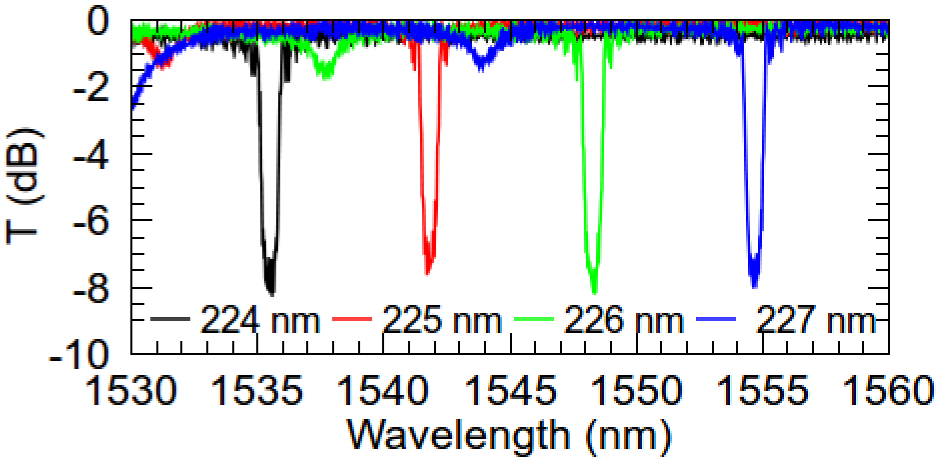
$$L_g = 4.5 \text{ mm}$$

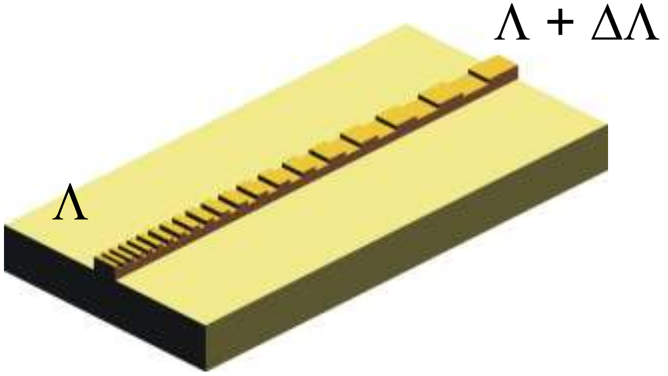
- Bandwidth:

$$\Delta \lambda = \lambda_{Bragg,end} - \lambda_{Bragg,front} \qquad \lambda_{Bragg,i} = 2 n_{eff} \Lambda_i$$

Implementation of the chirp

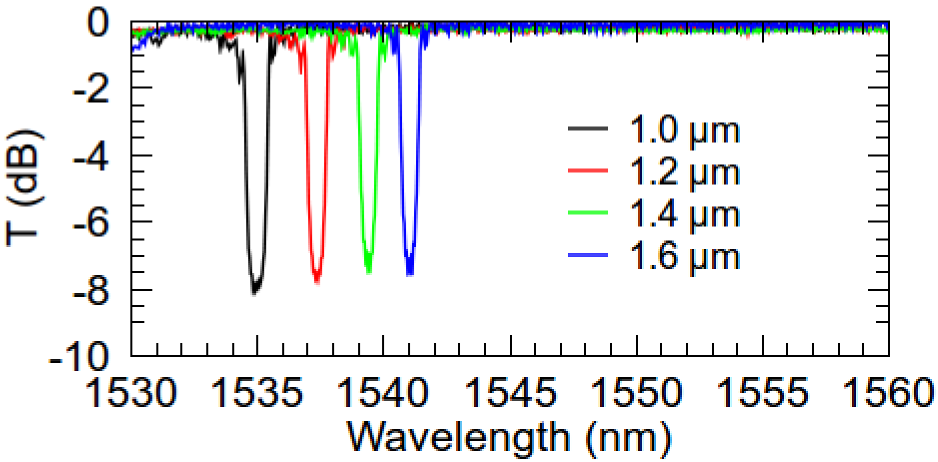
Variation of the grating period

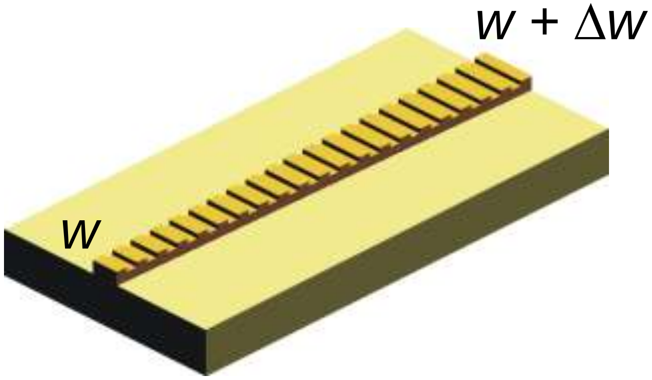




$\Delta\lambda$ = 1 nm → $\Delta\Lambda$ = 0.15 nm

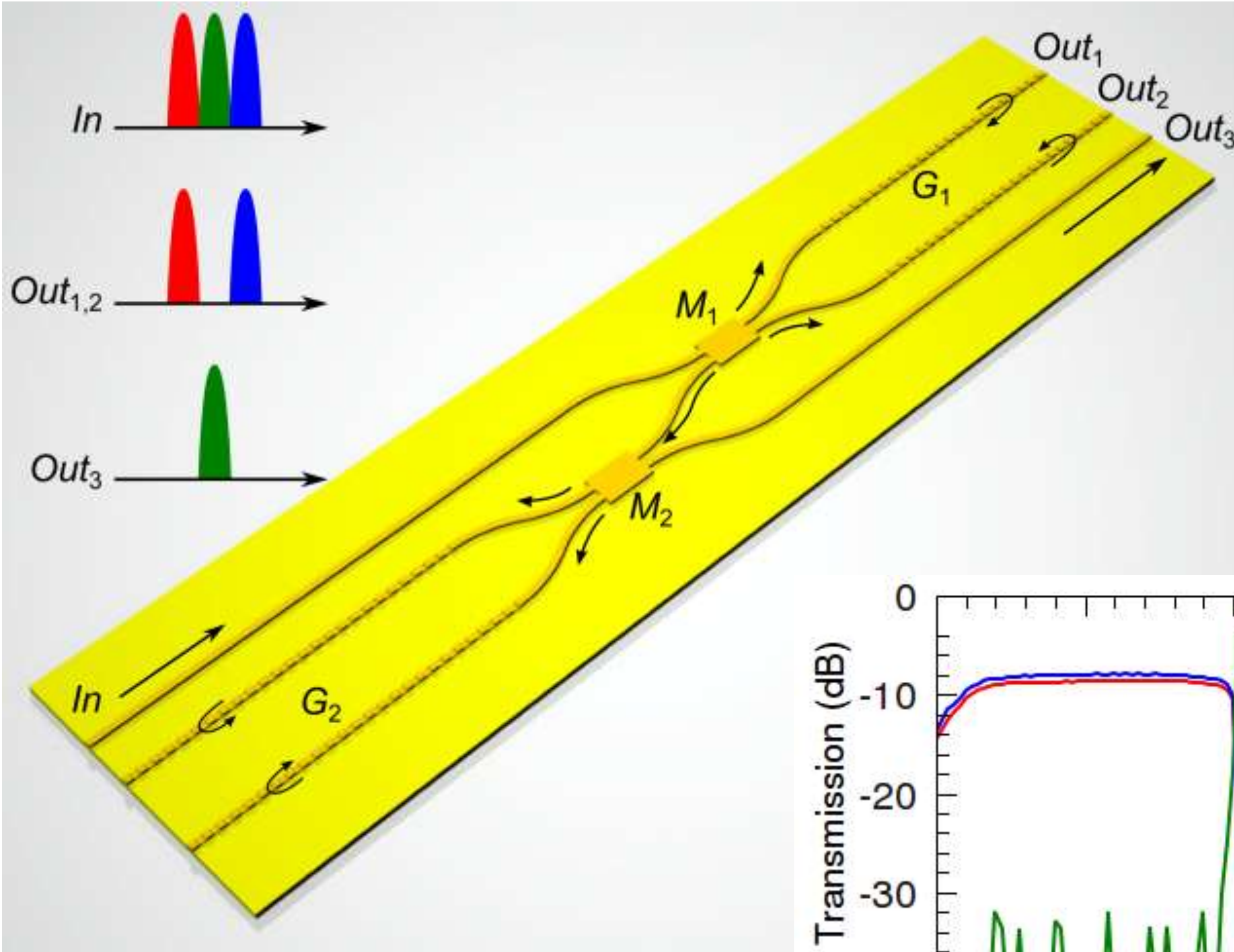
Variation of the waveguide width

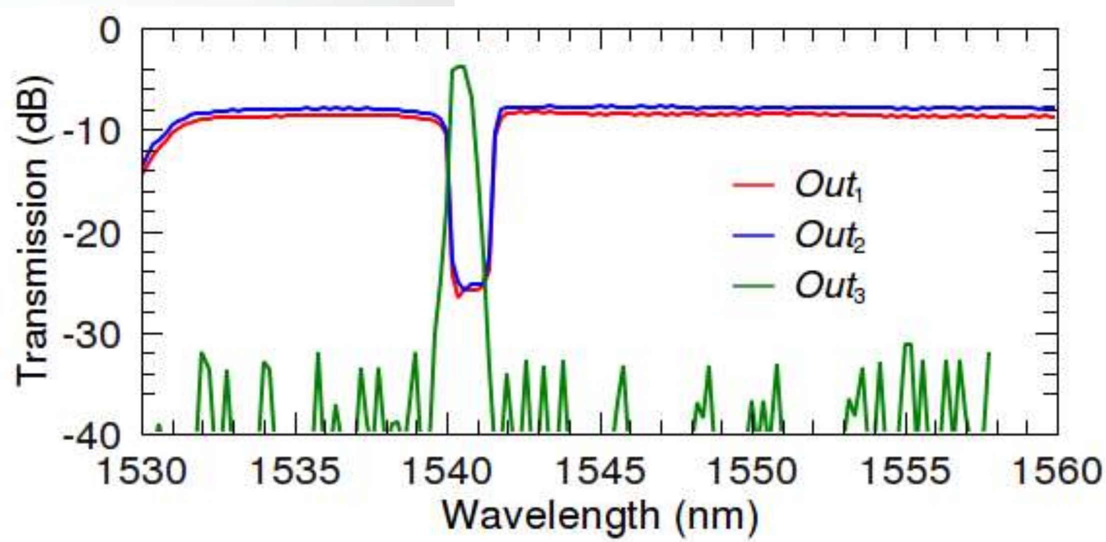




$\Delta\lambda$ = 1 nm → Δw = 150 nm

Dispersion compensating module





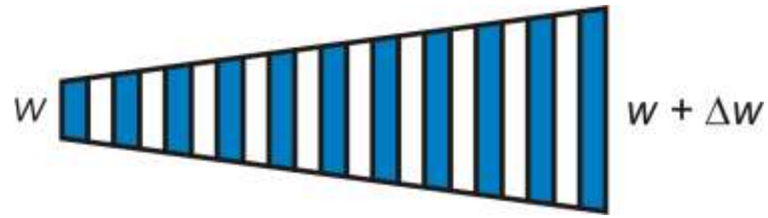
Device characterization – tapered gratings

Measurement of the transmission spectra with variation of the tapering width Δw

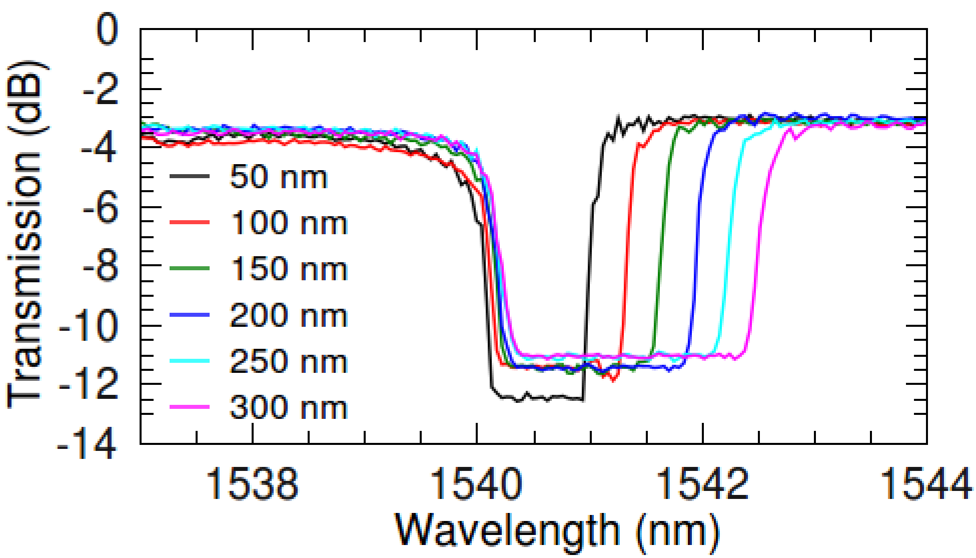
Linear dependence $\Delta\lambda(\Delta w)$

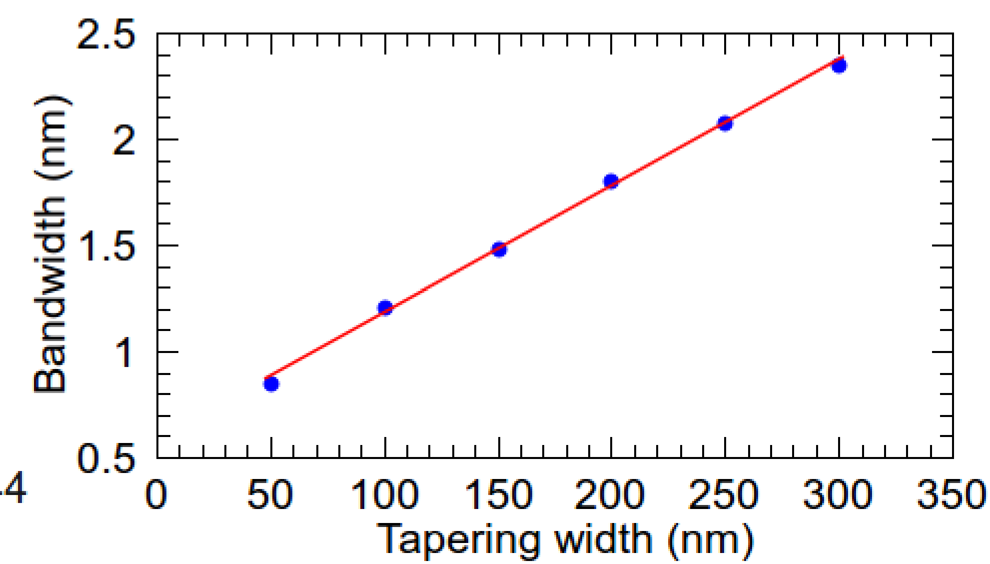
- Larger $\Delta w \rightarrow$ broadening on the red-side

$\rightarrow$ presence of the chirp proved



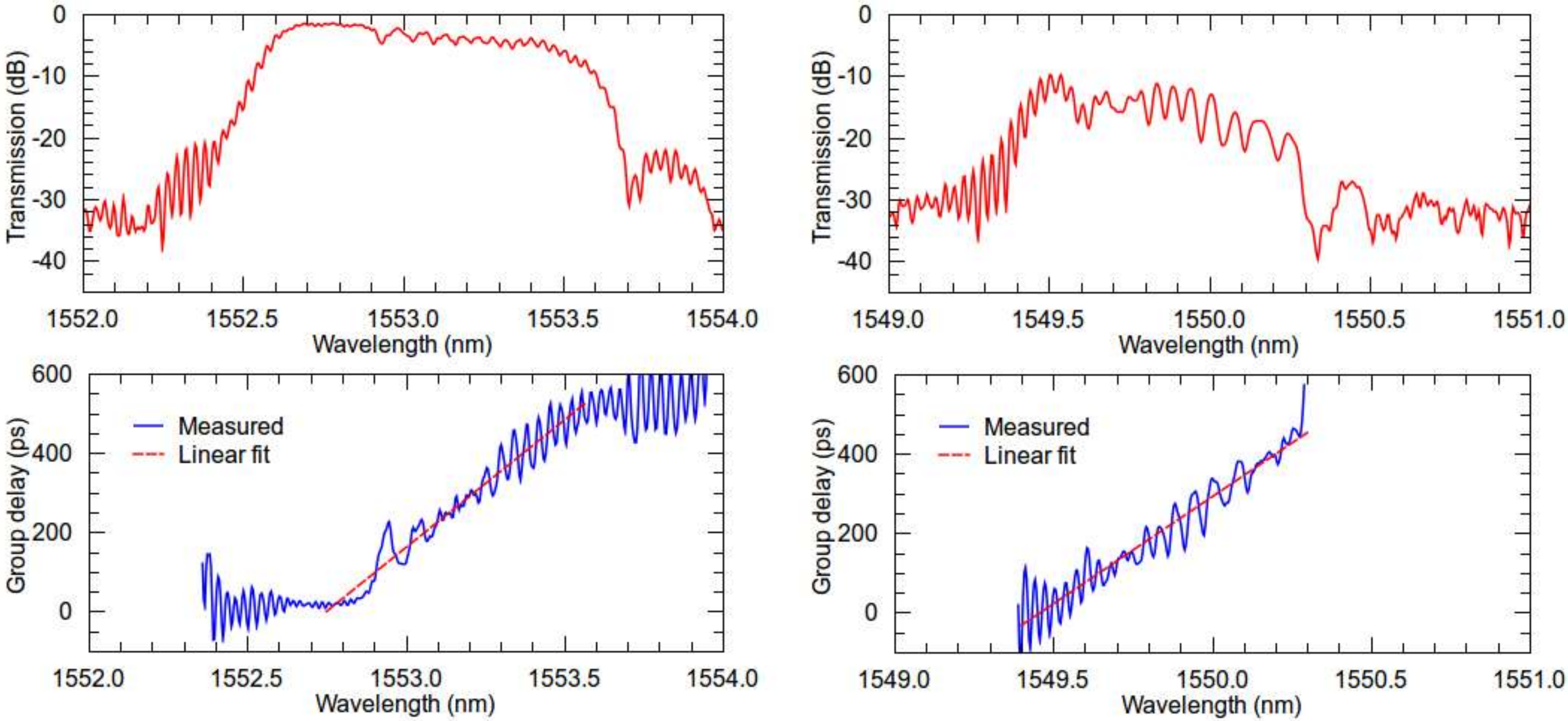
- Introduced loss ~ 3 dB





Dispersion measurement

TE | TM



D = 500 ps/nm (250 ps/nm per grating)

Conclusion

Integration of chirped Bragg gratings on Silicon-on-insulator

Implementation of the chirp via waveguide tapering: robust fabrication

Fabrication with a standard BiCMOS technology based on DUV lithography

Dispersion compensation on one channel over $\Delta\lambda$ = 1 nm with an overall loss of 3 dB

Measured dispersion = 500 ps/nm

Thank you for your attention!

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