Institute of Applied Physics
Friedrich-Schiller-Universität Jena

Coating-reduced interferometer optics

Resonant waveguide gratings

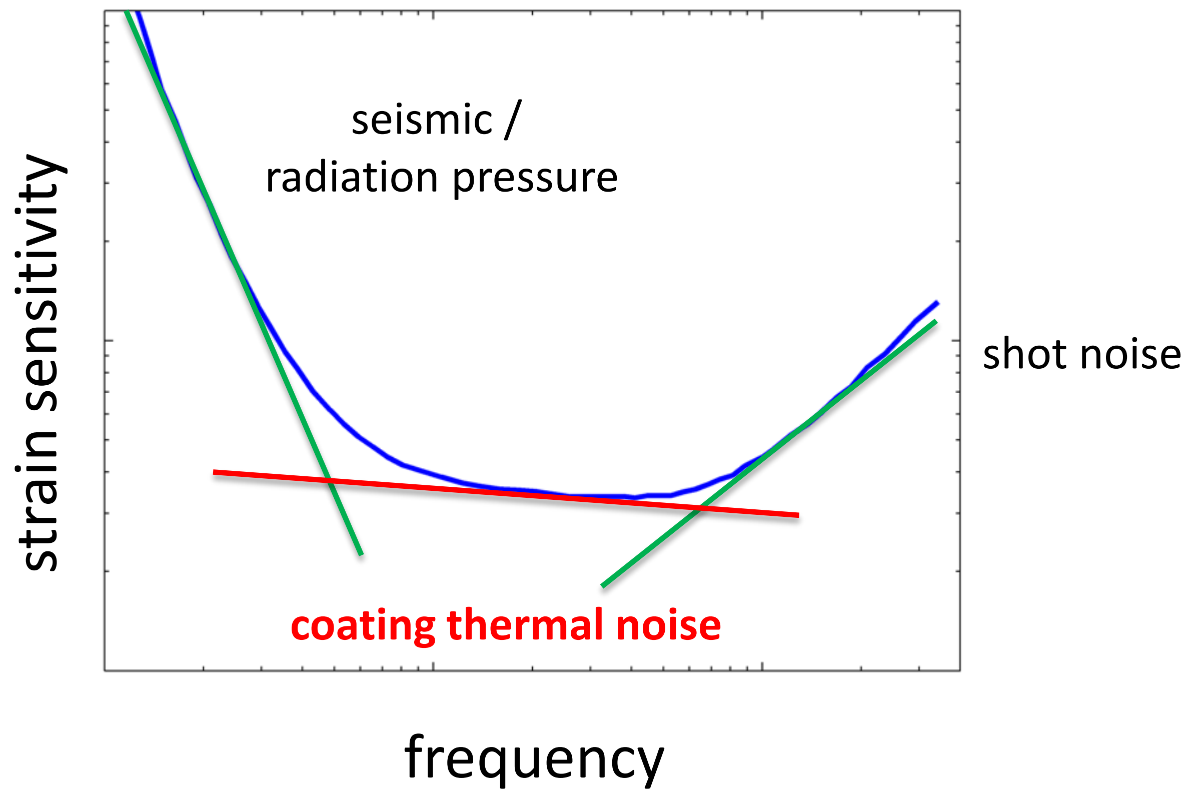
S. Kroker, T. Käsebier, E.-B. Kley, A. Tünnermann

Outline

- RWGs as mirrors
- Advanced grating concepts
- Fabrication
- Optical losses

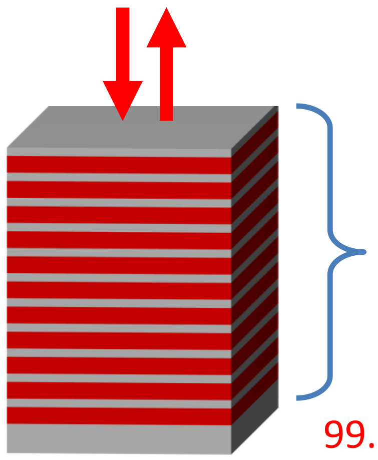
- Summary & Outlook

Introduction – coating thermal noise



Introduction – reducing coating thermal noise

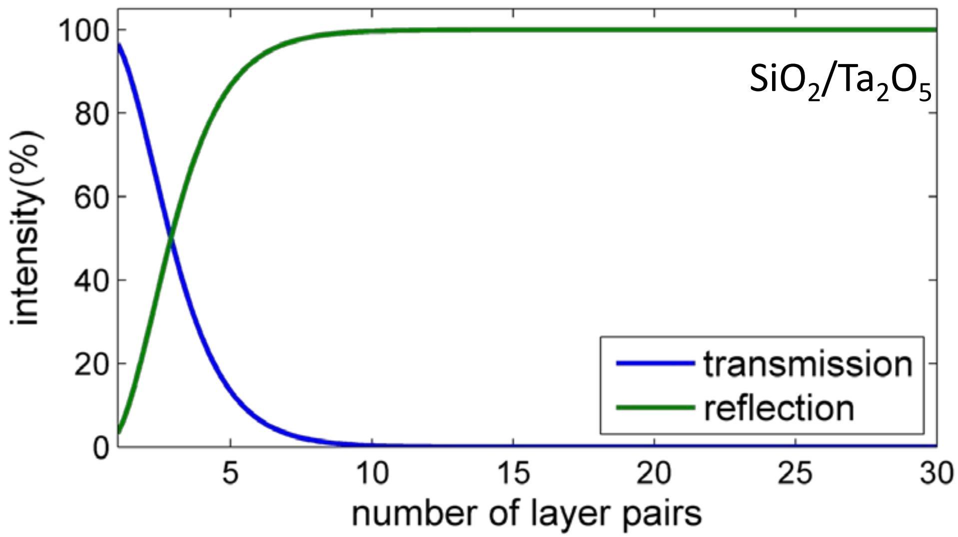
conventional: dielectric **crystalline**
multilayer stack



~3…8 µm

99.996% reflectivity
Harry et al. , CQG (2002)

multiple beam interference:

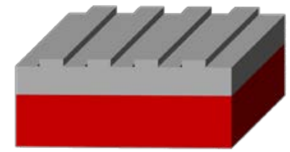


reflectivity ➡ Brownian coating thermal noise

1. **Possibility- optimization materials: crystalline coatings (Al_xGaAs)**
   See talk by G. Cole!

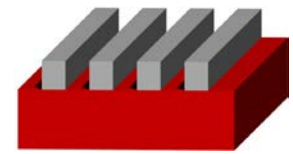
2. Possibility- alternative optical concepts + material optimization: Resonant waveguide gratings (RWGs)

Origin: weakly modulated high-index grating on low-index substrate (narrow band)

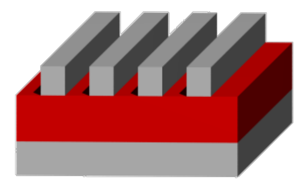


Popov et al., Opt. Comm .(1985)

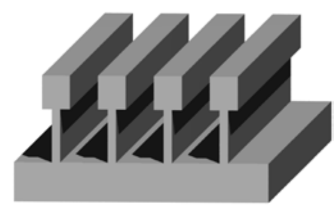
Stronger modulation: larger bandwidth



Replace low-index substrate



Replace low-index material



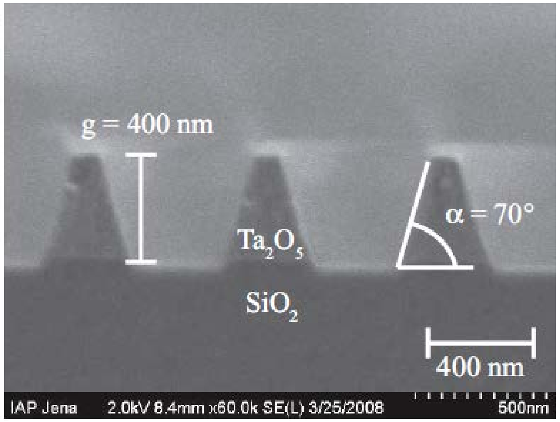
Brückner et al., PRL (2010)

high-index

low-index

RWGs as mirrors – so far

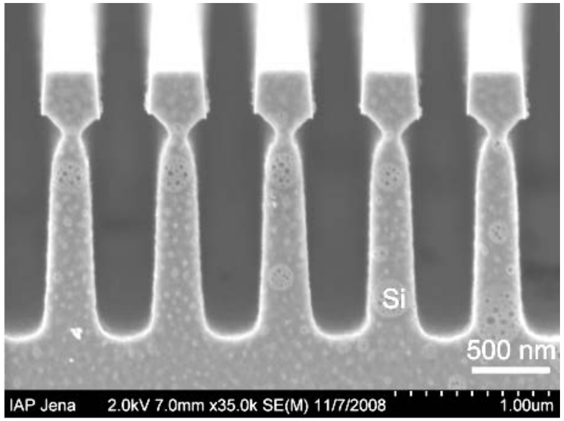
Tantala grating on silica for 1064 nm



Brückner et al., Opt. Express (2008)

$$R(1064\,nm) = (99.08 \pm 0.05)\%$$

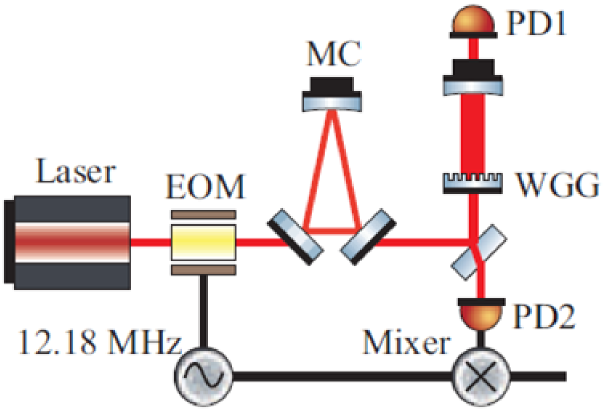
Monolithic silicon gratings for 1550 nm

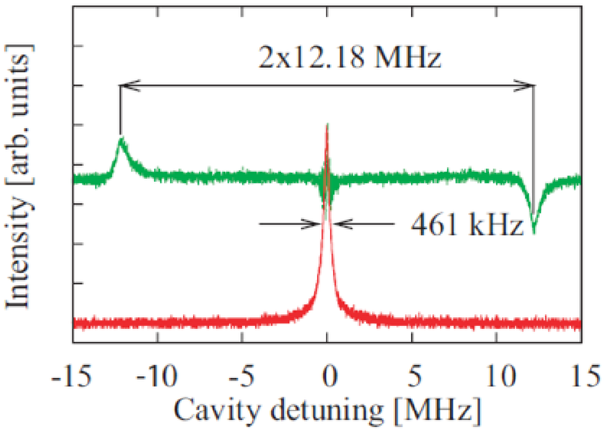


Brückner et al., PRL (2010)

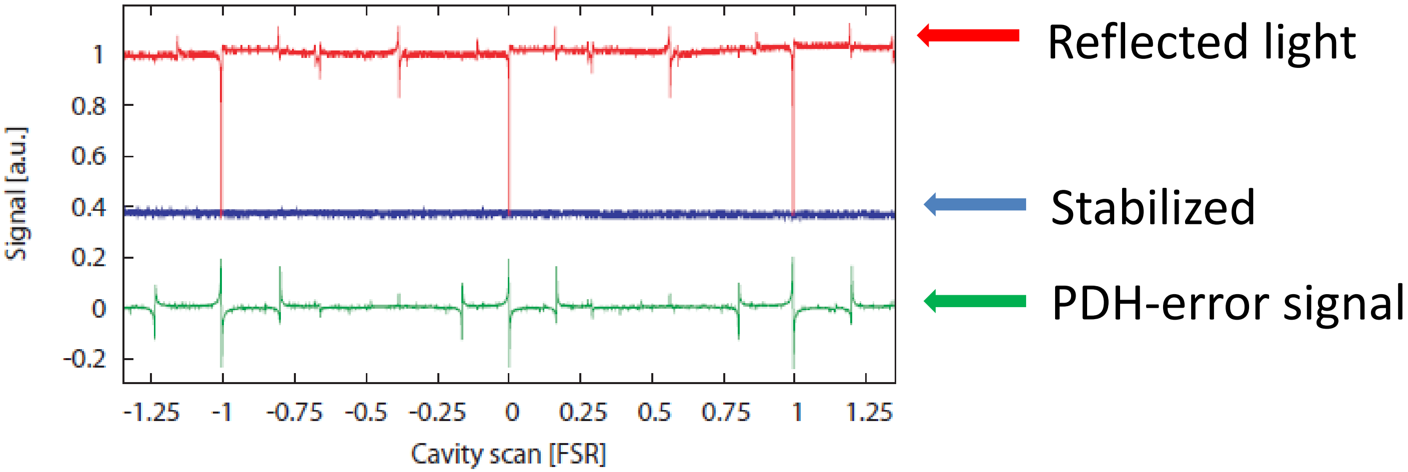
$$R(1550\,nm) = (99.77 \pm 0.01)\%$$

reflectivity measurements in cavity





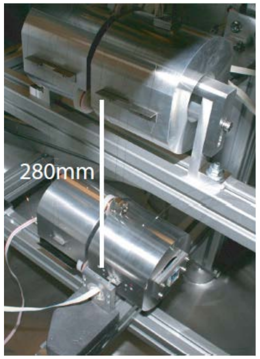
Tantala RWG

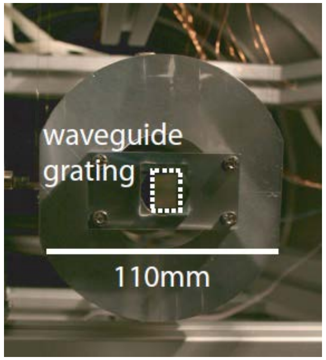


- Finesse= 790 (±100) → R ≥ 99.2(±0.1)%
- Cavity stabilization with standard PDH-technique

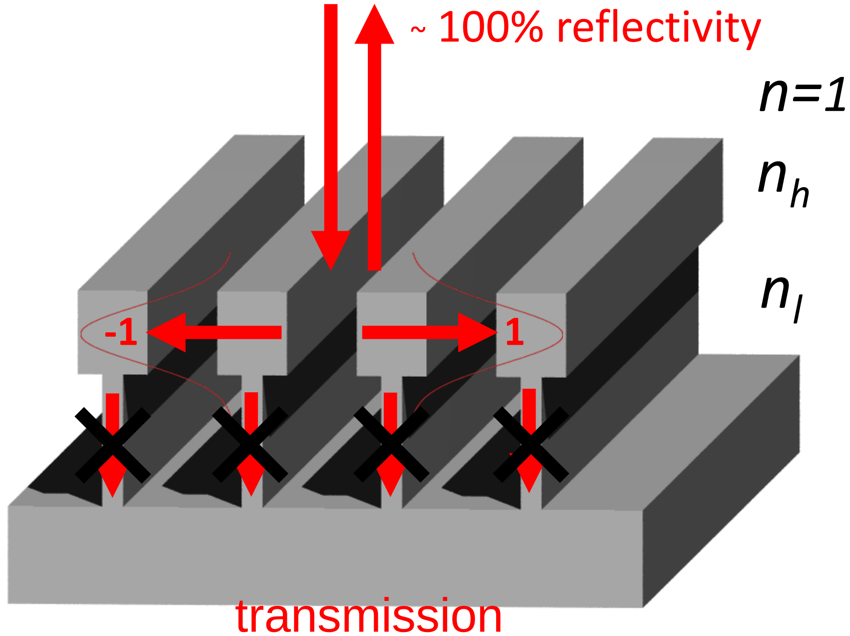
D.Friedrich et al. Opt. Express 19, 14955 (2011)

University of Glasgow
Institute of Applied Physics





Functionality of RWGS – horizontal modes



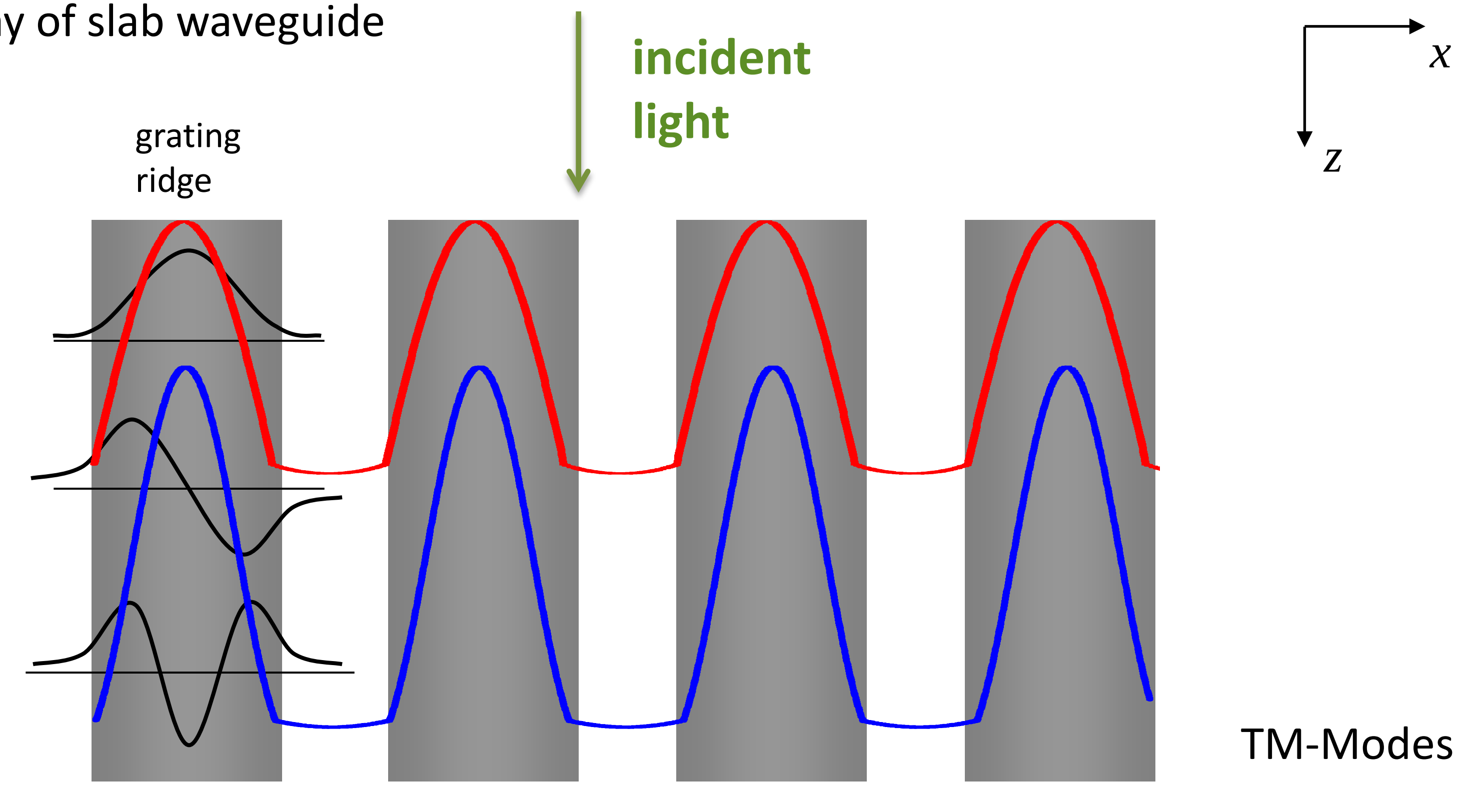
silicon as high-index material
(n_h=3.48 @ λ=1550 nm)

1st diffraction orders in grating ⇦ $\lambda/n_h<p<\lambda/n_l$ ⇨ 0th diffraction order outside grating

p… grating period

Functionality of RWGS – vertical (Bloch-) modes

periodic array of slab waveguide



Botten et al., Opt. Act. (1981)

Coating-reduced interferometer optics
Functionality of RWGs

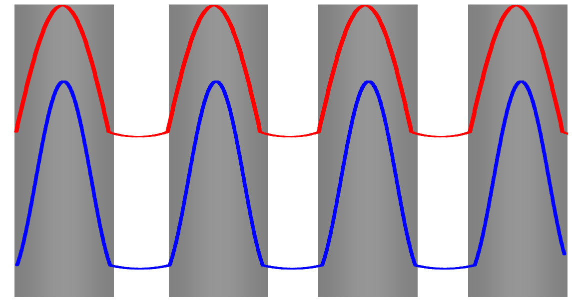
Effective index dependent on:

-fill factor

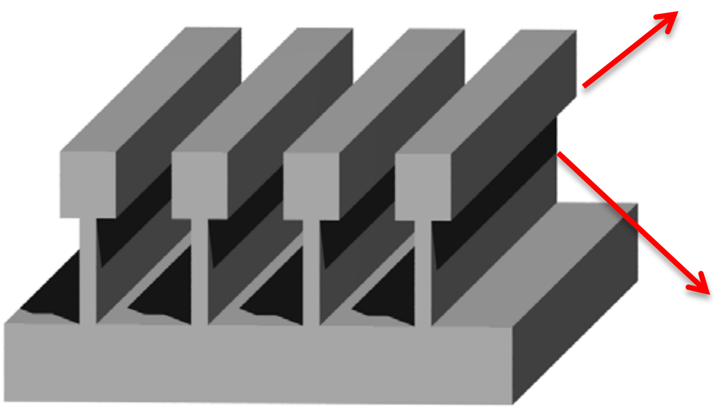
-period/ wavelength

-polarisation

-angle of incidence



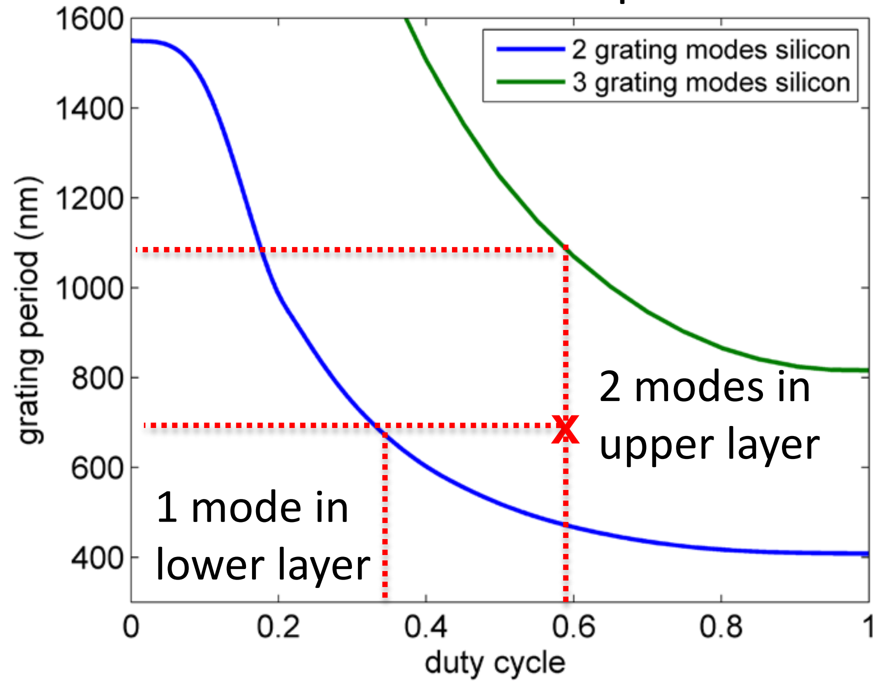
High efficiency:



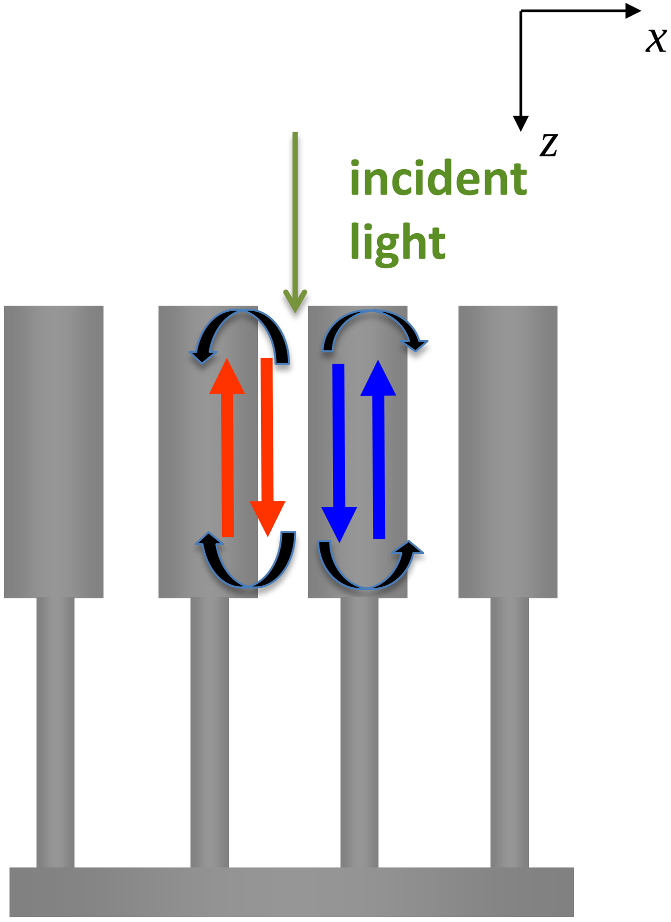
2 propagatir

1 propagat

TM-polarization



mechanism for R=100%:



- phase difference due to different effective indizes (different k_z),
- reflection/ interference at boundaries
- no additional phase in lower grating
- Amplitudes of grating modes need to cancel out

exact intensities and phases + physical insight

Lalanne , J. Lightwave Tech. (2006)

Karagodsky et al., Opt. Express (2009)

… interaction of light with surface structure…

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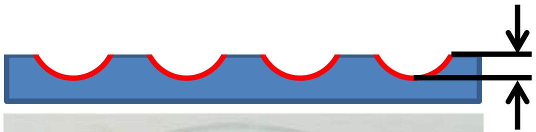
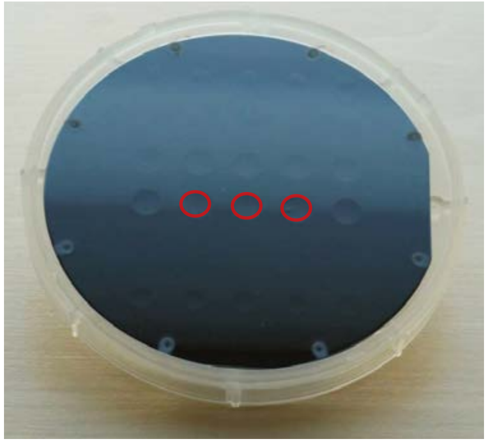
S. Hild

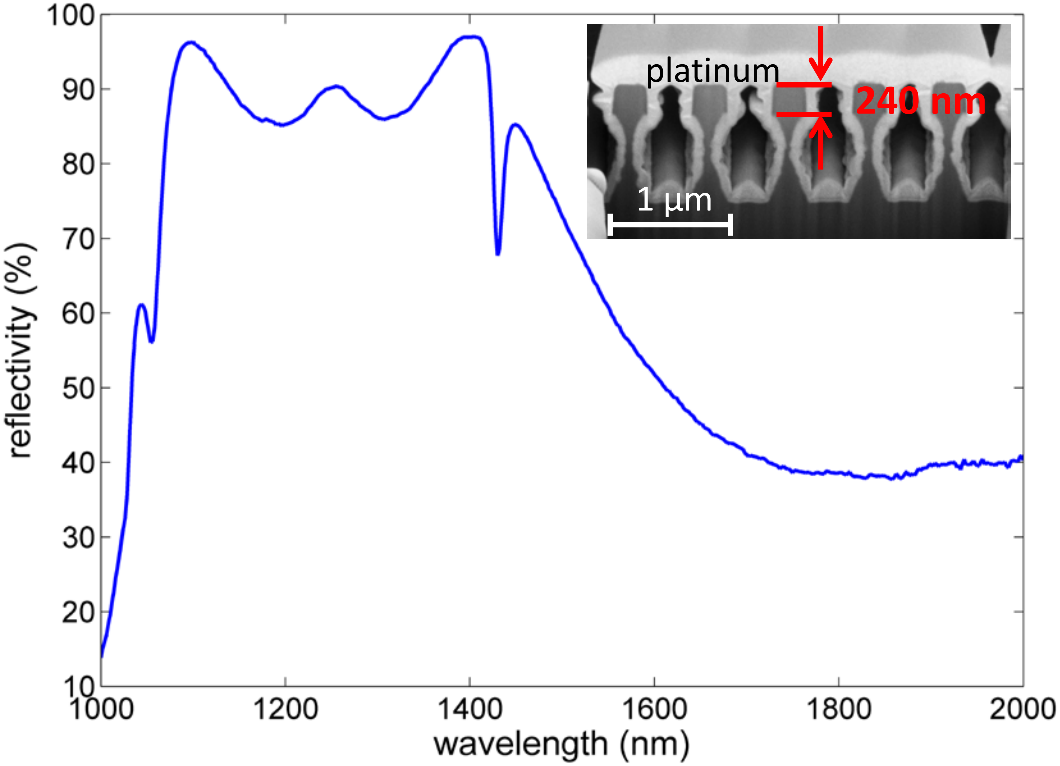
Feel free to join!

Mirrors on Curved Substrates





pre-structured wafer

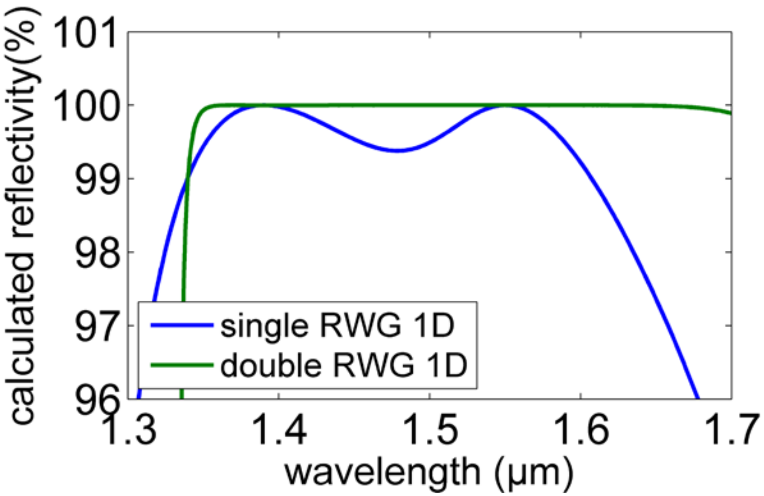


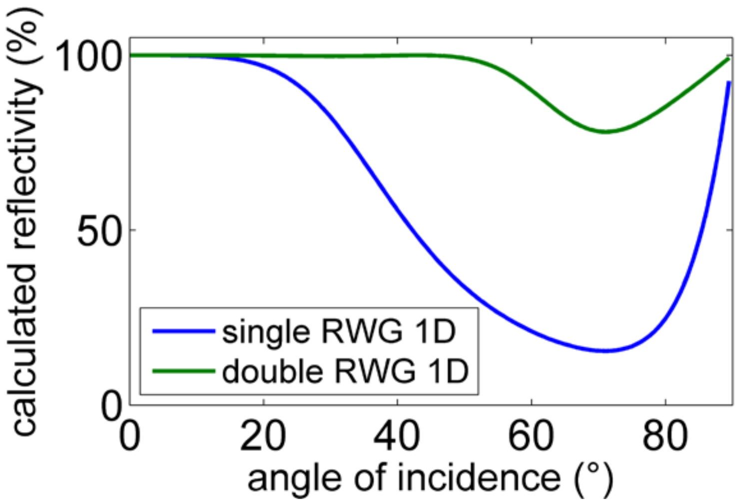
	grating	LIGO
ROC (m)	0.6	~2000
r_{Mirror} (m)	0.0035	0.17
depth (µm)	~10	~7

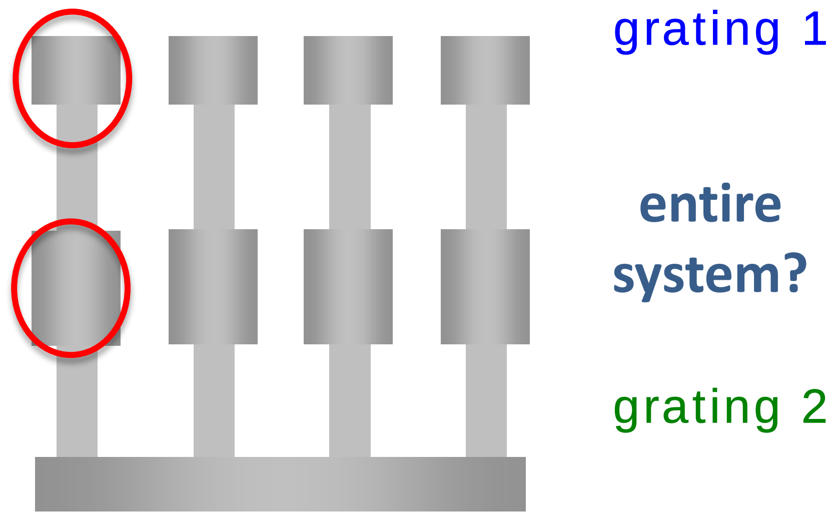
maximum reflectivity : **97%** (λ=1396 nm, θ=5°)

resonance to larger wavelength with larger period/thickness...

1. stacked RWGs



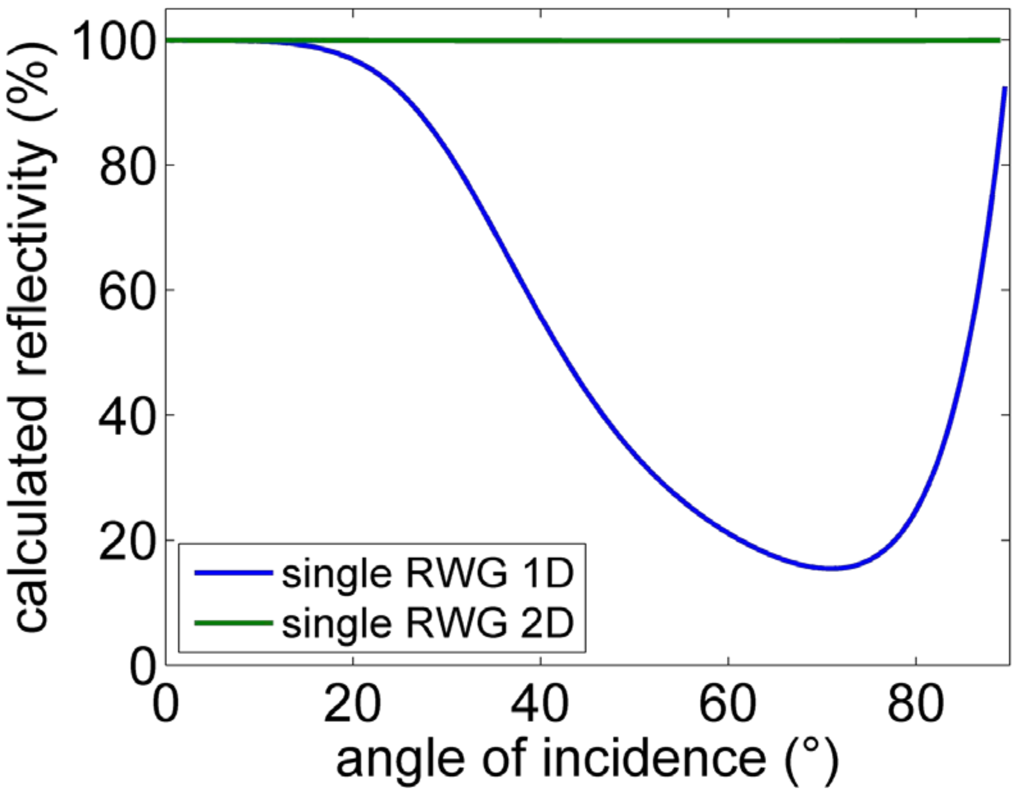


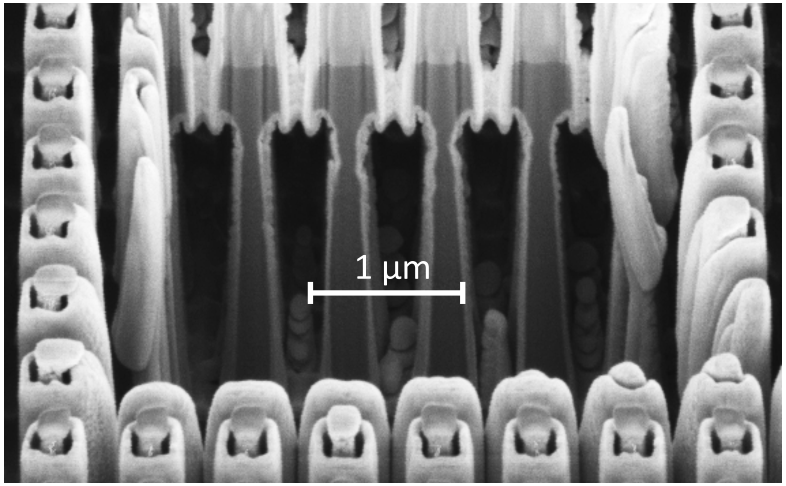


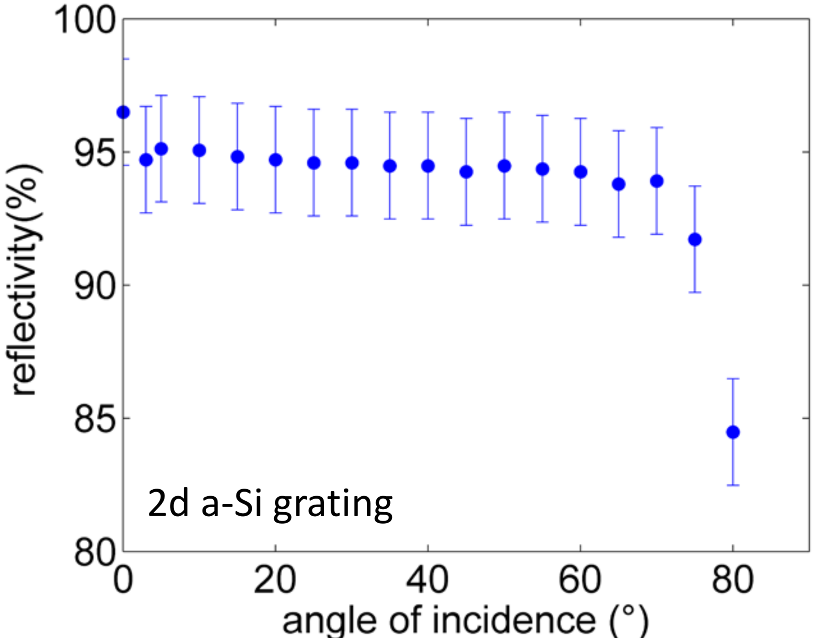
Thickness determines wavelength/ angle of max. reflection

- enhance angular/ spectral bandwidths
- enhance experimentally feasible reflectivity

2. RWGs with 2D periodicity







basis for flat focusing mirrors

Combination von highly efficient mirrors with diffraction grating

Highly efficient mirror

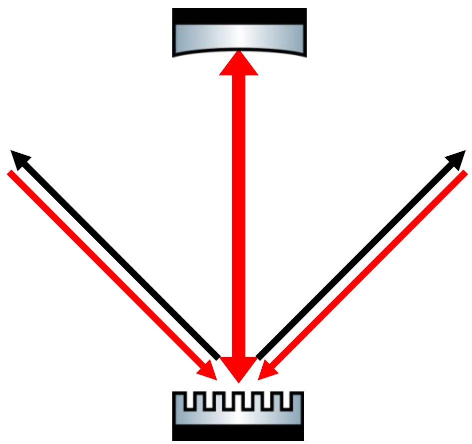
$p_{mirror} < \lambda$

only 0^{th} order

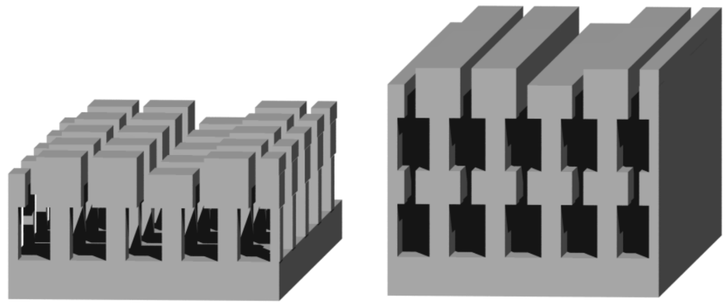
Diffraction grating

$p_{diff} = \lambda \dots 2\lambda$

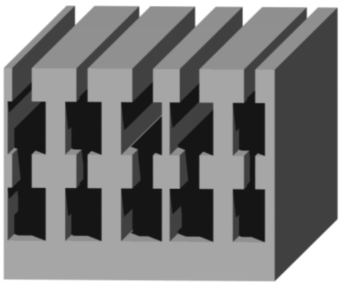
0^{th}, $\pm 1^{st}$ orders



high Finesse
→only weak perturbation



transversal modulation: Grating depth

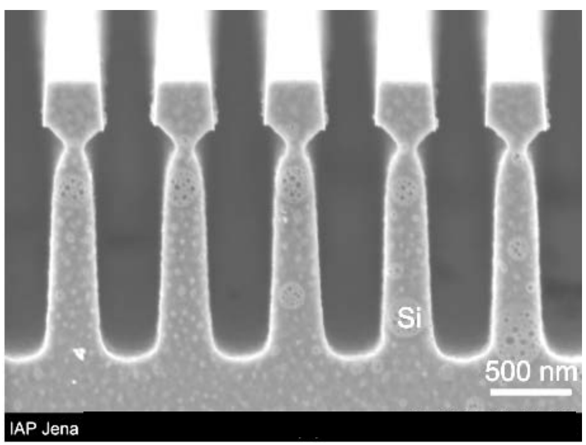


lateral Modulation: Ridge width/ -position

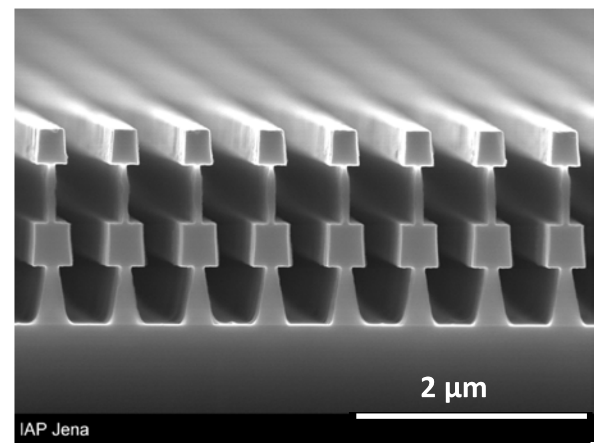
High angular tolerance of reflector necessary

Fabrication

electronbeam-lithography + development → anisotropic etching process+ sidewall passivation → isotropic etching process



More complex structures?



silicon | SiO_2 | chromium | electron-beamresist

Where is the missing light?

R=(99.8±0.01)%

absorption

material properties

See talk by J. Komma!

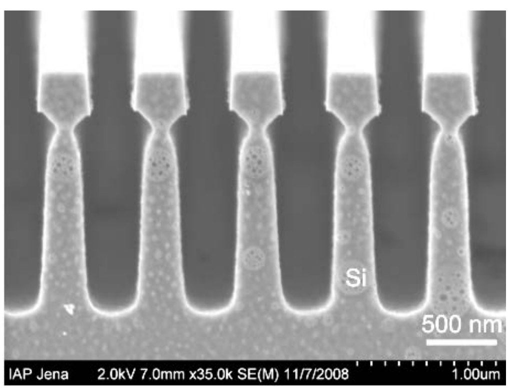
transmission

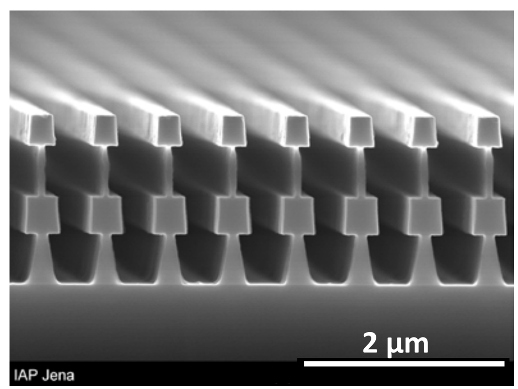
scattered light

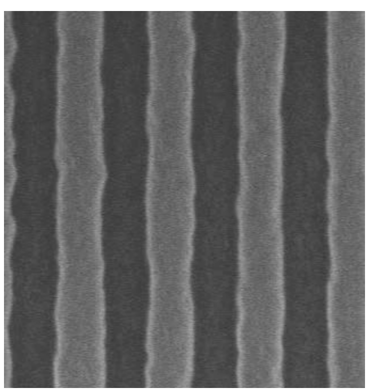
structure deviations

systematic (ridgewidth/-depth)

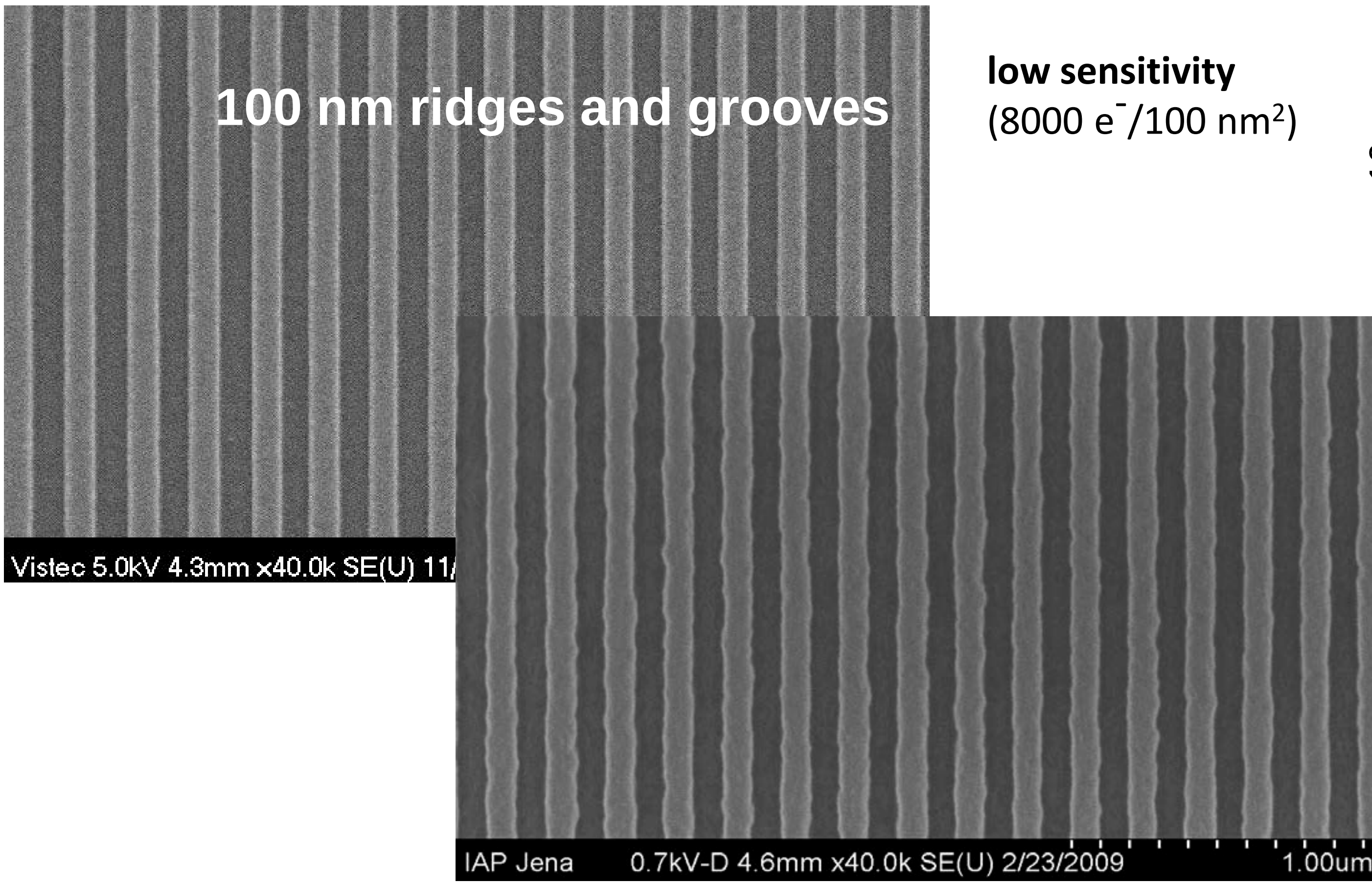
stochastic (line edge roughness)





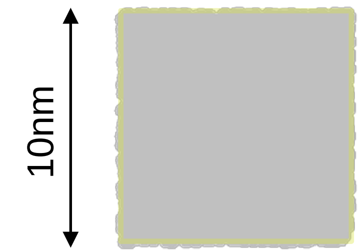


Line edge roughness due to particle statistics in the lithographic process

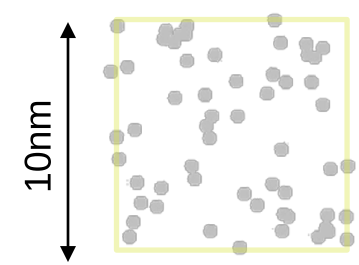


electron impacts

low sensitivity
(8000 e^-/100 nm^2)



high sensitivity
(60 e^-/100 nm^2)



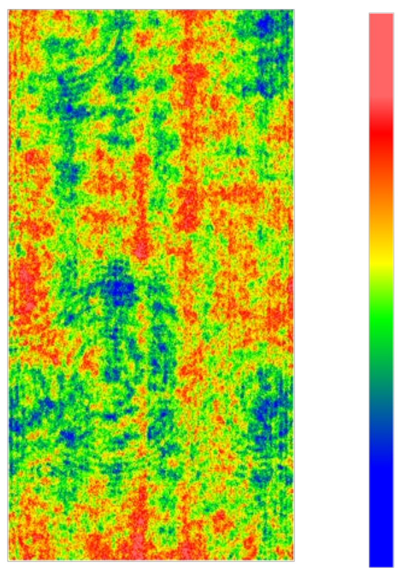
M. Heusingen, diploma thesis (2011)

Grating accuracy

wave-front measurement (1 µm period grating + technology, Littrow-Mount, λ=633 nm)

19 mm

50mm



+ 6.3 nm

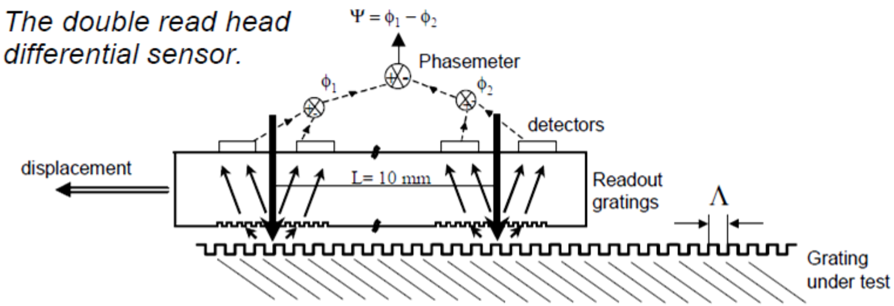
- 6.6 nm

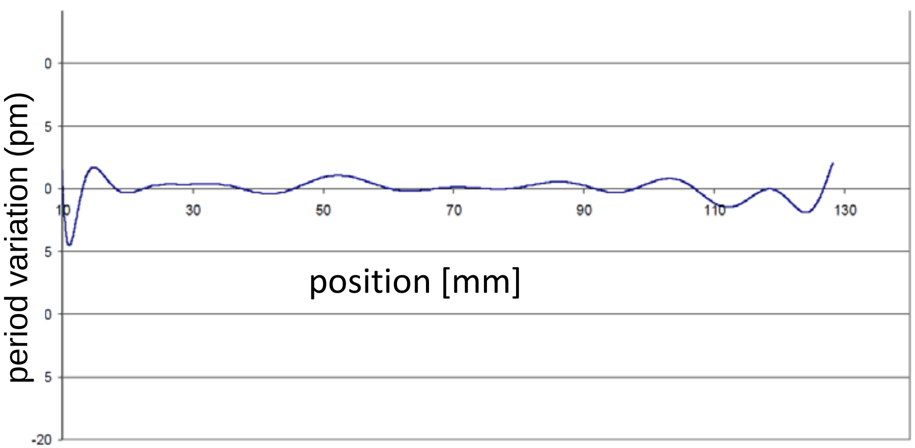
	wavefront	placement
PV	12.8 nm	< 10.3 nm
rms	1.4 nm	< 1.1 nm

significantly better than interferometric gratings

Report on the grating writing analysis
Laboratoire Hubert Curien CNRS - Fraunhofer IOF

The double read head differential sensor.





period variation < 5 pm

Sophisticated device for measurement of scattered light ALBATROSS at Fraunhofer Institute IOF

Measurements of scattered light at 1550 nm set up right now!

Summary

- RWGs capable of providing high reflectivity
- Experiments for higher R running
- Origin of optical losses to be identified
- Thermal noise to be investigated