Spectrometer gratings based on direct-write e-beam lithography

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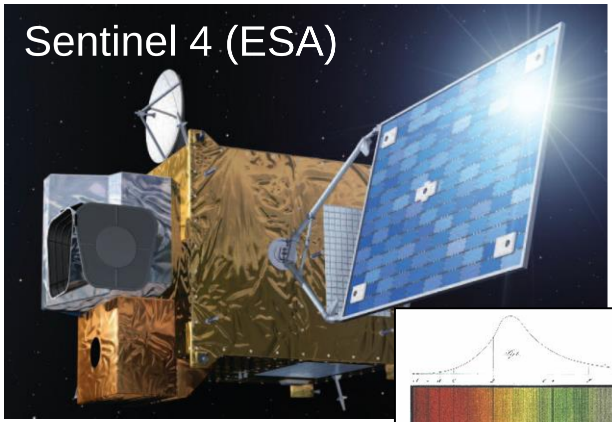
- Electron-beam lithography for grating fabrication
- Examples of astro-gratings:
  - CUBES UV-transmission grating
  - CarbonSat high-resolution gratings
  - Sub-λ structures for ultra-wide-band gratings

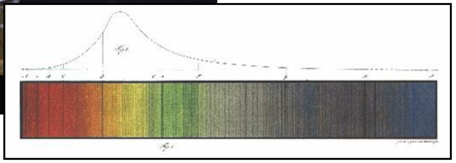
3µm

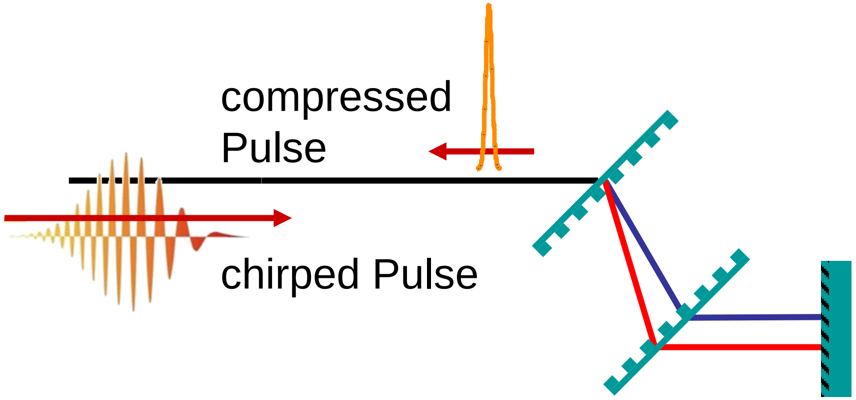
High Performance Applications of Gratings

Spectrometers for Astronomy and Earth Observation

Manipulation/Compression of Ultra-Short Laser Pulses



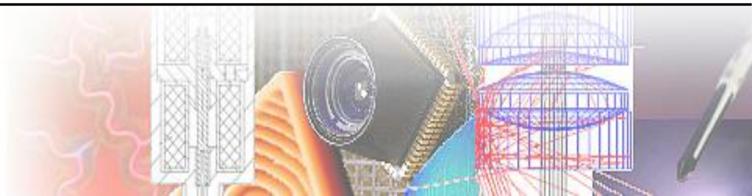




relevant parameters:

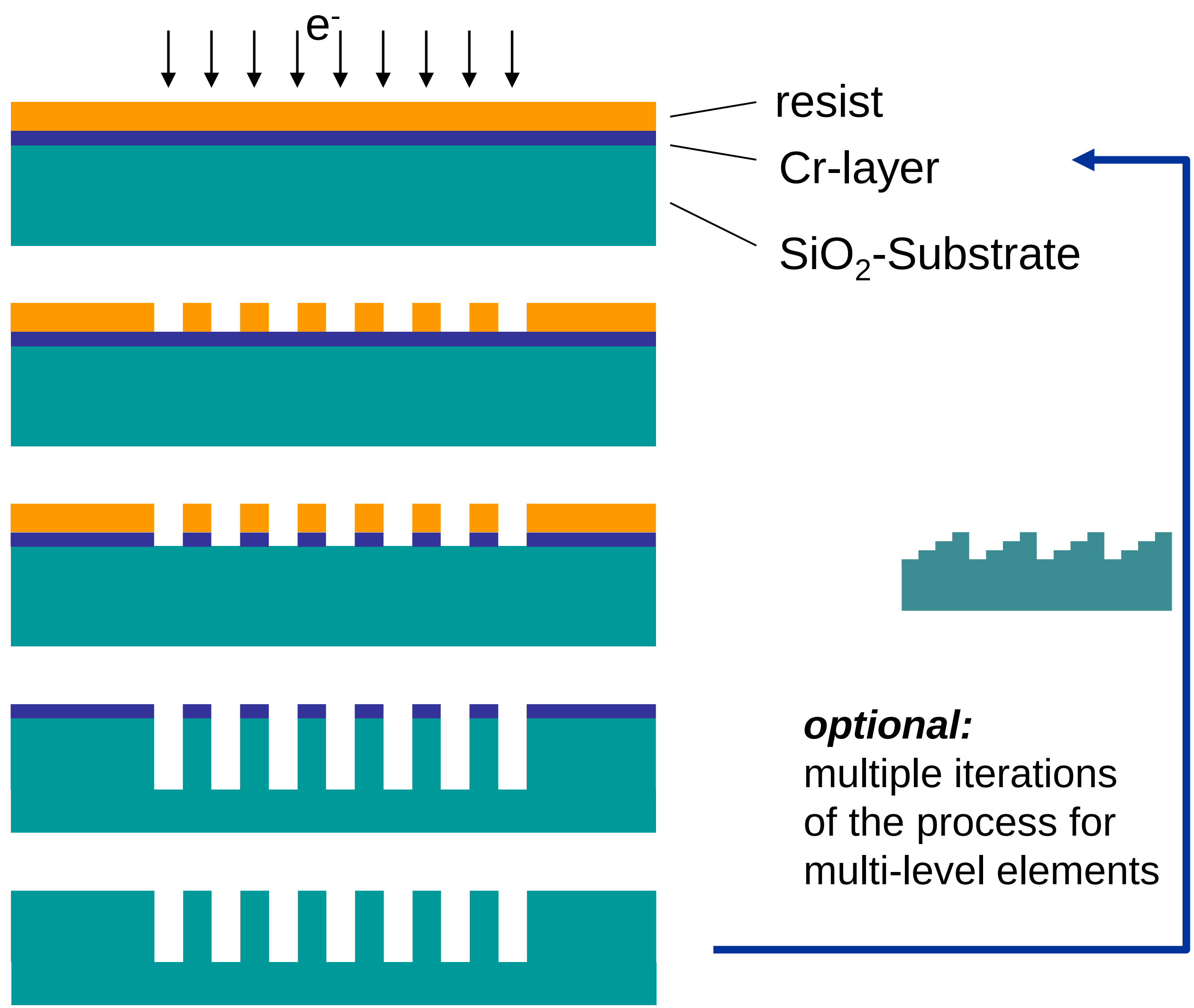
- spectral dispersion
- bandwidth
- efficiency / polarization
- wavefront
- straylight
- size, …

often extreme demands to obtain required performance

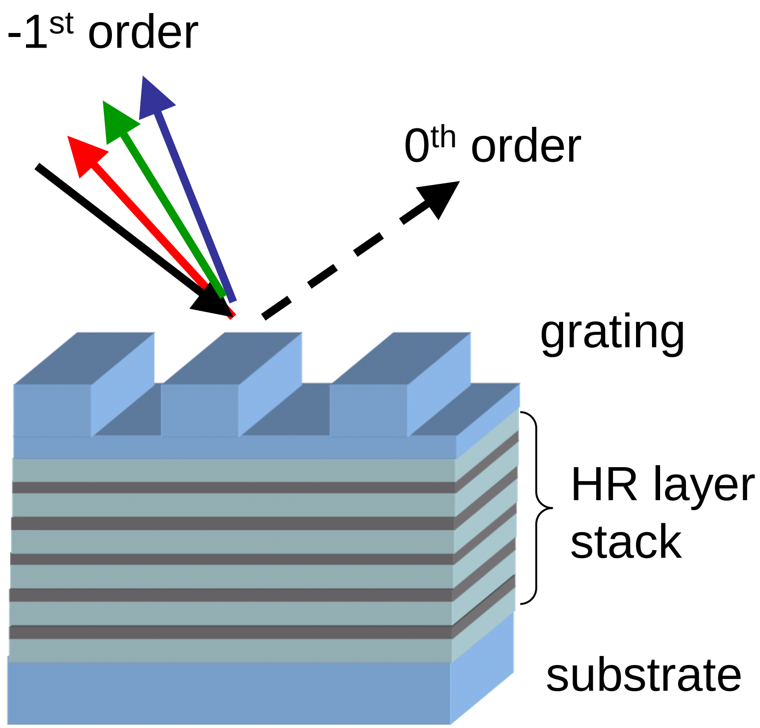


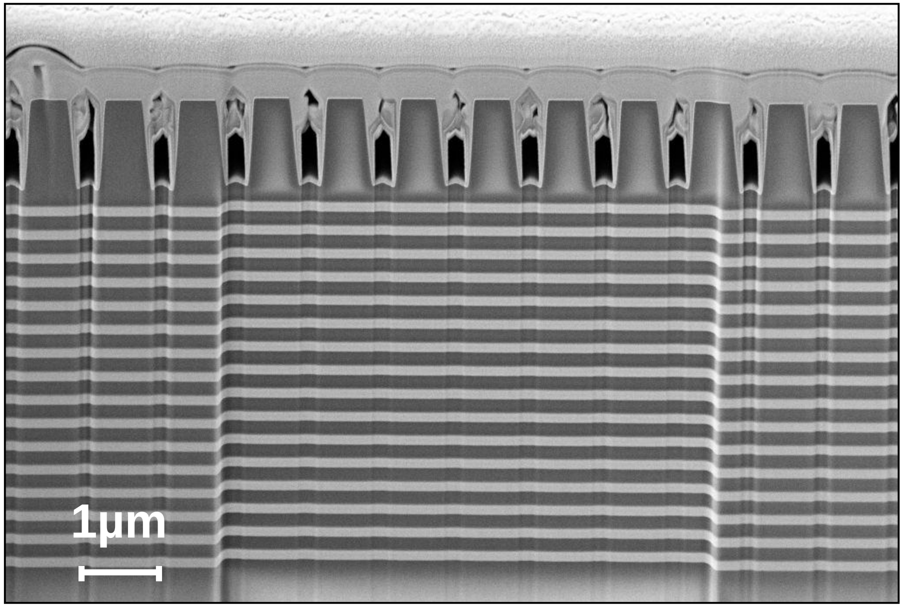
Grating Technology at the IOF

1. Resist exposure with e-beam lithography
2. Resist development
3. Chromium etching (RIE)
4. Deep etching into substrate (ICP)
5. Removal of Cr-layer



Gratings on dielectric layer stacks

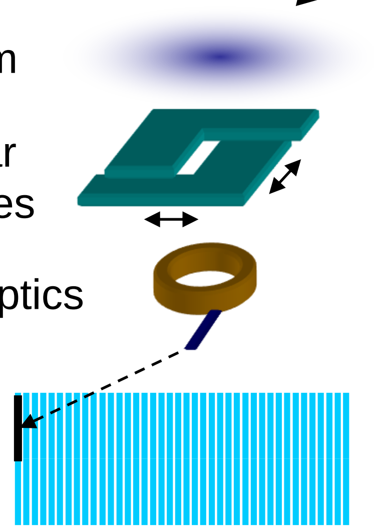




- highly efficient reflection gratings
- transmission gratings with tailored polarization properties

The Vistec SB350 OS e-beam writer

max. writing field:	300mm x 300mm
max. substrate thickness:	15mm
resolution (direct write):	**<50nm**
address grid:	1nm
stitching error:	**< 12nm P-V / < 2.2nm RMS**
placement error:	**< 14nm P-V**
writing strategy:	variable shaped beam / cell projection

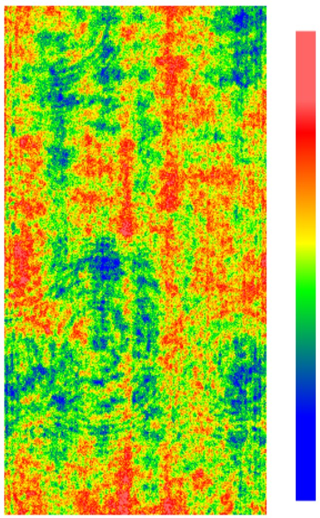


very fast writing process!

huge flexibility to tailor the structure parameters!

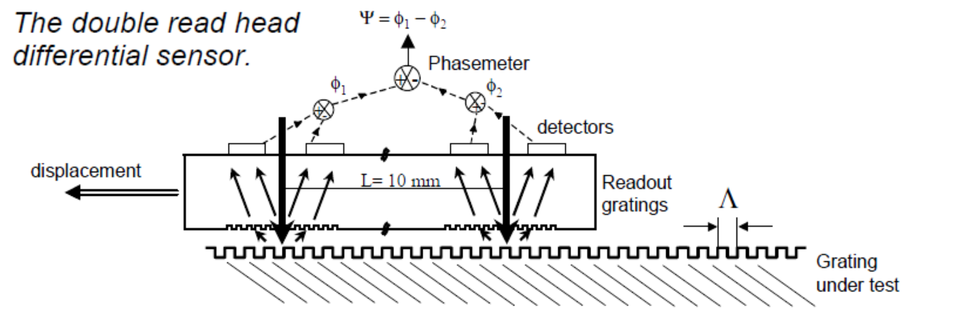
Key Performance: Writing Accuracy

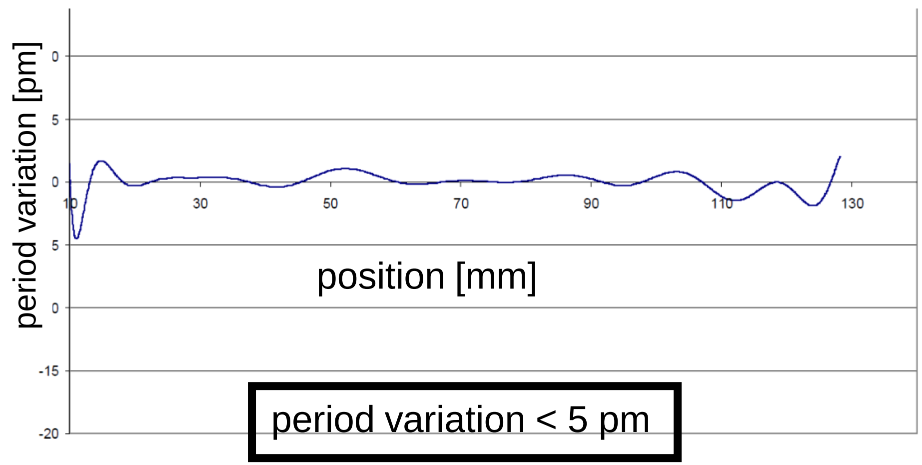
wave-front measurement
(1µm period grating + technology, Littrow-Mount)



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

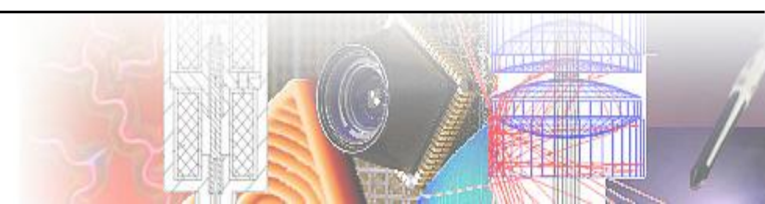
Report on the grating writing analysis
Laboratoire Hubert Curien CNRS - Fraunhofer IOF





Applications requiring this accuracy

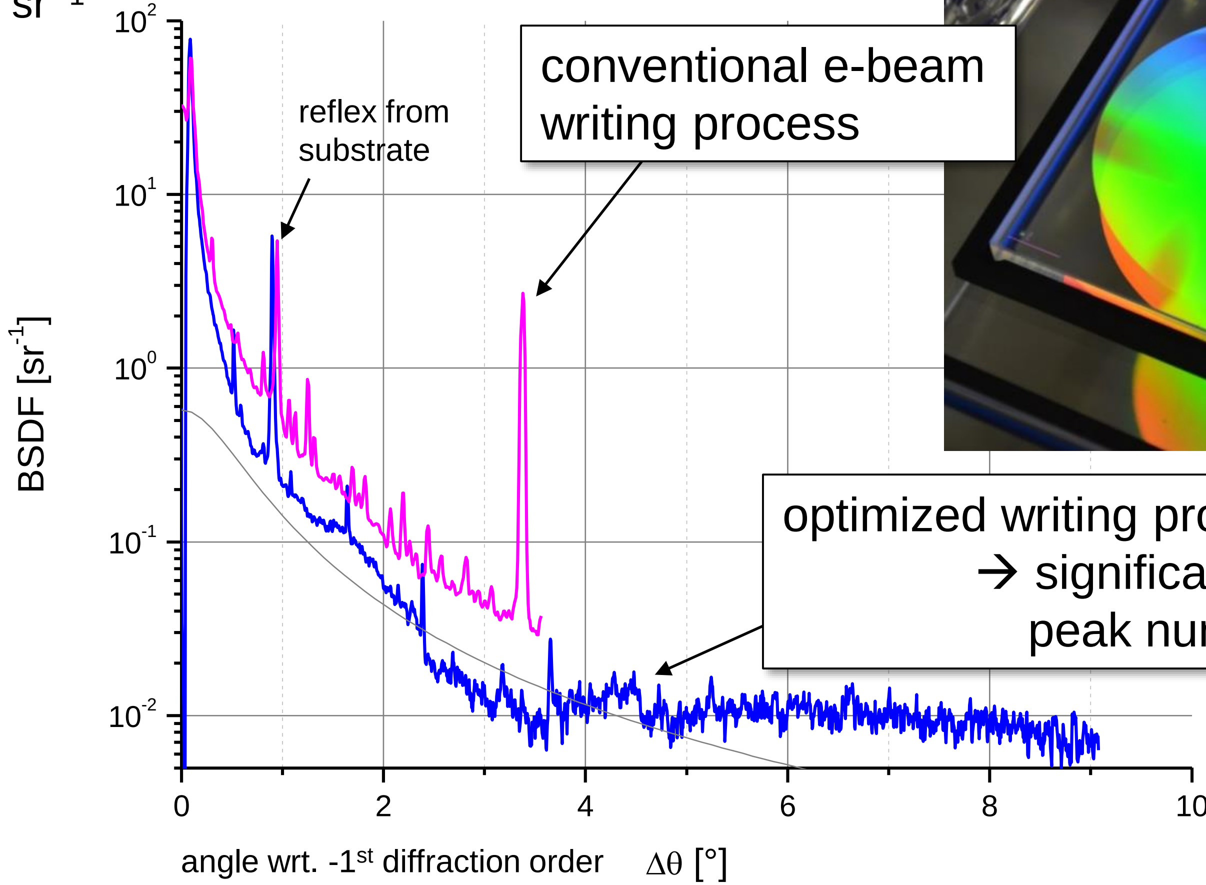
- Asphere-Test CGH
- Puls compression gratings
- Spectrometer gratings (space application)

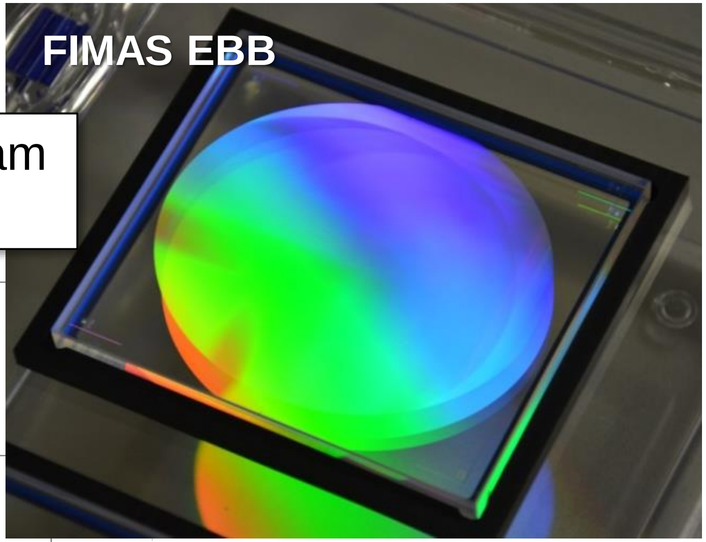


Accuracy of writing process: straylight

Optimization of e-beam writing process

BSDF of -1st DO:
51526 sr $^{-1}$





Examples of realized spectrometer gratings

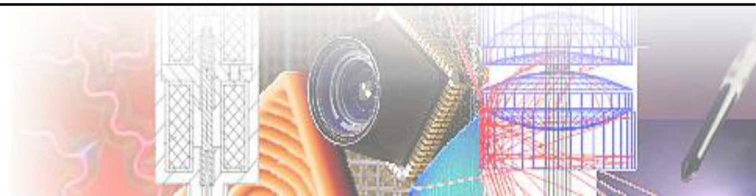
CUBES – UV Transmission Grating

- CUBES (Cassegrain U-Band Brazilian ESO-Spectrograph

- Requirements:
  - spectral band: **300nm – 400nm**
  - line density: 3448 lines/mm → **p=290nm**
  - AOI: 31°
  - grating size: 250 x 250 mm^2 ; mosaic of 2x [250mm x 130mm]

- Challenges:
  - **commercial VPH gratings difficult in the UV**

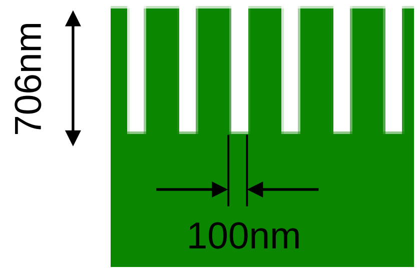
- Solution:
  - **Binary fused silica gratings**

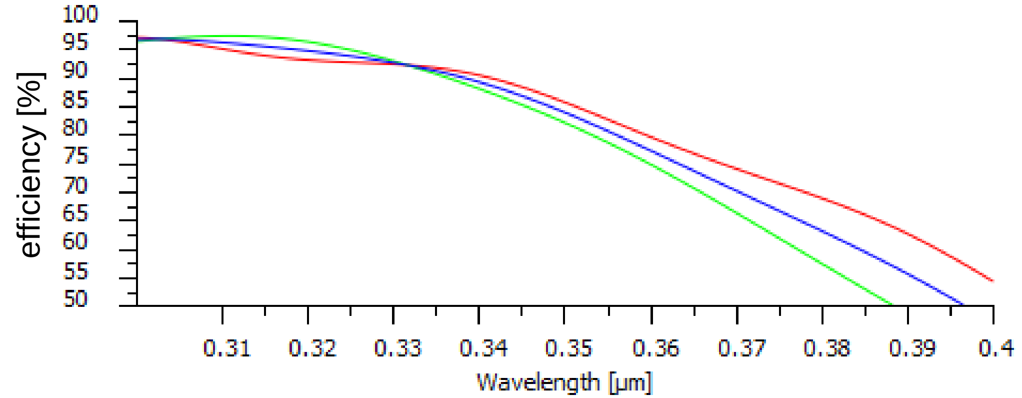


ESO Cubes Spectrometer

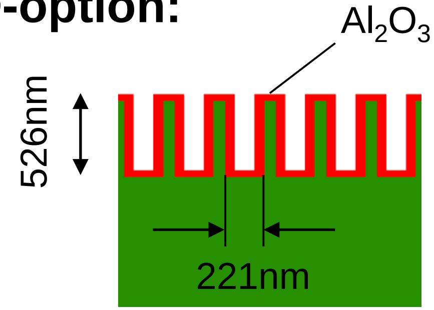
Grating parameters: wavelength: 300nm ... 400nm
period: 290nm

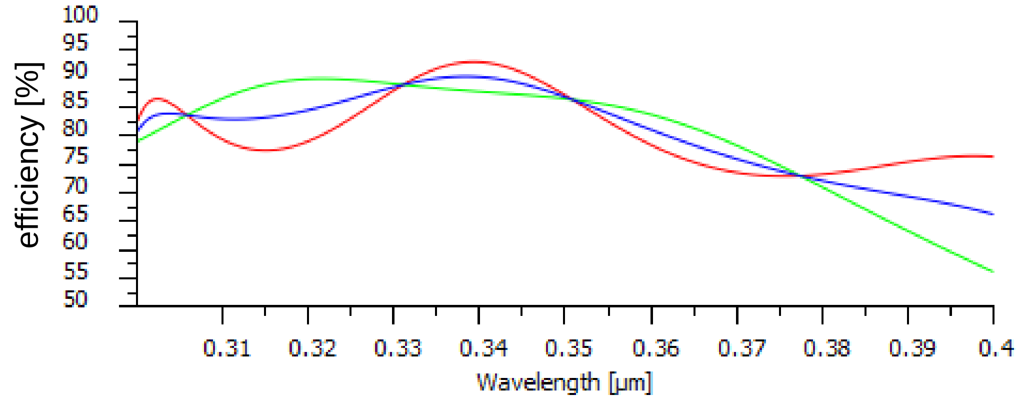
SiO_2-option:

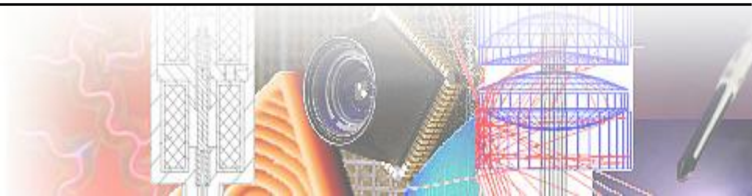




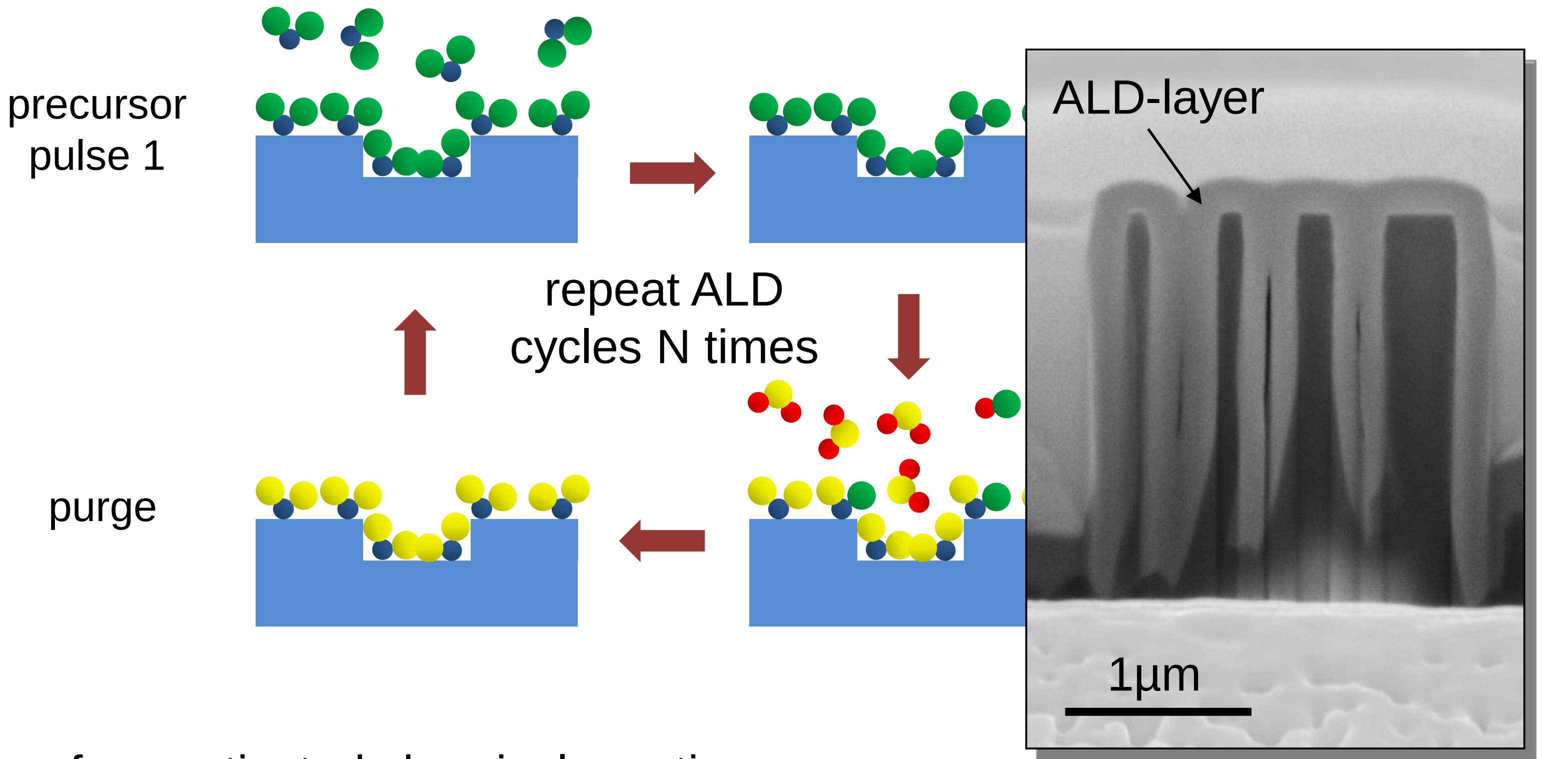
ALD-option:





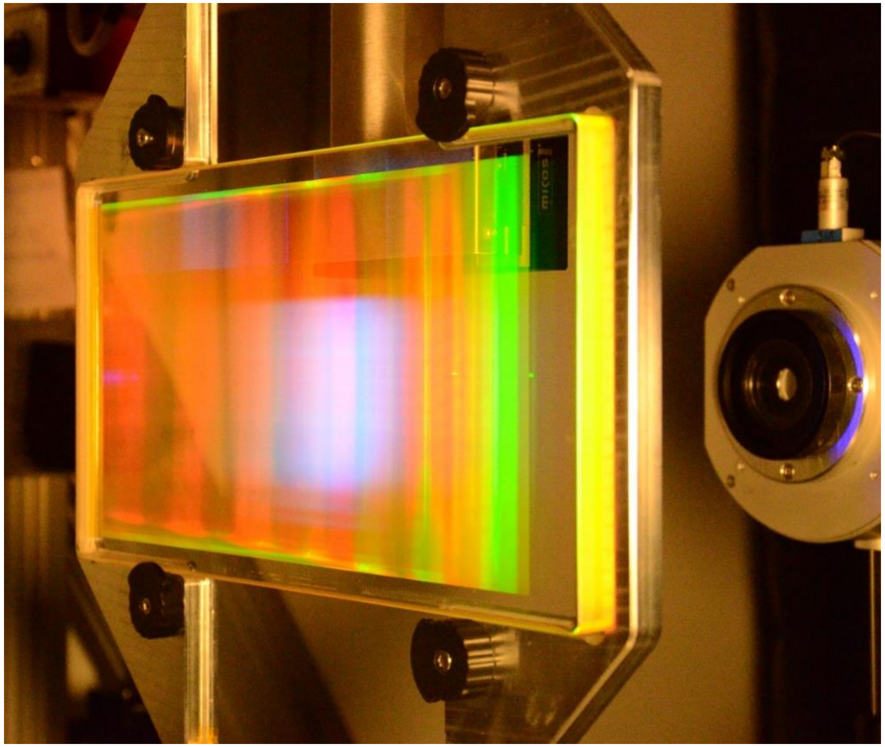


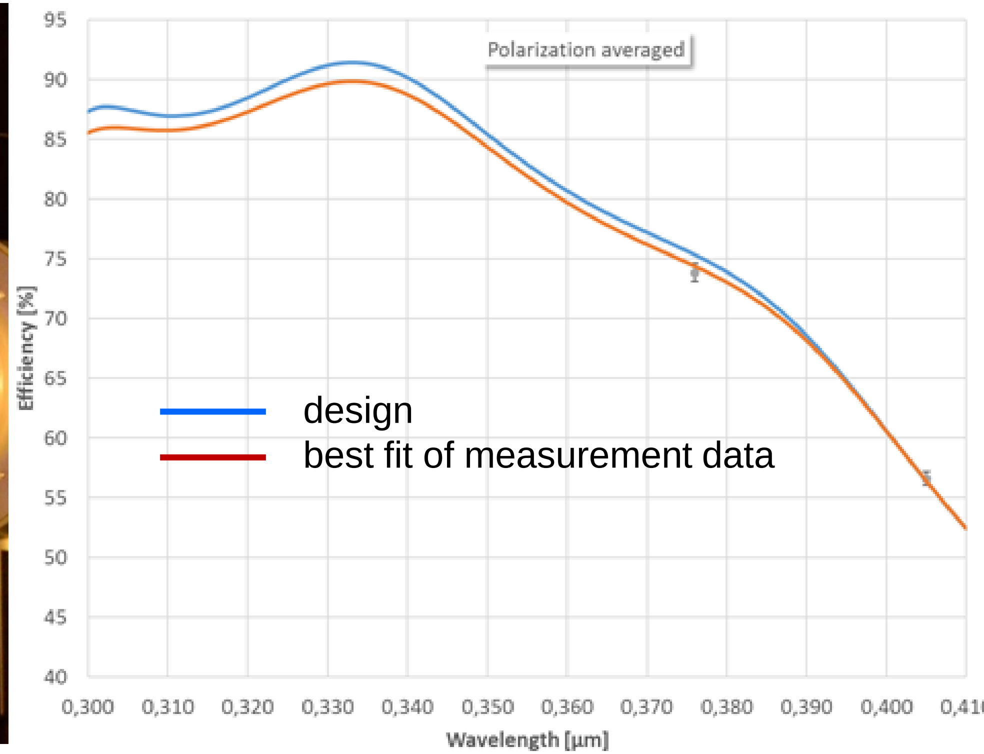
Atomic-Layer-Deposition (ALD)



- surface activated chemical reactions
- **conformal overcoating** of surface reliefs
- large number of materials possible, e.g. TiO_2, Ta_2O_5, Al_2O_3, HfO_2 …

CUBES – UV Transmission Grating

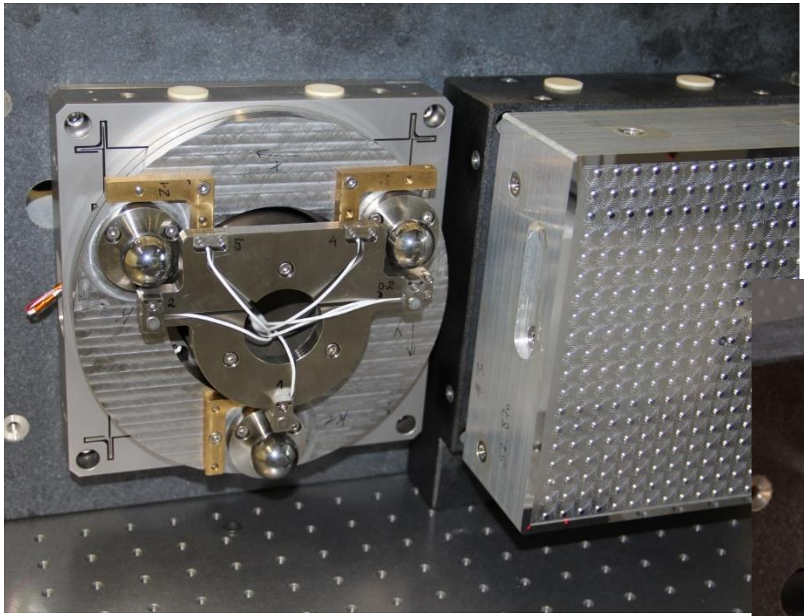




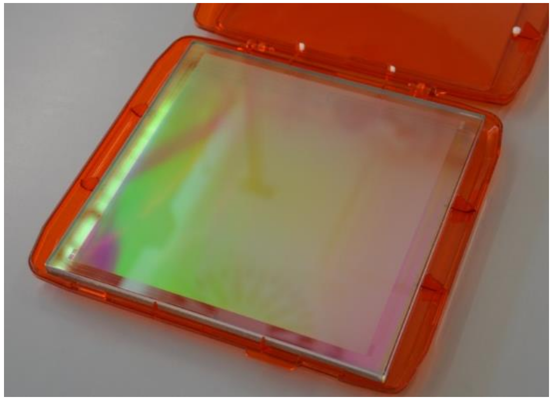
realized grating during efficiency measurement

grating size: 250mm x 130mm

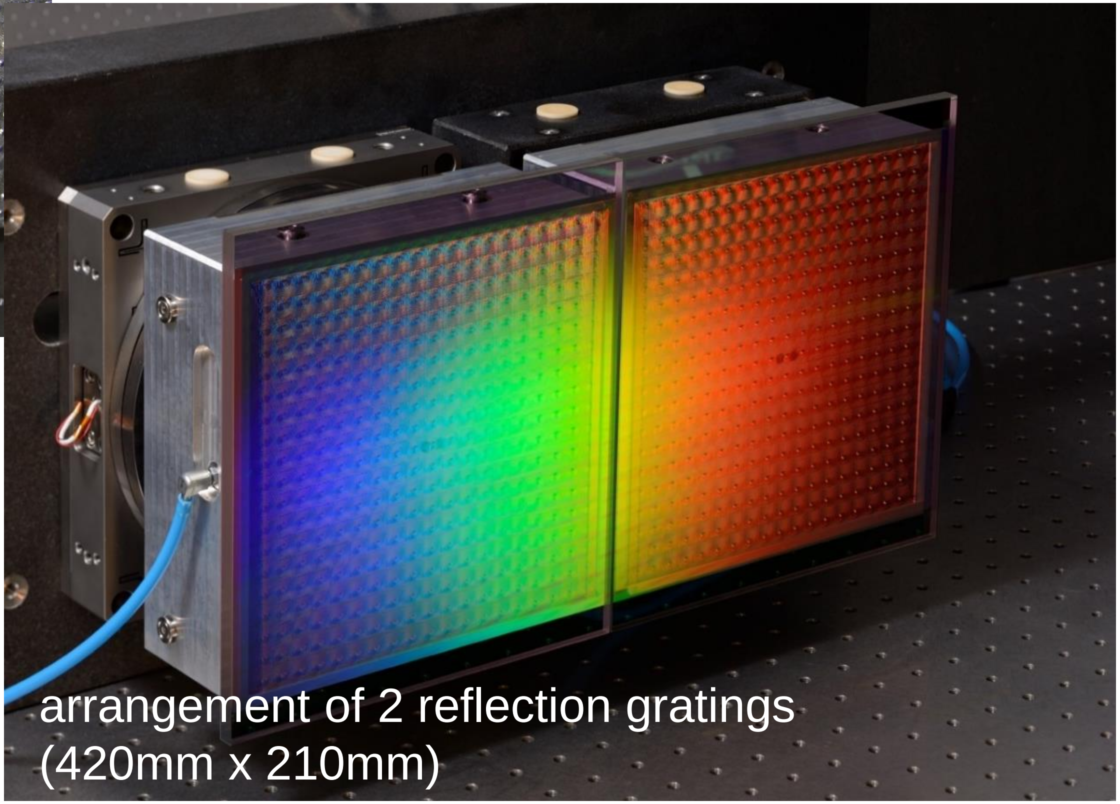
Tiling for Larger Gratings



active alignment for
wave-front optimization



single grating
210mm x 210mm

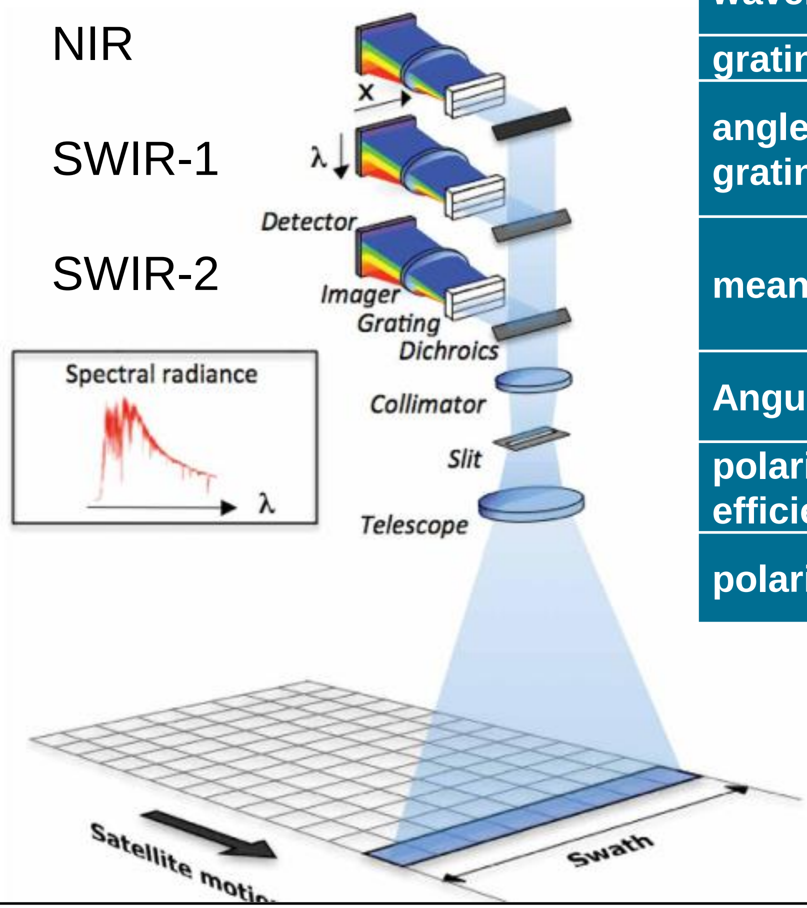


arrangement of 2 reflection gratings
(420mm x 210mm)

→ **also possible for transmission gratings**

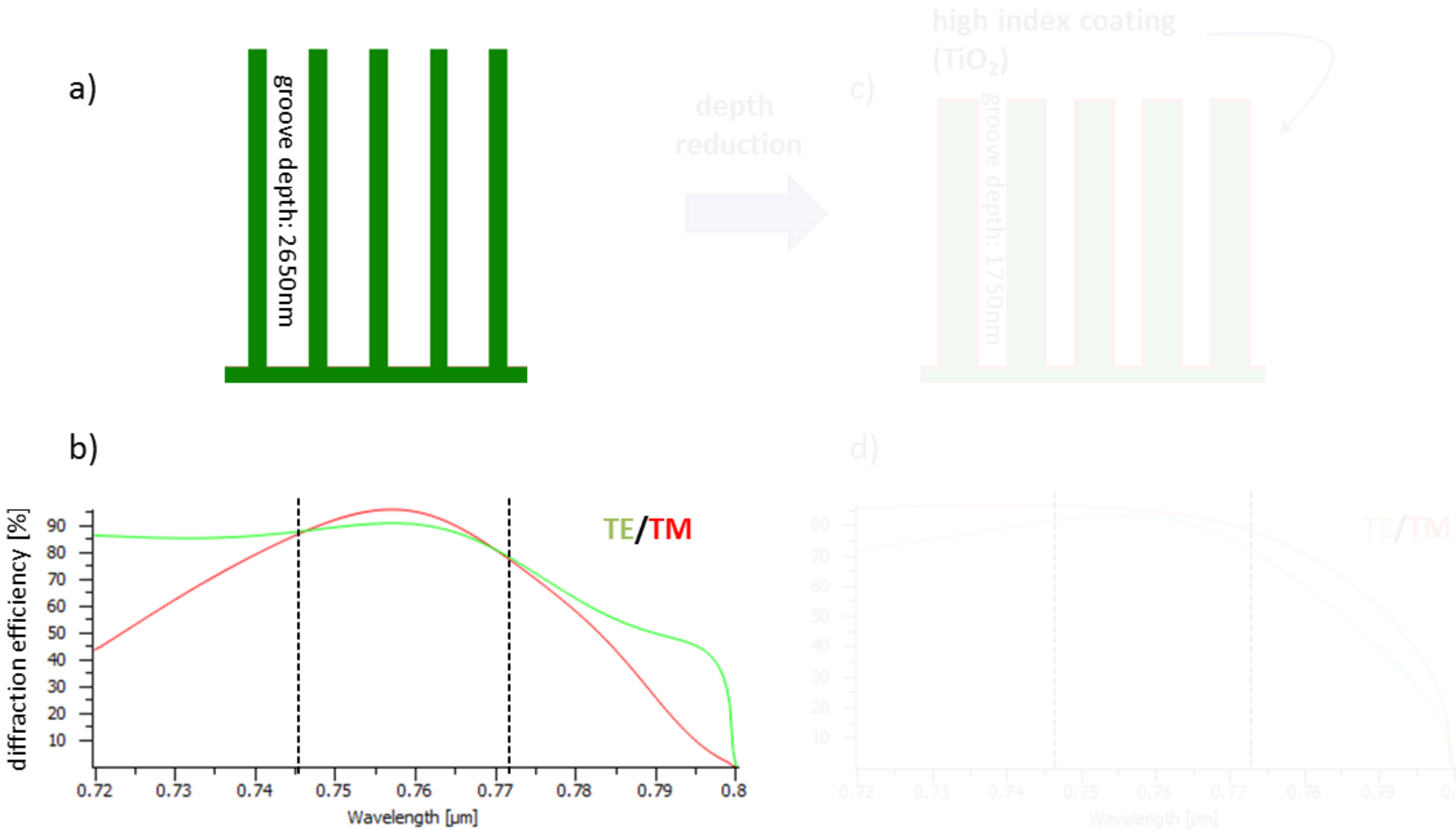
Carbon Monitoring Satellite (CarbonSat)

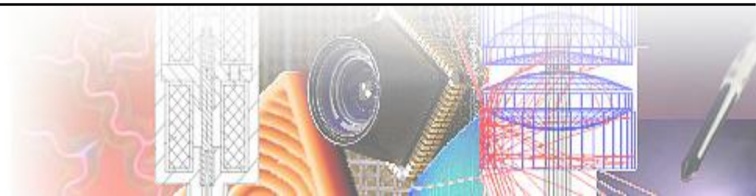
instrument concept:



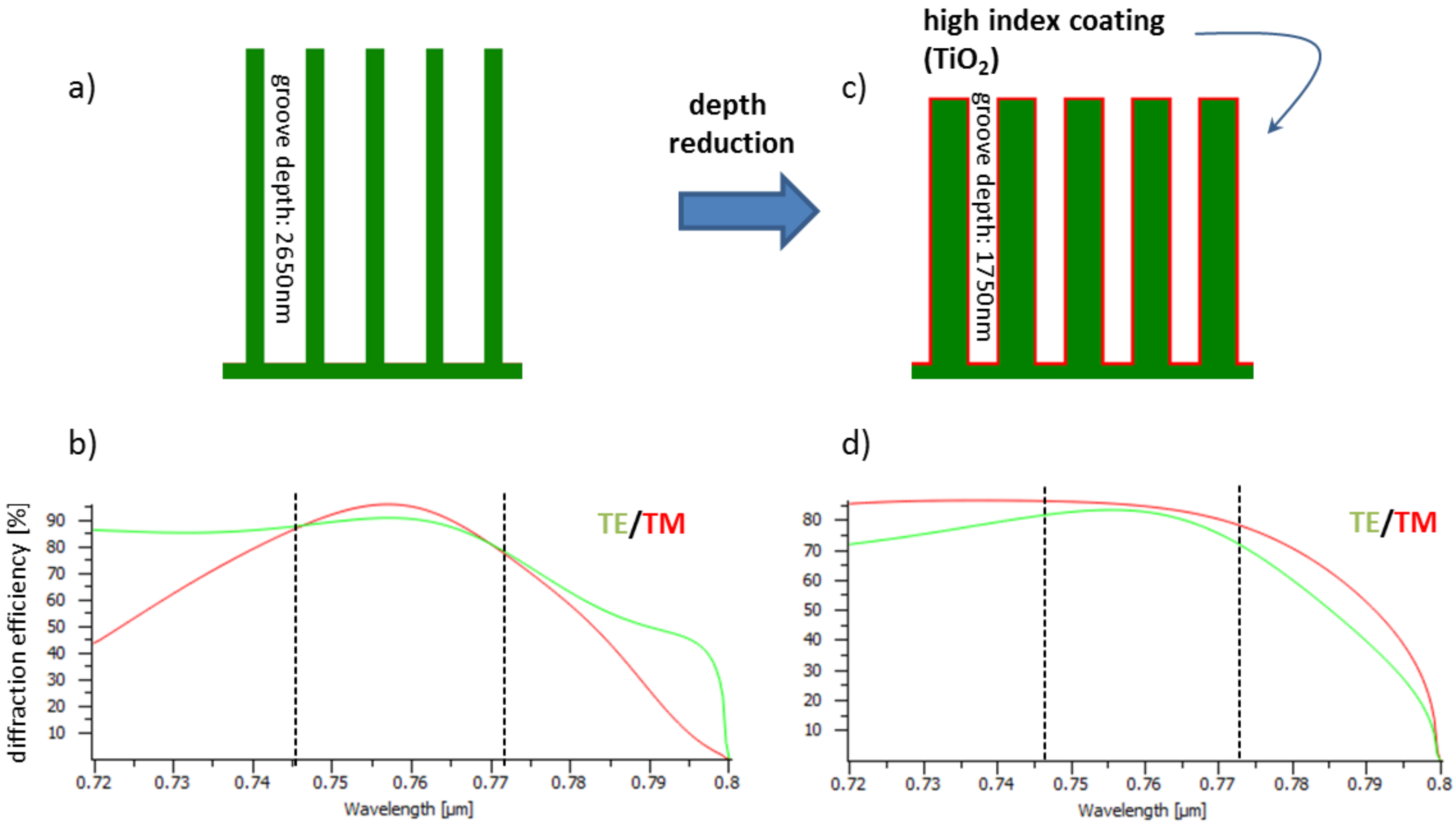
Parameter	NIR	SWIR-1
wavelength	747nm …773nm	1590nm …1675nm
grating period	423nm	991nm
angle of incidence to the grating (equivalent in air)	**63.6°**	**55.5°**
mean angle of diffraction	Transmission Gratings in -1. order Littrow configuration	
Angular dispersion	**0.3° / nm**	**0.1°/nm**
polarization avg. efficiency	>70%	>70%
polarization sensitivity	**<10%**	**<10%**

NIR – High Resolution Transmission Grating





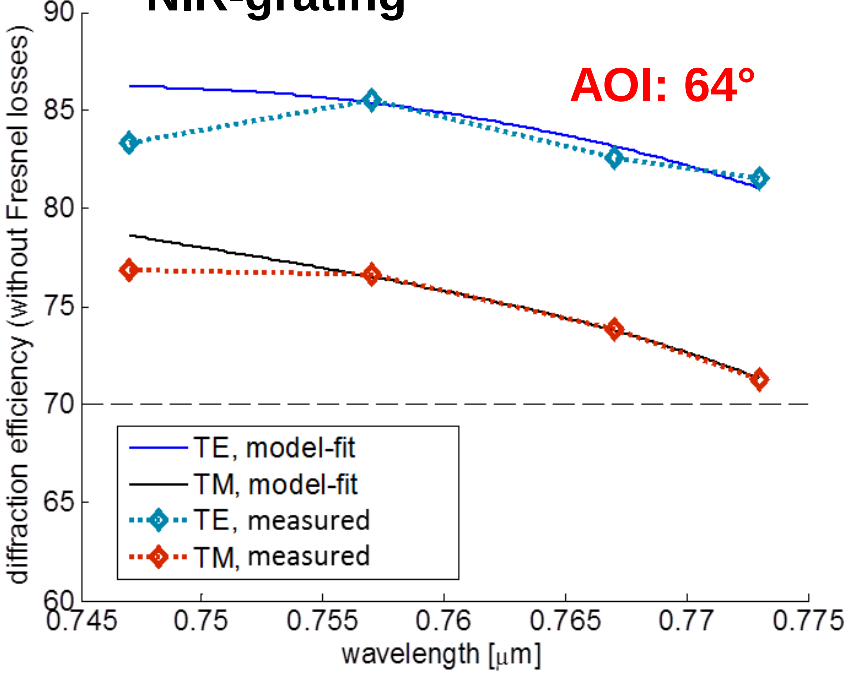
NIR – High Resolution Transmission Grating

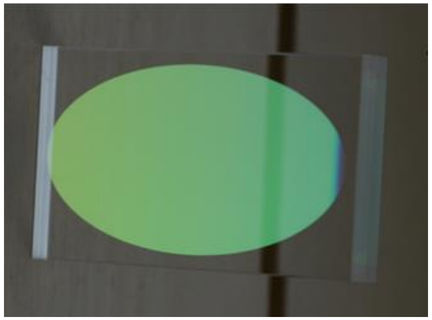


use high-refractive-index (dielectric) coating to reduce depth

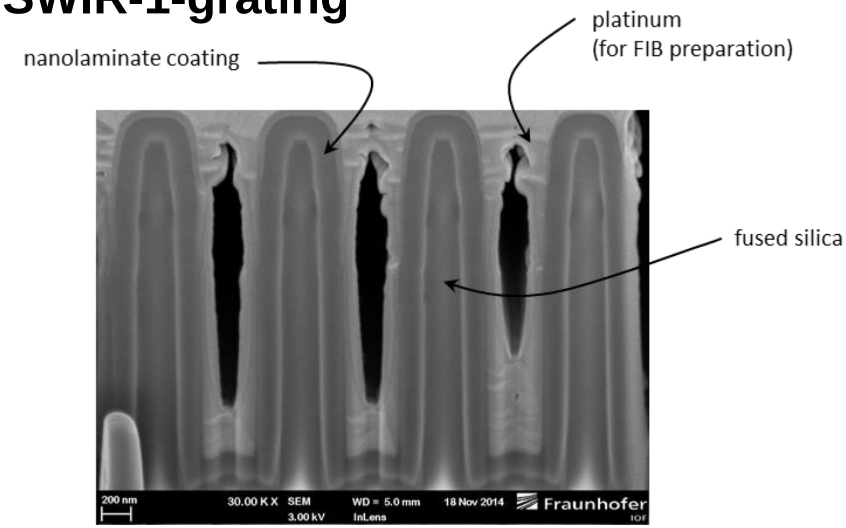
Optical Performance

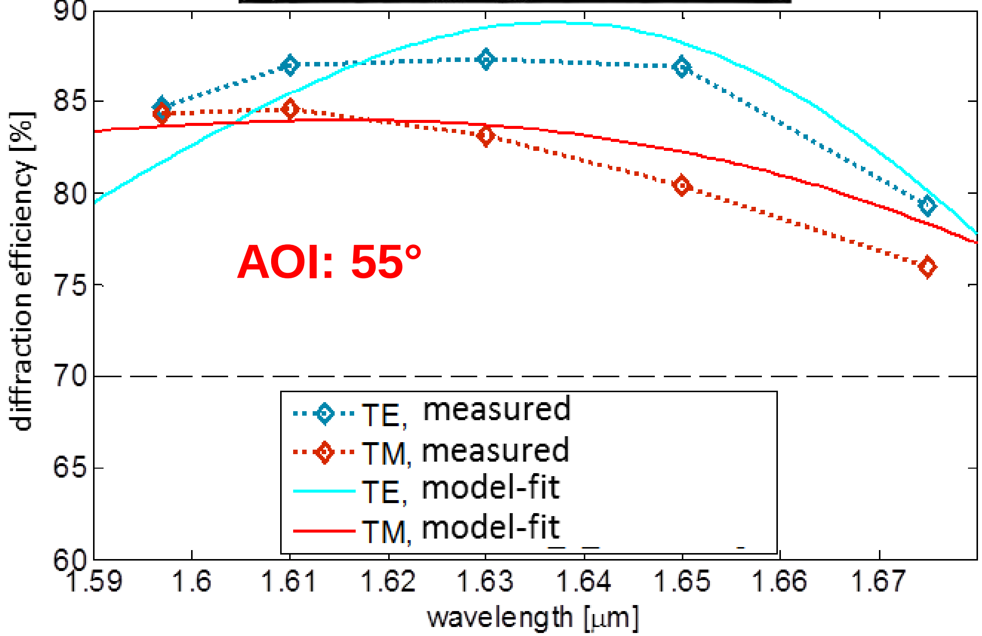
NIR-grating





SWIR-1-grating





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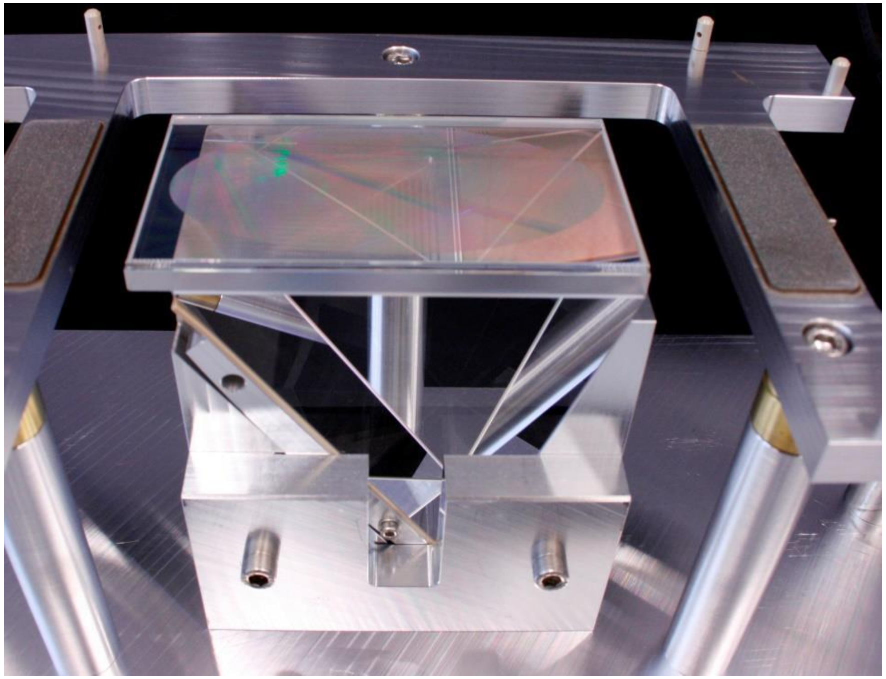
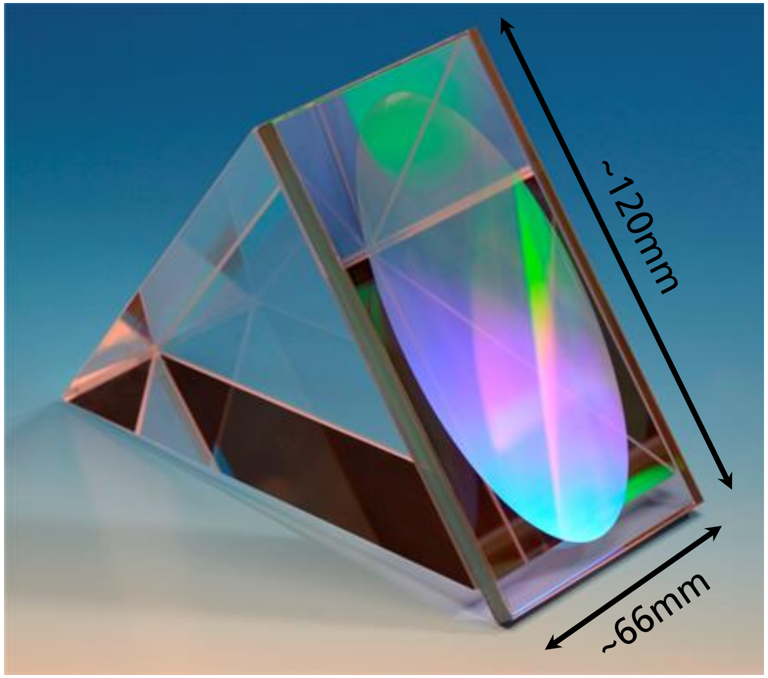
Fraunhofer IOF

Direct Glass-to-Glass Bonding

Advantages: adhesive free glass-to-glass connection
no additional optical interface



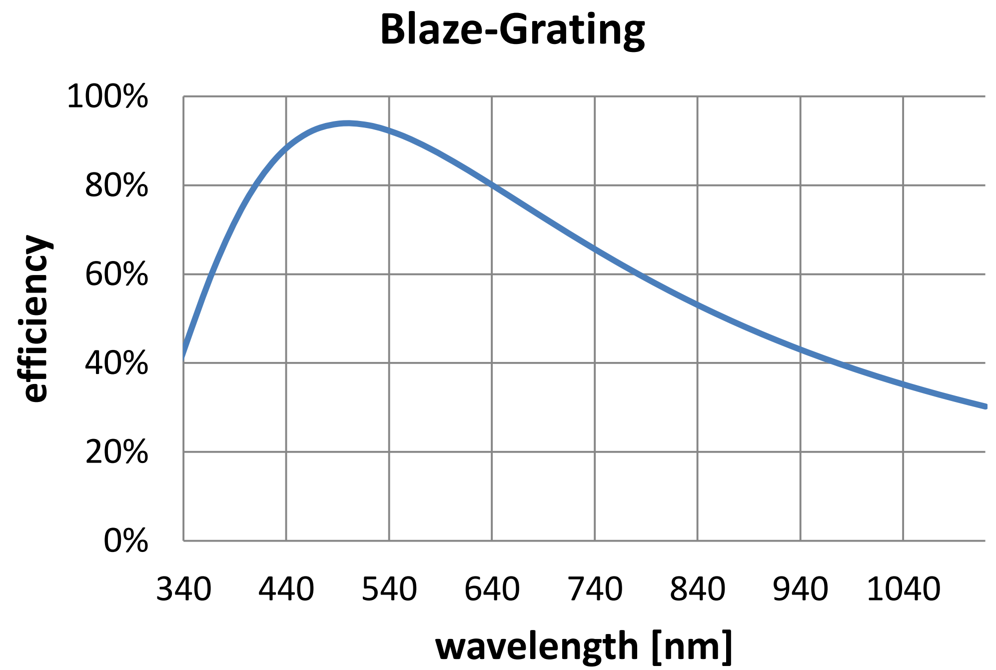


- achieved alignment accuracy: 0.25mrad (< 1 arcmin)
- **bond strength up to 2/3 of bulk fused silica**
- current TRL: 6

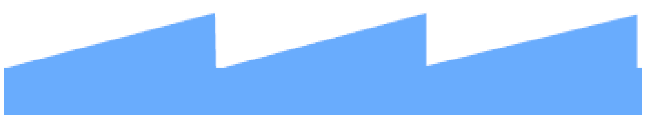
Wide-Band Gratings

- typical requirements for a low-resolution, broad-band disperser
  - spectral range: several 100nm
  - AOI: near-perpendicular incidence
  - period: few µm

classical approach



- blazed-grating in low order (saw-tooth profile)

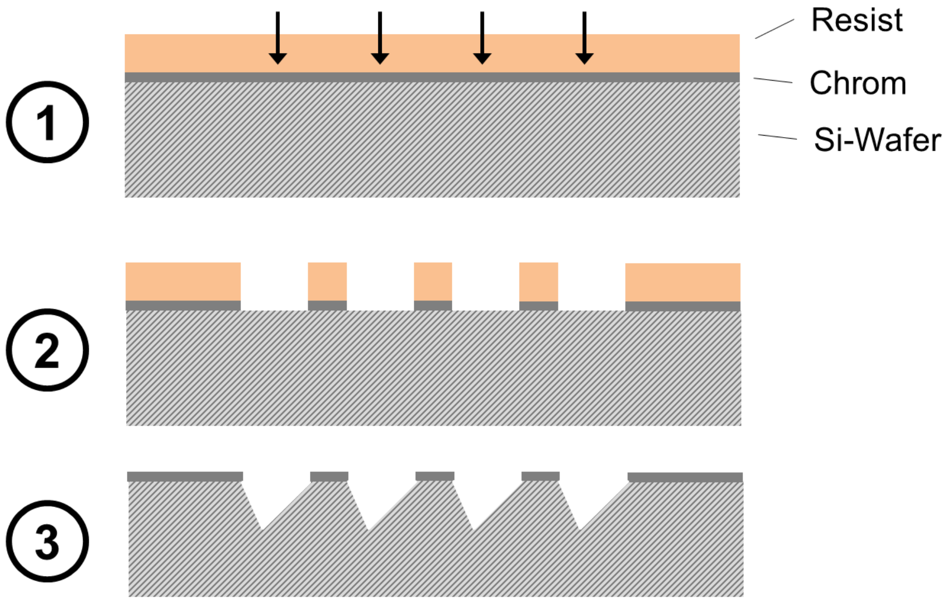


Echelle or Echellette Structures

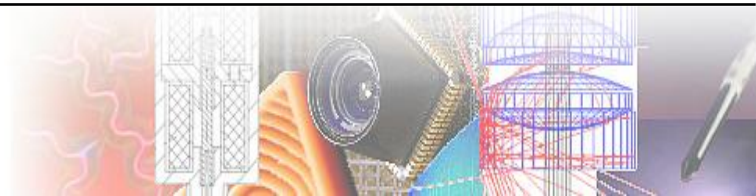
Electron Beam Lithography

Ion Beam Etching of Mask

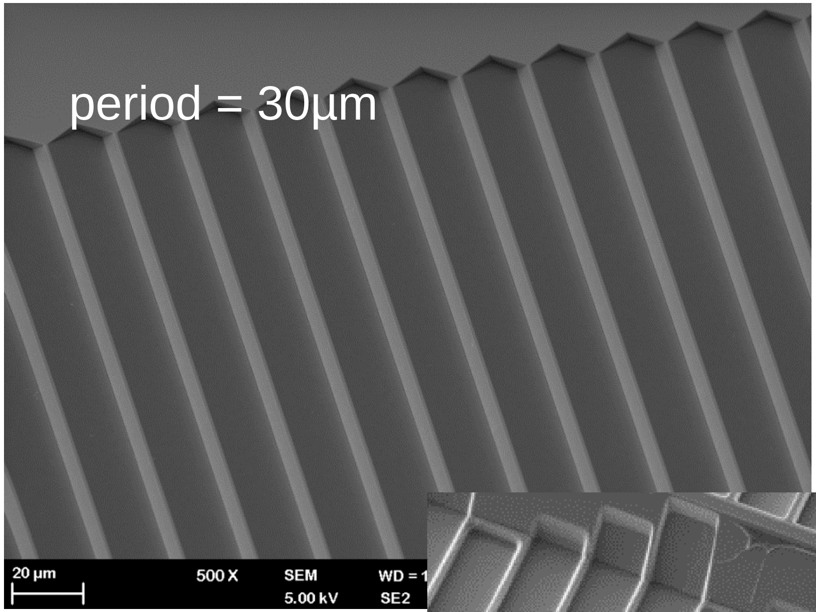
Wet Chemical Etching of Silicon

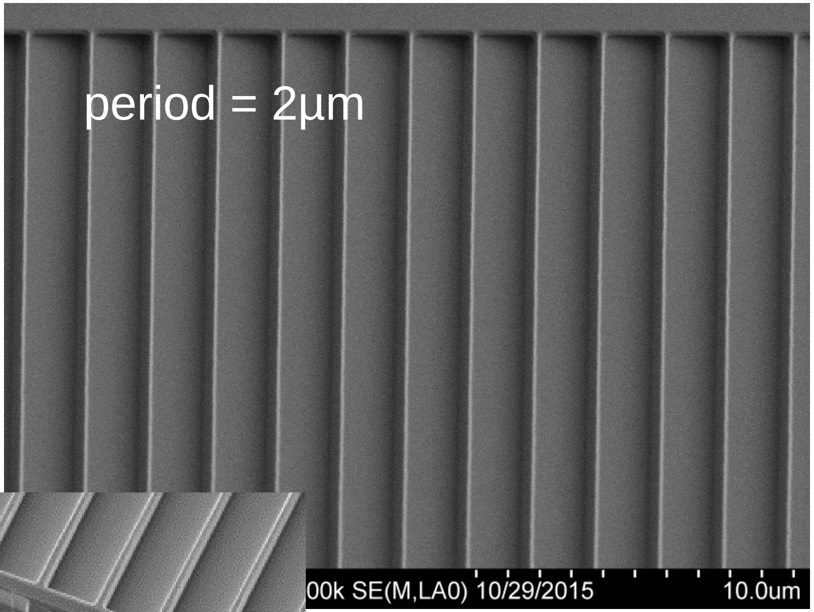


„Blaze Angle“ can be adjusted by crystalline orientation of Silicon substrate

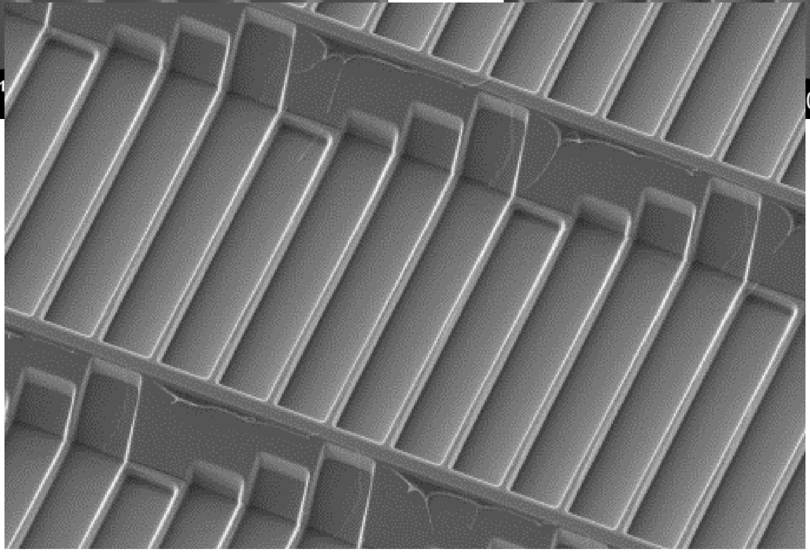


Echelle or Echellette Structures





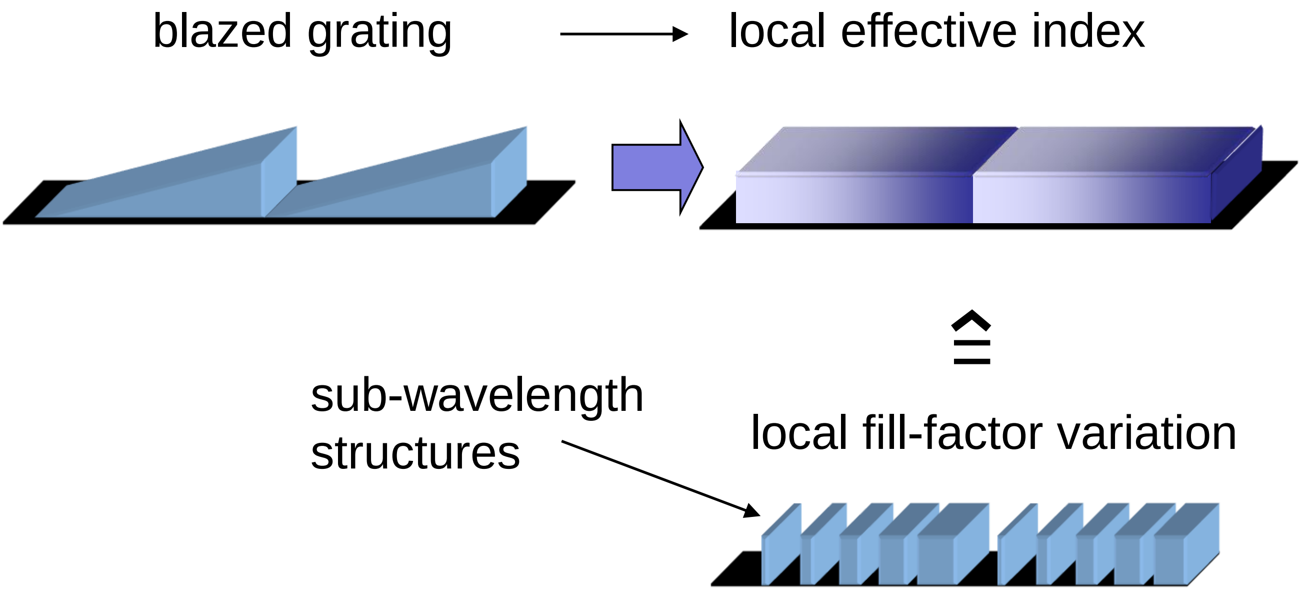
also lower line densities possible

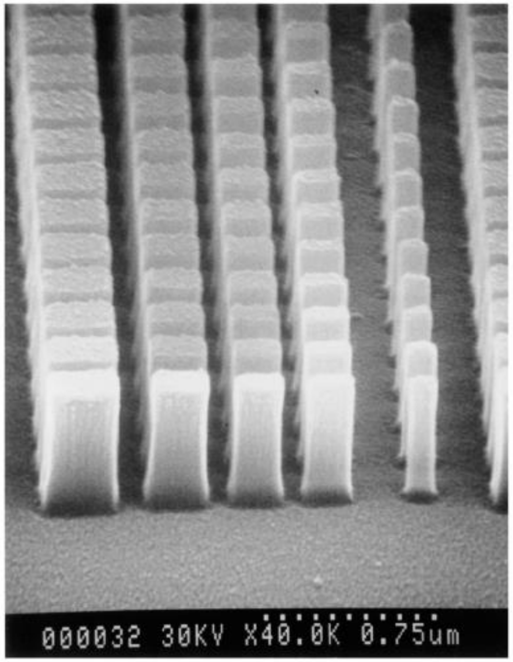


integrated cross-dispersion grating by direct-write structuring

Alternative: Effective Index Gratings

→ sub-wavelength pattern with varying fill factor



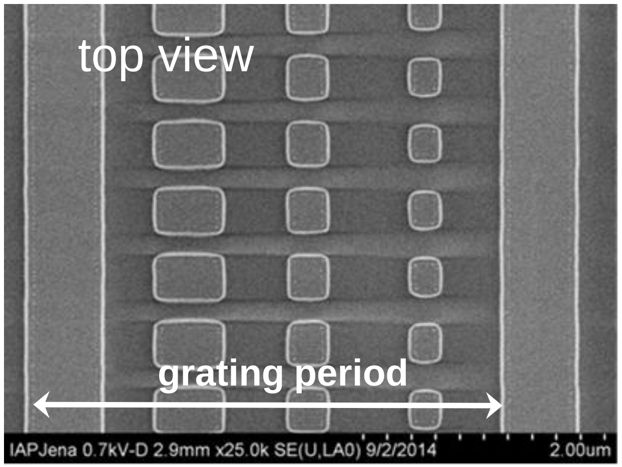


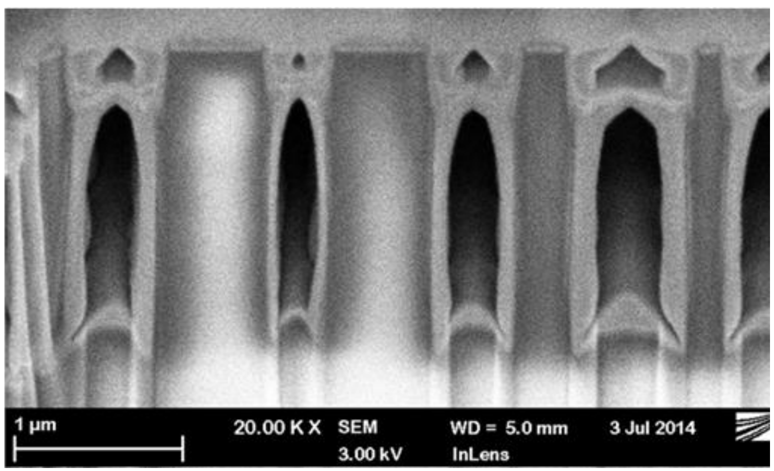
Ph. Lalanne et al. 1998

Advantages: **only one lithography step**
tailoring of dispersion properties

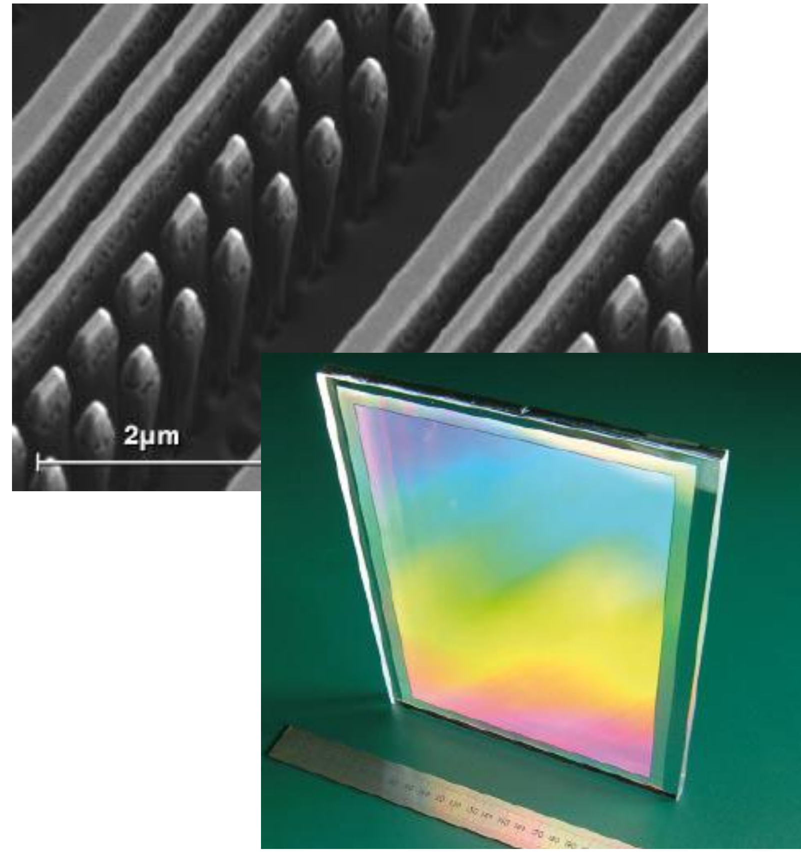
Effective Medium Gratings

FLEX (fluorescence explorer); [500nm – 800nm]





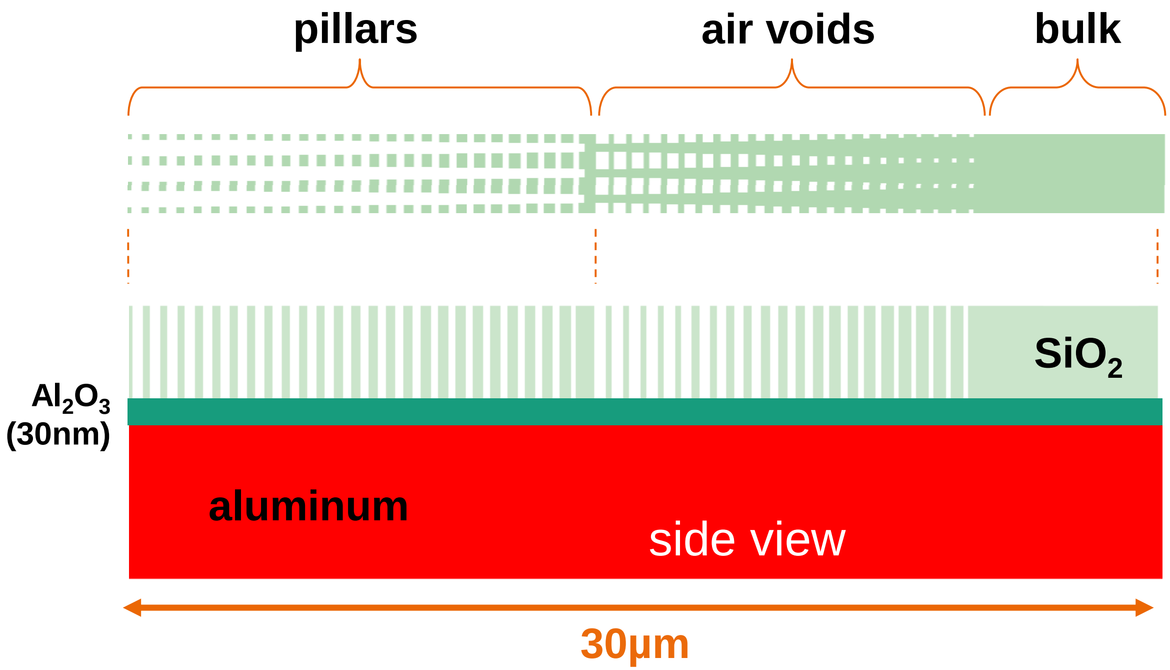
GAIA (global astrometic interferometer for astrophysics); [750nm – 800nm]

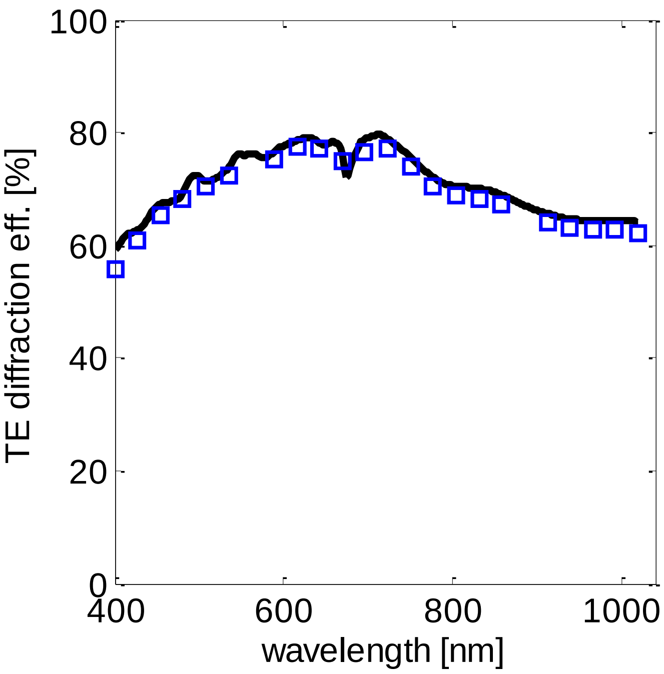


Wide-Band Reflection Grating

- typical requirements
  - based on a concave grating
  - spectral range: **340nm – 1050nm**
  - AOI: 0.5°
  - period: 30µm

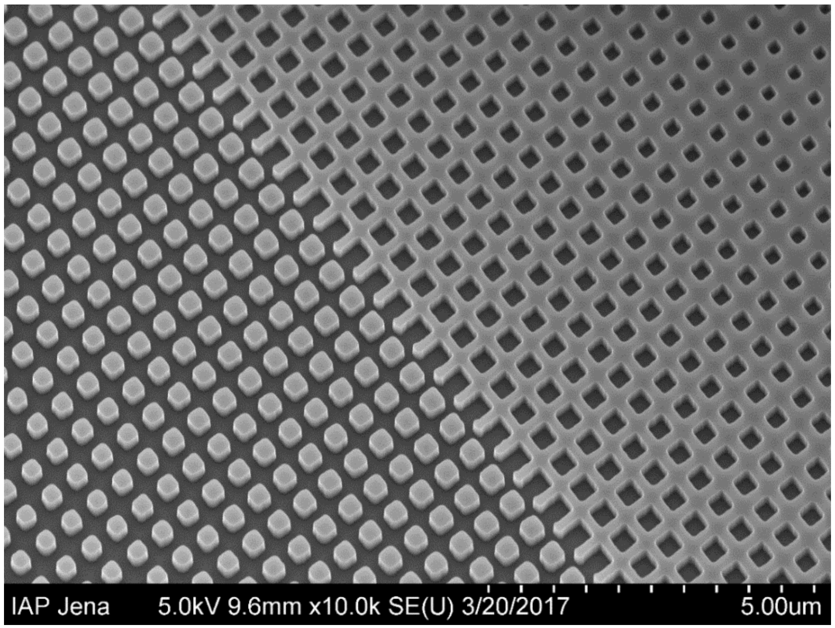
- ***effective medium approach***



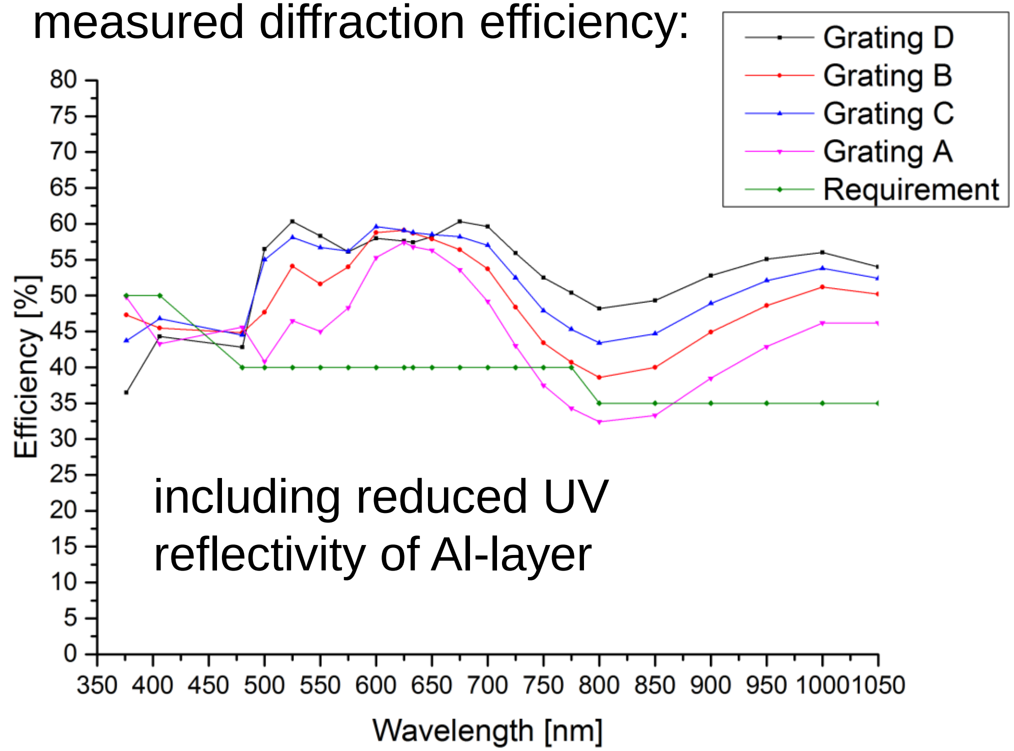


Wide-Band Reflection Grating …

… realized by E-beam lithography

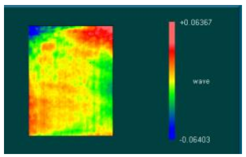


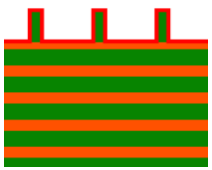
measured diffraction efficiency:

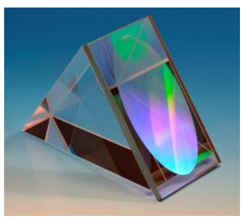


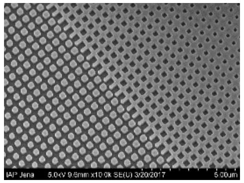
→ very weak spectral dependency of diffraction efficiency

Summary









- Direct write **electron-beam lithography** has a **huge potential** for the realization of high-performance gratings

Sub-period engineering by combining
E-Beam lithography and Atomic-Layer-Deposition L

To make use of the large flexibility and the advantageous optical properties requires talking with the grating manufacturer already during the design of the instrument !!!
(not after PDR…) L

- Examples are:
  - **high resolution** gratings with **low polarization sensitivity**
  - **echelle-type gratings** with **integrated cross-disperser**
  - **ultra-wide-band gratings** for lower resolution spectrometers