Immersed diffraction gratings for the Sentinel-5 earth observation mission

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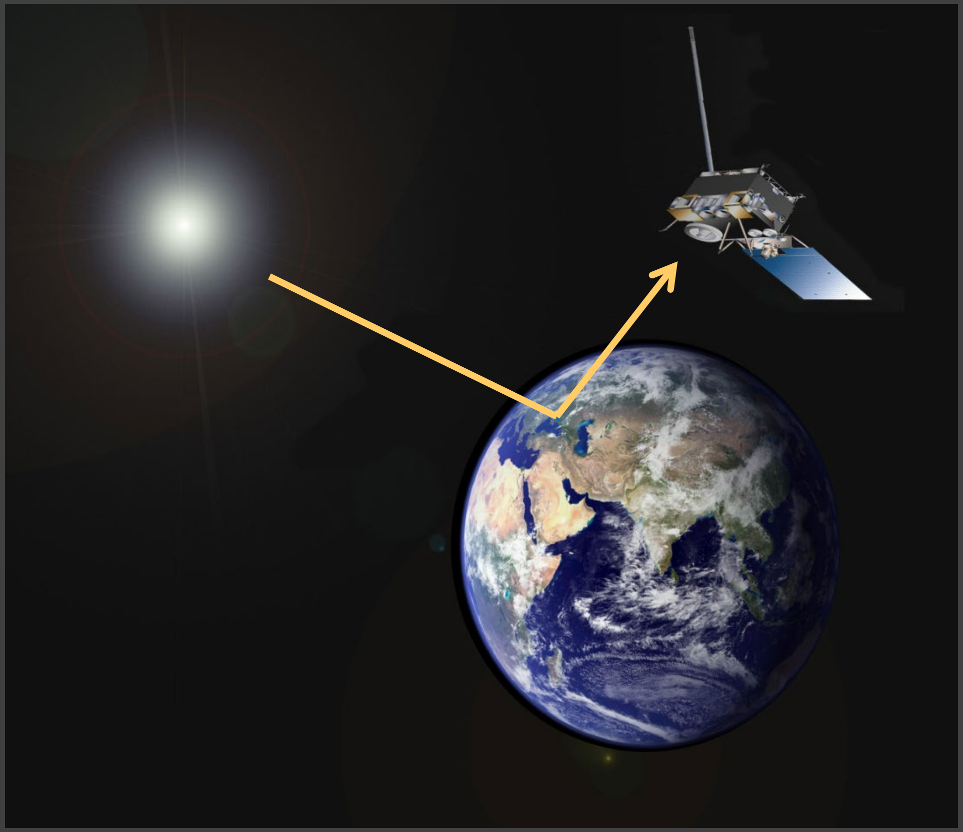
Introduction

SRON supports earth observation satellite missions with the delivery of immersed diffraction gratings.



Goal:

Greenhouse gas detection from space

Recent example:

Sentinel-5 precursor TROPOMI
(launch in 3 days)

Introduction

Currently, immersed gratings for the Sentinel-5 earth observation mission are in production.

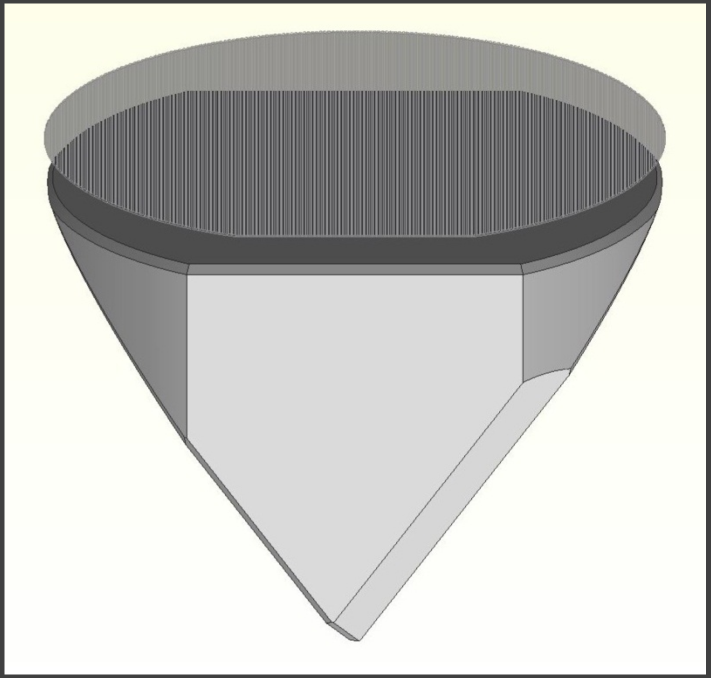
Sentinel-5 comprises three satellites to be launched in 2020, 2027 and 2034.

SRON will deliver for this mission 6 immersed grating flight models + qualification models and spares.

➡ Topic of this talk

Introduction

In addition to immersed gratings for earth observation missions, SRON has built in the past also a bread board model for the Metis instrument on the E-ELT.



Performance tests in:

"Optical tests of the Si immersed grating demonstrator for METIS," T. Agócs et al., Proc. SPIE 9912, (2016)

→ Grating candidate for Metis

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Outline

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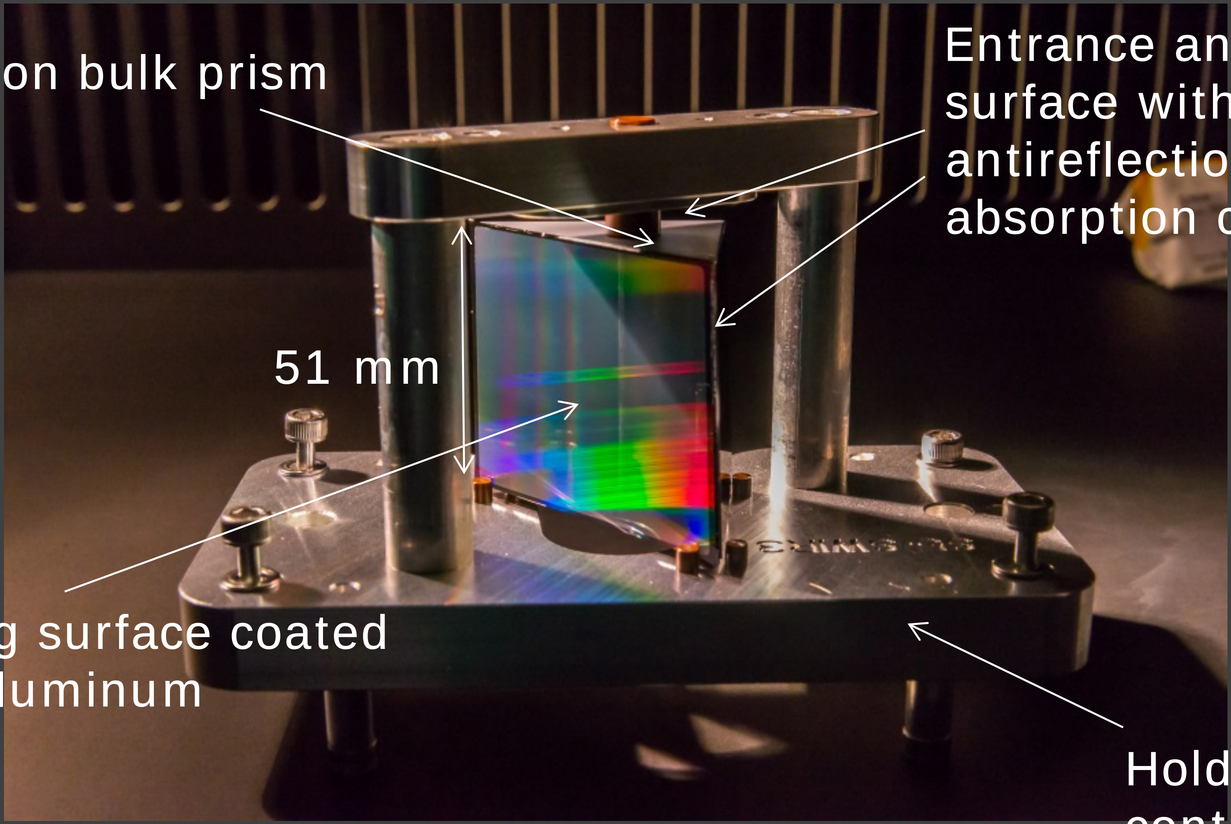
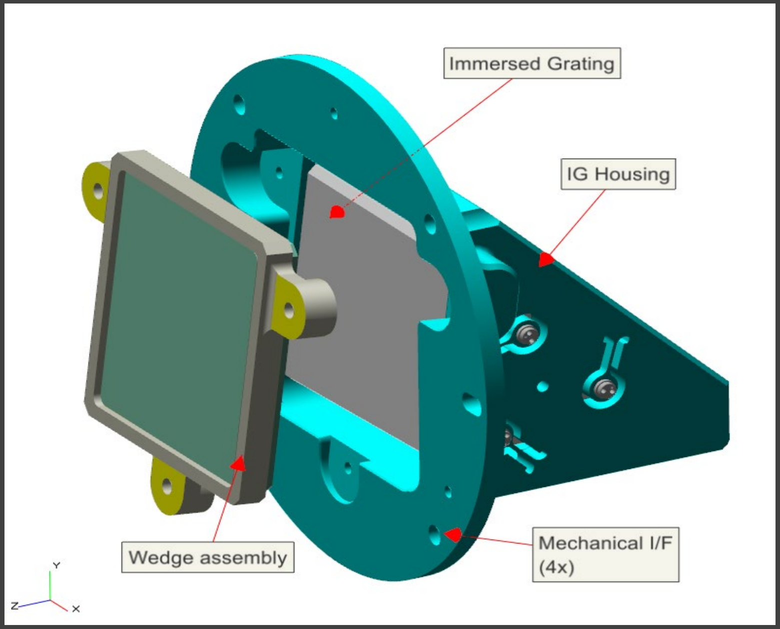
1. Overview of Immersed Gratings for Sentinel-5

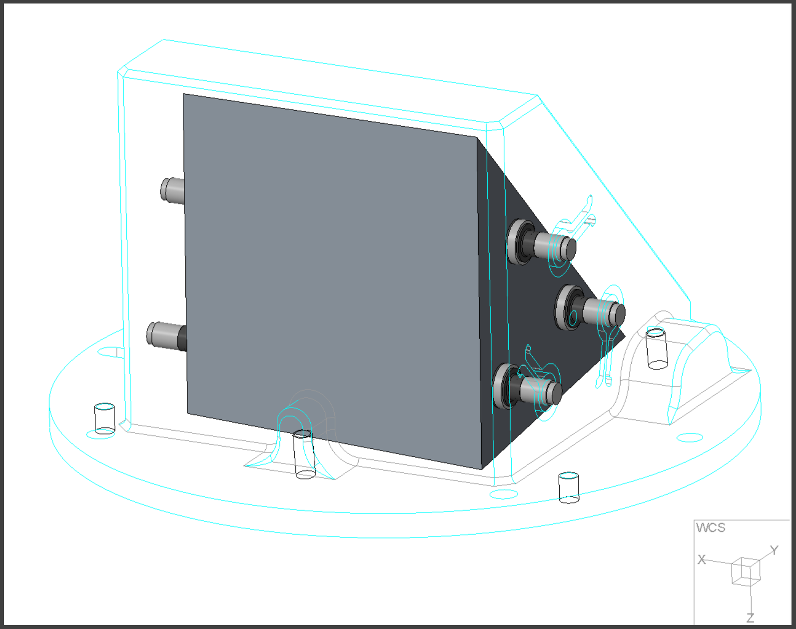
Image of IG bread board model:



1. Overview of Immersed Gratings for Sentinel-5

Immersed Gratings are delivered with mechanical housing



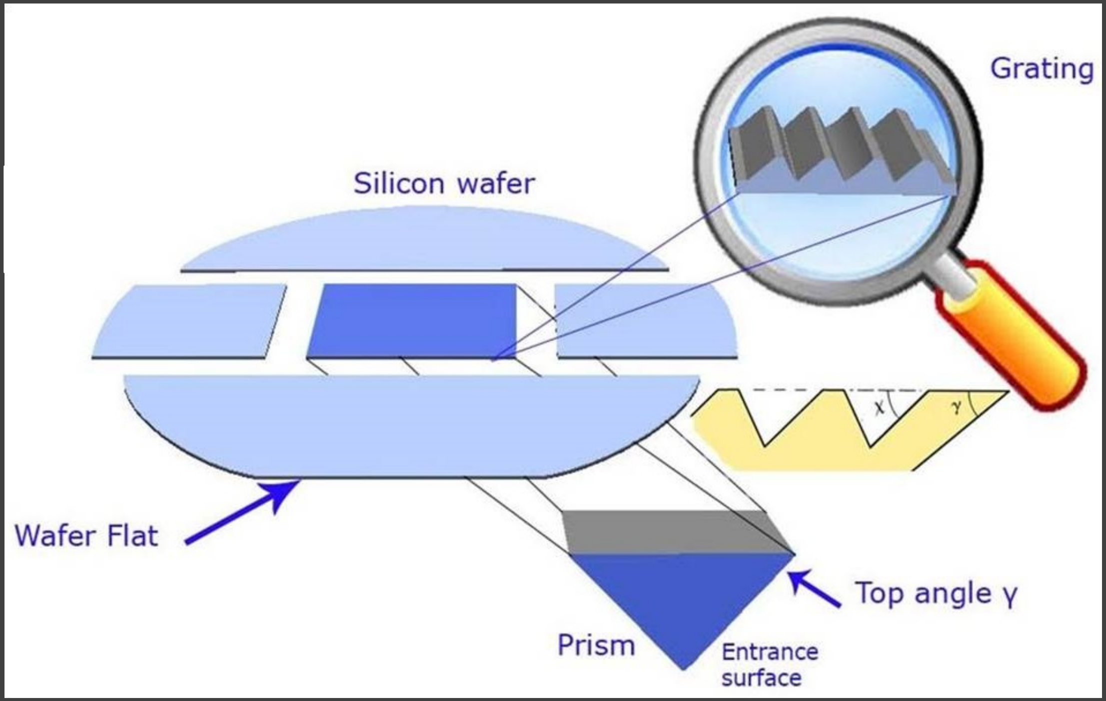


Grating = Immersed Grating + Housing

Two versions: SWIR-1 Gratings (1589 nm – 1676 nm)
SWIR-3 Gratings (2304 nm – 2386 nm)

2. Immersed Grating production

SRON uses a strategy of direct bonding of a silicon grating element with a silicon prism.



Steps:

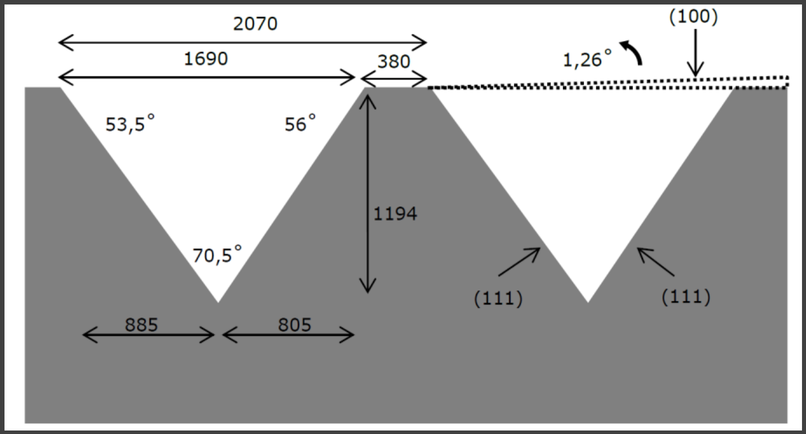
1. Grating element production
2. Bond and fuse to prism
3. Scribe and break to remove excess wafer parts
4. Apply coatings

Production methods allows combination of best grating elements with prisms with tight angle tolerances

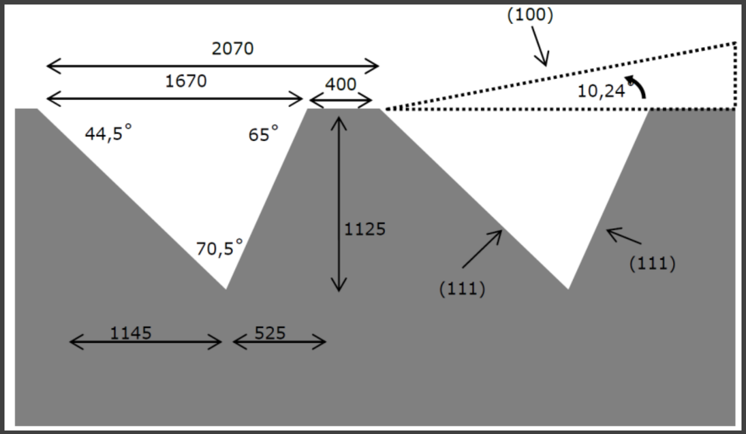
2. IG production – grating elements

The target profile of the silicon grating elements has been determined with optical simulation in PCGrate.

SWIR-3



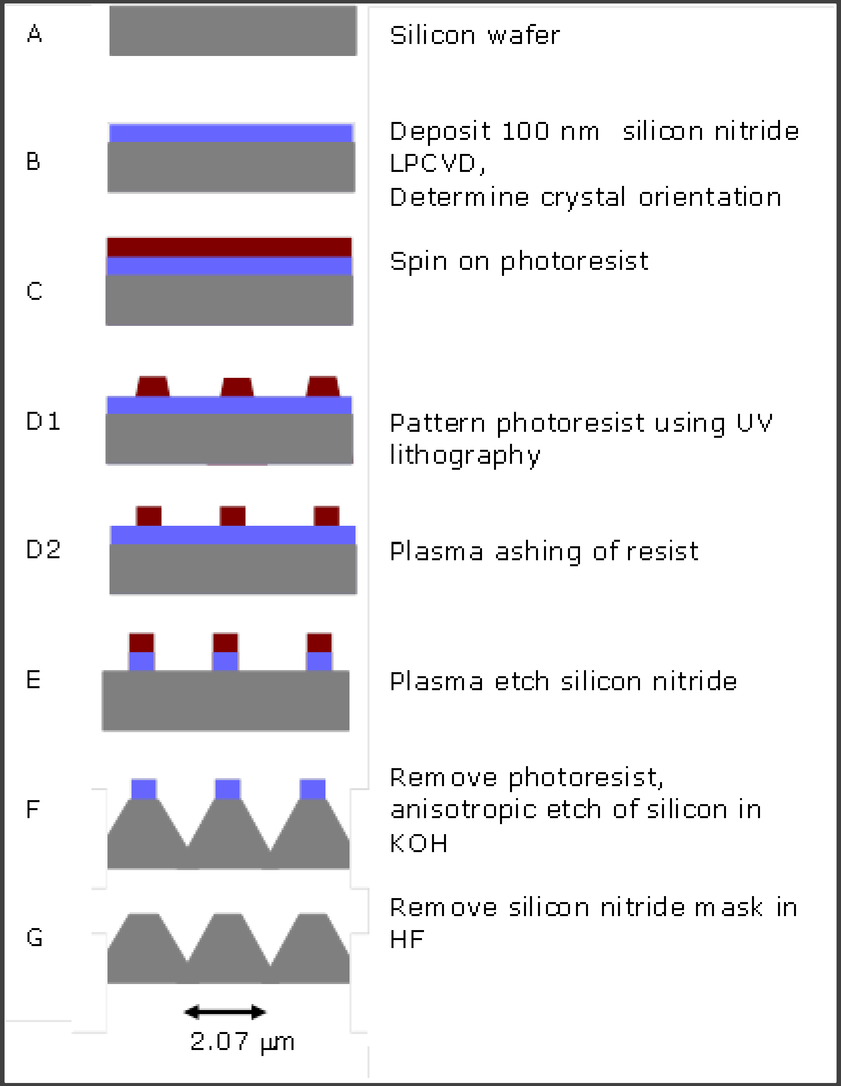
SWIR-1



Angles are fixed by Si crystal structure and off-cut angle

Dam width main production process parameter

2. IG production – grating elements

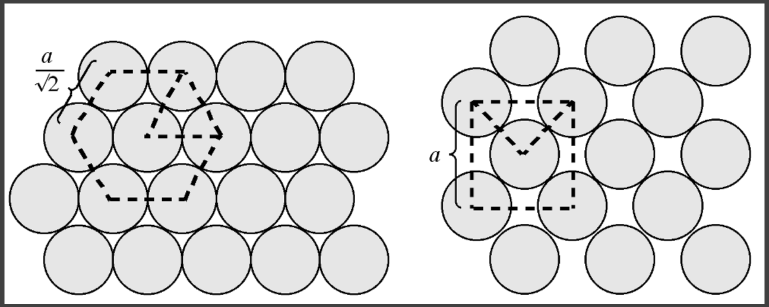


Standard UV lithography process

Start with float zone 150 mm Si wafers

500 nm linewidth on photomask leads to 380 nm dam width

<111> <100>



KOH two orders faster etching along <100> than <111>

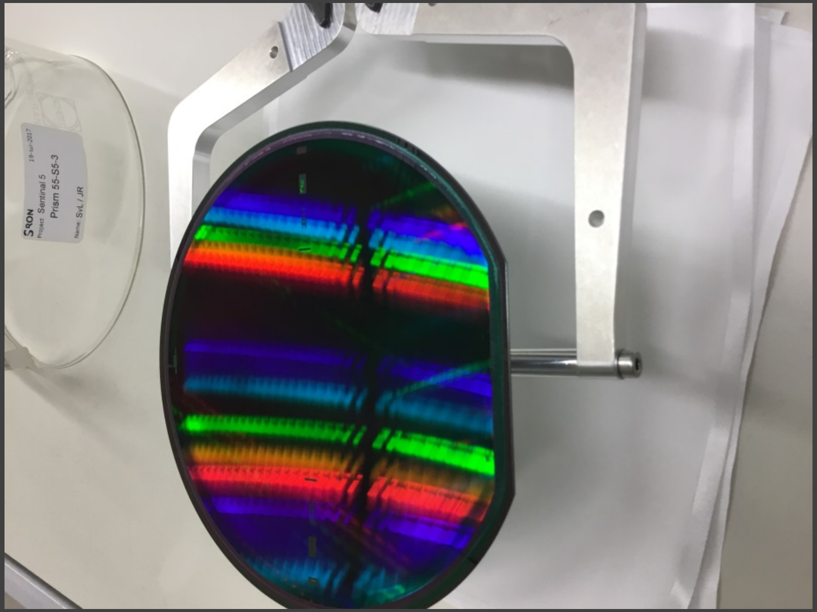
2. IG production – grating elements

Production results:

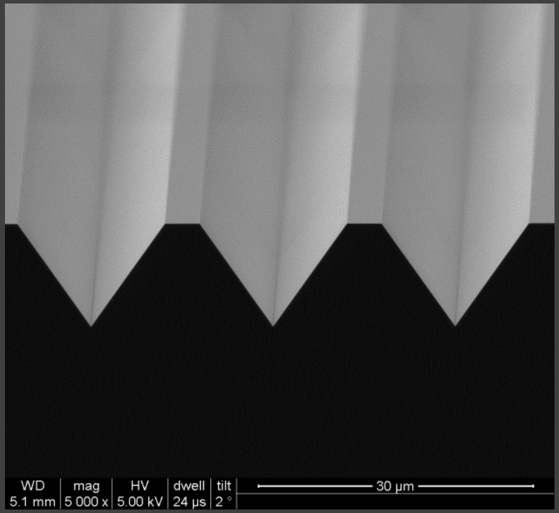
Dam width (380±15) nm

Defect density <1e-5

Grating surface roughness of
< 1nm



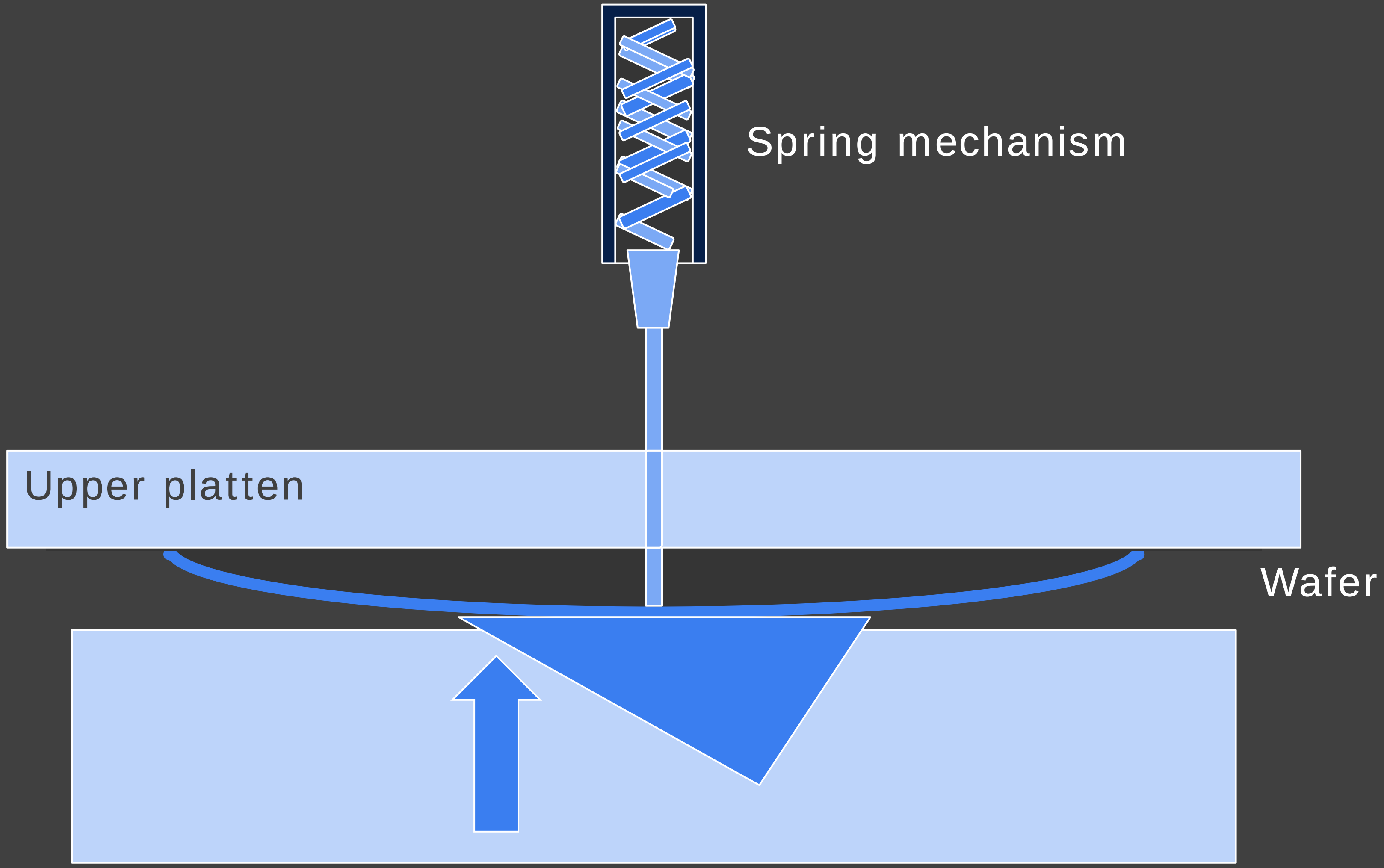
Example of finished grating element



SEM image of etched
grating element

2. IG production – bonding

Principle: Direct contact bonding over atomic forces

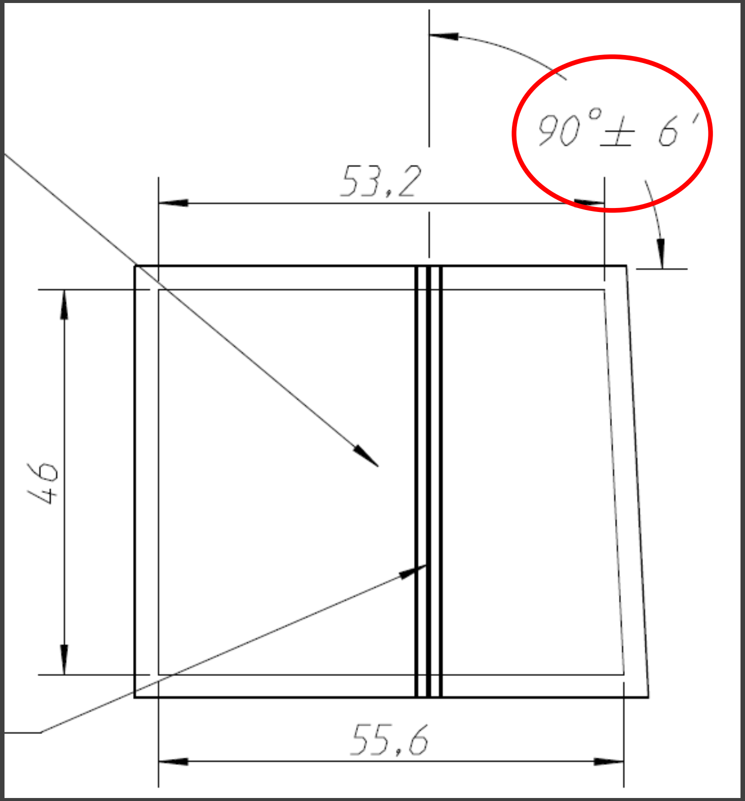


2. IG production – bonding

Main challenges:

- Perpendicularity between grating lines and prism
- Parallelism between wafer and prism to avoid bonding voids

➡ Improvements on standard bonding equipment needed for successful immersed grating bonding



2. IG production – bonding

Wafer to wafer bonder modified for immersed grating bondings
Moving and rotating parts of bonder were stabilized

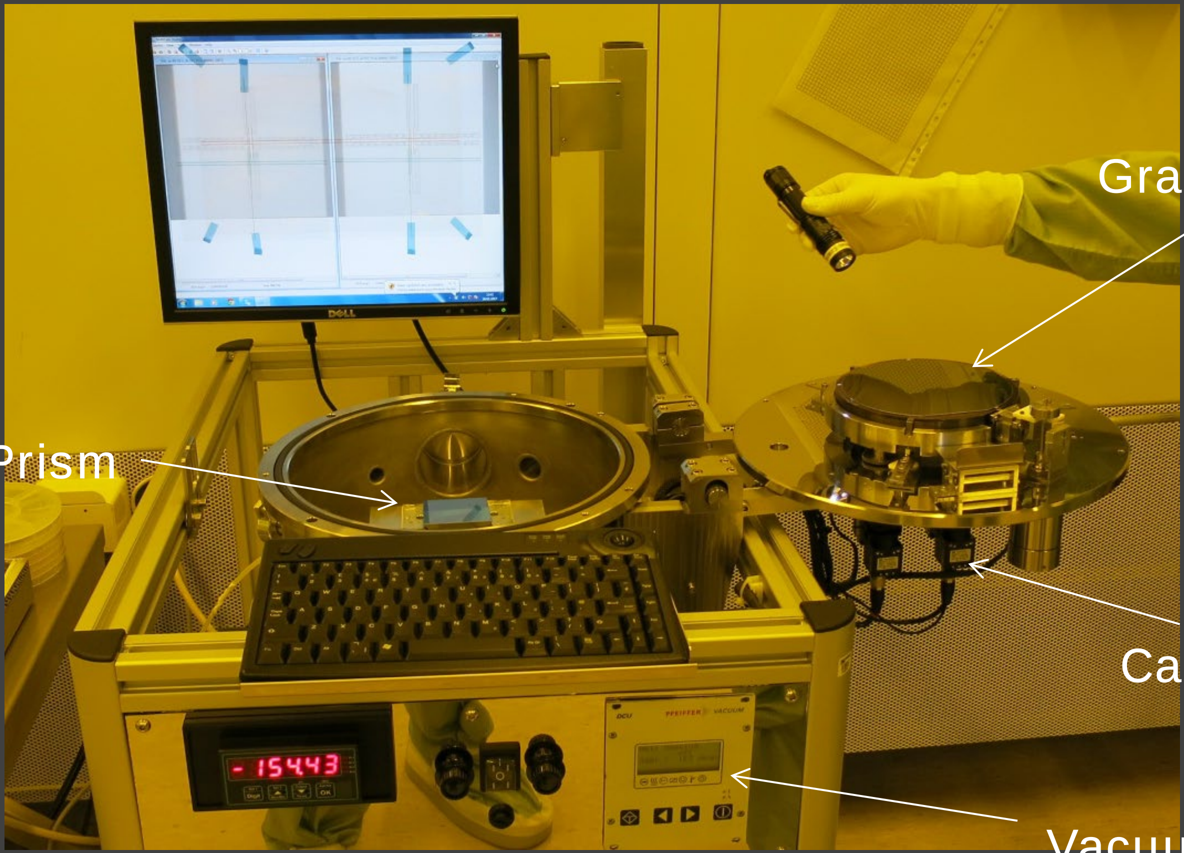
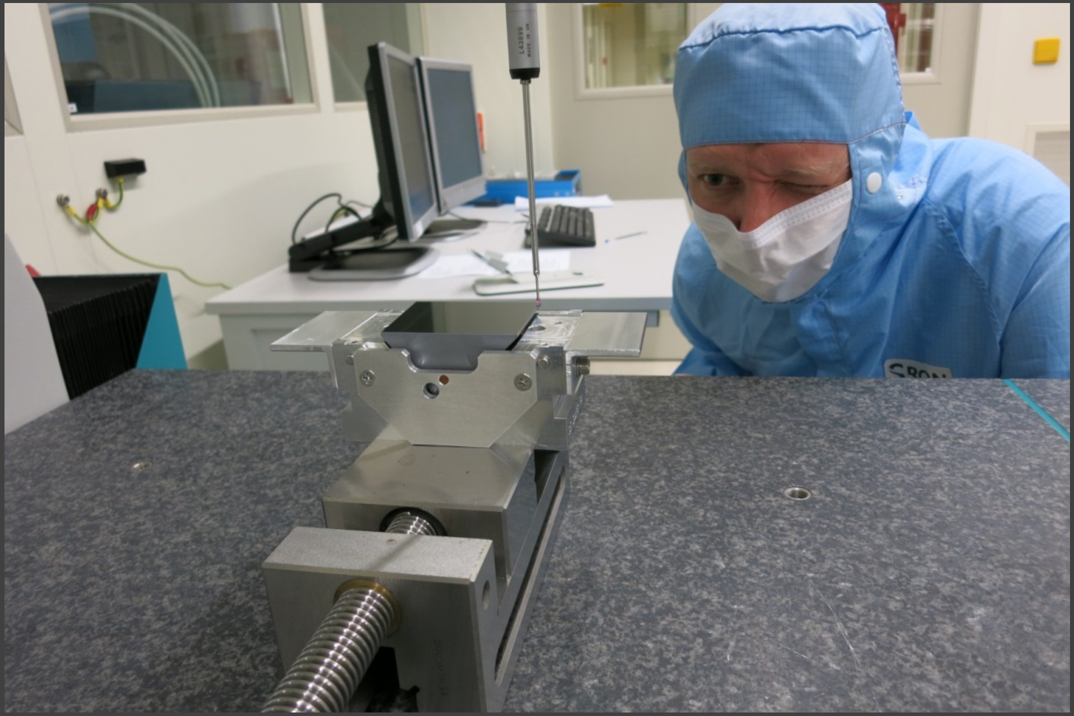


Image of AML bonder

2. IG production – bonding

Strategy for wafer-prism parallelism:

- Set upper and lower bonder platten parallel
- Measure prism in prism support before cleaning
- Compensate on bonder



CMM measurement of prism in support

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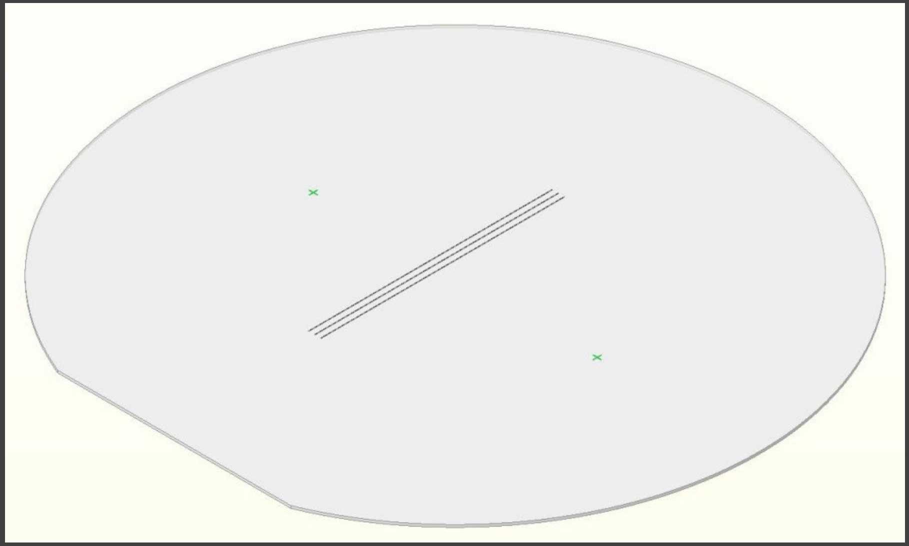
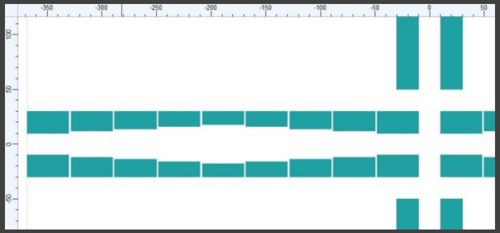
2. IG production – bonding

Strategy for grating line perpendicularity:

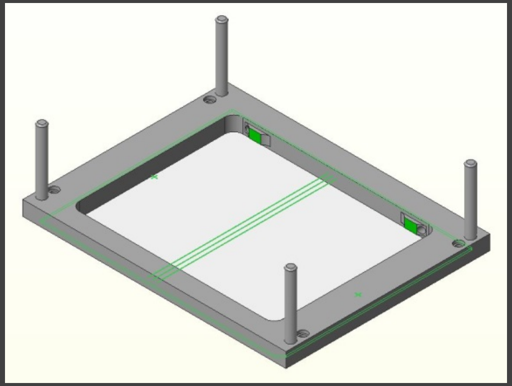
- Align microscopes to the grating element (GE)
- Align prism with an alignment tool to the microscopes
- Remove prism and GE and perform cleaning steps
- Replace GE and prism and perform bonding



Wafer with alignment marks



Zoom of alignment mark



Alignment tool for prism support

2. IG production – bonding

Perpendicularity verification with microscope

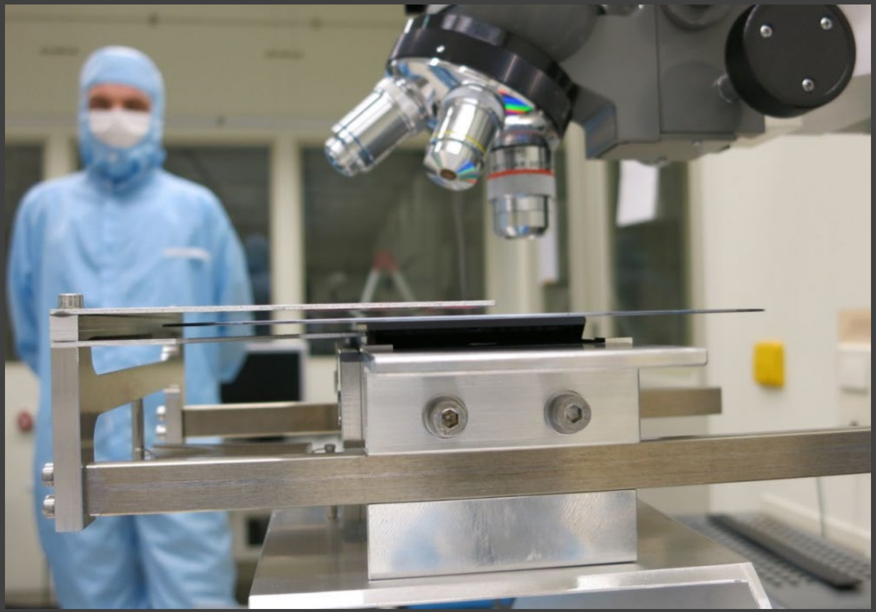
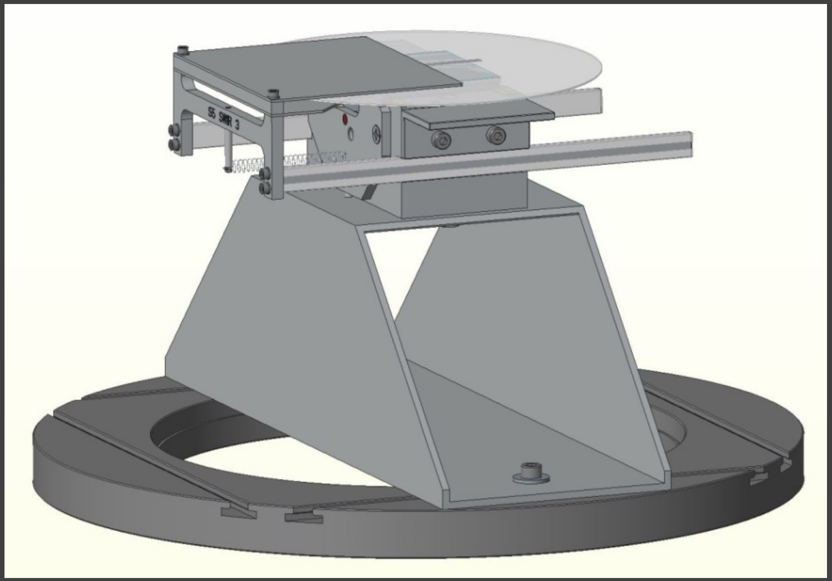


Image of setup under microscope



CAD drawing of measurement setup

Result: compliant with perpendicularity requirement

At this moment, three immersed grating have been produced. Absorption (R<0.5%) and AR (R<0.2%) coatings were applied.

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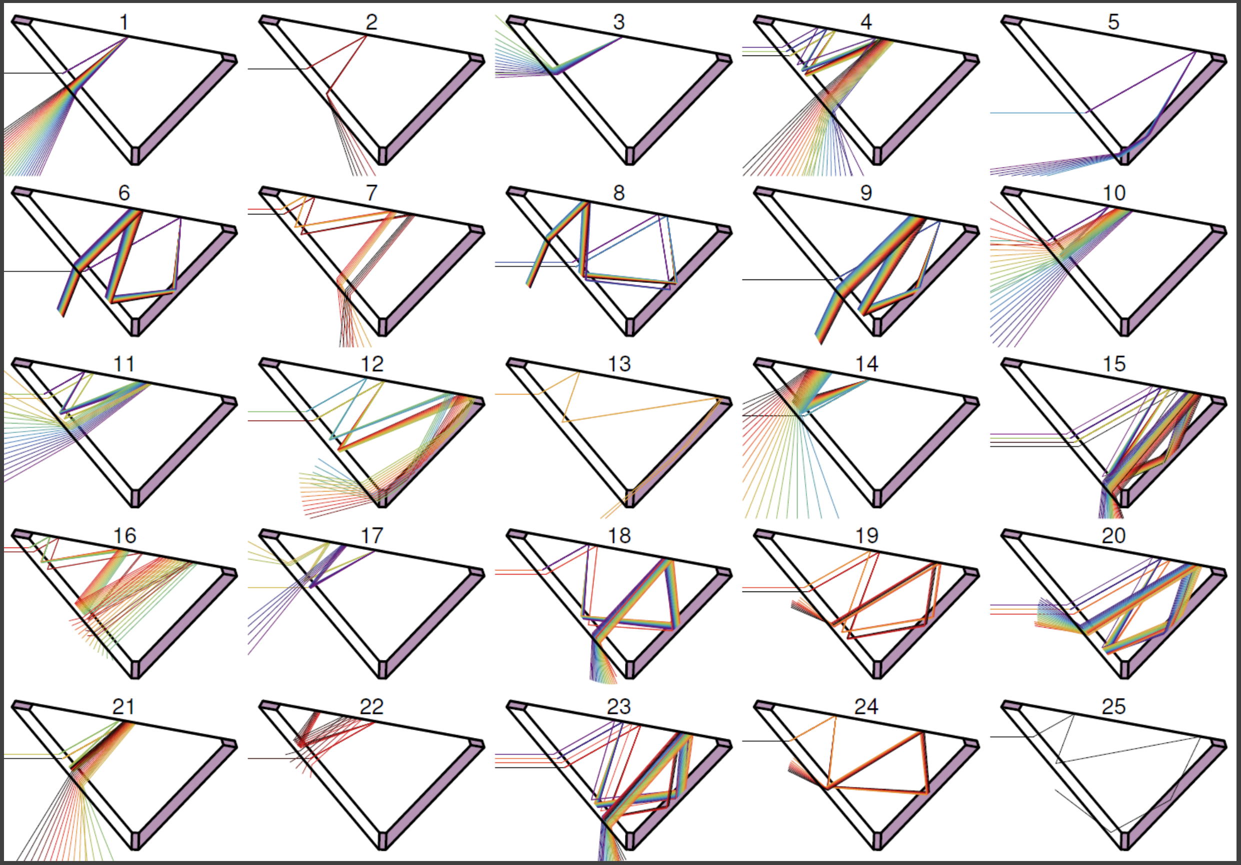
3. Optical performance – stray light

- Grating design optimized to reduce internal reflections
- Immersed Grating entrance surface wedged to such that internal reflections cannot reach detector



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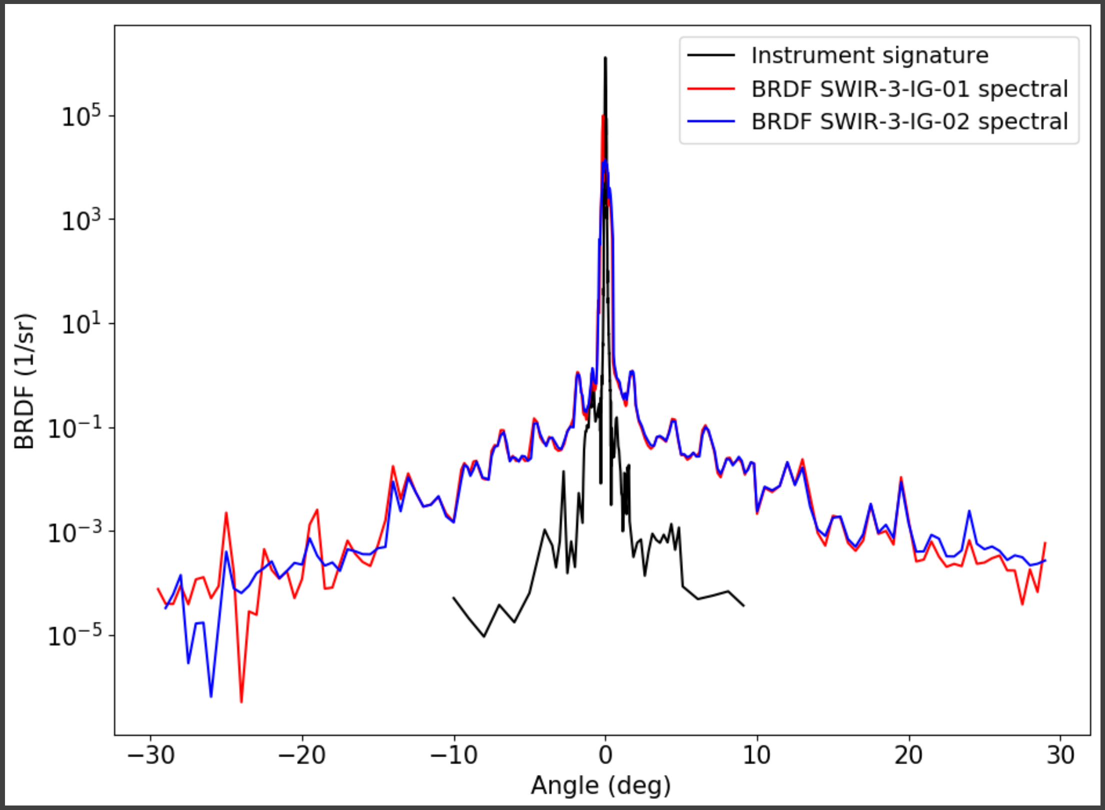
3. Optical performance – stray light

Results from measurements of Bidirectional Reflectance distribution function (BRDF) at ESA-ESTEC:



Stray light on spectral axis

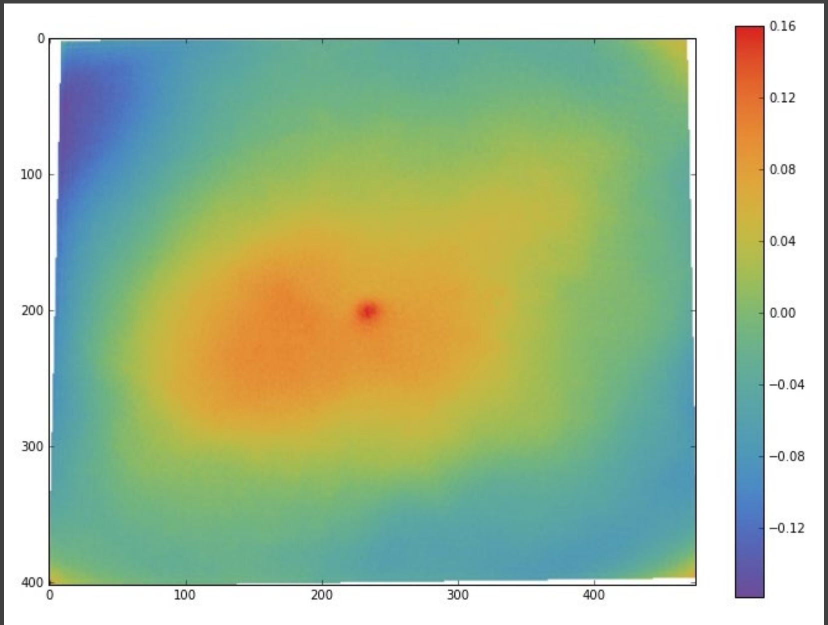
Total integrated scatter (TIS) excluding internal reflections <0.1%

Reproducible ghosts with intensity $<10^{-4}$

Wanted: lithography mask with minimum of ruling errors

3. Optical performance – wavefront error

Wavefront error measured from outside with Fizeau interferometer, result translated to operational conditions.



Results:

WFE (250±50) nm vs. requirement of 900 nm

WFE with power removed of (145±25) nm vs requirement of 180 nm

IR Hartmann-Shack setup in preparation for direct in immersion wavefront error measurements

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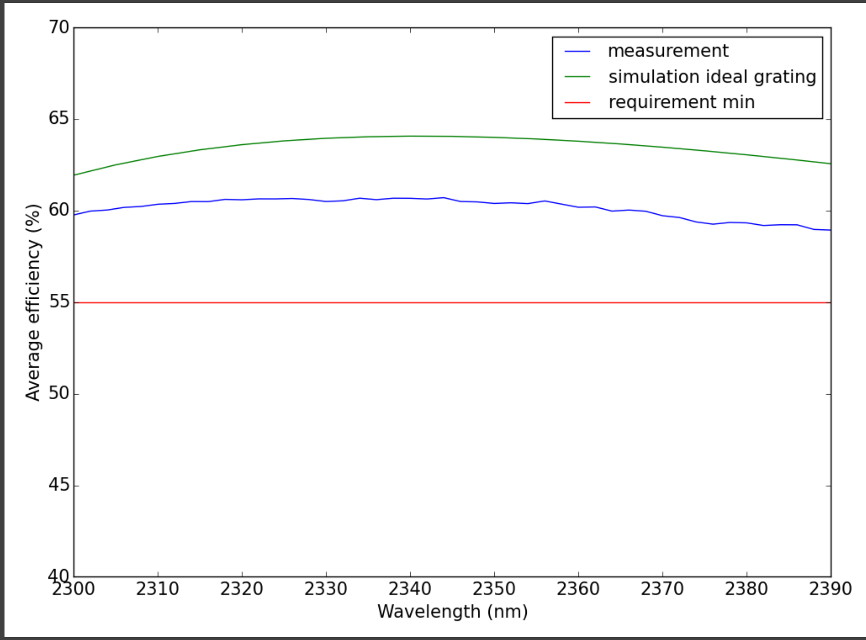
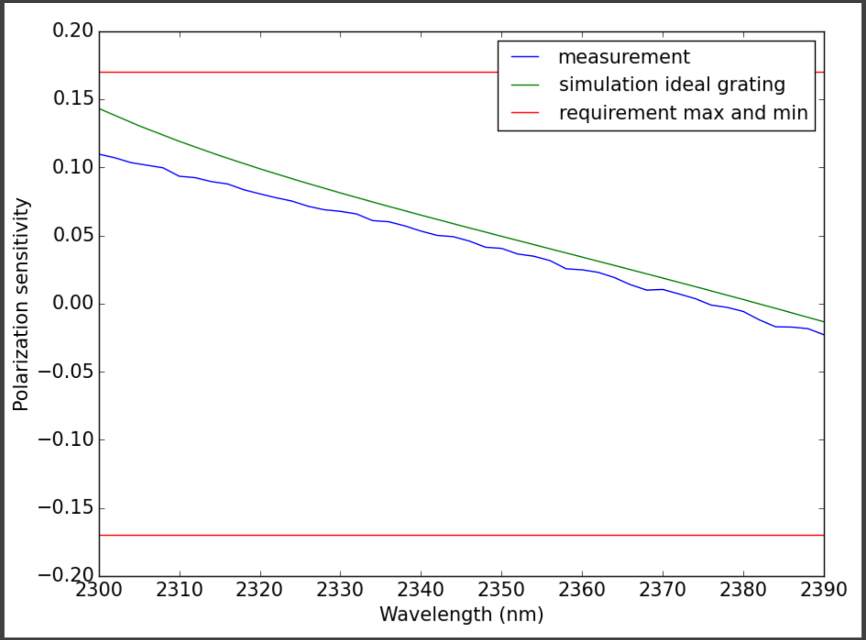
3. Optical performance – polarized efficiency



Average efficiency



Polarization

Polarization sensitivity and average efficiency meet requirements and are close to simulation

Reason for lower efficiency than in simulation is unknown

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4. Environmental tests

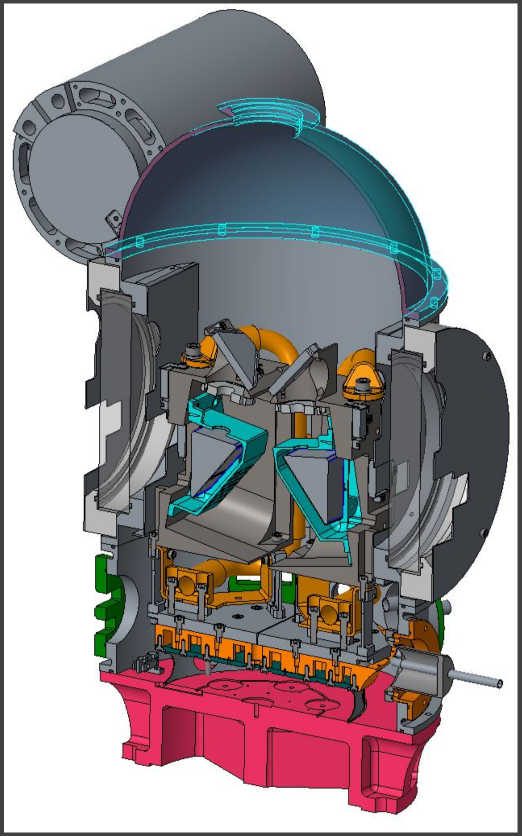
Immersed gratings in mechanical housing need to pass:

- Shock and vibration tests
- Thermal cycling between 170 K and 330 K

Further, rotational stability of 0.2 arcsec/K and no change of optical performance under operational conditions to be shown.

➡ Dedicated cryostat test setup built including autocollimator and interferometer setup.

First tests foreseen in December.



Cryostat for Grating performance tests

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5. Conclusions

- Bonding of grating elements and prisms excellent strategy to meet both tough requirements on prism geometry and grating elements

- SRON delivers immersed gratings in their housing which can withstand the conditions during satellite launch and thermal cycling

- For astronomy applications, the wavefront error is likely the largest challenge for the presented manufacturing method, due to thickness variations of the used grating wafers