Potential of Machined devices for European Large Telescope

可視赤外線観測装置技術ワークショップ 2025

Takashi. SUKEGAWA

Optical Products Operations

10.November.2025

Canon

外部公表申請-2510-00006

Contents

Introduction

Potential of optical accuracy by Machining(cutting)

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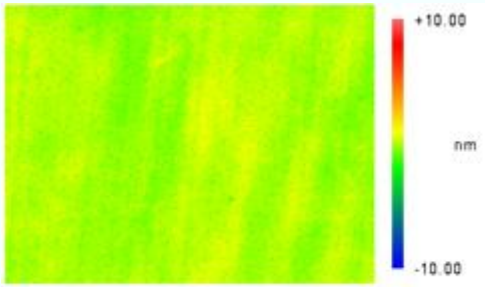
Surface roughness by just cutting

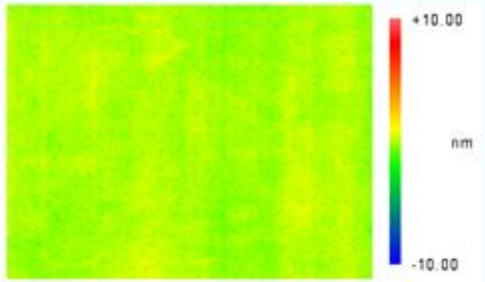
Roughness: Machine stability, process and materials


Wikipedia

Cupper



0.40nm(RMS)
3.4nm(PV)

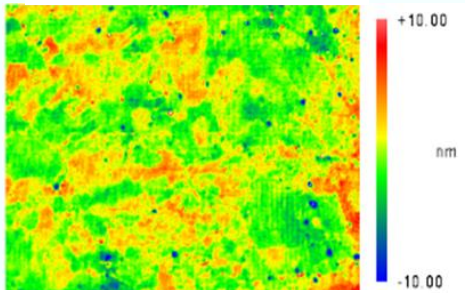


0.36nm(RMS)
3.5nm(PV)

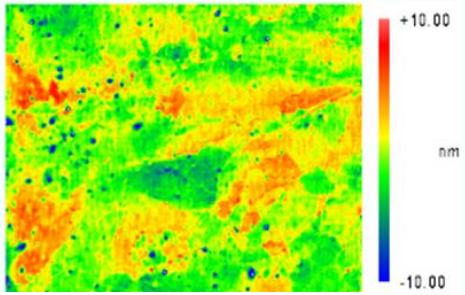
Zygo NewView 3D profiler
Evaluation area：70 x 50μm


Wikipedia

Aluminum
RSA-6061 T6

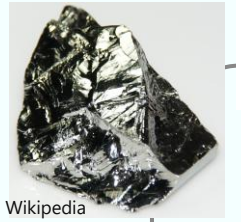


2.2nm(RMS)
57.0nm(PV)

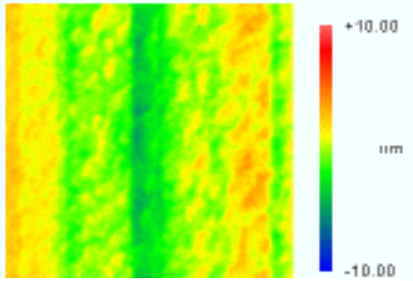


2.4nm(RMS)
50.6nm(PV)

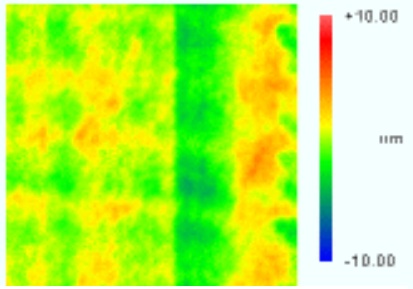
Zygo NewView 3D profiler
Evaluation area：70 x 50μm


Wikipedia

Germanium
(Single Crystal)



1.6nm(RMS)
9.8nm(PV)



1.5nm(RMS)
9.9nm(PV)

Zygo NewView 3D profiler
Evaluation area：50 x 50μm

Flatness / Wavefront accuracy

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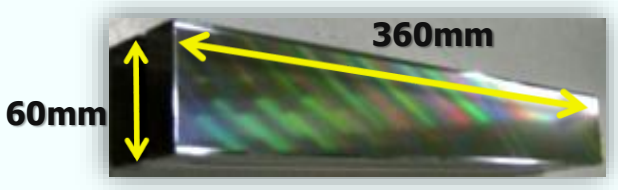
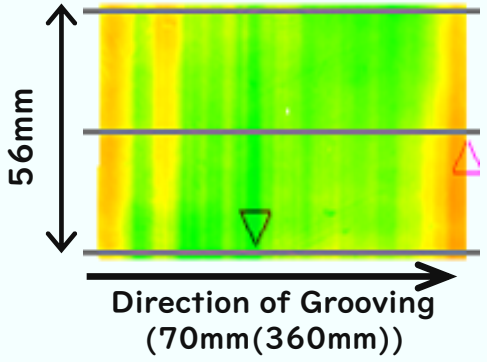
Flatness / Wavefront accuracy: Machine stability (Scale Accuracy)

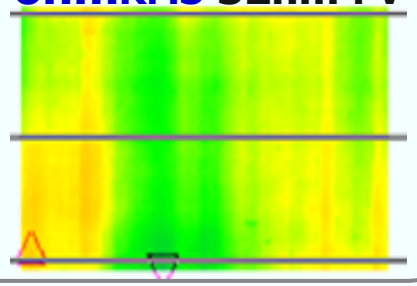
Reflection



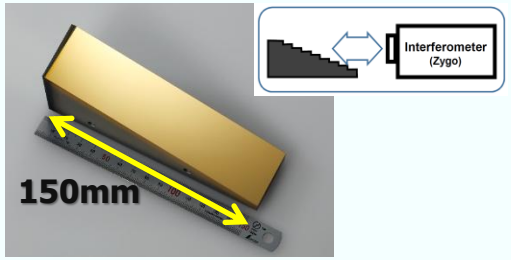
#1 **6nmRMS 32nm PV**



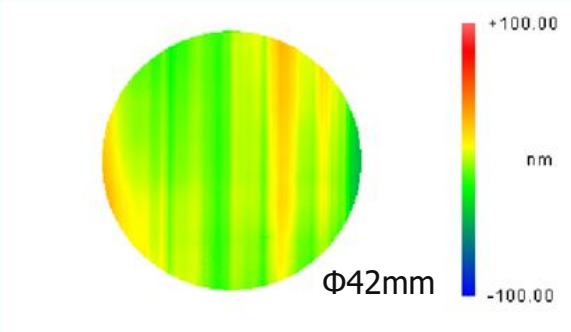
#2 **6nmRMS 32nm PV**



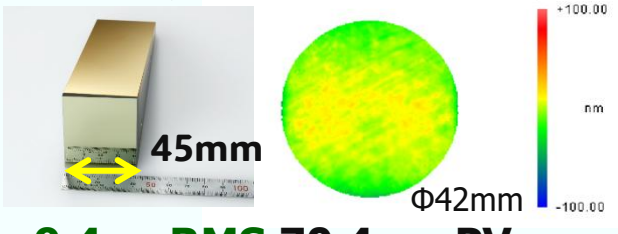
Immersion



10.5nmRMS 78.5nm PV

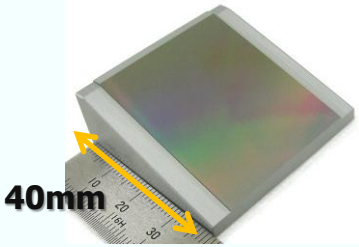


Ref.:In/Out face/Polishing

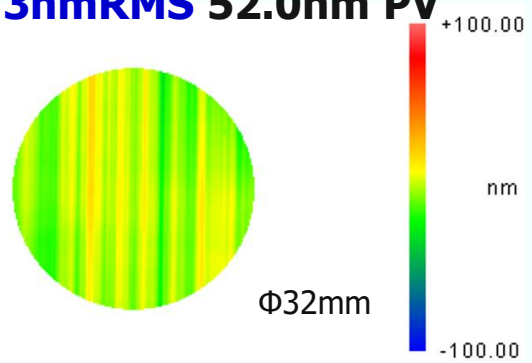


9.4nmRMS 70.4nm PV

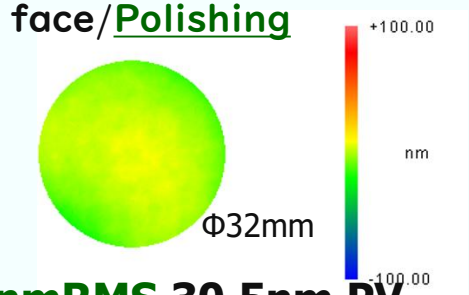
GRISM



8.3nmRMS 52.0nm PV



Ref.:In face/Polishing



5.3nmRMS 30.5nm PV

Machined devices for European Large Telescope

可視赤外線観測装置技術ワークショップ 2025

VLTI/GRAVITY InP/Ge GRISM

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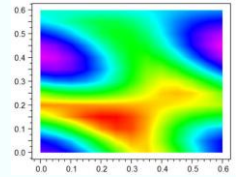
https://www.mpe.mpg.de/ir/gravity

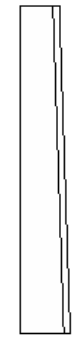
Senol Yazici, Takashi Sukegawa, et.al. "GRAVITY upgrade with high-performance grisms with factor >2 enhanced throughput"
SPIE 2020. 11446, Optical and Infrared Interferometry and Imaging VII

Trivial Name (Part Name)	Material	refractive index n*	prism angle (°)	ruling frequency (1/mm)	spectral resolution R (λ/Δλ)
R4000 Germanium #1 (GIMG W44R T1PT1)	Germanium	~ 4.15	19.19	460	4000
R4000 Germanium #2 (GIMG W44R T1PT2)					
R500 Germanium (GIMG W44R T2PT1)			2.32	58	500
R500 Indium (IIMG W44R T2PT1)	InP	~ 3.12	3.48	59	
R4000 old (ITEM 32435)	ZnSe	~ 2.44	37.92	400	4000
R500 old (ITEM 32436)			5.24	60	500

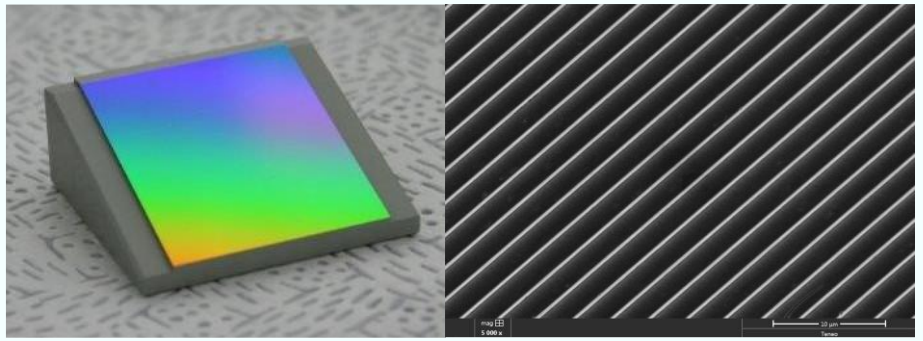


Plane **Grating**

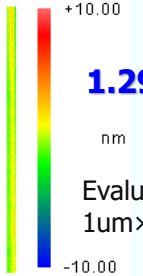
AR AR



High refractive materials (n>3) cannot be used as practical devices due to large performance loss unless a good anti-reflection coating is applied to the grooved surface.



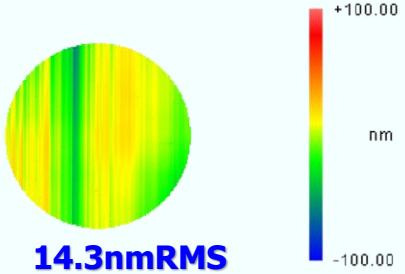
Surface roughness on grooves



1.29nmRMS

Evaluation area
1um×30um

Wavefront Error on grooves



14.3nmRMS

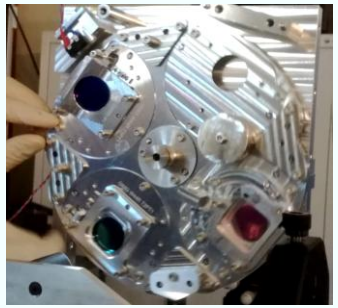
Performance improvement in Devices

Grism	T_{avg}	T_{new}/T_{old}
R500 Germanium	93.91 %	1.783
R500 Indium	89.18 %	1.693
R500 old	52.67 %	–
R4000 Germanium #1	67.69 %	3.032
R4000 Germanium #2	68.02 %	3.017
R4000 old	22.44 %	–

Evaluation by Dr. Frank Eisenhauer (MPE)

Performance improvement at instrument

R500 : x 220% up
R4,000 : x 280% up



Goes To ELT(ESO)

ELT/METIS

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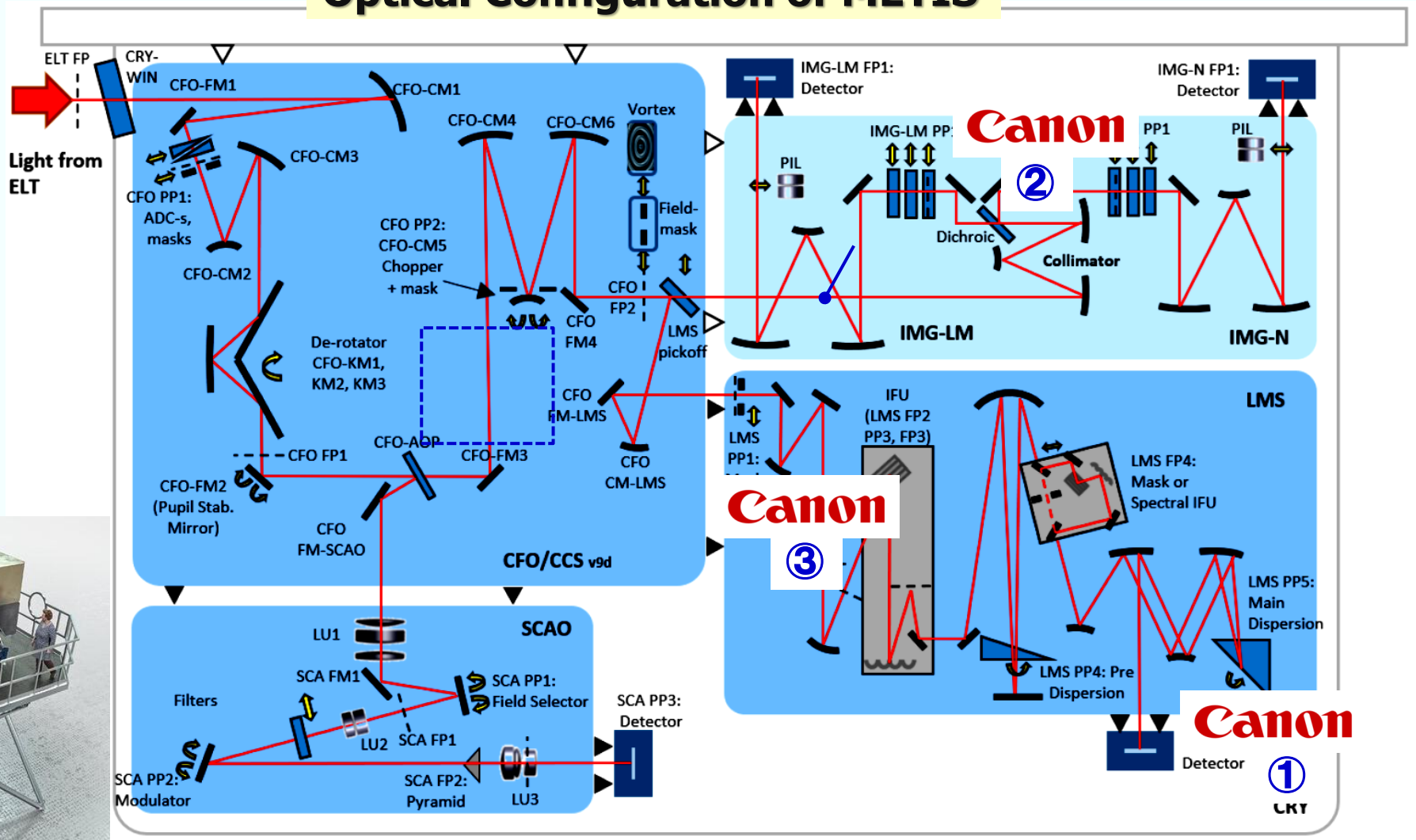
https://metis.strw.leidenuniv.nl/

European Large Telescope

METIS
(Mid-infrared Spectrograph)

Optical Configuration of METIS



The number is the order of introduction as follow.

可視赤外線観測装置(中間赤外線スペクトログラフ)

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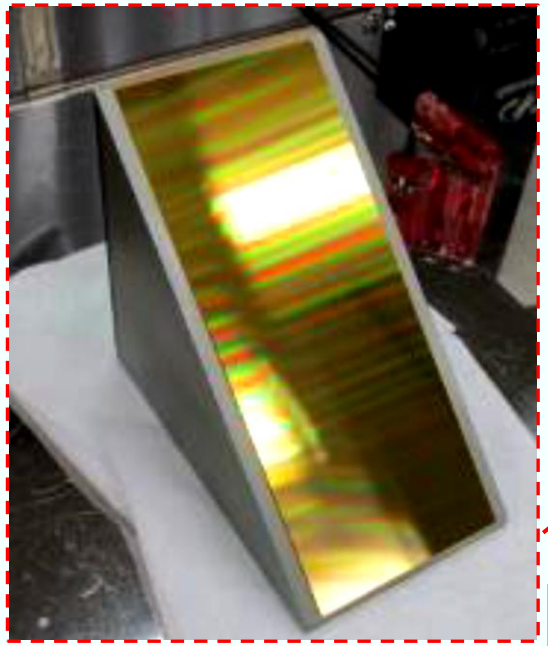
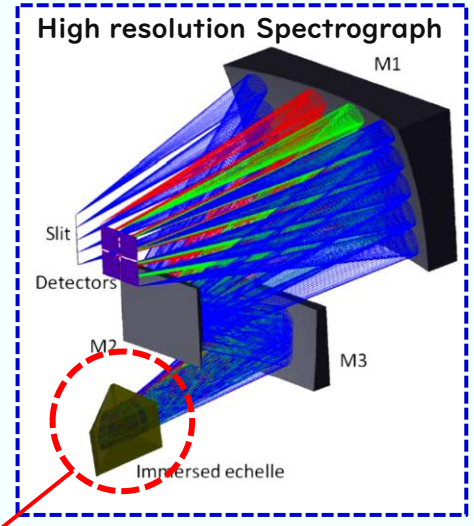
ELT/METIS ① Germanium Large immersion grating

外部公表申請-2510-00006

https://metis.strw.leidenuniv.nl/

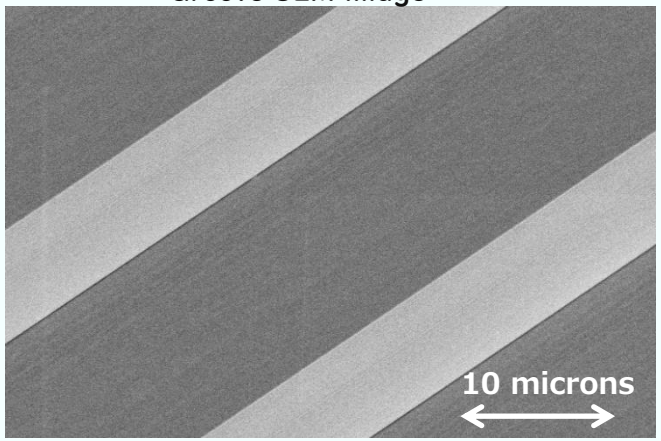
Tibor Agócs, Takashi Sukegawa, et.al. "Ge immersed grating manufacturing and optical verification for the METIS high-resolution spectrograph"
SPIE 2020. 11451, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation IV

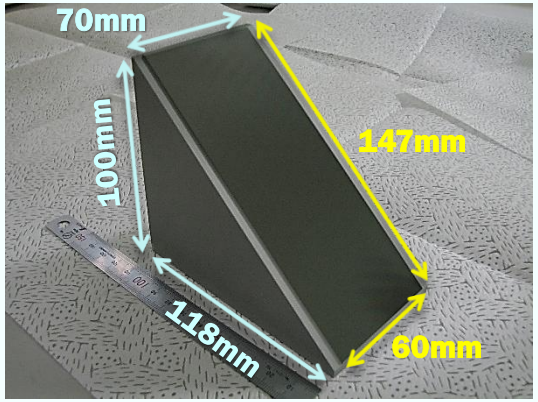




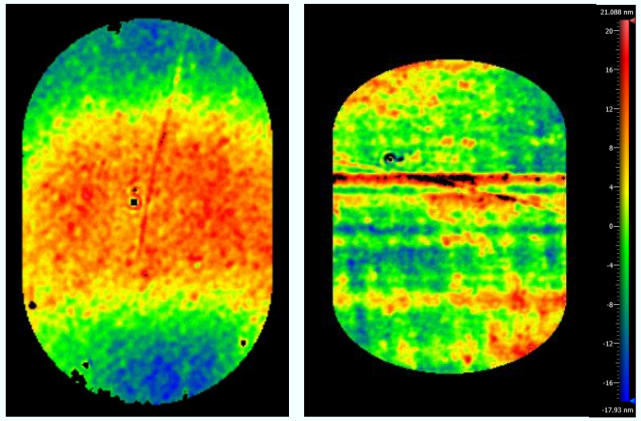
Item	Spec
Effective input size	55mm
Blaze Angle	50 degrees
Apex Angle	90 deg
Pitch	18.2um
Grooved Area	60mm x 147mm 8120grooves
Grooved length	4870m

Groove SEM image





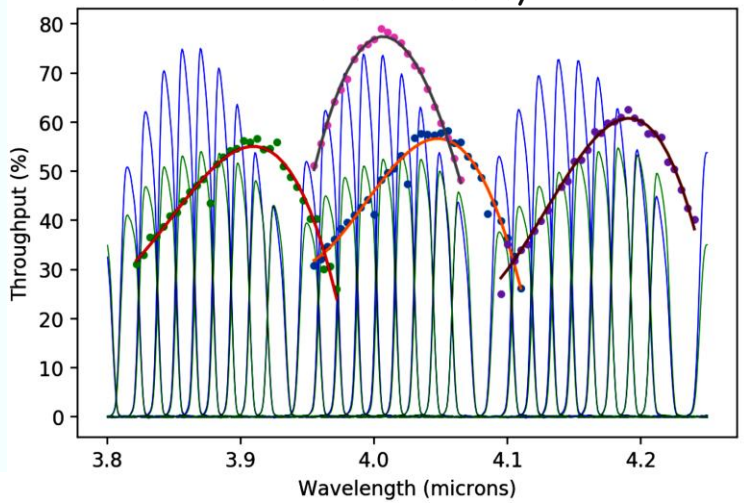
Surface Flatness



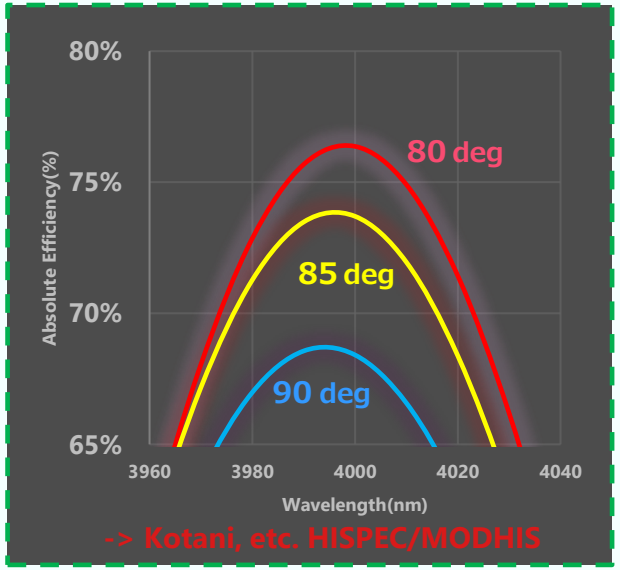
In/Out(flat) 14.1nmRMS

Grooved area 6.1nmRMS

Diffraction Efficiency



Ref: Apex angle and average diffraction efficiency with same pitch and blaze angle in theory



$WFE_{IG} = \sqrt{[\sqrt{2}(n-1)\cdot\#1]^2 + [n\cdot\#2]^2}$ WFE_{IG}=64.6nmRMS

ELT/METIS ② Germanium GRIMS

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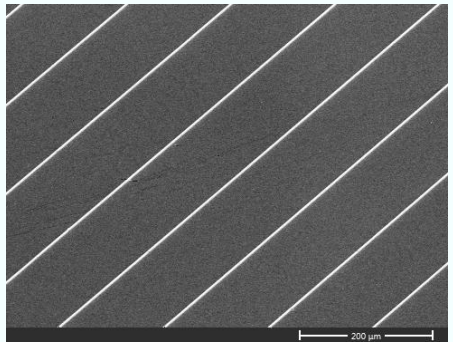
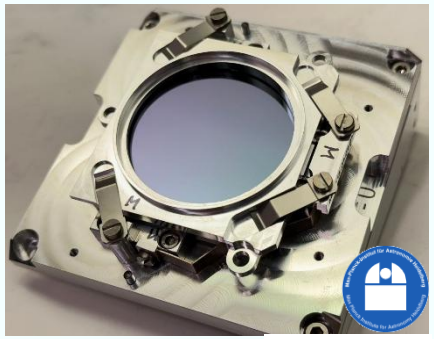
GRISM name	Waveband (um)	Pitch(um) @20°C
L-Band	2.9 - 4.2	33.3
M-Band	4.5 - 5.2	18.6
N-Band	7.5 -13.5	111.4

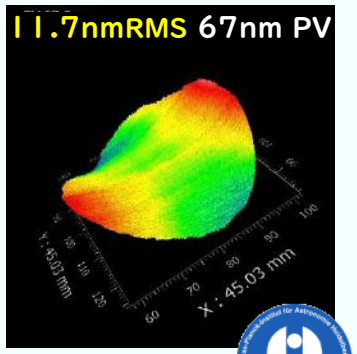


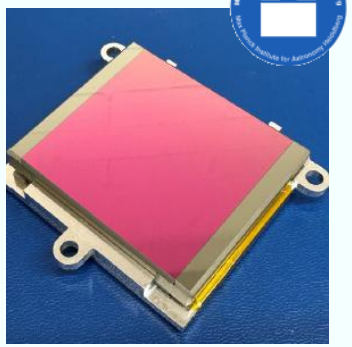
L-Band after Multi-layer AR



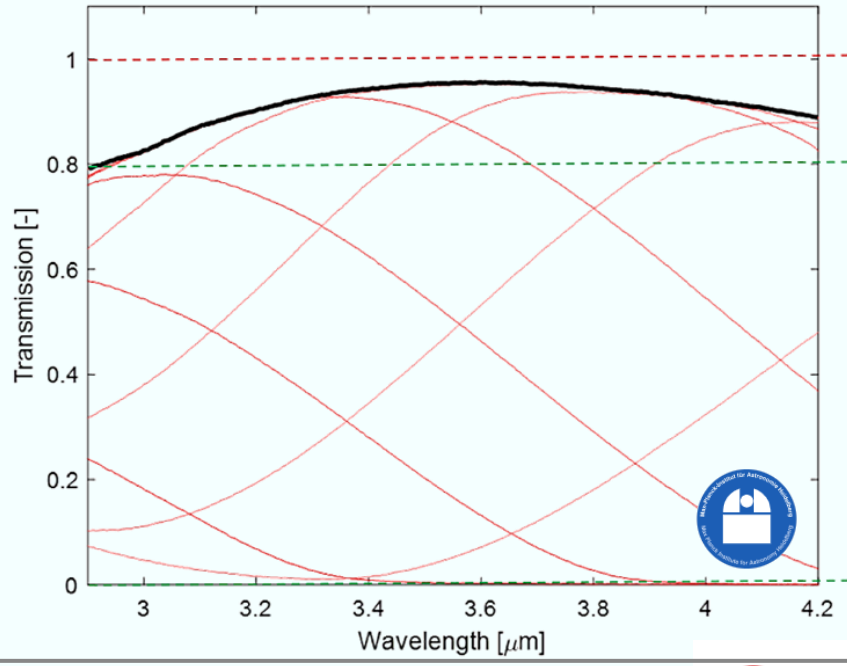
M-Band

Performance of L-Band



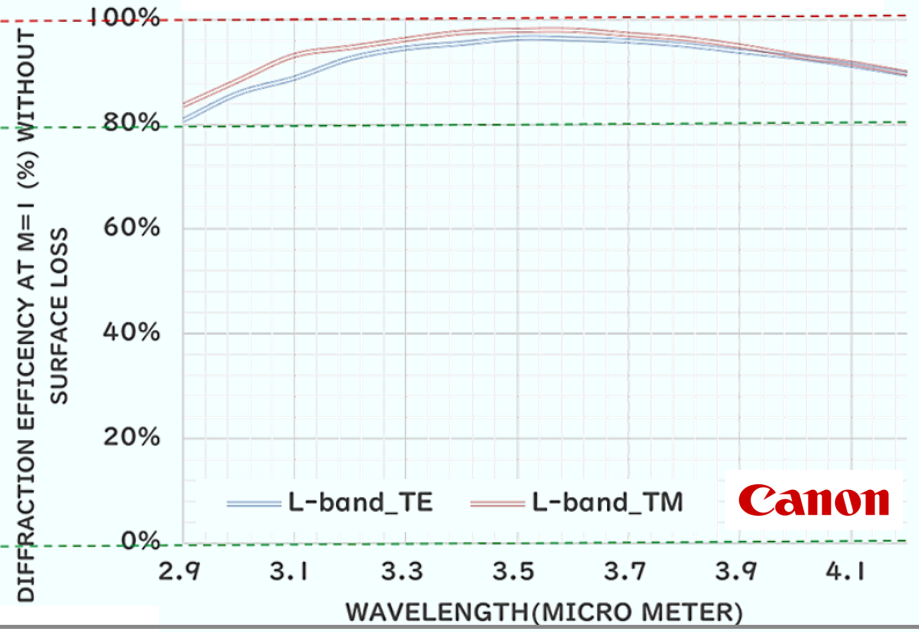


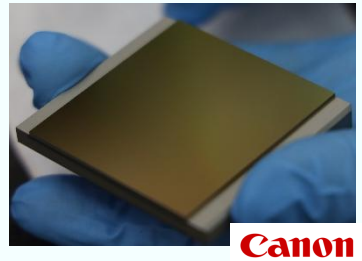
Measurements Result



Theoretical value

Does not include backside (flat side) loss.





ELT/METIS ③ Spherical Image Slicer (Monolithic)

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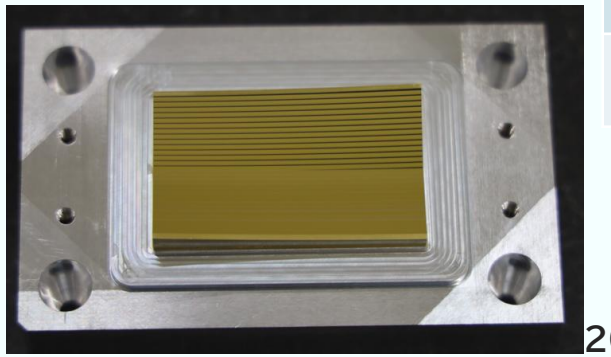
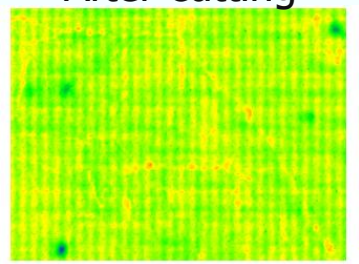
https://metis.strw.leidenuniv.nl/



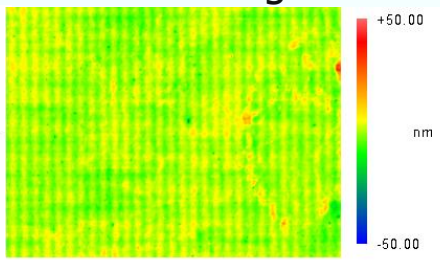
Item	Spec
Mirror number	30
Mirror length	50mm
Mirror width	1mm
Surface roughness	< 5nm RMS
Curvature error (R) Absolute	±1mm@452mm
Curvature error (R) Relative (Max-Min)	±0.2mm
Center Position	±0.01mm
Slope error	< 25 μrad

Surface roughness

After cutting

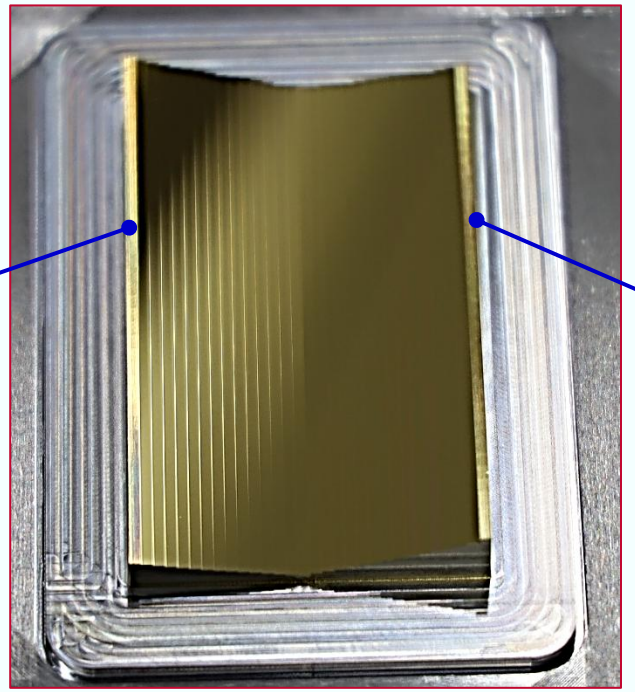


After coating



3.1nmRMS 60nm PV 3.2nmRMS 69nm PV

New View 6000 Area 0.14x0.1mm



2025 Nov.10

Closing Remarks

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Remarks

1. Cutting is not equivalent to polishing, but devices with a practical surface quality can be fabricated even with visible light without any post-processing.
2. This precision is achieved by a three-dimensional machine, which can produce quite complex shapes, but "coating" is the next limitation. We are now in an age where complex optical surfaces including diffraction gratings can be fabricated in one piece, and all but simple devices are waiting for your ideas.

Japan has many prior technologies, most notably materials technology, and it can be a contact point for projects in Europe and US.

Even Canon, like HWO, ELT 2nd generation

Thank you for your attentions and interests

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