次世代観測装置用の新しい回折格子 III

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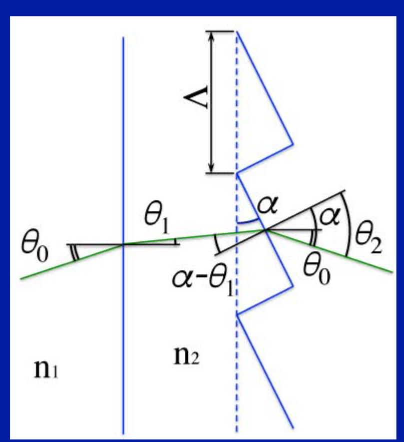
Limitation of surface relief (SR) grating



$$\sin\theta_0 = n\sin\theta_1$$
$$n\sin(\alpha-\theta_1) = \sin\theta_2$$
$$\theta_2 = \alpha+\theta_0$$

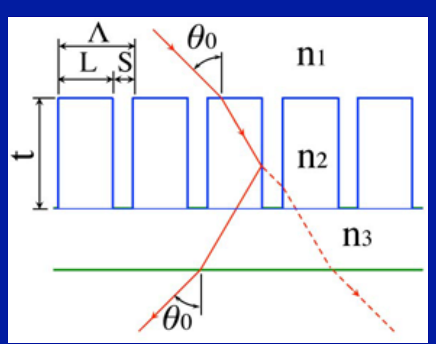
Transmission gratings for WFOS
Vertex angle: θ_0 = 36~53°
Period : Λ= 2~5 μm
Size : 400 x 550~750 [mm]

$$n\sin(\alpha-\theta_1) = \sin(\alpha+\theta_0)$$
$$n(\sin\alpha\cos\theta_1 - \sin\theta_1\cos\alpha) = \sin\alpha\cos\theta_0 + \sin\theta_0\cos\alpha$$
$$(n\cos\theta_1 - \cos\theta_0)\sin\alpha = (\sin\theta_0 + n\sin\theta_1)\cos\alpha = 2\sin\theta_0\cos\alpha$$
$$\tan\alpha = 2\sin\theta_0/(n\cos\theta_1 - \cos\theta_0)$$

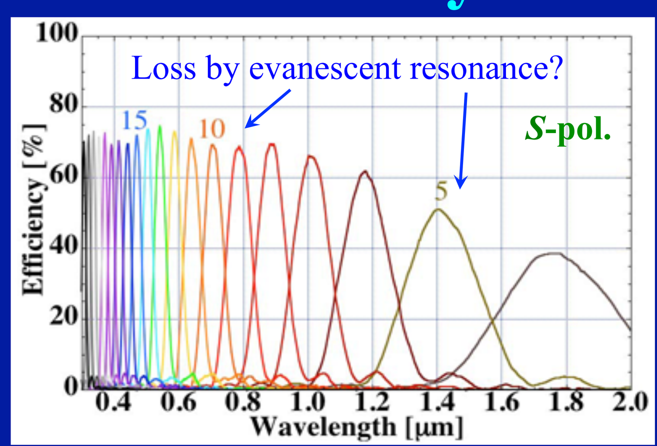
n = 1.5, $\theta_0 \le 30°$ ($\theta_2 < 90°$)
n = 1.8, $\theta_0 \le 36°$
n = 2.3, $\theta_0 \le 45°$
n = 3.0, $\theta_0 \le 54°$
Diamond: n = 2.46@400nm

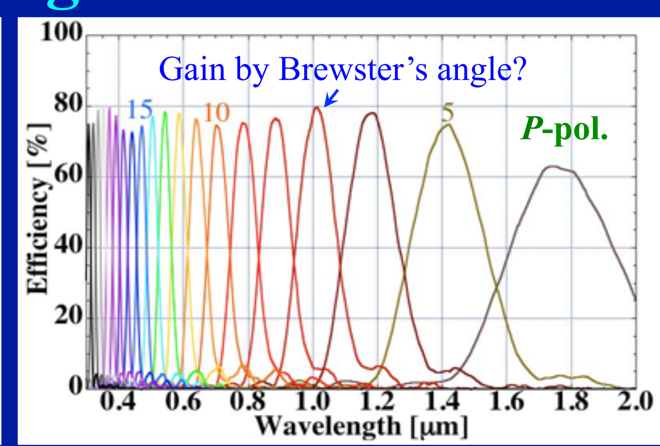
SR grating with saw tooth grooves is not feasible for the high-dispersion transmission grating.

Volume Binary Grating



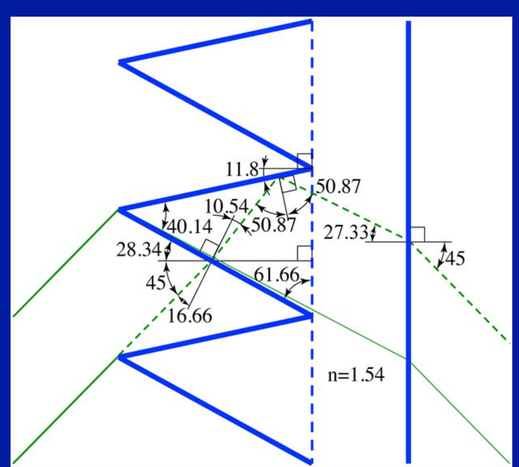
Total reflection at boundary between ridge and groove.
→ Function as a Quasi Bragg grating.

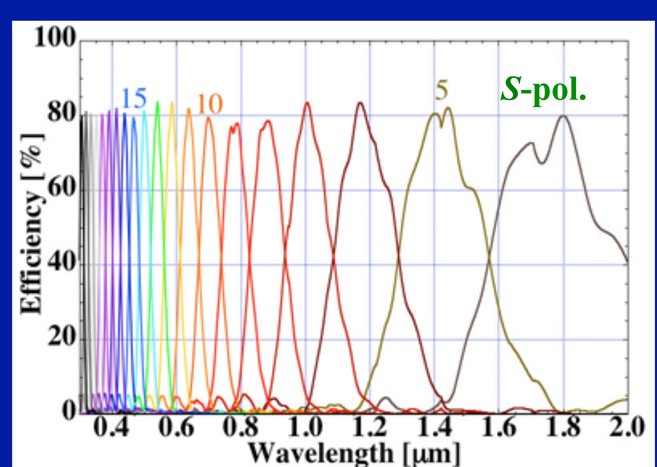


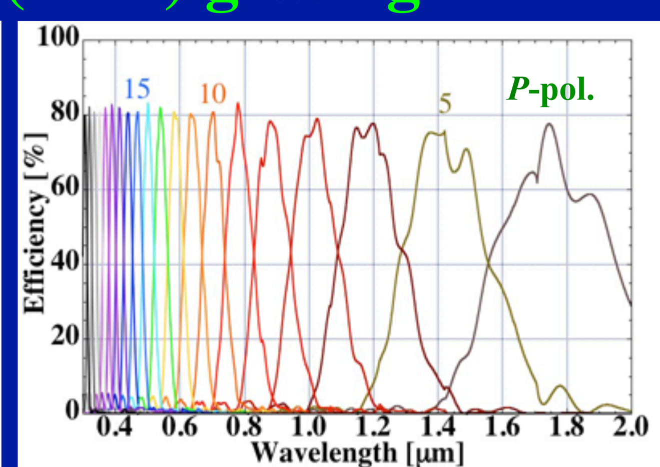


Diffraction efficiency of volume binary grating calculated by RCWA. Λ=5μm, L&S=4.75:0.25 [μm], θ_0=45°, n_1=1.0, n_2=1.54, n_3=1.5, t=9μm.

Reflector facet transmission (RFT) grating

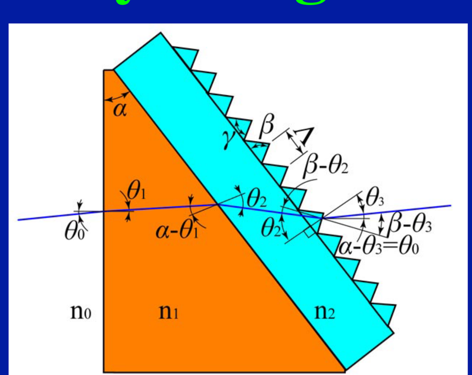






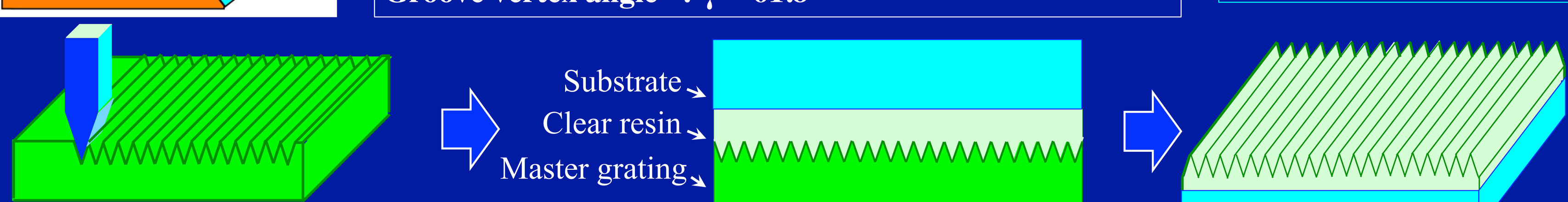
Diffraction efficiency of RFT grating calculated by RCWA. Λ=5μm, θ_0=45°, n=1.54.

Hybrid grism for MOIRCS (as a prototype of RFT grating)



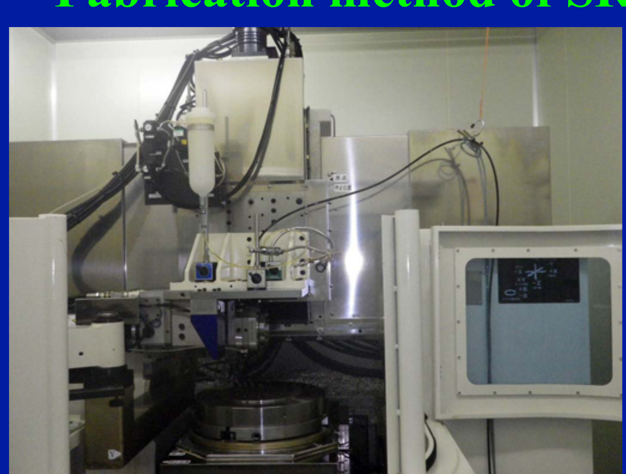
Prism material	: ZnSe (n_1= 2.4529@1.65 μm)
Plate	: S-FPM3 (n_2= 1.5240@1.65 μm)
Prism vertex angle	: α = 23.8°
Grating period	: Λ= 10.79μm (92.68 grooves/mm)
Incident angle	: θ_0= 5°
Groove blaze angle	: β = 64.8°
Groove vertex angle	: γ = 61.8°

Slit width: 0.3"
7th, R= 2,900@0.88 μm
6th, R= 2,790@1.02 μm
5th, R= 2,750@1.25 μm
4th, R= 2,800@1.65 μm
3rd, R= 2,770@2.20 μm

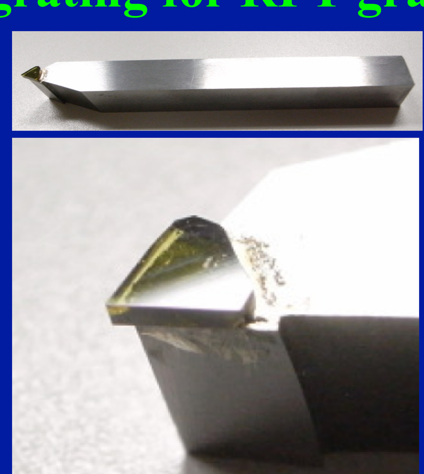


Shaper cutting of master grating.
Work: Ni-P alloy of non-electrolytic plating
Replication
Finish

Fabrication method of SR grating for RFT grating and MOIRCS hybrid grism

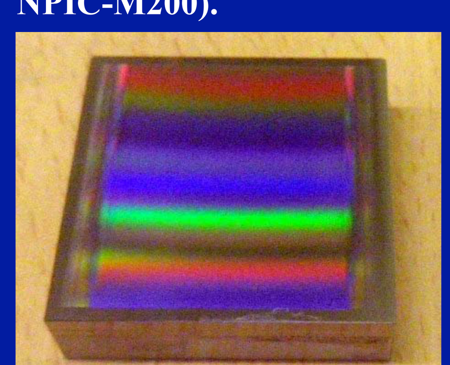


Ultra-high precision machine (Nagase-I, NPIC-M200).

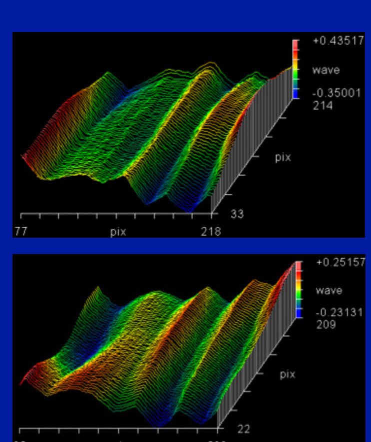


Single-crystal diamond tool.

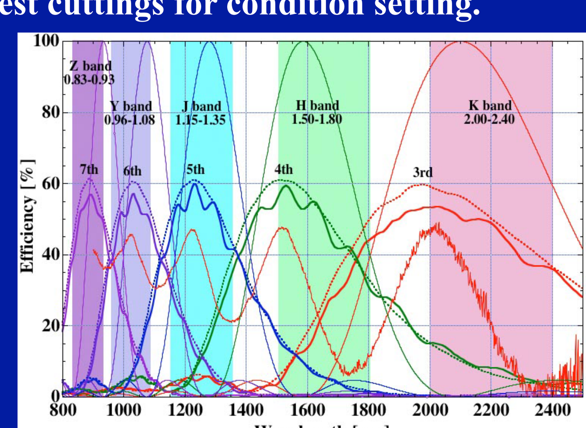
Test cuttings for condition setting.



Mold for replication experiment size: 50×50 [mm].

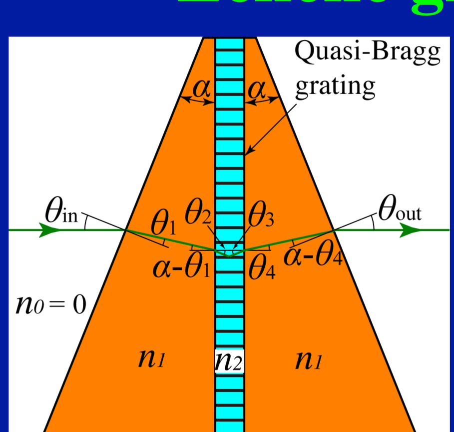


Master ; PV: 0.79λ, RMS: 0.12λ, (upper left)
1st replica ; PV: 0.76λ, RMS: 0.12λ (upper right)
2nd replica; PV: 0.48λ, RMS: 0.07λ (left)



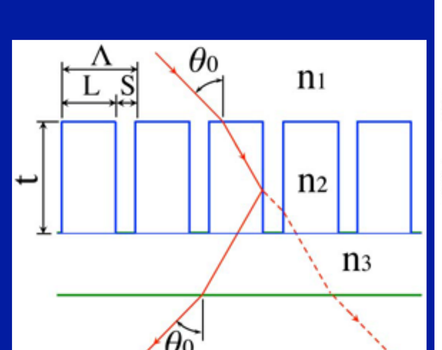
Diffraction efficiency of replicated transmission grating.

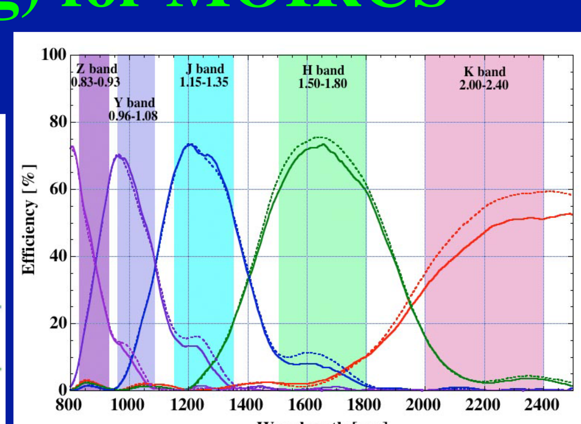
Echelle grism (Volume binary grating) for MOIRCS



Schematic representation of echelle grism for MOIRCS

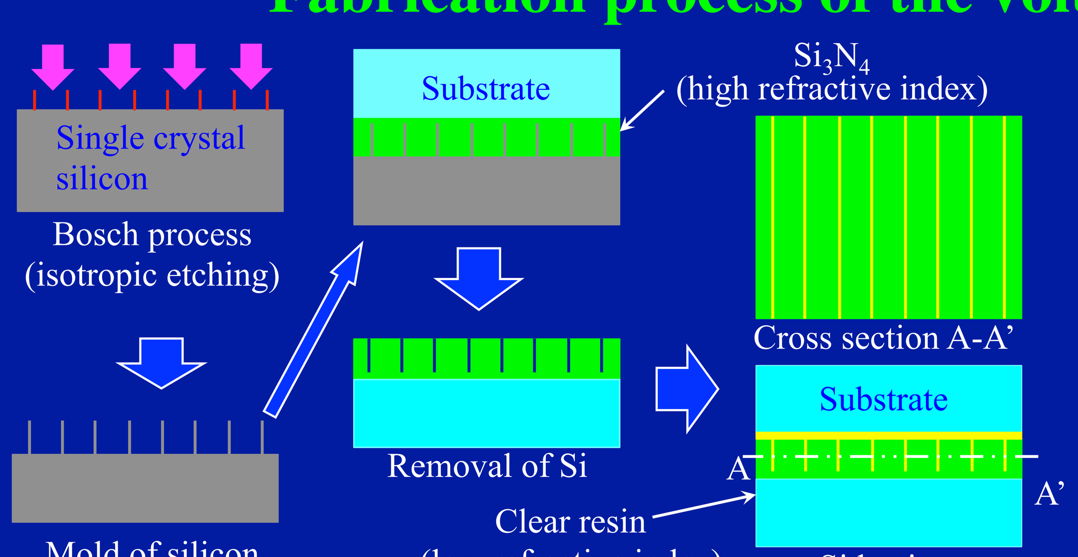
Slit width: 0.3"
5th, R= 4,630@1.02 μm
4th, R= 4,420@1.25 μm
3rd, R= 4,270@1.65 μm

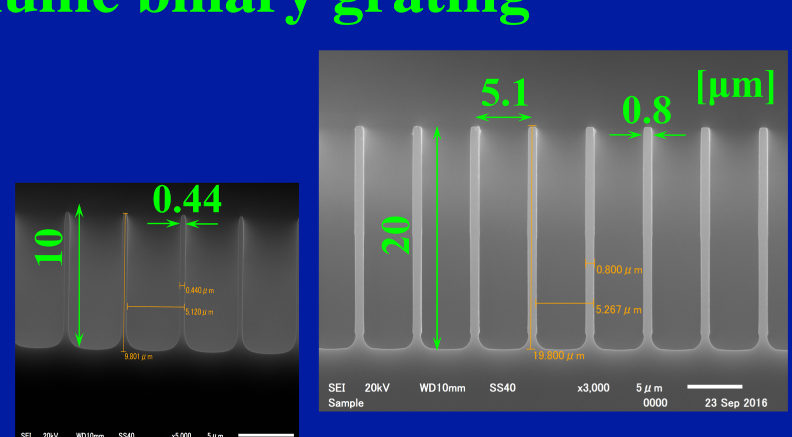




Schematic representation of volume binary grating (left) function as a quasi-Bragg (QB) grating and diffraction efficiency calculated by RCWA (right). L&S=4.6:0.5 [μm], θ_0=28.4°, n_1=1.33, n_2=1.6, n_3=1.6, t = 16 μm

Fabrication process of the volume binary grating





Silicon mold for volume binary grating. Fabricated by Nanotechnology platform of Toyota Institute of Technology.

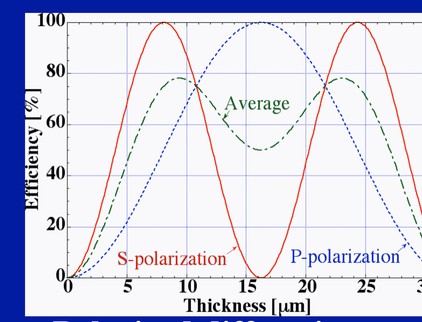
Birefringence volume phase holographic (B-VPH) grating

$$\eta_S = \sin^2\left\{\frac{\pi(n_{S\max}-n_{S\min})t}{\Lambda(n_{S\max}+n_{S\min})\sin 2\theta_S}\right\} \quad \eta_P = \sin^2\left\{\frac{\pi(n_{P\max}-n_{P\min})t\cos 2\theta_P}{\Lambda(n_{P\max}+n_{P\min})\sin 2\theta_P}\right\}$$

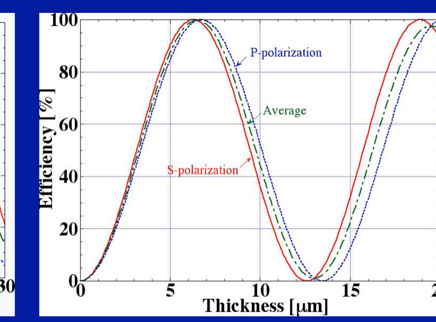
$$\frac{(n_{S\max}-n_{S\min})}{(n_{S\max}+n_{S\min})\sin 2\theta_S} = \frac{(n_{P\max}-n_{P\min})\cos 2\theta_P}{(n_{P\max}+n_{P\min})\sin 2\theta_P}$$

$$\frac{(n_{S\max}-n_{S\min})}{(n_{S\max}+n_{S\min})*2\sin\theta_S\cos\theta_S} = \frac{(n_{P\max}-n_{P\min})\cos 2\theta_P}{(n_{P\max}+n_{P\min})*2\sin\theta_P\cos\theta_P}$$

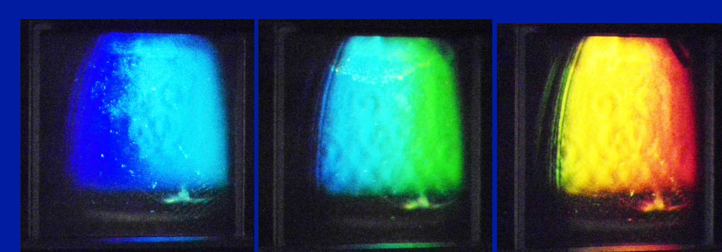
$$\frac{(n_{S\max}-n_{S\min})}{\cos\theta_S} = \frac{(n_{P\max}-n_{P\min})\cos 2\theta_P}{\cos\theta_P}$$

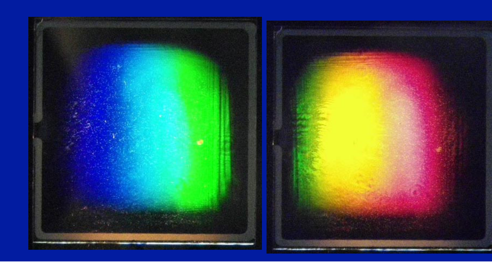


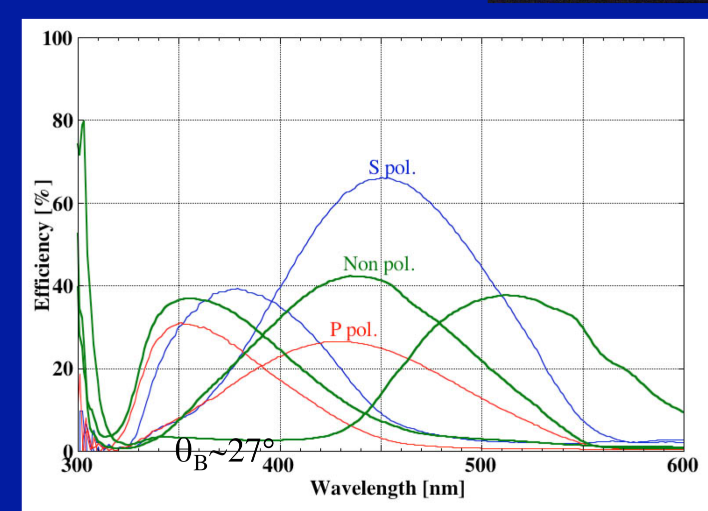
Polarized diffraction efficiencies of Dicson's VPH grating (Polarizer) calculated by Kogelnik method. Λ= 0.646, n_L= 1.46, n_H=1.54, θ_B=48.5°.



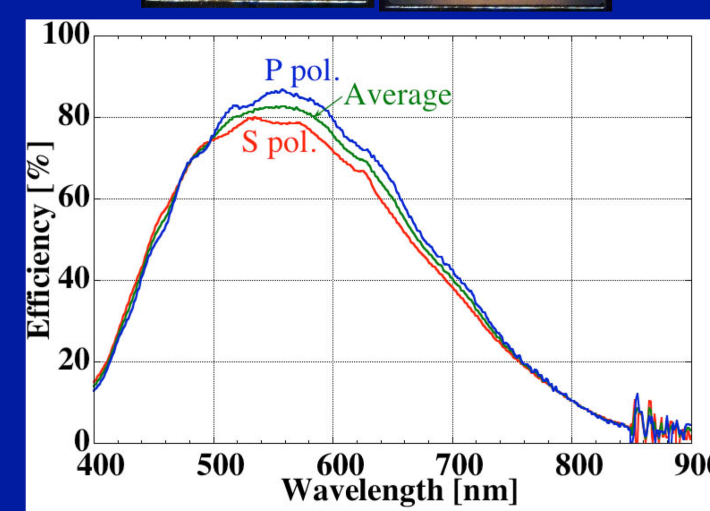
Birefringence VPH grating and calculated polarized diffraction efficiencies versus grating thick-ness *t*. Λ= 0.646 μm, n_L=1.46, n_s= 1.544, n_p = 1.60, θ_B=45°.





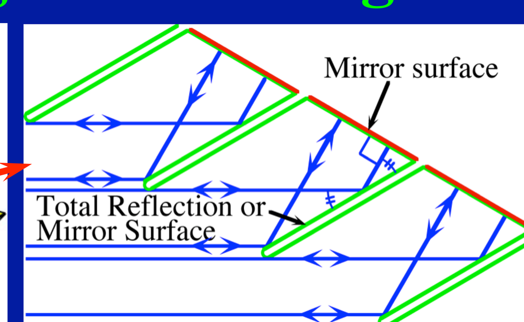


UV curable LC (no=1.55, ne=1.72) + normal LC (no=1.50, ne=1.65), t=10 μm, 2,235 grooves/mm (Λ~ 0.45 μm), UV (315nm) : 1.3mW/cm2, 1sec.

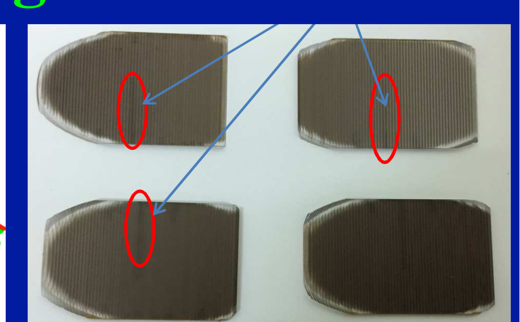


Vis curable resin (nd=1.51) + UV curable LC (no=1.55, ne=1.72), t=20 μm, 616 grooves/mm (Λ= 1.62 μm), Vis (532nm) : 2.0mW, 100sec.

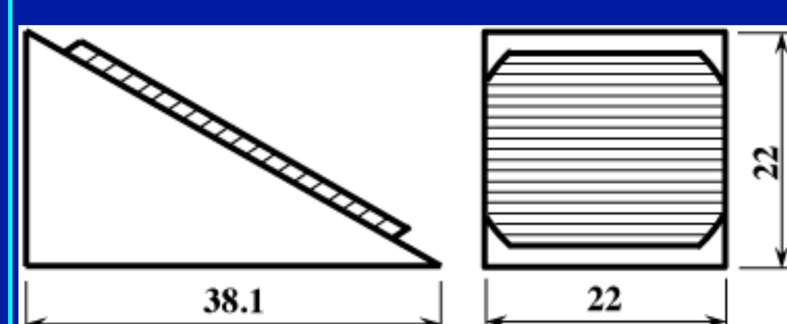
Quasi-Bragg immersion grating



Schematic representation of quasi-Bragg immersion (QBI) grating. (Ebizuka, SPIE 6273, 2006)

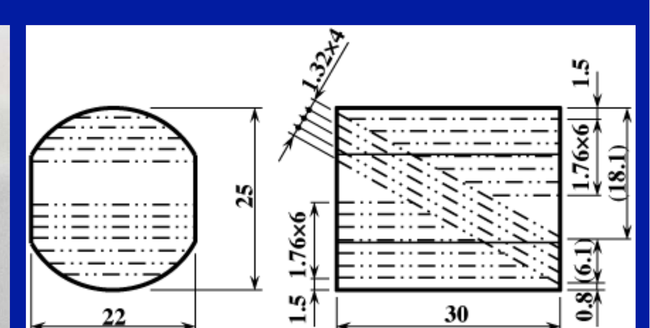


QB grating with tilted mirror lattice.

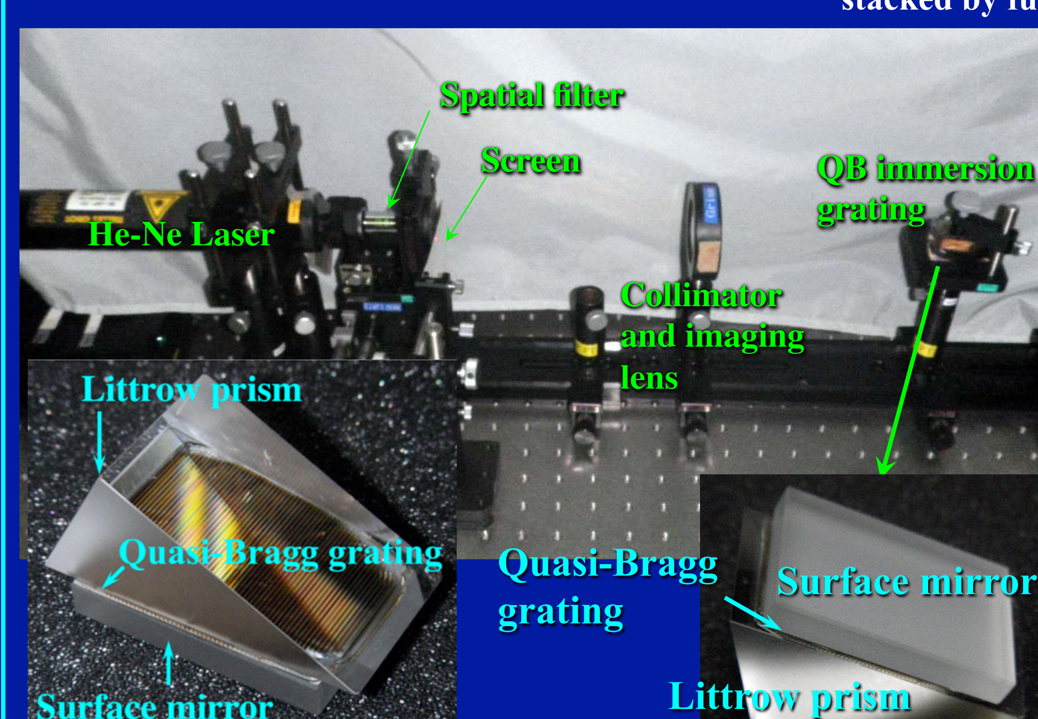


Size of QBI grating.

Block of mirror substrates stacked by fusion of gold.

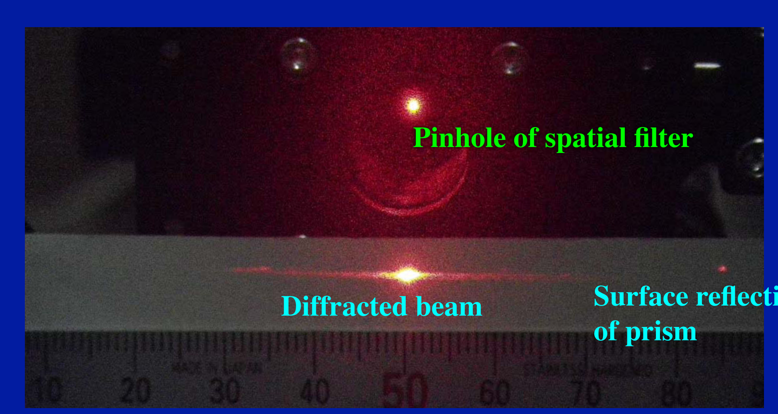


Cutting position of wire saw.



Attached by matching oil.
Measurement optical system.

Diffraction pattern (about 1,000th order) of QB grating. Beam is split up and down.



The diffracted beam is concentrated (blazed). However diffraction orders cannot separate because a point source image is larger than the interval of the diffraction orders (about 2,000th orders).

Summary

	Optimal Order	Eff. [%] (λ-λ [μm])	Status of development
Reflector facet transmission grating	2th~	~ 80 (0.32~2.4)	Evaluations of diffraction efficiency by numerical calculations of RCWA.
Hybrid grism	2rd~	~ 70 (0.32~2.4)	Performing diamond cutting of a master grating of Ni-P alloy for MOIRCS. Replication method is under developing.
Volume binary grating	1st~	~ 80 (0.2~1000)	Performing test fabrications by using MEMS technique.
VPH grating →B-VPH grating	1st	~90 →~100 (0.32~2.4)	Installed in FOCAS, MOIRCS, Kools and WSGS2. (photopolymer) Developing new recording materials for volume hologram with liquid crystal.
Quasi-Bragg immersion grating	5th~	~ 80 (0.2~1000)	Performed test fabrications of lamination by atoms fusion bonding and lamination of embossed substrates.

Current and future works

- Trial fabrication of a mold for the RFT grating is on going.
- SOQ (silicon on quartz) wafer will use for a substrate of the VB grating.
- Performance of a 3D holographic printer (colinear two beam exposure system) for the VPH grating with a large size (~1x1 [m]) will be evaluated.
- The mold for the hybrid grism of the MOICS will fabricate in this business year.