次世代観測装置用の新しい回折格子の開発状況 IV

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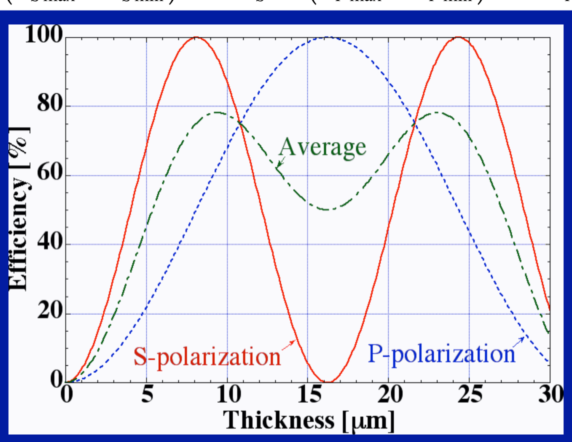
Birefringence volume phase holographic (VPH) grating

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

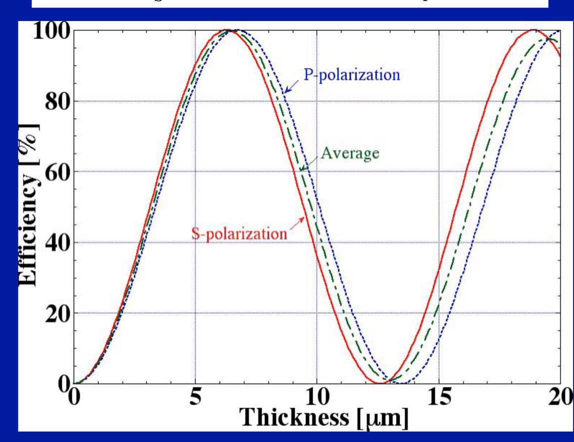
$$\frac{(n_{S\max}-n_{S\min})}{(n_{S\max}+n_{S\min})\sin 2\theta_S} = \frac{(n_{P\max}-n_{P\min})\cos 2\theta_P}{(n_{P\max}+n_{P\min})\sin 2\theta_P}$$

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

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

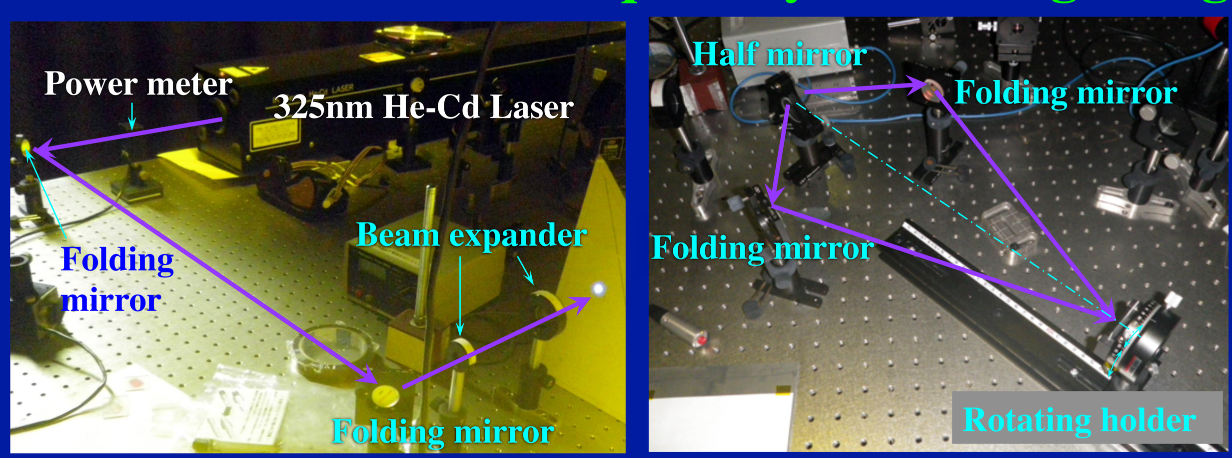


Polarized diffraction efficiencies of Dicson’s VPH grating (Polarizer) calculated by Kogelnik method. Λ= 0.646, n_L= 1.46, n_H=1.54, θ_B=48.5°.

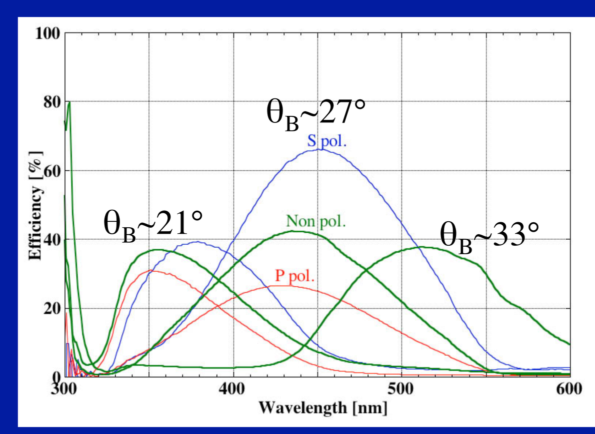


Birefringence VPH grating and calculated polarized diffraction efficiencies versus grating thick-ness t. Λ= 0.646 μm, n_L=1.46, n_s= 1.544, n_p = 1.60, θ_B=45°.

Liquid crystal VPH grating

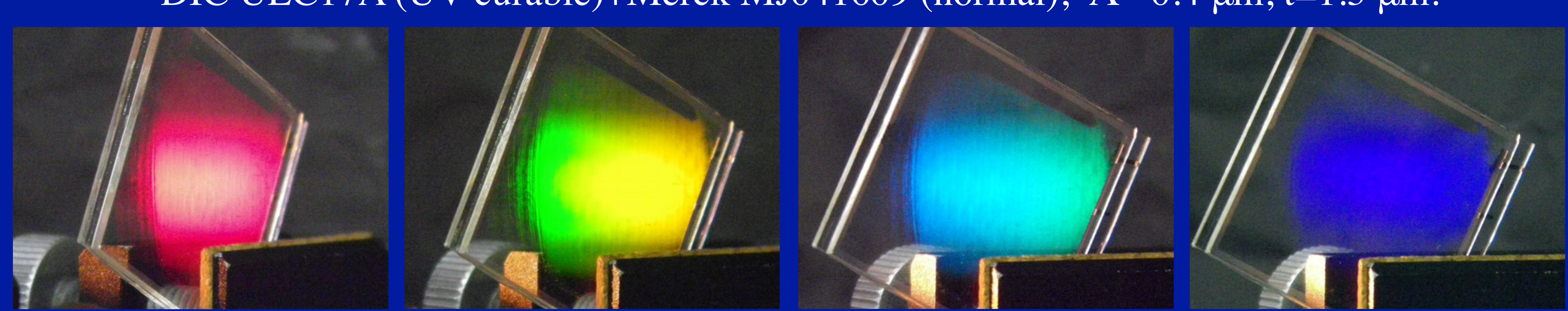


Two beam interference exposure optics



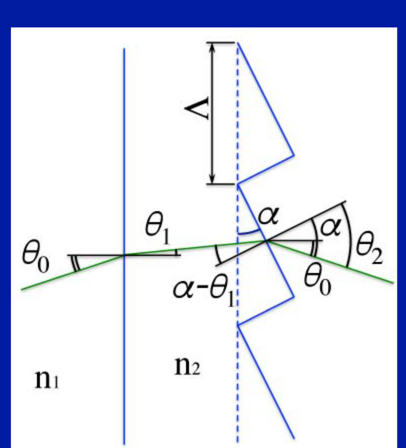
DIC ULC17A +Merck MJ041609, Λ~ 0.5 μm, t=10 μm.

DIC ULC17A (UV curable)+Merck MJ041609 (normal), Λ~ 0.4 μm, t=1.3 μm.



DIC TKN (UV curable)+Merck MJ041609 (normal), Λ~ 0.4 μm, t=1.3 μm.

Limitation of surface relief (SR) grating

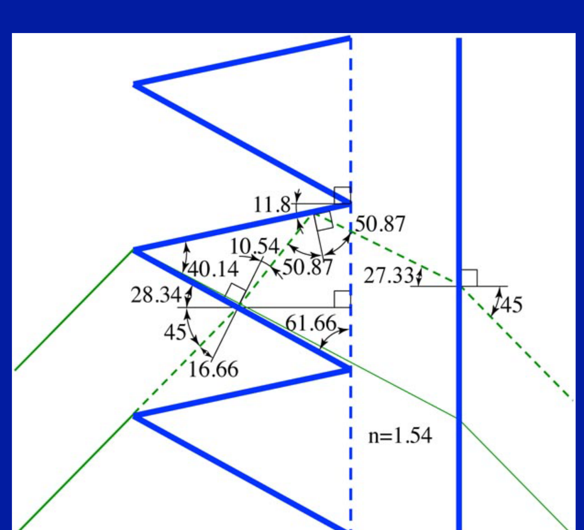


$$\sin\theta_0 = n\sin\theta_1$$
$$n\sin(\alpha-\theta_1) = \sin\theta_2$$
$$\theta_2 = \alpha+\theta_0$$
$$n\sin(\alpha-\theta_1) = \sin(\alpha+\theta_0)$$
$$n(\sin\alpha\cos\theta_1 - \sin\theta_1\cos\alpha) = \sin\alpha\cos\theta_0 + \sin\theta_0\cos\alpha$$
$$(n\cos\theta_1 - \cos\theta_0)\sin\alpha = (\sin\theta_0 + n\sin\theta_1)\cos\alpha = 2\sin\theta_0\cos\alpha$$
$$\tan\alpha = 2\sin\theta_0/(n\cos\theta_1 - \cos\theta_0)$$

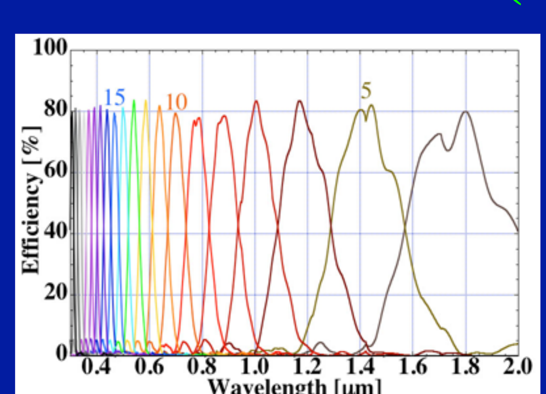
n = 1.5, $\theta_0 \le 30°$ ($\theta_2 > 90°$)
n = 1.8, $\theta_0 \le 36°$
n = 2.3, $\theta_0 \le 45°$
n = 3.0, $\theta_0 \le 54°$
Diamond: n = 2.46@400nm

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

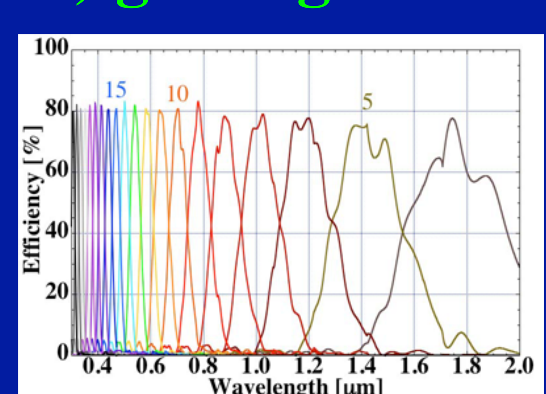
Reflector facet transmission (RFT) grating



Λ=5μm, θ_0=45°, n_1=1.0, n_2=1.54



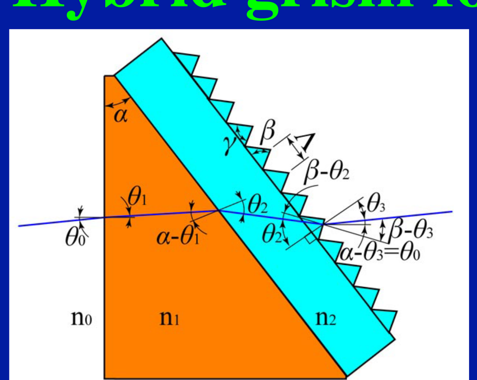
S polarization



P polarization

RTF gratings for WFOS of TMT
Groove vertex angle : γ = 35~45°
Grating period : Λ= 2~5 μm

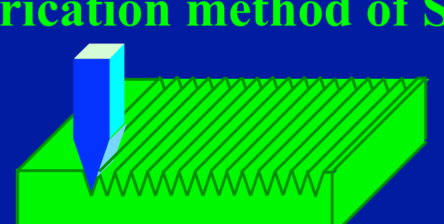
Hybrid grism for MOIRCS (Near infrared instrument for Subaru Telescope)



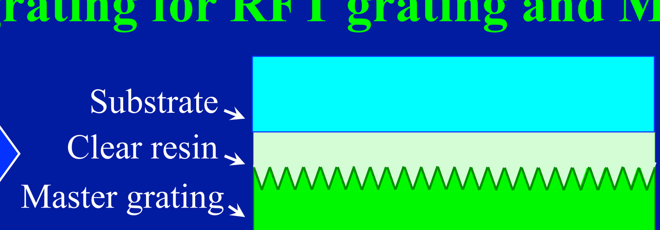
Prism material	: ZnSe (n_1= 2.4529@1.65 μm)
Plate	: S-FPM3 (n_2= 1.5240@1.65 μm)
Prism vertex angle	: α = 23.8°
Grating period	: Λ= 10.79μm (92.68 grooves/mm)
Incident angle	: θ_0= 5°
Groove blaze angle	: β = 64.8°
Groove vertex angle	: γ = 61.8°

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

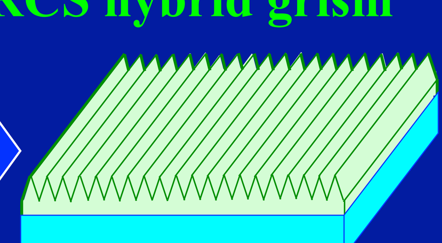
Fabrication method of SR grating for RFT grating and MOIRCS hybrid grism



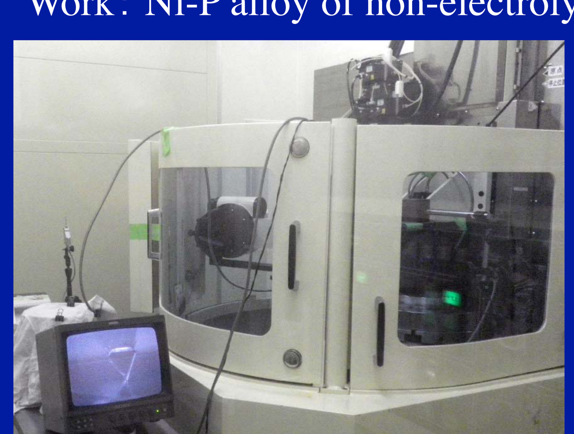
Shaper cutting of master grating.
Work : Ni-P alloy of non-electrolytic plating



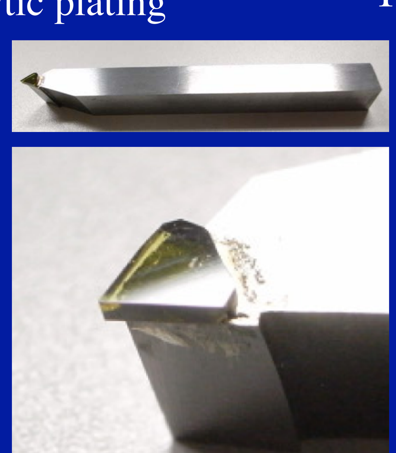
Replication



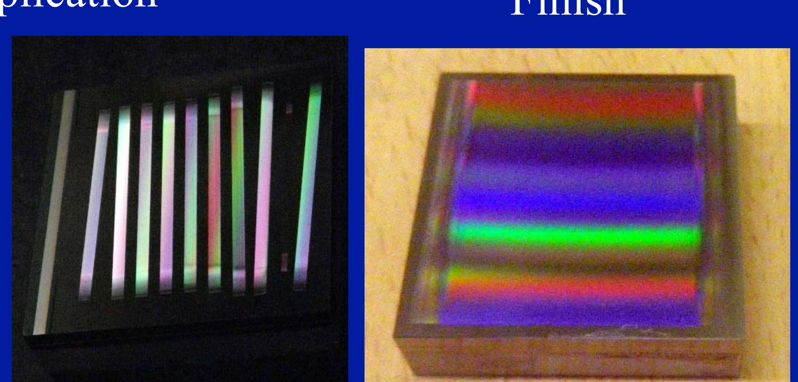
Finish



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

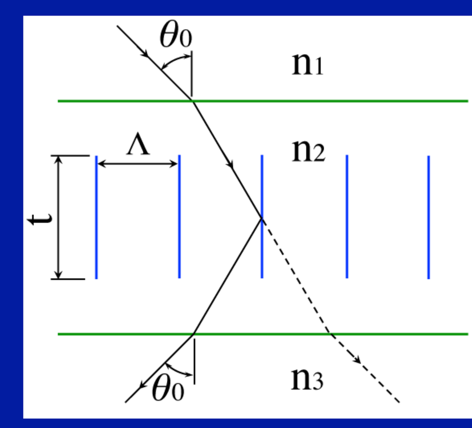


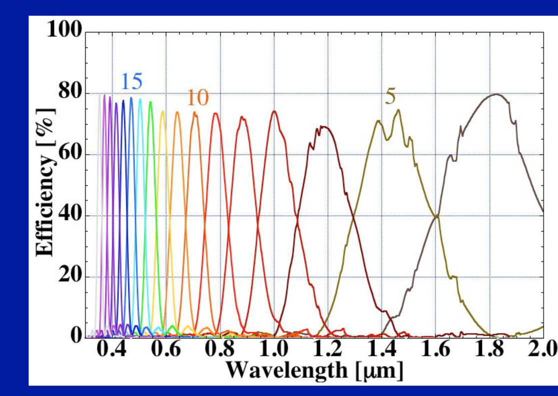
Single-crystal diamond tool.



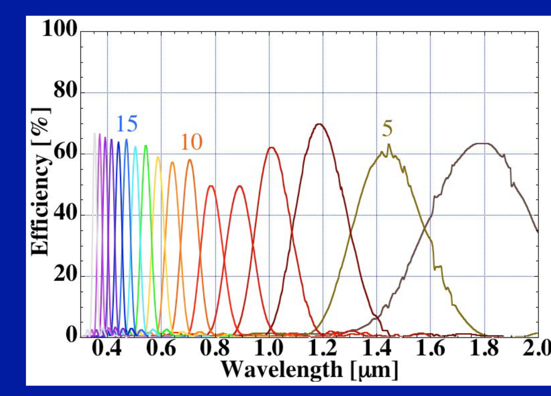
Test cuttings for condition setting (left), mold for replication experiment (right). Work piece: 50×50 [mm].

Quasi-Bragg (QB) grating





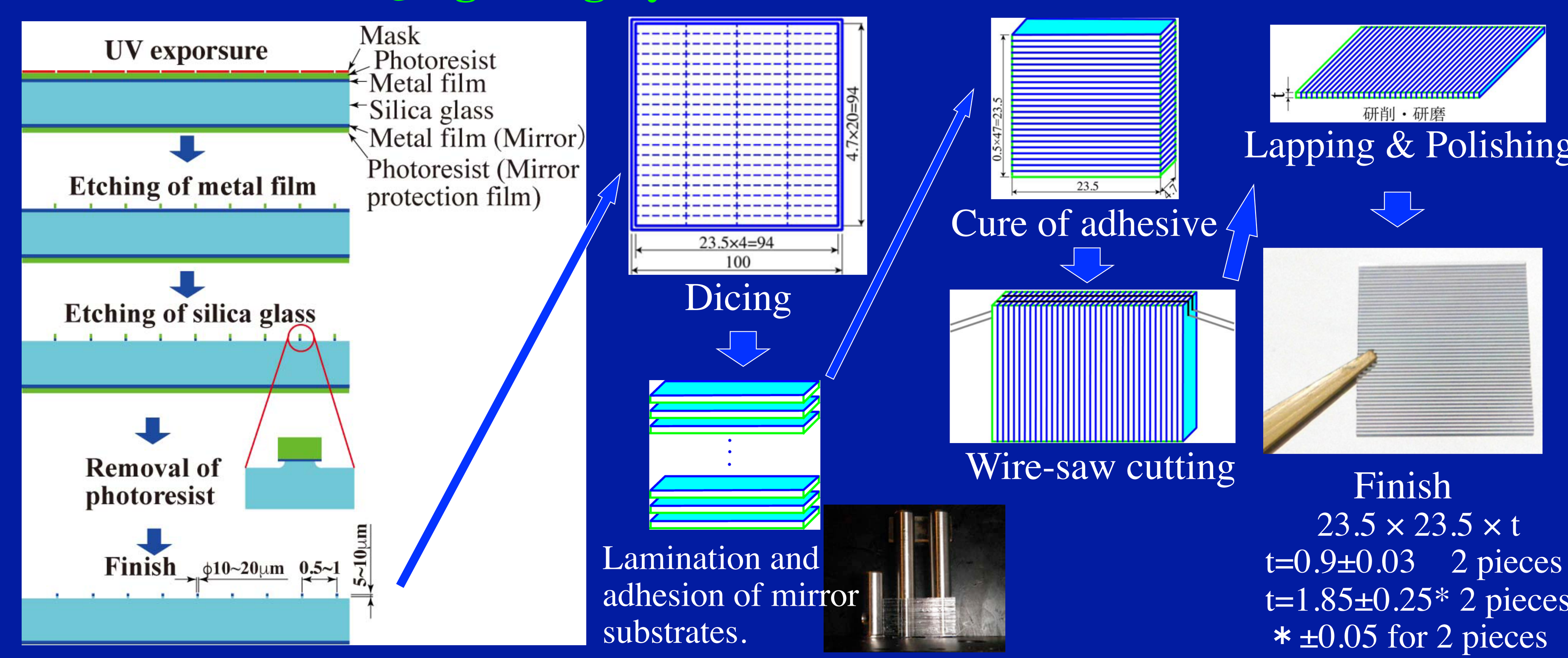
S polarization



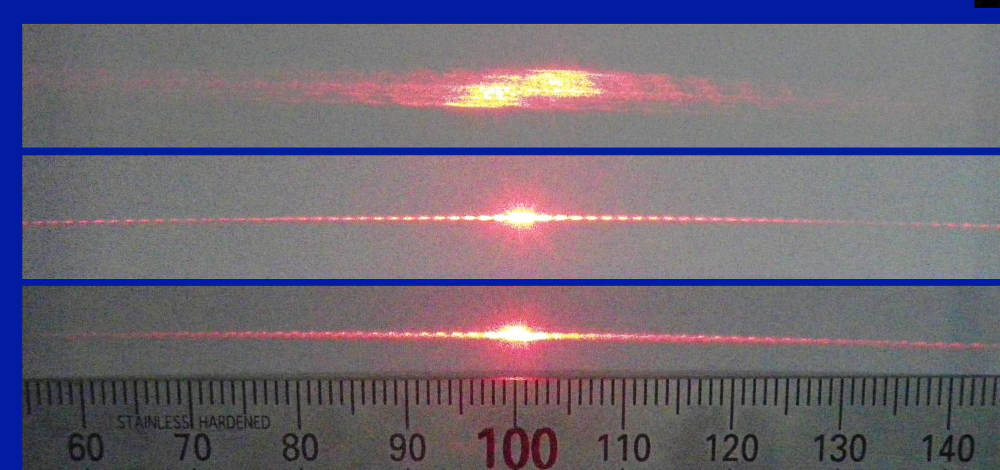
P polarization

Λ= 5μm, θ_0= 45°, n_1=1.0, n_2=1.54, n_3=1.0, t = 9 μm, Al: w = 50nm

Fabrication of QB grating by lamination of embossed mirror substrates

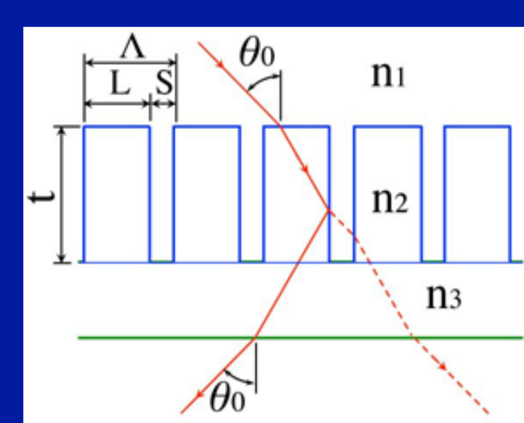


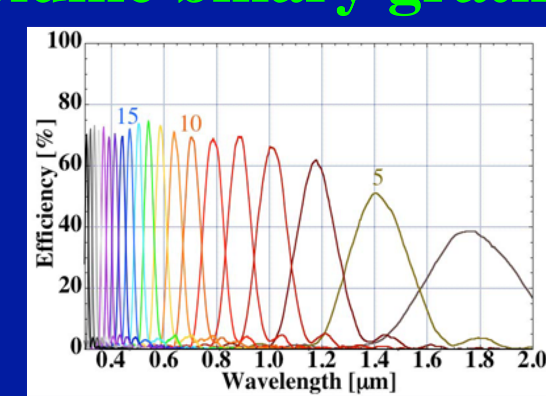
23.5 × 23.5 × t
t=0.9±0.03 2 pieces
t=1.85±0.25* 2 pieces
＊±0.05 for 2 pieces



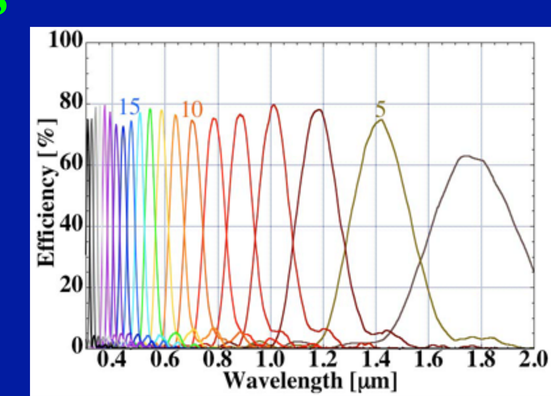
Diffracted beam images of far field of QB gratings. Mirror substrates laminated by adhesive mixed with glass beads (upper). Mirror substrates laminated by pressure fusion of gold and chromium (middle). Mirror substrates with emboss laminated by adhesive (lower).

Volume binary grating





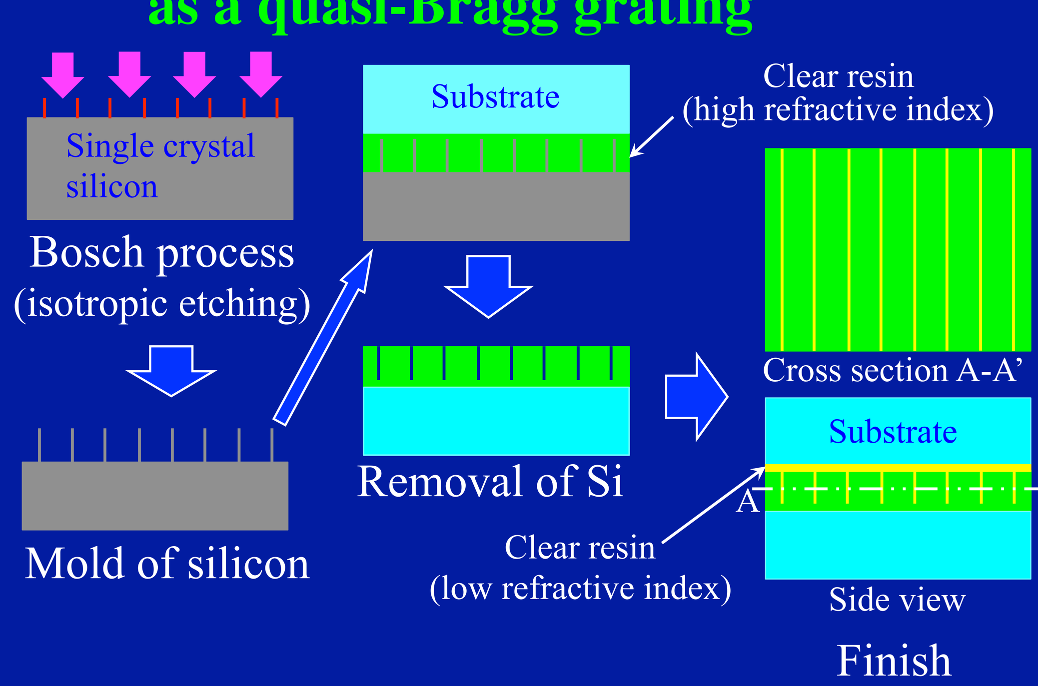
S polarization

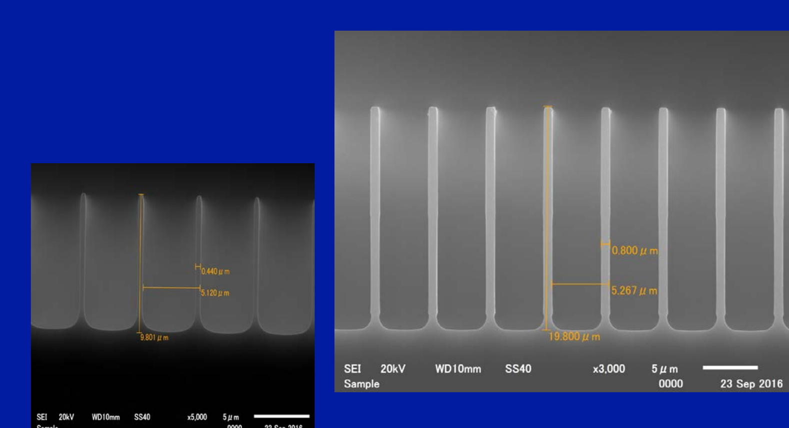


P polarization

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 = 9 μm

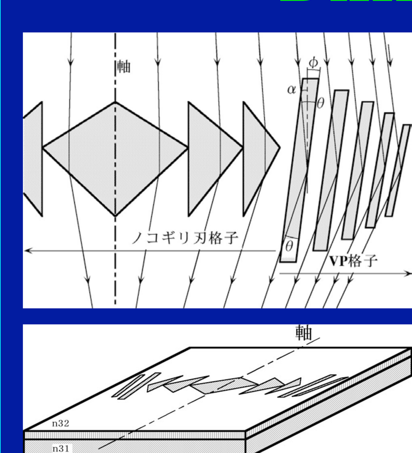
Fabrication process of the volume binary grating which functions as a quasi-Bragg grating

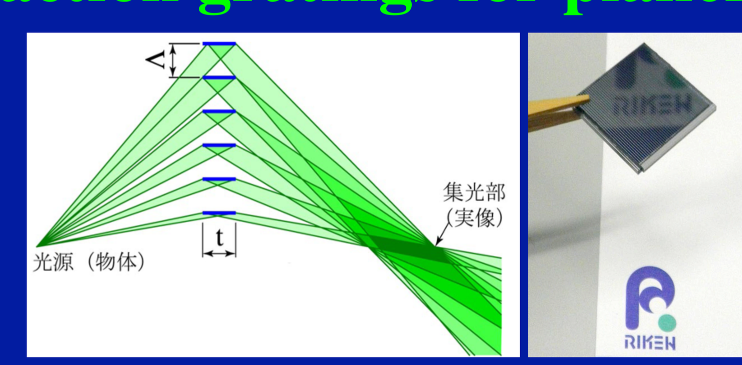




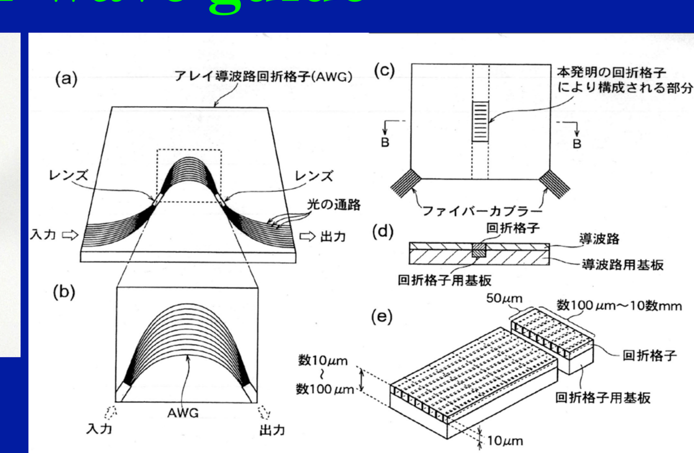
Silicon mold for volume binary grating.
Fabricated by Nanotechnology platform of Toyota Institute of Technology.
Left: Λ=5.1μm, L=0.44 μm, t = 10 μm.
Right: Λ=5.1μm, L=0.80 μm, t = 20 μm.

Diffraction gratings for planer wave guide





Aerial imaging by double quasi-Bragg grating.



Summary

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