Optimal Fabrication of Volume Phase Holographic Grisms with High Efficiency, High Dispersion and Wide Spectral Bandwidth, and its Applications to Near-Infrared Astronomy

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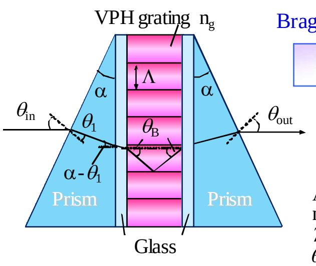
Background

VPH (Volume Phase Holographic) grating

Principle

VPH grism = VPH grating + 2 prisms



Bragg's condition

$$2n_g\Lambda\sin\theta_B = m\lambda$$

Λ : grating pitch
n_g : refractive index
λ : incident light
θ_B : bragg angle
θ_{in} : angle of incidence
θ_{out} : diffraction angle
m : diffraction order

Features

Direct vision transmission type

Diffracted light passes straight–through transmission at a specific wavelength

High efficiency

The diffraction efficiency of VPH graitings can approach nearly 100%, when the angle of incident light satisfies Bragg's condition.

High dispersion

The VPH grating has the potential for achieving high dispersion in wide area by using holographic exposure.

Photosensitive media

The photopolymer is transparent, low scattering and small absorption even in K-band.

Challenges

High efficiency and wide range of spectral bandwidth in the near infrared region are needed.

Maximun diffraction efficiency

$$\eta = \sin^2\frac{\pi\cdot t\cdot\Delta n}{\lambda\cos\theta_B}$$

Δn : refractive index modulation,
t : thickness of a VPH grating,
λ: incident wavelength,
θ_B : bragg angle

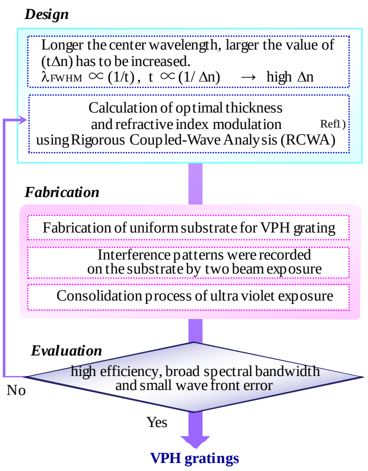
$\lambda \propto t$ λ → longer, t → larger $\lambda_{FWHM} \propto \frac{1}{t}$

When the thickness of a VPH grating is larger,

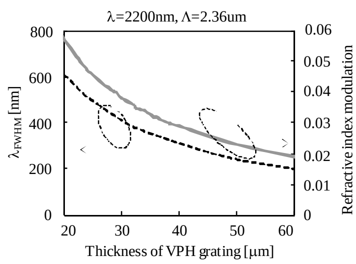
Low refractive index modulation
Shrinkage of resin
Narrow spectral bandwidth

Design and fabrication of k-band VPH gratings

Algorithm of VPH grating

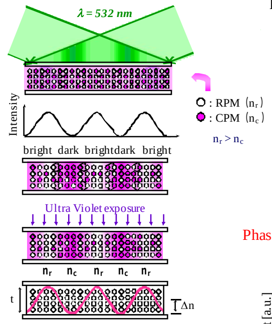


Dependence of spectral bandwidth and refractive index modulation on the thickness of gratings

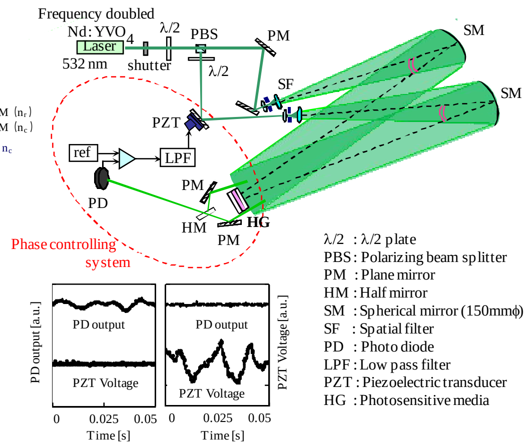


RCWA program was developed by JWU Ref1)

Fabrication process of VPH grating



Optical setup for fabrication of VPH grating with active phase control



λ/2 : λ/2 plate
PBS : Polarizing beam splitter
PM : Plane mirror
HM : Half mirror
SM : Spherical mirror (150mmφ)
SF : Spatial filter
PD : Photo diode
LPF : Low pass filter
PZT : Piezoelectric transducer
HG : Photosensitive media

Wide spectral bandwidth, High efficiency → High refractive index modulation is needed.

To block the phase fluctuation is very important.

Ref1) K. Oka, A. Yamada, Y. Komai, E. Watanabe, N. Ebizuka, T. Teranishi, M. Kawabata, K. Kodate, Proc. of SPIE 5005, 8-19 (2003).

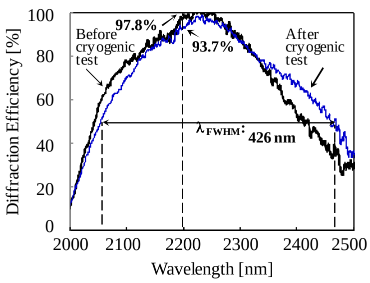
Ref2) K. Nakajima, Y. Komai, E. Watanabe, F. Moritsuka, S. Anzai, and K. Kodate, Opt. Rev, 14, No.4, 201-207(2007).

Ref3) K. Nakajima, N. Ebizuka, M. Iye, and K. Kodate, Proc. SPIE, Vol.7014, p.70141Q (2008).

Evaluation

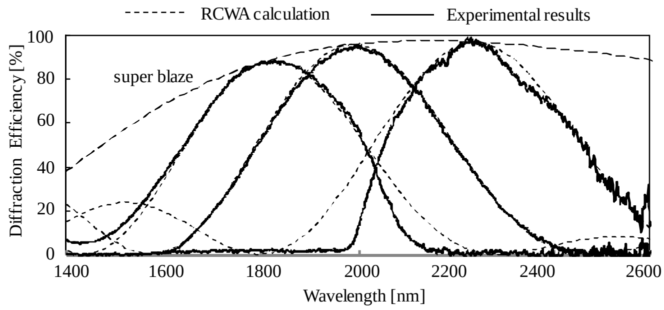
Cryogenic test

Grating pitch: 2.36 μm (424 lines/mm)
Thickness: 29 μm



No deterioration and large difference in the performance after cryogenic temperature 100K from that measured in room temperature.

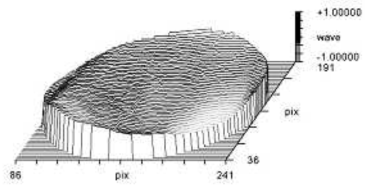
Diffraction efficiency dependence on wavelength



Refractive index modulation: 0.039

The 1st order diffraction wavefront error measurement by Zygo interferometer

Light source :He-Ne Laser (633 nm)



Wave front error 0.041λ (@2200 nm) 0.141λ (@ 633 nm)

High-performance VPH grating was successfully fabricated !!

High efficiency: 97.8%, wide spectral bandwidth: 426 nm , small wavefront error: 0.041λ at 2200 nm

Conclusions

* We showed that high refractive index modulation is needed to get high performance VPH gratings in near infrared region using calculation engine RCWA.
* We designed VPH gratings by using high-power light source for holographic exposure and active feedback phase control.
* The diffraction efficiency reached 97.8% (λ=2200 nm), refractive index modulation is 0.039, spectral bandwidth (λ_{FWHM}) is 426 nm, and small wavefront error is 0.041 waves in r.m.s. at 2200 nm.
* After cryogenic temperature 100 K, no deterioration and large difference in the performance from that measured in room temperature.
* The VPH grism is one of the promising dispersion devices for astronomical observation in the near-infrared region. The prototype will soon be installed into MOIRCS, and will be tested in observation in partnership with Tohoku University and the National Astronomical Observatory of Japan.

Acknowledgements

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