Polarization independent narrow-band filters using sub-wavelength resonant gratings


Contact: Olivier.Gauthier-Lafaye@laas.fr
Motivations for this work

How do I filter the laser communication line from the stellar background?
Motivations for this work

- Narrowband filter
  - High rejection ratio
  - Polarization independent
  - Tunable

- Filter working in transmission
- Under high oblique incidence

- Rules out Fabry-Perot like filters
Outline

- Resonant gratings theory
  - 1D analysis
  - Polarization sensitivity
- Fabrication using C-MOS compatible techniques
- Characterization
  - Normal incidence
  - Demonstration of oblique incidence filters
- Conclusion
Resonant gratings

Based on the so called Wood anomalies (1902)

For some wavelengths incident on a periodic medium, sharp peaks of reflection occur
Resonant gratings

Conditions for resonance:

Guiding by the waveguide
\[ \lambda_i \sim \lambda_p \]

Coupling by the grating
\[ \alpha_{inc} + K \rightarrow \text{Re}(\alpha_p) \]
Interesting features

100% theoretical efficiency
Rejection dominated by AR coating quality
$\Delta \theta$ given by the geometry of the grating
We thus achieve coupling with a symmetric or an antisymmetric TE mode.

Necessary to couple to 2 independent modes, symmetric with respect to the incidence plane.
Polarization insensitivity

Polarization insensitivity can be achieved using:

\[ \varepsilon_{12} = 0 \]
\[ \cos(\phi) = 0 \]
Polarization insensitivity: using $\varepsilon_{12} = 0$

- High precision needed on holes diameter
- Practical realisation difficult

Polarization independance becomes angular sensitive

Used to achieve narrow filters with good angular tolerance
Polarization insensitivity using \( \cos(\phi) = 0 \)

Possible using an hexagonal lattice
s and p resonance have equivalent spectral width
Fabrication

Normal incidence

- Grating:
  - lattice period 590nm
  - holes ~ 120 nm
- AR coating:
  - 2 layers
  - AR ~ 1% @850 nm expected
Layers deposition

Glass substrate
LPCVD deposit of Si$_3$N$_4$
PE-CVD deposition of SiO$_2$
PMMA coating
Al deposition
E-beam lithography calibration

Processing margin
Etching

- Dry etching
  - ICP
  - CHF3 etching
  - Low speed/selectivity
- Reproducibility
  - Chamber conditionning using O2 plasma
Physical characterization

AFM measurements:
- surface roughness: < 1 nm
- reproducibility OK

SEM measurements:
- homogeneity on large areas
**Test set-up**

Collimated broadband SLD light source

Filtered through a 1 m monochromator
Collimated

Chopper

$\frac{1}{4}$ wavelength plate

Pinhole (2 mm to 600µm)

50/50 beamsplitter

Sample

R or T using a camera or photodiode
Characterization : normal incidence

$R_{\text{max}} = 54\% \ (100\% \ \text{th.}) \ \text{FWHM} = 0.38 \text{ nm} \ (0.22 \ \text{th.})
Normal incidence : angular tolerance

Theoretical : 0.16 °

FWHM = 0.26°
Angular tolerance

Theoretical: 0.16°
Normal incidence

Resonant wavelength: 842.4 nm on first try
849.6 nm by adjusting lattice constant

Max Reflexion 54% (100% theoretical)

R + T 100% no optical absorption

FWHM resonance 0.38 nm (0.22 nm theoretical)

Angular tolerance 0.26° (0.16° theoretical)
Finite size effects?
Dispersion effects?

Non resonant

Resonant
Stitch fields?

1mm² filter.

10x10 stitched fields

FFT
Spatial filtering

1 cm² Photodiode

Transmission (%)

Wavelength (nm)

Iris diameter:
- infini
- 1000 µm
- 800 µm
- 600 µm
- 400 µm
Spatial filtering

Not yet equal to theoretical predictions
Oblique incidence filters
Characterization

s polarization

\[ \theta = 63.5^\circ \]

\[ \Delta \lambda \ (s/p) = 0.38 \text{ nm} \]

p polarization
Evolution with incident angle

Tuning rate: 1.3 nm /°
Conclusion

- Demonstration of 2D resonant grating filters
  - At both normal incidence and high oblique incidence
  - With state of the art performances
    - $R = 54\%$
    - Work under $60^\circ$ angle of incidence
    - Large tuning range

- Reliable and repeatable processing

- Work to be done on
  - Polarization independance
  - Diffusion through imperfections