High Q polarization independent Guided Mode Resonant Filter with « doubly periodic » etched Ta2O5 bi-dimensional grating

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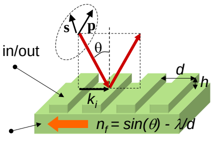
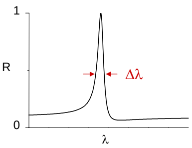
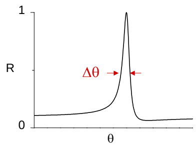
Basic principle, interests and drawbacks of GMRF







* ε_n = n^{th} Fourier coefficient of the grating

- **Main interest :**
  - $\Delta\lambda$ proportional to $h^2 |\varepsilon^*_1|^2$ ➡ narrow band filtering $Q=\lambda/\Delta\lambda > 6000$ experimentally [1]
- **Main problems**, in simple cases when one mode is excited:
  - $\Delta\theta$ proportional to $h^2 |\varepsilon_1|^2$ ➡ weak angular acceptance $\Delta\theta/(\Delta\lambda/\lambda) \approx n_i/\cos(\theta)$
  - strong polarization dependence

Example: λ=1.55μm $\Delta\lambda$=0.2nm ➡ $\Delta\theta$=0.02° beam diameter 6mm

Design of a polarization independent GMRF with a broaden angular acceptance

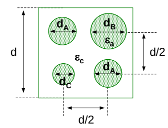
- 2 counter propagative modes excited:
  - $\Delta\theta$ proportional to h $|\varepsilon_1|$ (h $|\varepsilon_2|)^{1/2}$
  - $\Delta\lambda$ proportional to $h^2 |\varepsilon_1|^2$
- 2 independent modes excited:
  - Polarization independence

4 modes:
- conditions naturally fulfilled for a 2D grating under normal incidence
- conditions can be fulfilled for a 2D grating under oblique incidence illuminated along the bisector plane of the directions of periodicity [2]

"Doubly periodic" pattern

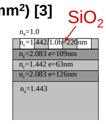
$|\varepsilon_1| = | (\varepsilon_c-\varepsilon_a) / 2 * [d_A/d\ J_1(\pi d_A/d) - d_A/d\ J_1(\pi d_A/d) + d_B/d\ J_1(\pi d_B/d) - d_C/d\ J_1(\pi d_C/d)] |$

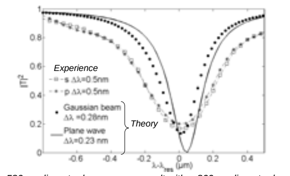
$|\varepsilon_2| = | (\varepsilon_c-\varepsilon_a) / 4 * [d_A/d\ J_1(2\pi d_A/d) + d_A/d\ J_1(2\pi d_A/d) + d_B/d\ J_1(2\pi d_B/d) + d_C/d\ J_1(2\pi d_C/d)] |$



First sample (3x3mm²) [3]

d = 960nm ; d_A = 280nm; d_B = 372.5nm ; d_C = 185nm; λ_0=1545,5nm
$\Delta\lambda$ =0.24nm ; $\Delta\theta$=0.17°

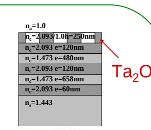


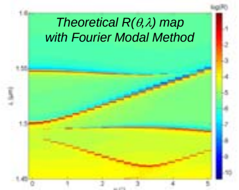


580μm diameter beam, same result with a 800μm diameter beam

Second sample (3x3mm²)

d = 980nm ; d_A = 377.5nm ; d_B = 422.5nm ; d_C = 320nm; λ_0=1548.0nm
$\Delta\lambda$=0.211nm ; $\Delta\theta$=0.52°

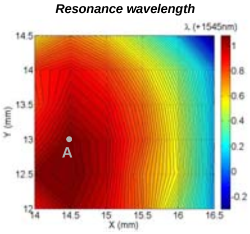


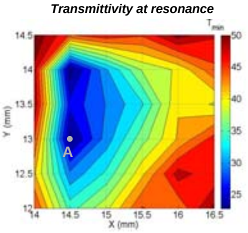


Theoretical R(θ,λ) map with Fourier Modal Method

Characterizations

Inhomogeneity over the sample surface





- edge effects
- homogeneous region around point A ➡ lowest transmittivity
- global wavelength shift 1.4nm, may be caused by errors on:

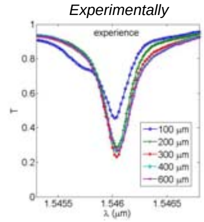
	Guiding layer thickness	Period	Holes diameter	Grating depth
Variation (nm) necessary for 1nm shift	2.9	0.7	10	2.9
Variation (nm) expected per mm length	0.01	0.0245	0.1	0.5

Angular divergence vs illumination spot size

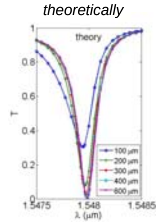
A small beam size would illuminate less defaults, but the beam divergence may be greater than the angular acceptance of the filter.

Transmittivity spectra for varying beam diameter

Experimentally



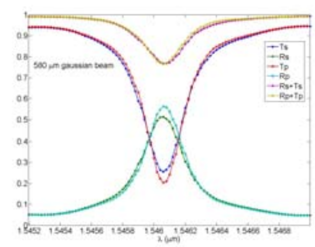
theoretically



- best compromise obtained for 300μm
- good angular acceptance (theoretically and experimentally) down to 300 μm beam diameter
- for the 100 μm diameter beam, the shoulder at lower wavelength is due to the excitation of out of normal resonances

Spectra at point A with a 580μm diameter Gaussian beam

- **Experimentally $\Delta\lambda$=0.28nm**
  ≈ $\Delta\lambda$=0.21nm theoretically
- **Q ≈ 5500**
- **Polarization independence**



at resonance

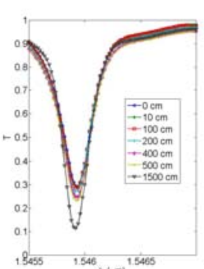
- **R = 53 % instead of 100 %**
- **T = 24 % instead of 0 %**
- **1- R - T = 23 % instead of 0 %**

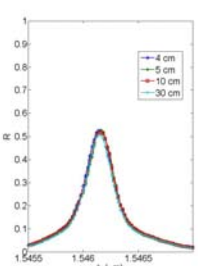
Complementary characterizations

Diffusion ?

Impact of field stitching errors and writing resolution [4] ?

Transmittivity and reflectivity spectra for increasing sample to detector distances

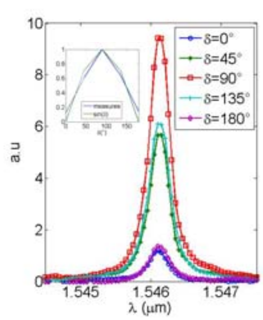


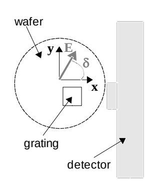


- Same spectra when increasing the distance from 0cm: low diffusion
- For distances greater than 400cm the specular beam is cut

Guided modes ?

Spectra measured from the edge of the sample, when varying the incident linear polarization

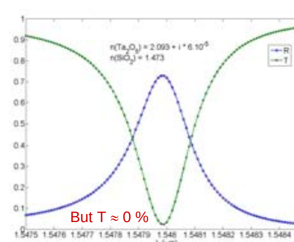




energy measured at resonance wavelength varies as sin(δ) ➡ guided modes

Absorption in materials ?

Theoretically, Im(n Ta_2O_5) = 6e-5 ➡ 20% losses



Conclusions and perspectives

- Ta_2O_5 grating ➡ theoretical quality factor of 7400, achievable with a 300μm diameter Gaussian beam ➡ experimentally: polarization independent filter with Q = 5500
- variation of the resonance wavelength throughout the surface of the filter, attributed meanly to a variation in the holes depth ➡ coupling and decoupling process incomplete
  ➡ at resonance R = 53.2% and T = 23.6% instead of 100% and zero and ~20% of the incident energy remains trapped in the guided modes
- holes depth could be more homogeneous if the etching were stopped at the interface between two materials.

[1] *Resonant grating waveguides structure*, D. Rosenblatt, A Sharon, A. A. Friesem, I. E. E. E. J. Quant. Elec., **33**, pp 2038-2059 (1997)
[2] *Angular tolerant resonant grating filters under oblique incidence*, A. Sentenac and A.-L. Fehrembach, J. Opt. Soc. Am. A, **22**, pp 475-480 (2005)
[3] *Experimental demonstration of a narrowband, angular tolerant, polarization independent, doubly periodic resonant grating filter*, A.-L. Fehrembach, A. Talneau, O. Boyko, F. Lemarchand, Opt. Lett., **32**, pp 2269-2271 (2007)
[4] *Impact of electronic lithography irregularities across mm-scale resonant grating notch filters*, A. Talneau, F. Lemarchand, A.-L. Fehrembach, A. Sentenac, soumis à Appl. Opt.