Design of a mid infrared resonant grating filter

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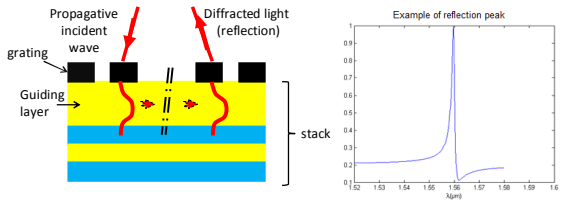
Outline

- Principle of resonant grating filters
- State of the art
- Design of a MIR filter
- Theoretical results
- Conclusions

Resonant grating filters

Definition : Filter composed of a few layer guiding stack comprising a sub-wavelength diffraction grating

Principle : Excitation of modes in waveguide through (-1) diffraction order



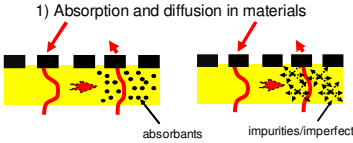
Filtering obtained if amplitude of reflected 0th order very low out of resonance

Resonant grating filters

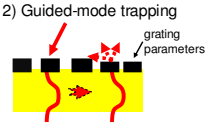
Losses → efficiency at resonance, spectral width

Main origins of losses → Materials, Grating parameters, Divergence of beam

1) Absorption and diffusion in materials



2) Guided-mode trapping



Fehrembach et al. IEEE, 2010

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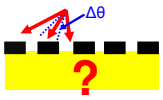
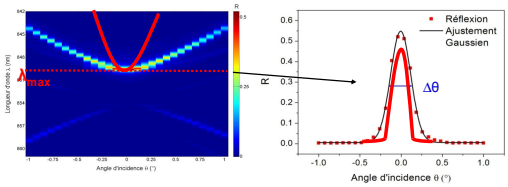
Resonant grating filters

3) Divergence of beam > angular tolerance (Δθ)



tunability ↗ if Δθ ↘



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State of the art

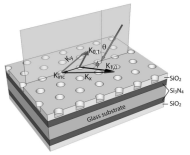
❖ Resonant grating filters = new generation of optical components for free-space filtering

❖ Realization of filters based on 1D diffraction grating ➔ high potentials

BUT 2 major drawbacks : - Large angular tolerance Rosenblatt et al. IEEE, 1997
- Polarization dependence

❖ Theoretical works on 2D gratings to solve these problems Mizutani et al. JOSA A, 2001

❖ Experimental demonstration in NIR range by a CMOS-compatible process Hernandez et al. APL, 2008



Highly oblique incidence (~ 60°):
- λ_0 = 850 nm
- $\Delta\lambda_s$ ~ 0.8 nm, $\Delta\lambda_p$ ~ 0.5 nm
- quasi-independent polarization
- tunability of ~ 1.5 nm/°

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Objectives

Interest of MIR : spectroscopic detection of methane

Design of a filter characterized by:

- **working wavelength: 4.65 µm**
- **high reflectivity :100% at resonance**
- **narrow bandwidth: 0.5 nm at half maximum**
- **oblique incidence ~10°**
- tunability on a range of 100 nm
- polarization independence
- rejection ratio > 500
- surface ~ 5 cm^2

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Design of the structure

NIR → materials ? → MIR

~~CMOS materials~~

- ZnSe, SrF_2, CaF_2, ... } - epitaxy difficult
- Si, SiGe } - very constrained materials

III-V semiconductors :
- InGaAsP → - weak optical index contrast - growth difficult for thick layers - epitaxy on larges surfaces not mastered
- AlGaAs → - better optical index contrast - system well-known and used in lab - deposition of many layers with
  - good thickness control
  - good material composition control
  - good precision on optical index

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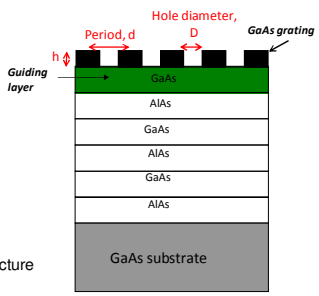
Design of the structure

Materials chosen: AlGaAs system

Limitations:

- rapid oxidation of Al in contact with air
  => upper layer = GaAs
- interface roughness emphasized by deposition of $Al_xGa_{(1-x)}As$ on AlAs
  => pairs GaAs / AlAs
- high optical index substrate + weak index contrast inside stack
  => imperatively no losses in structure



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Theoretical results

Grating etched in high optical index material ⇒ increases fabrication errors + complexifies antireflection coating (AR)

Weak optical index contrast + high optical index substrate:

- Difficulty to obtain good AR
- Many layers needed
- Lots of modes in structure
- Lots of peaks in the reflectivity spectrum

⇨ Leaky modes in substrate

Need to isolate a mode far from substrate

Need to destroy all other propagating modes

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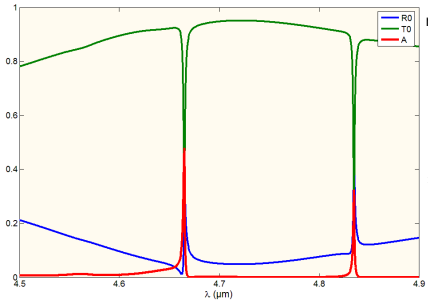
Theoretical results

Calculations based on Fourier Modal Method*

mode not isolated from substrate



$n_{eff} = 2.73+0.0224i$

$A(loss)=1-R_0-T_0 \neq 0$
⇒ energy lost mainly in (-1) order

* L. Li, J. Opt. Soc. Am. A. vol 14, pp.2758-2767, 1997

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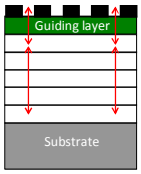
Theoretical results

To isolate a mode :

- High optical index upper layer = thick
  ⇒ guiding layer for specific mode
- Low optical index layers = thick
  ⇒ min 2 optical wavelengths
  ⇒ $Im(n_{eff})$ small
  ⇒ field of mode less sensitive to substrate
- Other propagating modes destroyed
  ⇒ either using absorbant substrate
  ⇒ or using roughly back-sided substrate



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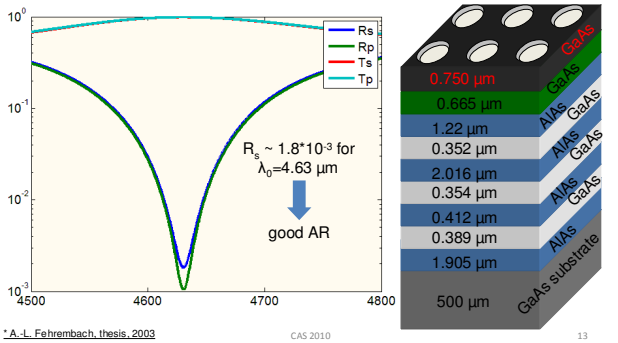
Theoretical results

on optimized structure

Calculations based on a perturbative method*



* A.-L. Fehrembach, thesis, 2003

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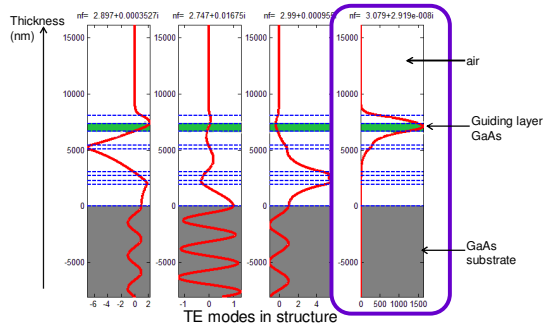

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Theoretical results

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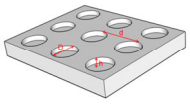
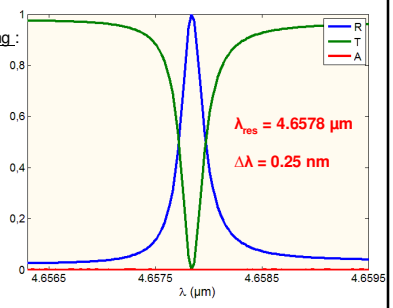
Characteristics of squared grating :

- Period, d = 1.4298 µm
- Grating height, h = 670 nm
- Holes diameter, D = 216 nm





* L. Li, J. Opt. Soc. Am. A, vol 14, pp.2758-2767, 1997

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Conclusions

- ✓ Resonant grating structures very promissing narrowband filters
- ✓ Wide application domains in Mid-Infrared
- ✓ Use of high optical index substrate original
- ✓ Structure feasible provided that some care taken during design

Thank you for your attention

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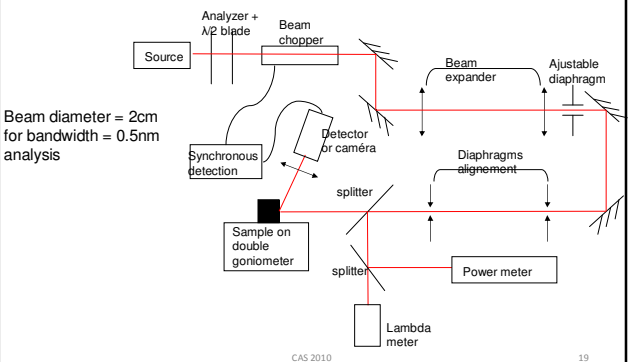
Characterization



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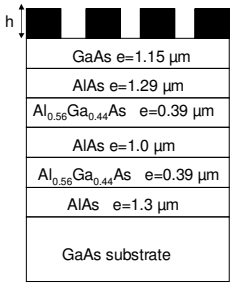
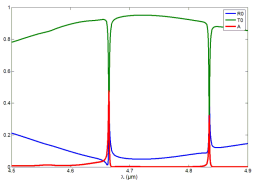
Theoretical results

mode not isolated from substrate

h=0.41 µm of $Al_{0.9}Ga_{0.1}As$



n_{eff} = 2.73+0.0224*i*

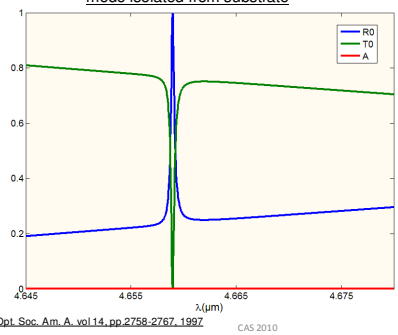


Theoretical results

on optimized structure

Calculations based on Fourier Modal Method*

mode isolated from substrate



for e.g :

n_{eff} = 3.08+1.16*e*-8*i*

$A(loss)=1-R_0-T_0 = 0$
⇒ few energy lost

* L. Li, J. Opt. Soc. Am. A, vol 14, pp.2758-2767, 1997