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Federal Institute of Metrology METAS

EMRP
European Metrology Research Programme
• Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Fabry-Perot etalon for characterzing the wavelength scale of UV spectrometers

Peter Blattner, Stella M. Foaleng, Steven van den Berg, Omar El Gawhary, Mario Blumthaler, Julian Gröbner, Luca Egli

Contributions

METAS Federal Office of Metrology

pmod wrc

Medizinische Universität Innsbruck

VSL Dutch Metrology Institute

- Stella M. Foaleng: Practical realization / initial characterizations of the devices
- Omar El Gawhary, Mario Mario Blumthaler, Julian Gröbner: Helping analysing the data
- Manfred Heuberger (EMPA): Present work is based on his paper : Perret E., Balmer T., Heuberger M., „Self-consistent algorithm for calibrating spectrometers to picometer accuracy over the entire wavelength range“ Applied Spectroscopy, Vol. 64, Issue 10, pp. 1139-1144 (2010)

EMPA Materials Science & Technology

- EMRP Project ENV03

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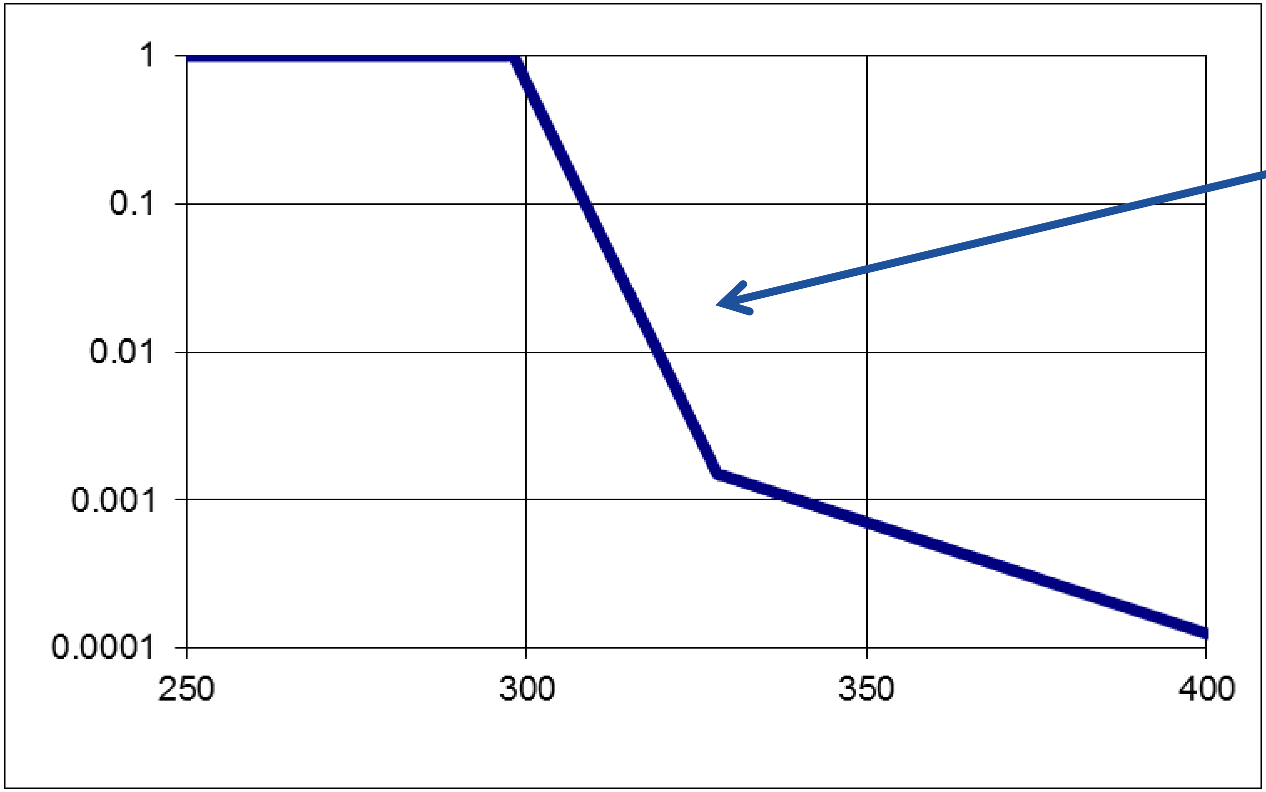
Wavelength accuracy is important for UV radiometry

Example: Eyrthemal function

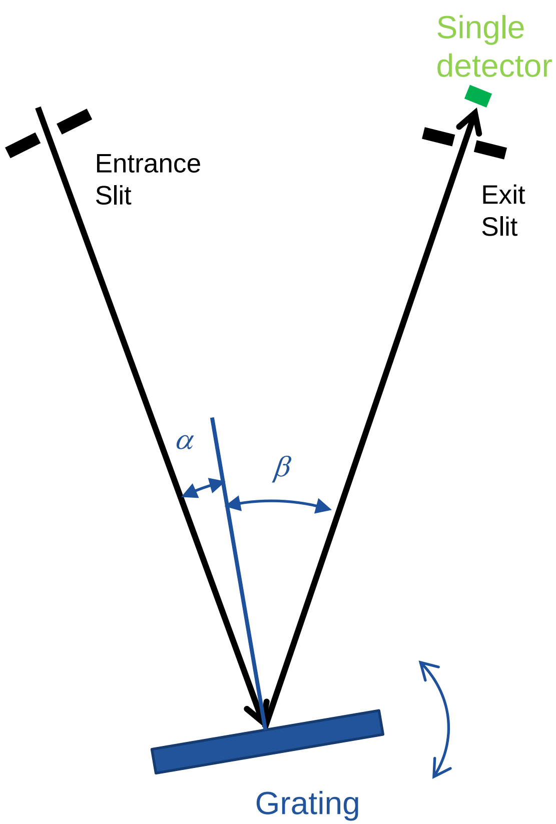
$$s_{er}(\lambda) = 1.0 \quad \textit{für} \quad 250\text{nm} \le \lambda \le 298\text{nm}$$
$$s_{er}(\lambda) = 10^{\wedge}(0.094*(298\text{nm} - \lambda)) \quad \textit{für} \quad 298\text{nm} < \lambda \le 328\text{nm}$$
$$s_{er}(\lambda) = 10^{\wedge}(0.015*(140\text{nm} - \lambda)) \quad \textit{für} \quad 328\text{nm} < \lambda \le 400\text{nm}$$



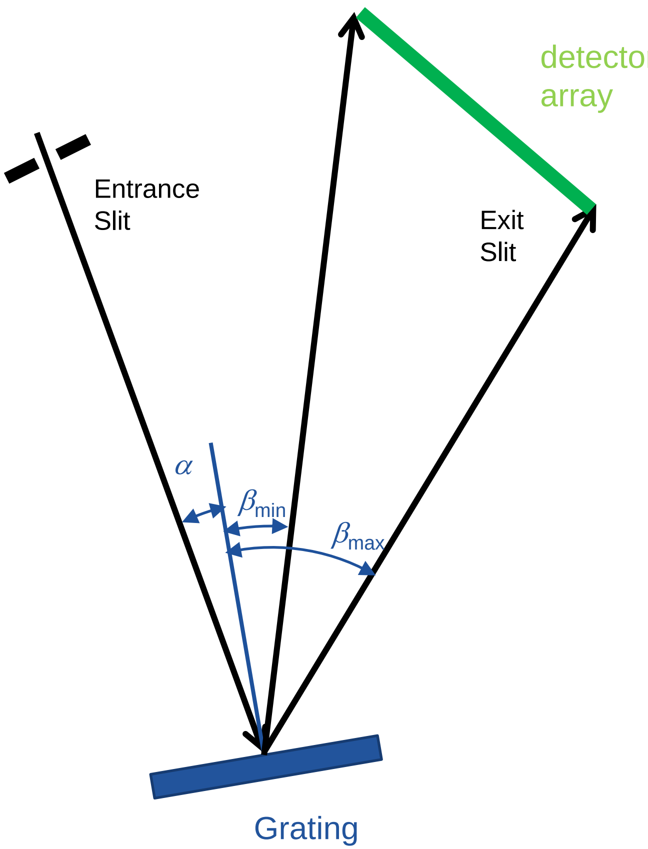
- 20 % / nm

Spectrograph : Non-linear relation between pixel position and wavelength

$$\sin(\alpha) + \sin(\beta) = n\lambda/d$$



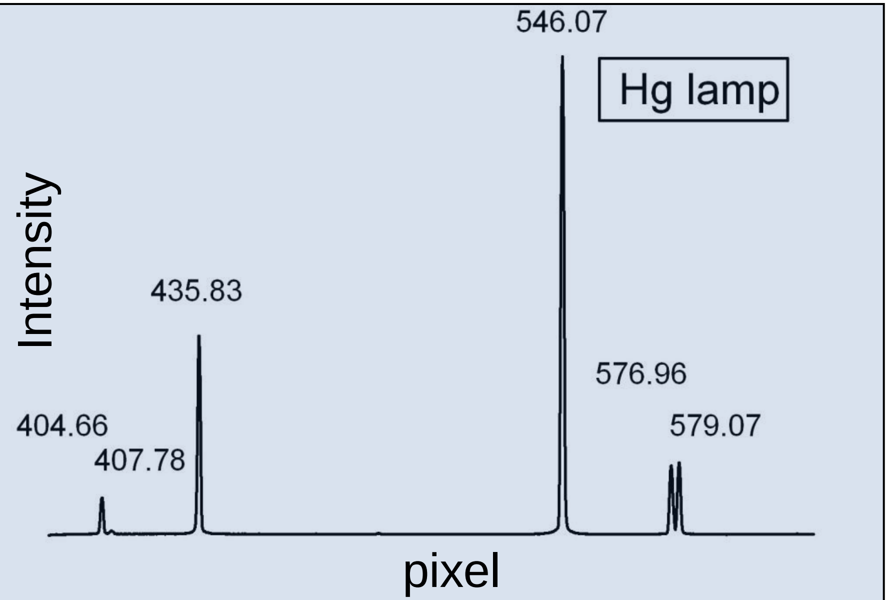
Monochromator



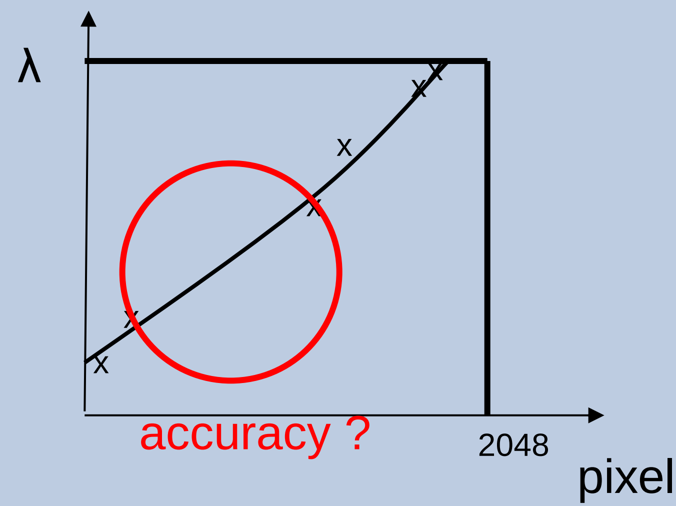
Array Spectrometer/ Spectrograph

Conventional Calibration using Penlamp

Mercury Argon calibration source

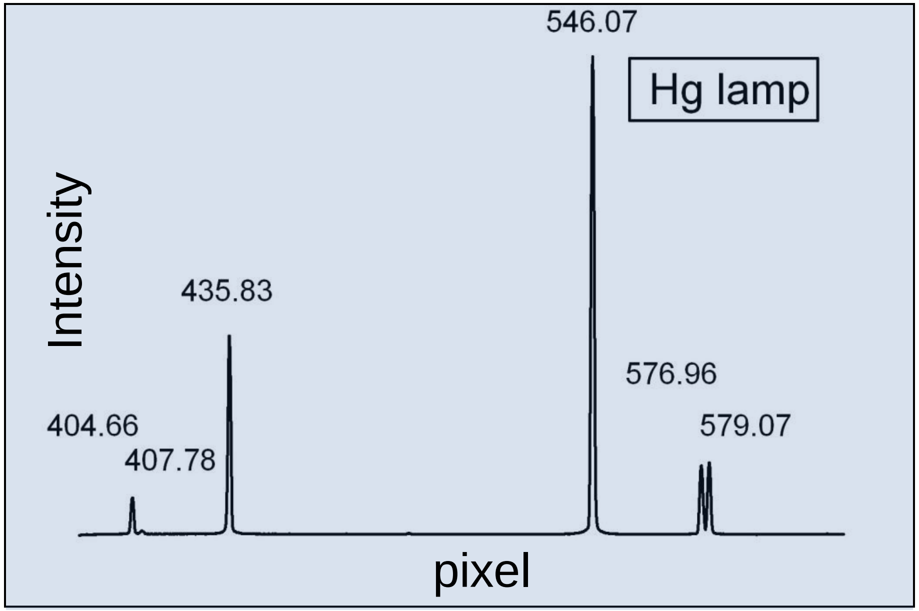


Polynomial fit of 2nd degree



penlamp accuracy ~1pm

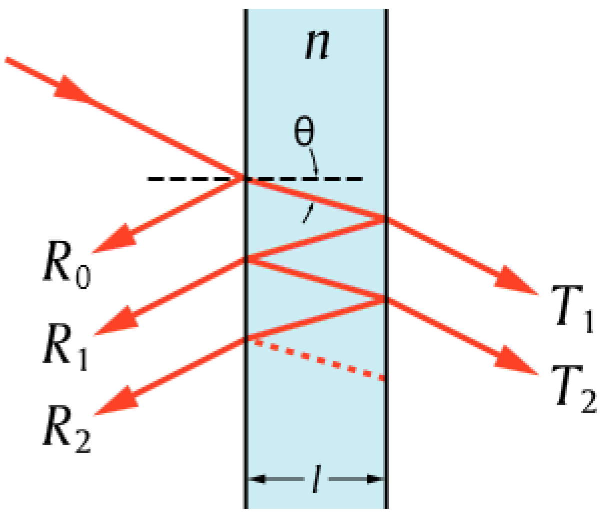
Limitations of Conventional Calibration



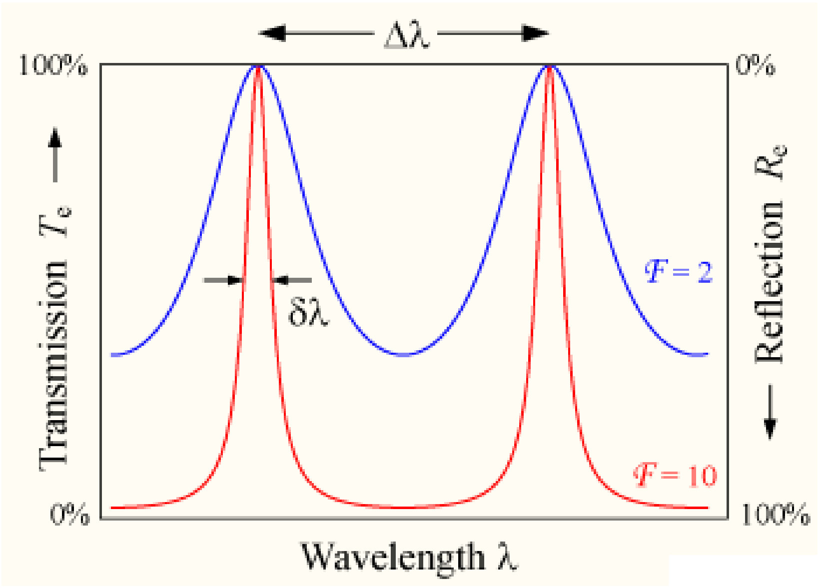
1. irregular peak locations
2. limited number of peaks
3. multiplet peaks
4. large peak intensity differences (peak detection!)
5. additional calibration lamp required

new calibration tool published by M. Heuberger (EMPA), 2010

A Fabry-Perot element offers a high peak density
at wavelengths that are determined by one single parameter, D



wikipedia



Phase difference

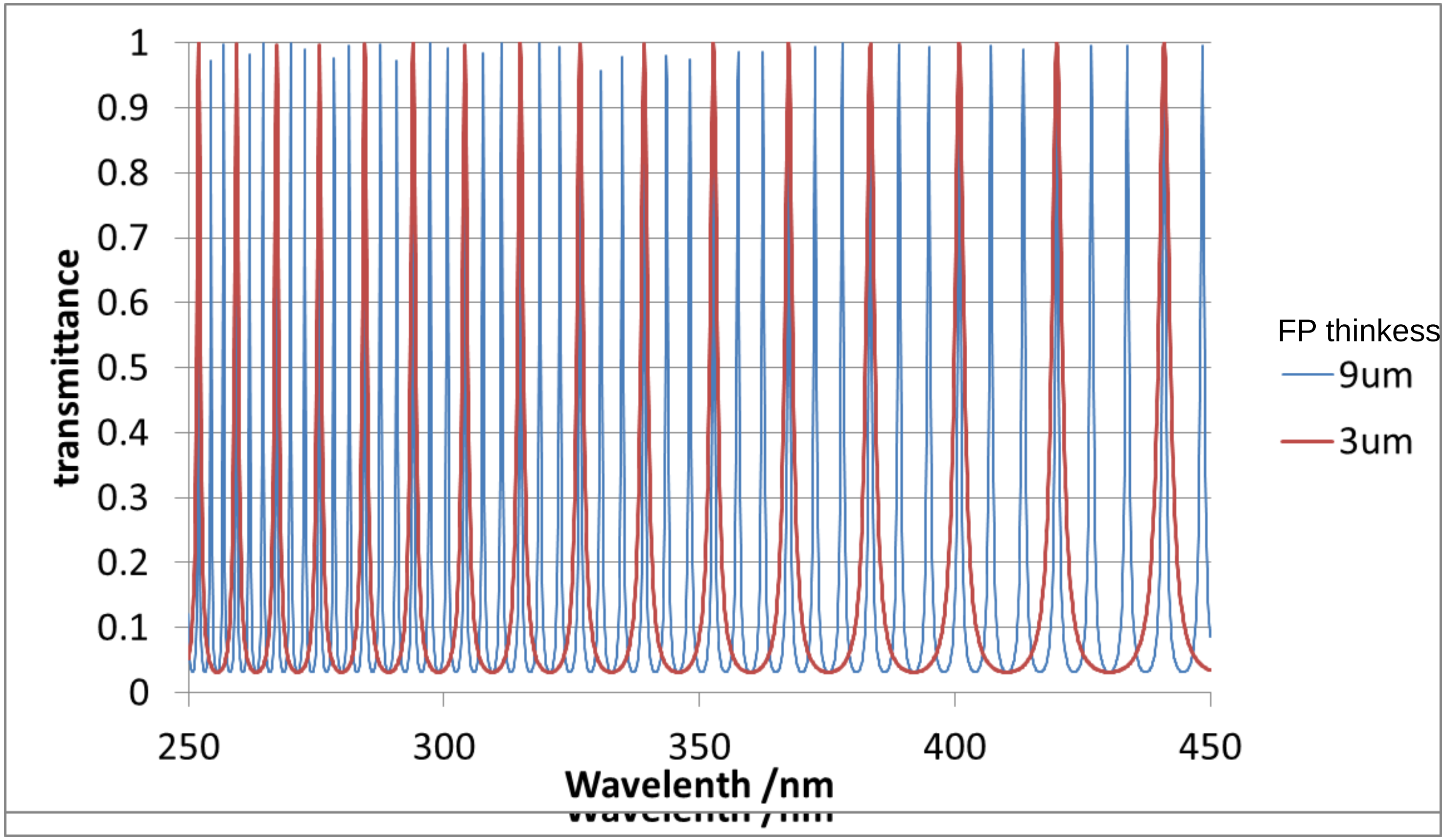
$$\delta = \left(\frac{2\pi}{\lambda}\right) 2n\ell \cos\theta.$$

Transmittance

$$T_e = \frac{(1-R)^2}{1+R^2-2R\cos\delta}$$

Design of Fabry Perot for UV spectrometer

Peak position: $$\lambda_m = \frac{2nl\cos\theta}{m}$$

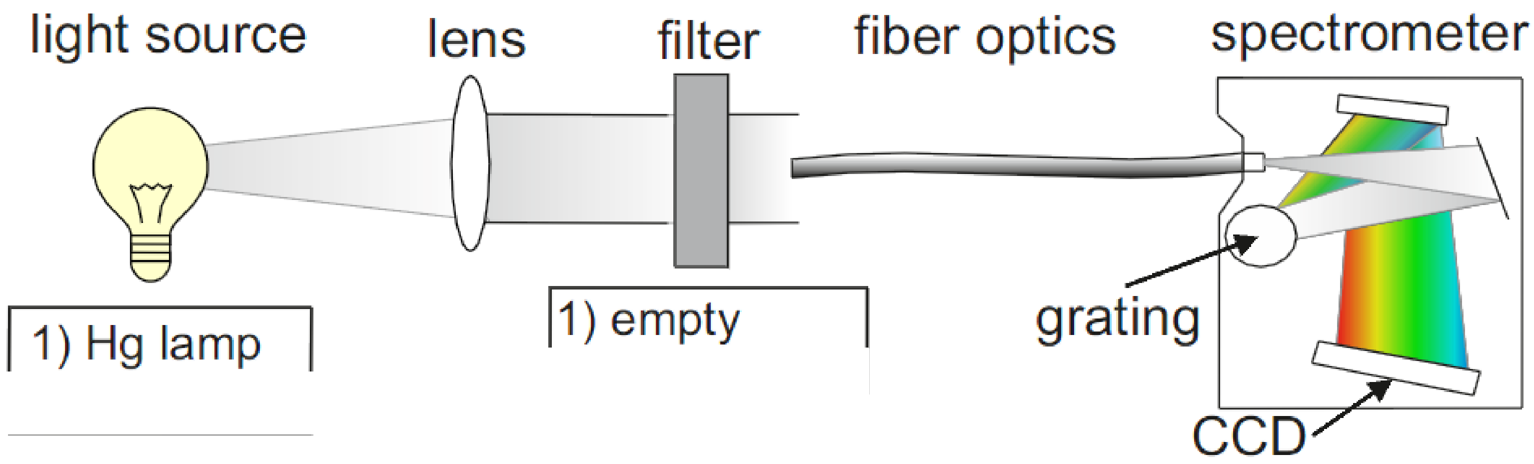


250 nm to 450 nm

48 peaks

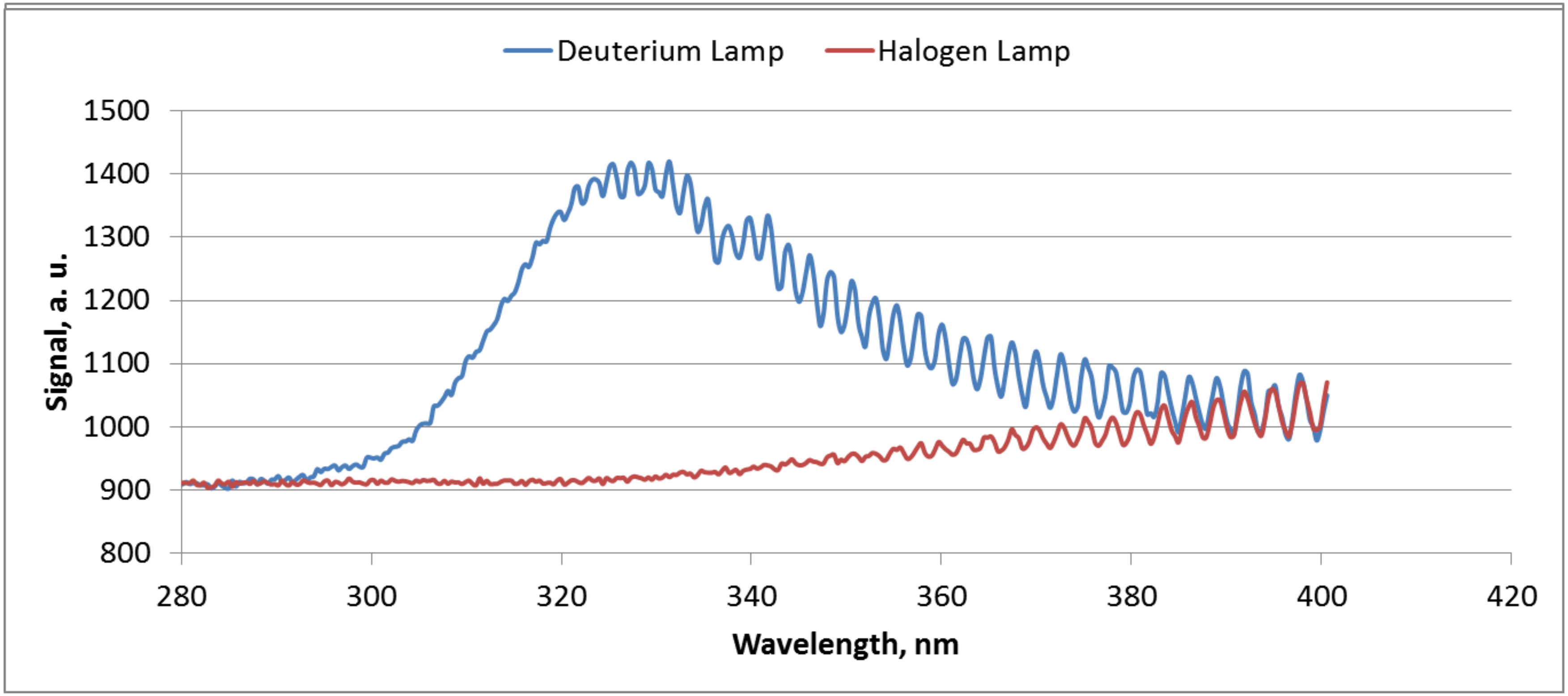
16 peaks

The HICALOS setup

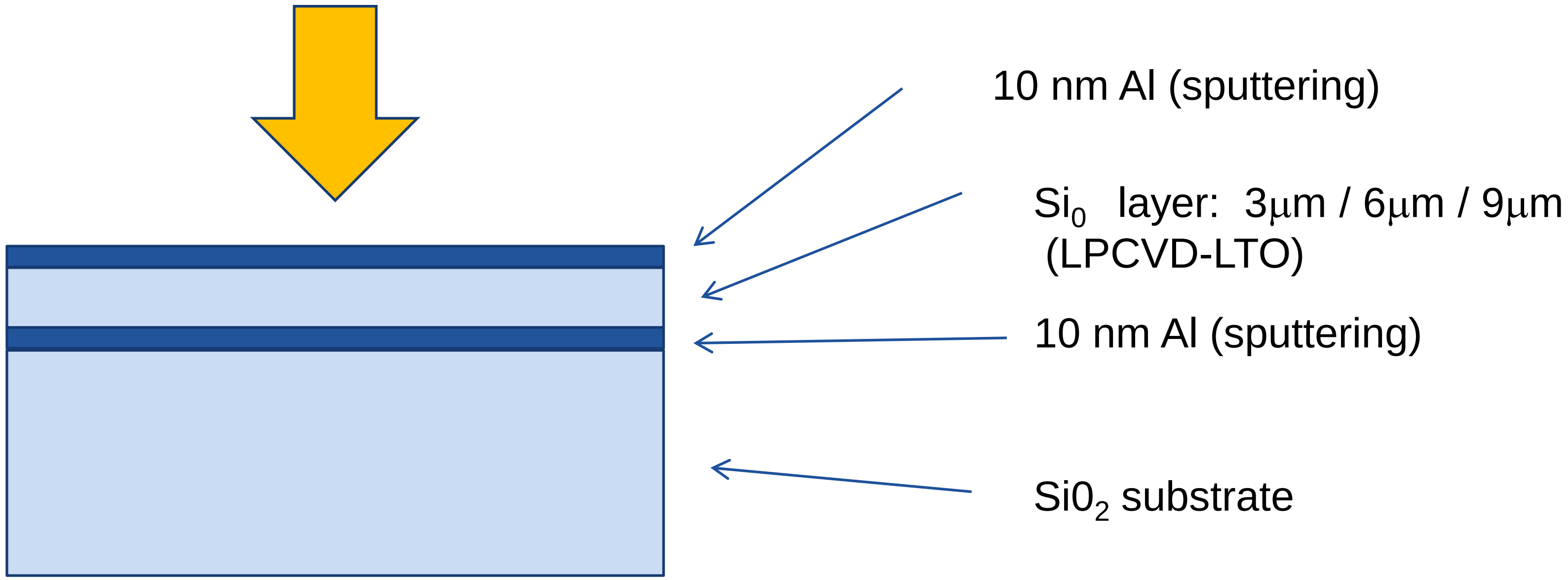


lamp and filter are interchangable

Mica layer: Bad transmission in UV



Realization of $Si0_2$ micro Fabry-Perot

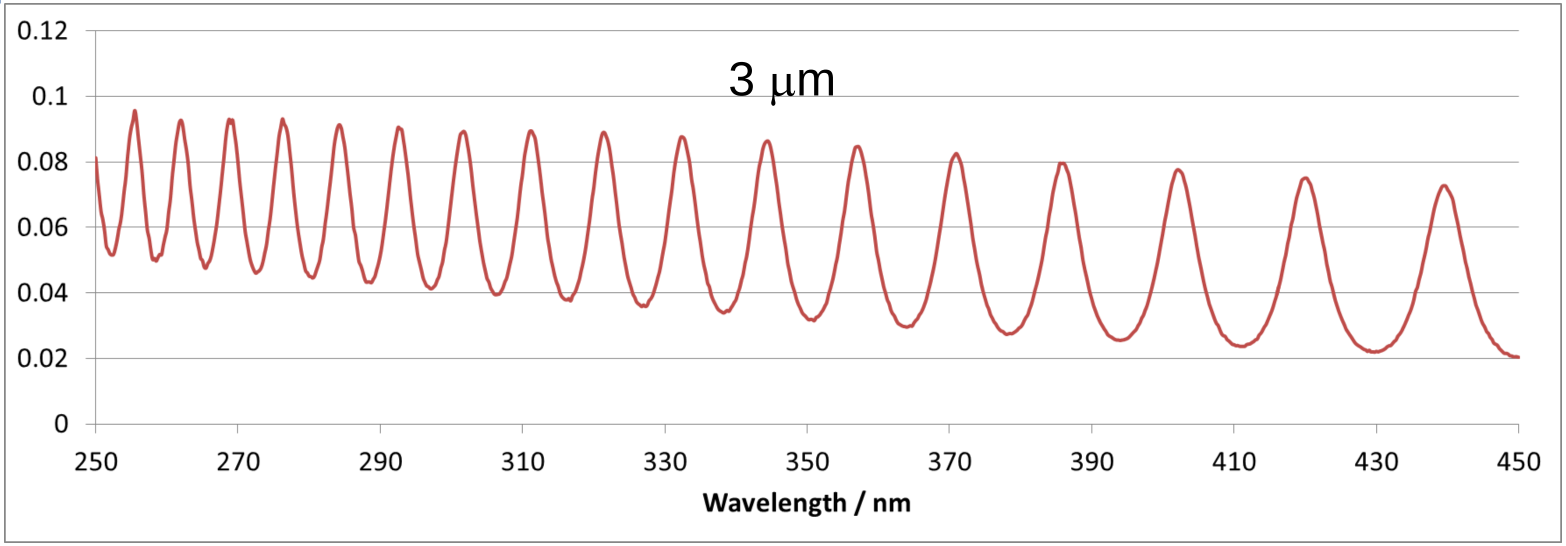


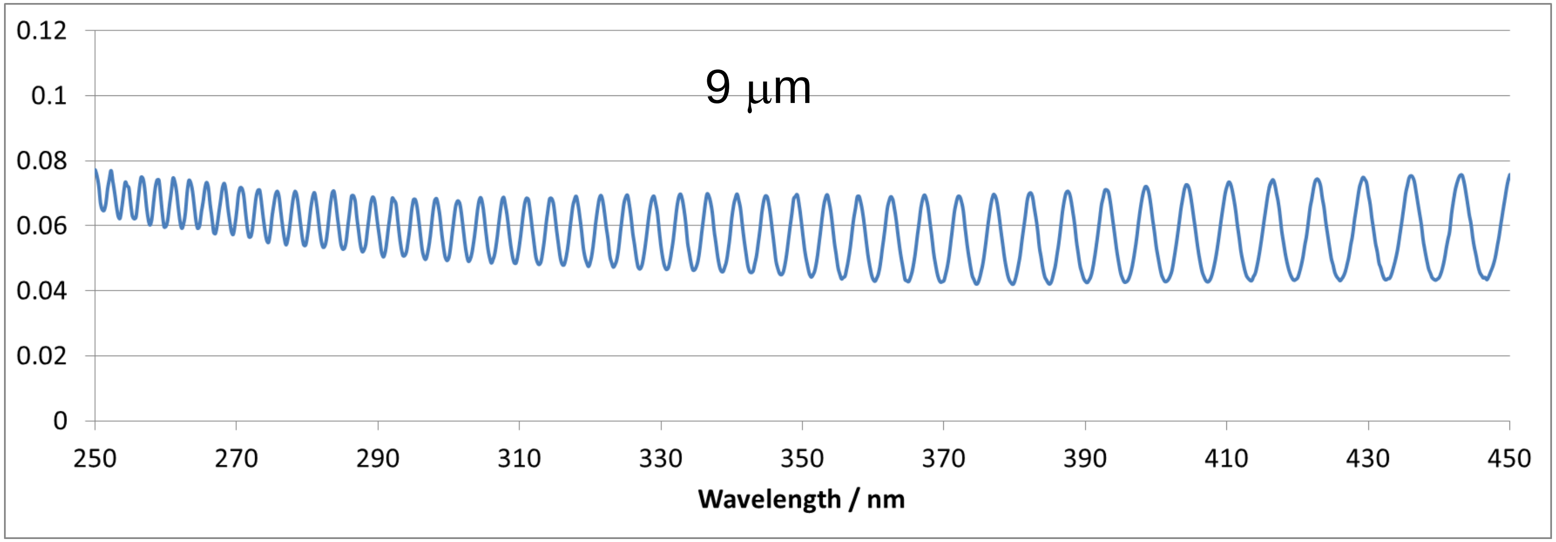
LPCVD-LTO : Low Pressure Chemical Vapor Deposition at Low Temperature Oxide

- Center of Micronanotechnology, EPFL, CH
- Deposition rate: 3h / µm of SiO_2

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

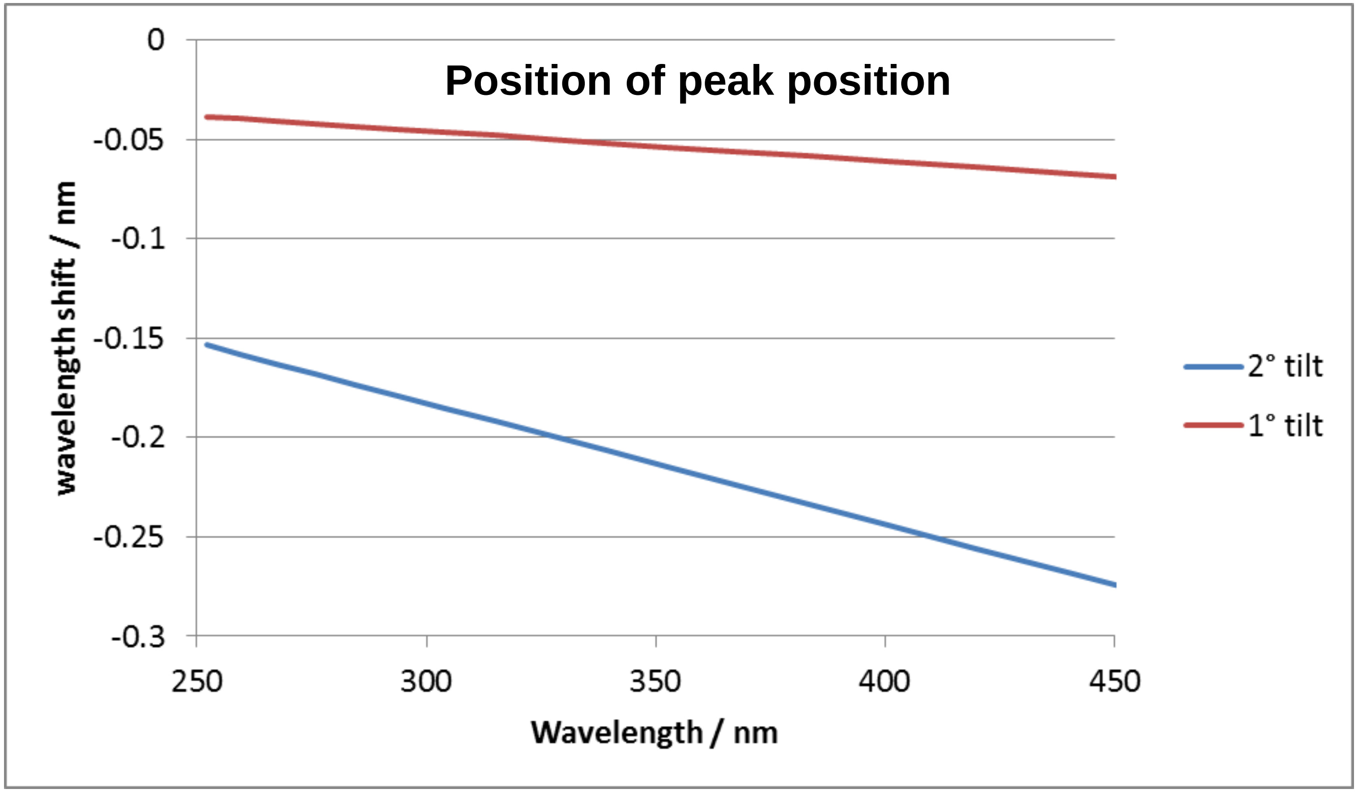
Measured Transmittance of SiO_2 micro Fabry-Perot





Angular sensitivity of Fabry Perot

Peak position: $$\lambda_m = \frac{2nl\cos\theta}{m}$$ $$\Delta\lambda_m \approx \frac{-\theta^2}{2}\lambda_m$$



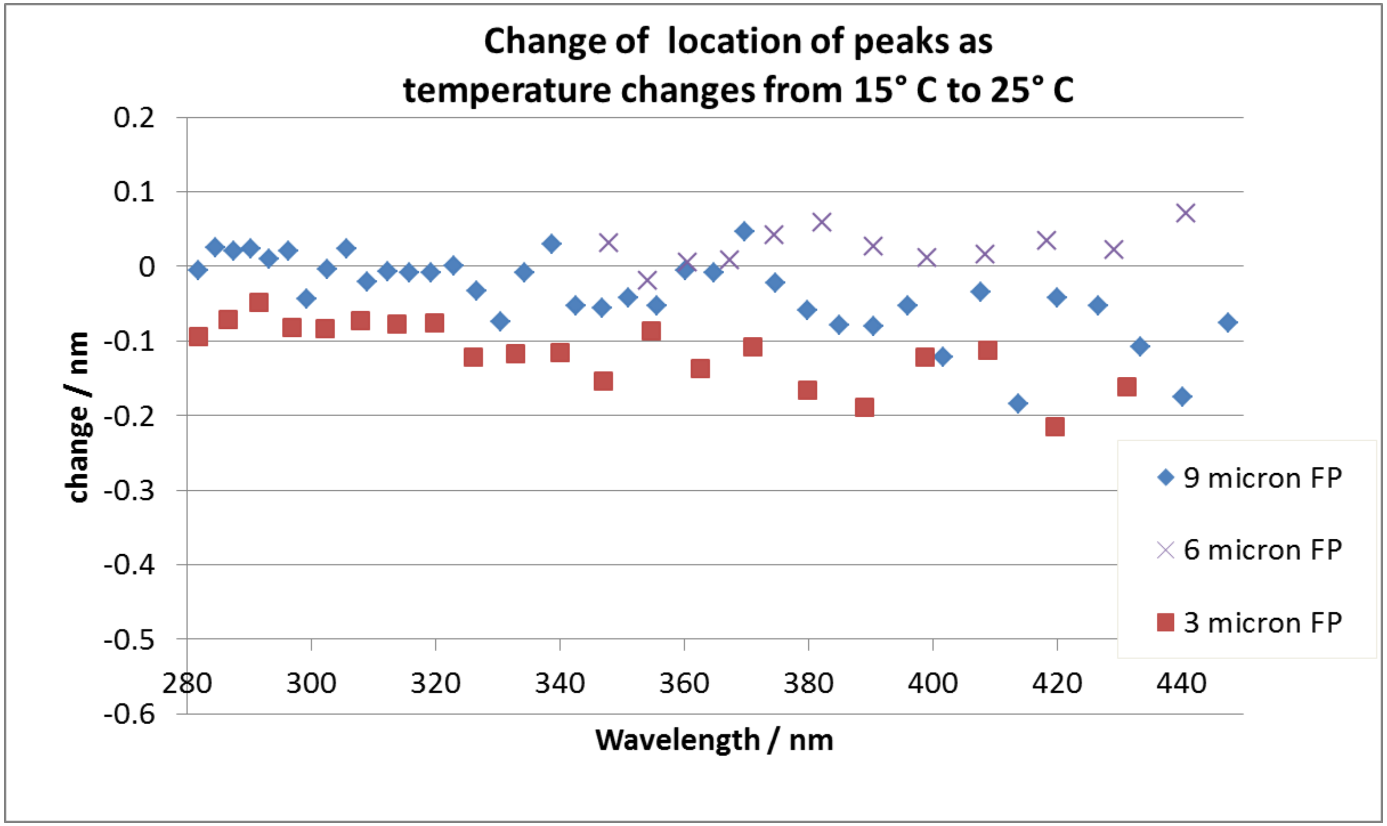
Angular alignment is critical

Sensitivity to temperature

Fused Silica:

- Thermal expansion coefficient 5.5 x 10^{-7} / °C
- Change of refractive index [1] 6.8 x 10^{-6} / °C

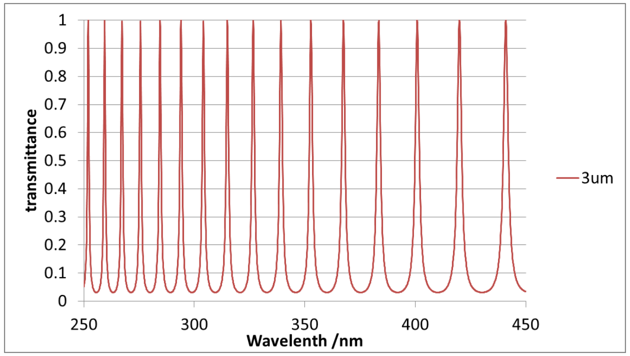
Expecting about 0.06 nm /10° at 450nm



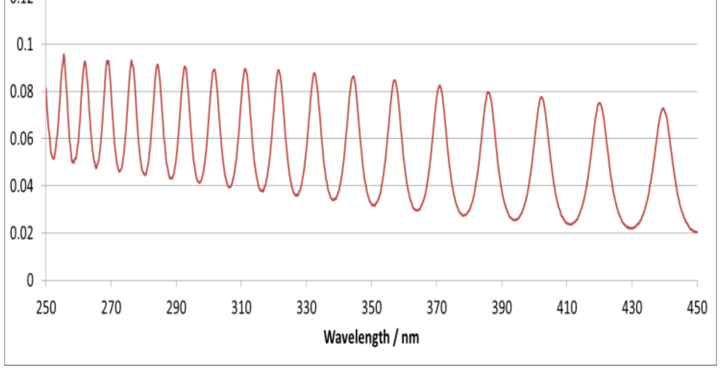
[1] Leviton2008 (Temperature-dependent absolute refractive index measurements of synthetic fused silica), arXiv:0805.0091

More rigorous analysis:

theory



measurement

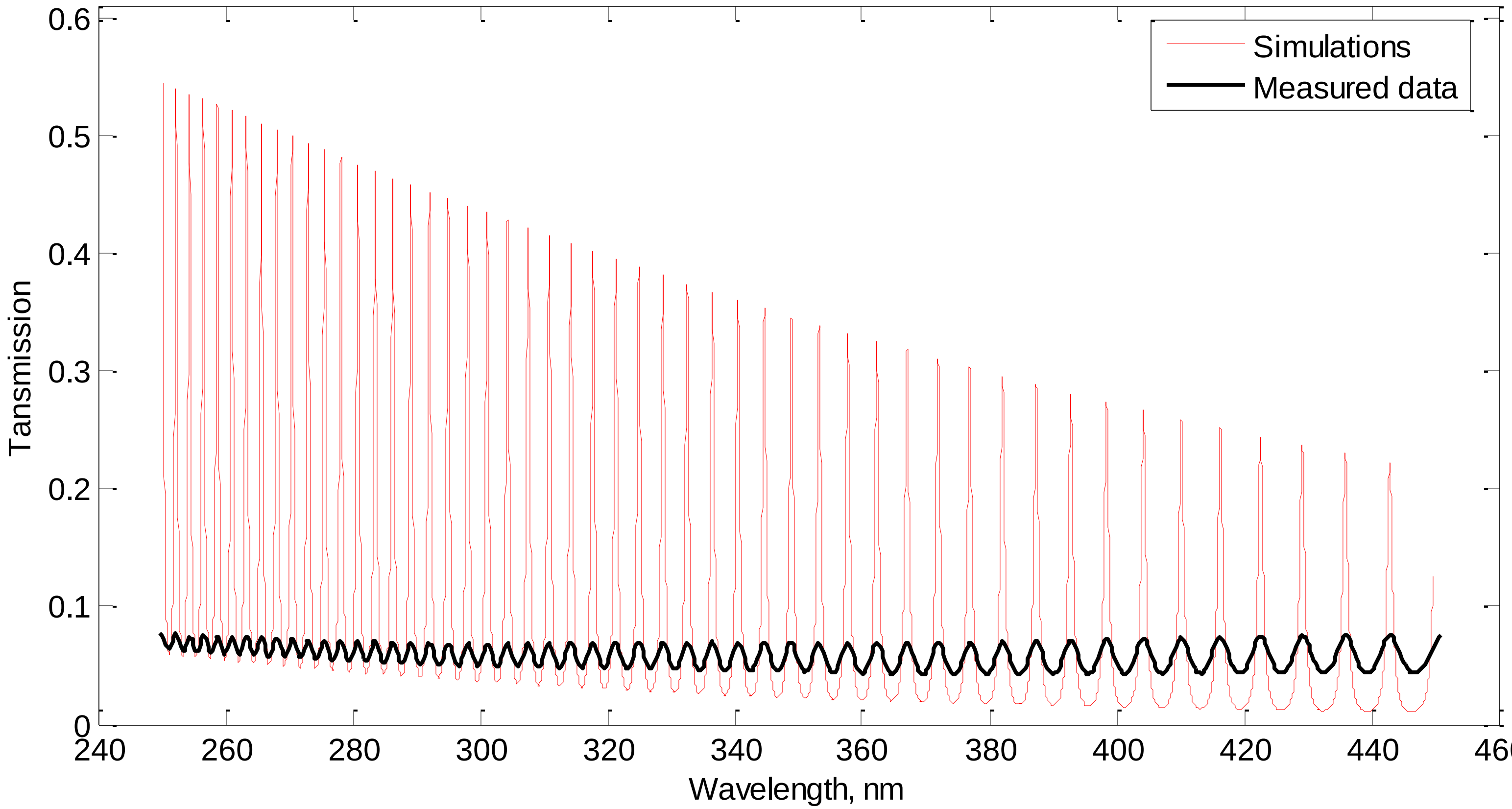


thin-film modelling

Input parameters:
- refractive index (and its dispersion) of SiO_2 and Al
- thickness of Al –layer (has little impact on the position of the peak)

Free parameter: thickness of the SiO_2 layer

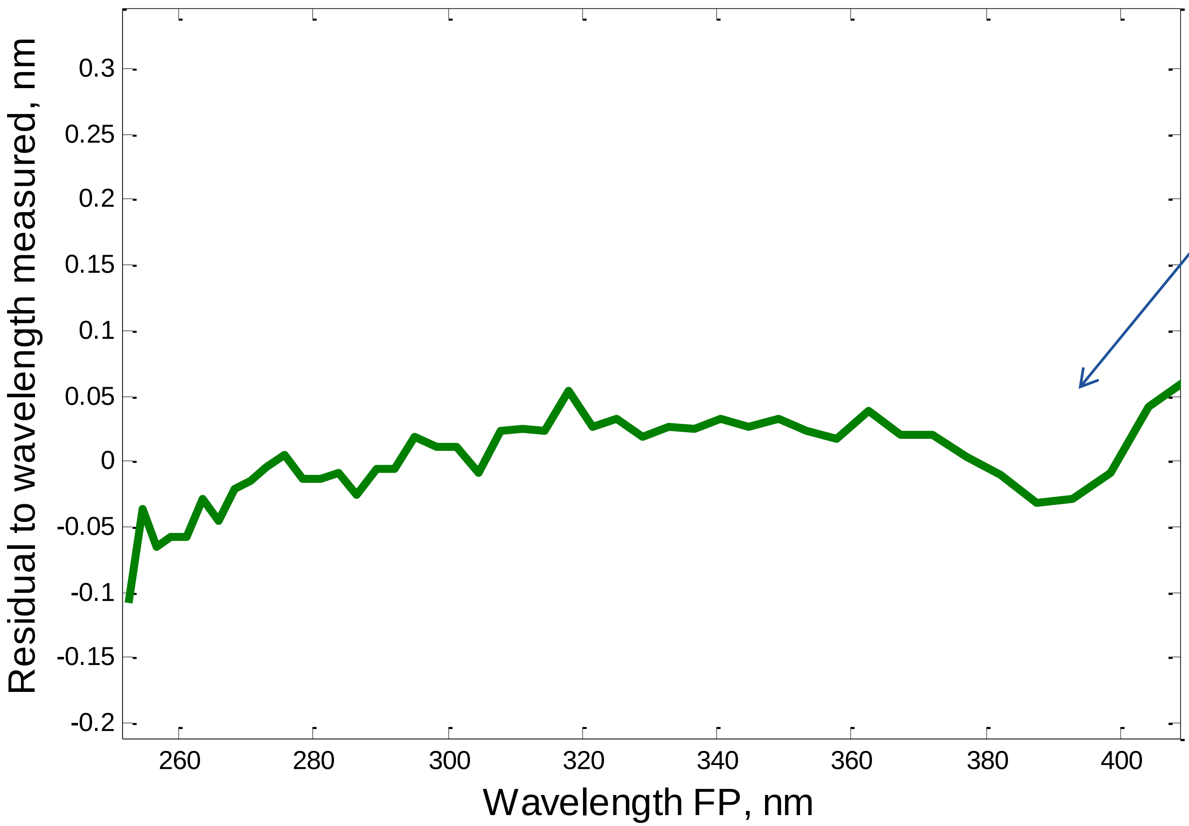
Let’s apply the method to a high accurate spectroradiometer (Quasume)



Observation : Less contrast than expected
(lower finess of the Fabry Perot, probably Al less thick than expected?)

What about the peak positions?

Wavelength scale of Quasume characterized by the Faby Perot (9µm)



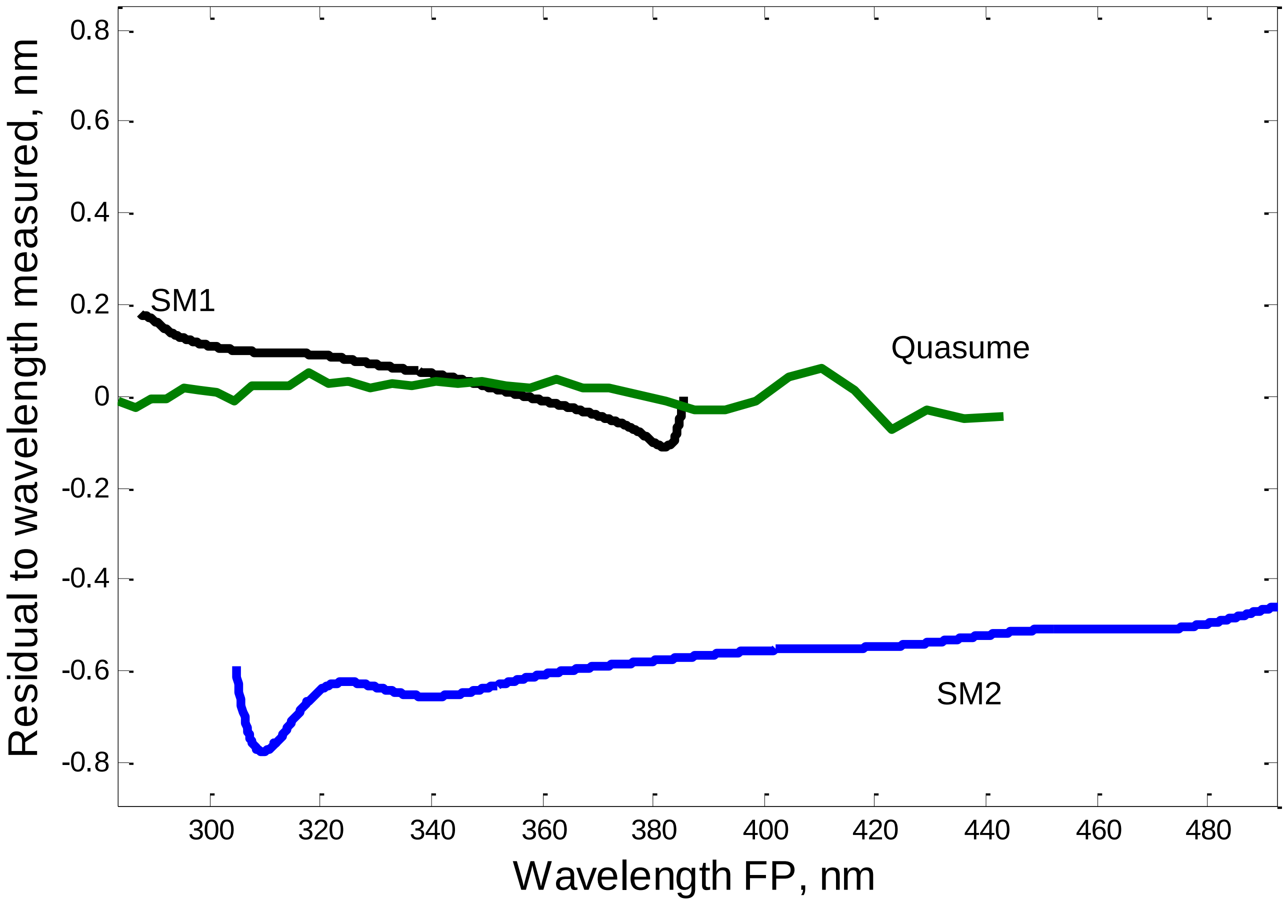
Problem of refractive index data?

Additional validation through comparison with 2 laser lines

Instruments: 2 array spectrometer + 1 scanning spectroradiometer (Quasume)

	Array SM 1		Array SM 2		Quasume	
	Not corrected	With FP correction	Not corrected	With FP correction	Not corrected	With FP correction
Residual, pm (Laser 355 nm)	11.09		-622		-3.39	
Residual, pm (Laser 374 nm)	-74.82		-640		-14.61	

Correction function of the three spectrometers



Additional validation through comparison with 2 laser lines

Instruments: 2 array spectrometer + 1 scanning spectroradiometer (Quasume)

	Array SM 1		Array SM 2		Quasume	
FP thick., μm	9.183520		9.1864231		LDLS	9.183090
	Not corrected	With FP correction	Not corrected	With FP correction	Not corrected	With FP correction
Residual, pm (Laser 355 nm)	11.09	**4.78**	-622	**3.1**	-3.39	**-25.43**
Residual, pm (Laser 374 nm)	-74.82	**-22.75**	-640	**-51,0**	-14.61	**-35.70**

Conclusions

- Fabry Perot are very promising devices for the characterization of wavelength scale
- < 0.02 nm uncertainties are possible
- Critical parameter: angular alignement (or divergence of source/detector)
- Further investigation are necessary:
  - is D a physical parameter (and thus independent of alignment)?
  - Why the contrast of the modulation is less than expected?