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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

Wavelength calibration devices

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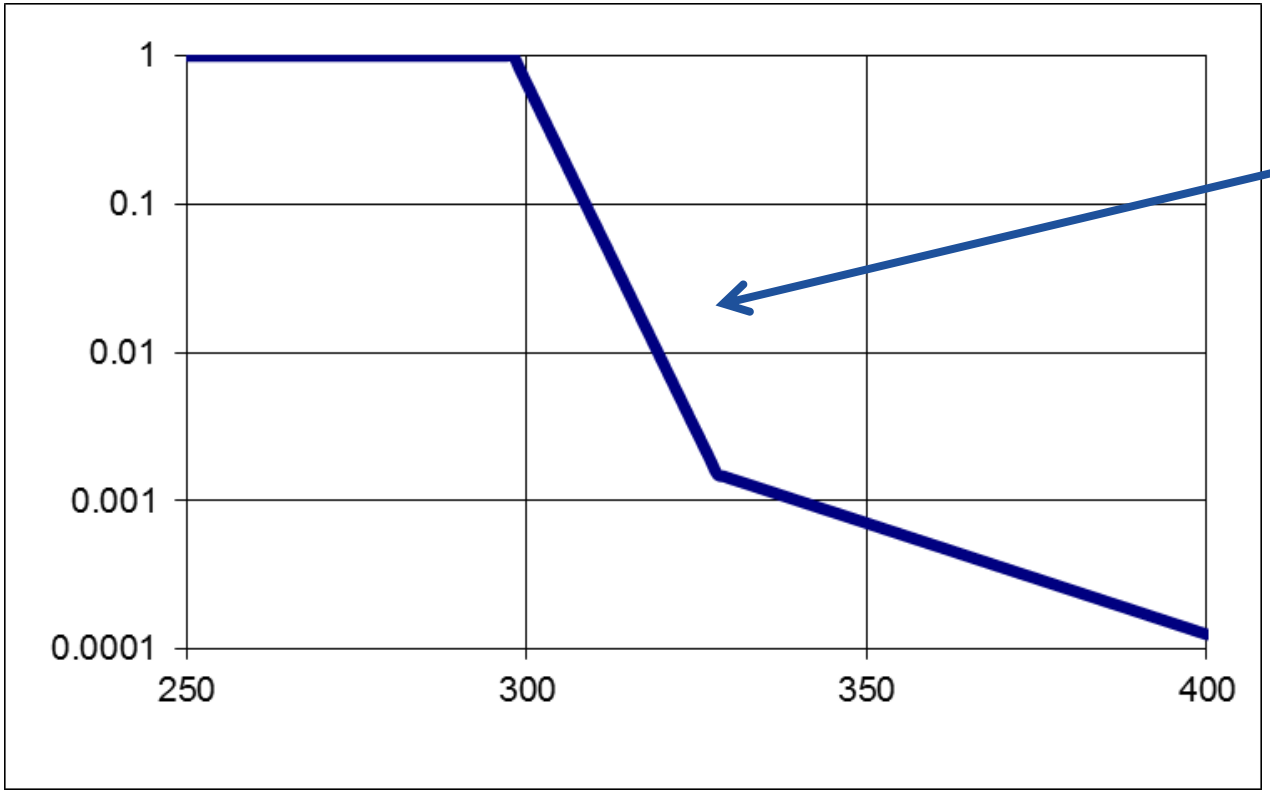
Wavelength accuracy is important for UV radiometry

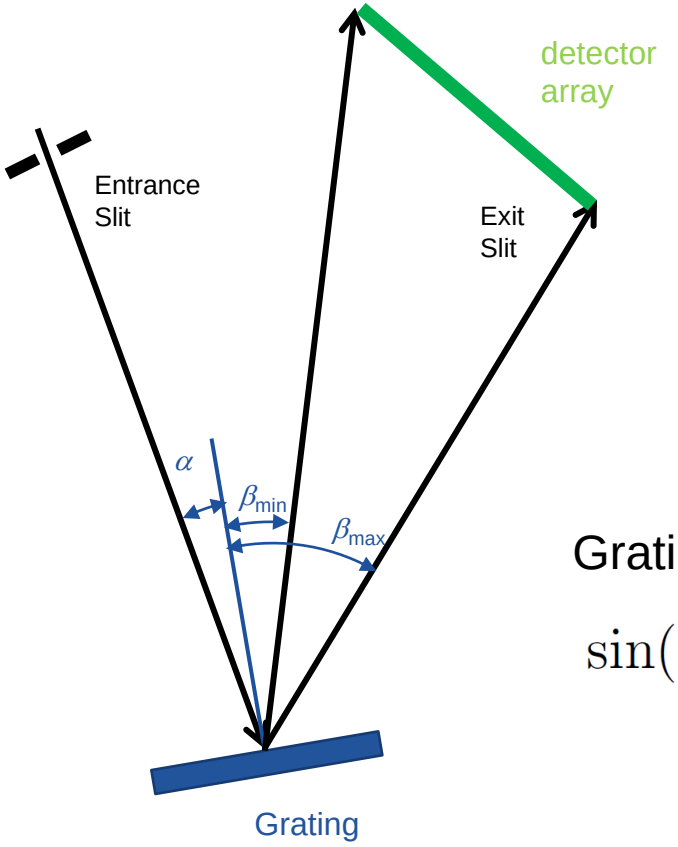
Example: Eyrthemal function

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



- 20 % / nm

Spectrograph : Non-linear relation between pixel position and wavelength



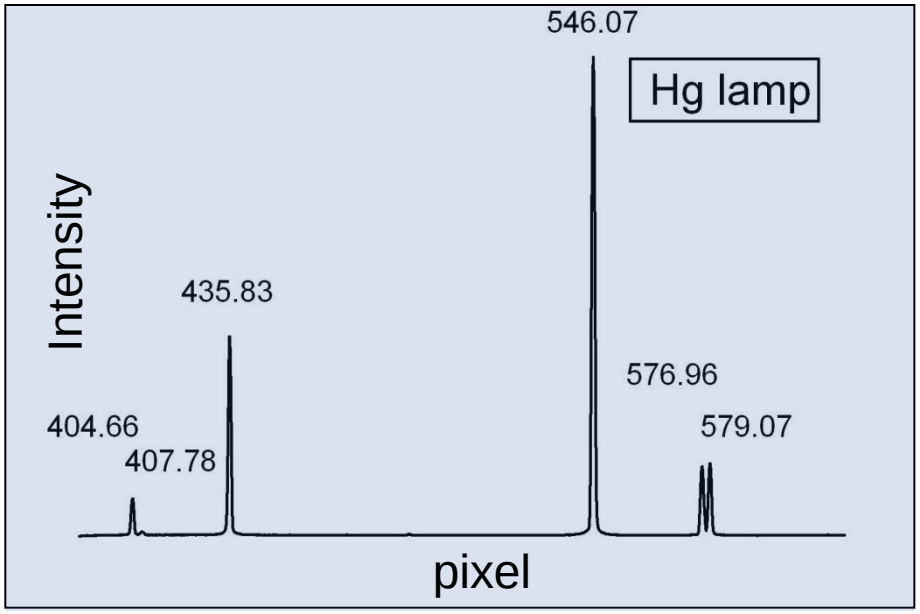
Grating equation

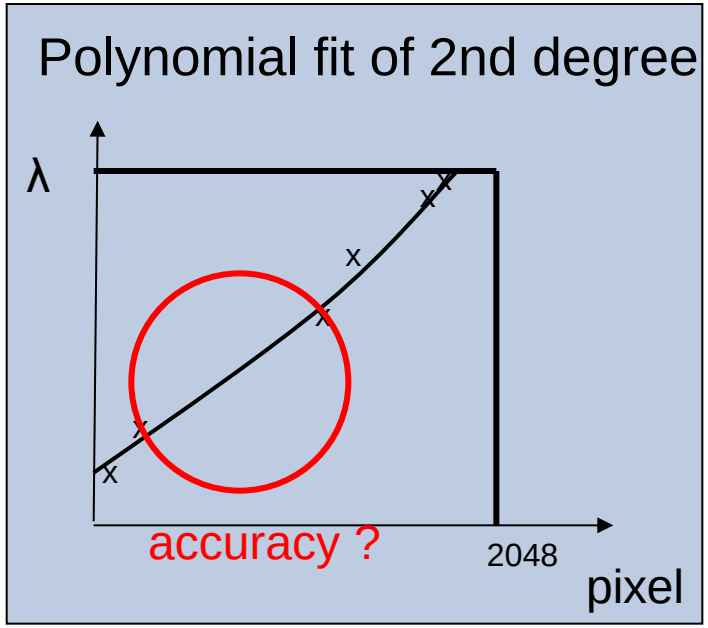
$$\sin(\alpha) + \sin(\beta) = n\lambda/d$$

Array Spectrometer/ Spectrograph

Conventional Calibration using Penlamp

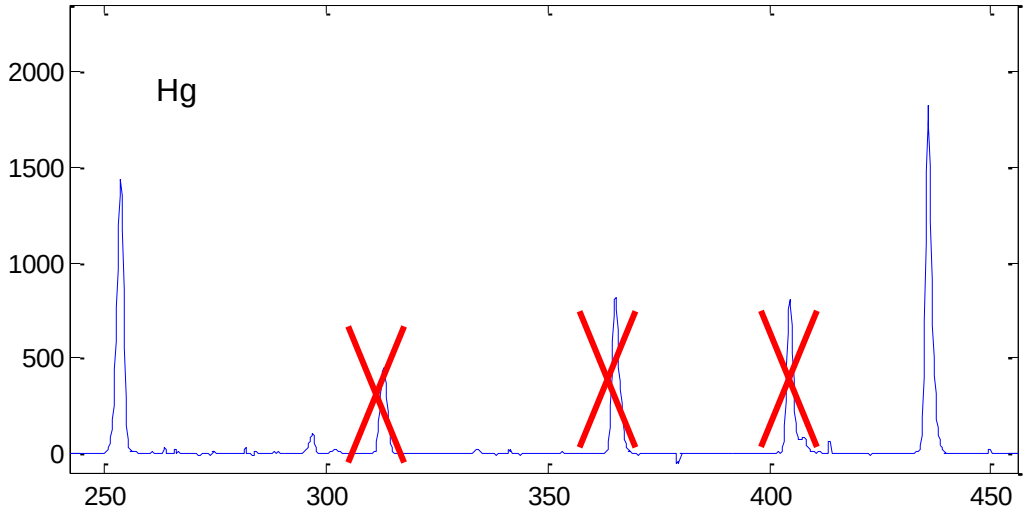
Mercury Argon calibration source





penlamp accuracy ~1pm

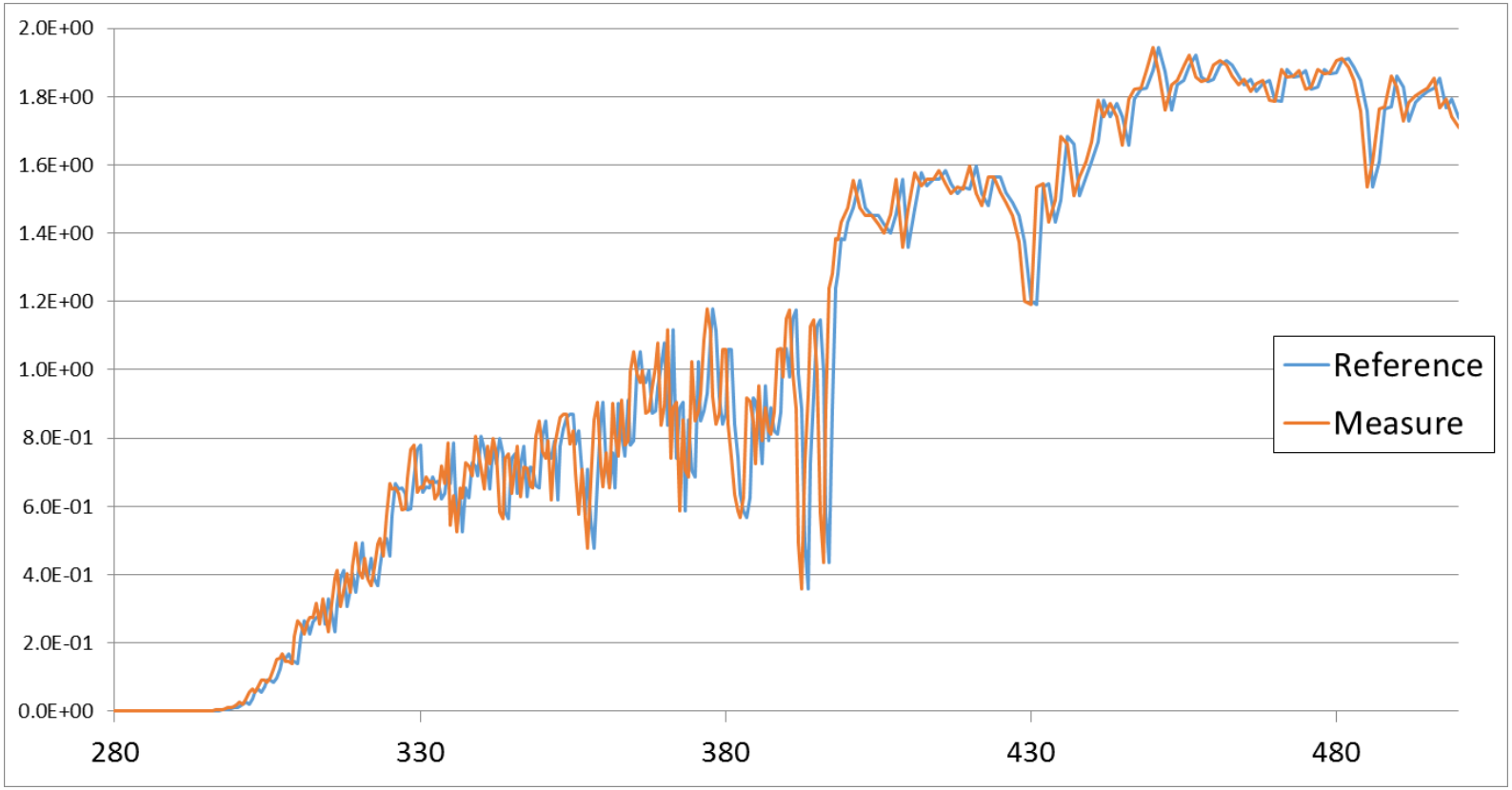
Limitations of Conventional Calibration



1. limited number of peaks (253.6 nm, (297nm), (302nm), (334nm), 435nm)
2. multiplet peaks (313nm, 365nm, 404nm, 407nm)
3. large peak intensity differences (peak detection!)

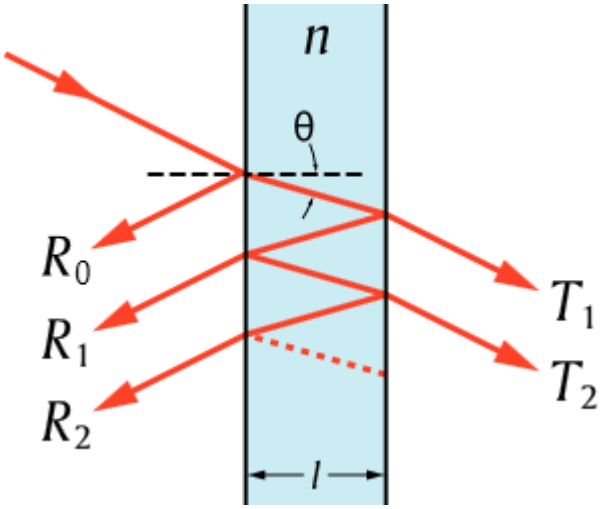
Alternative characterisation methods

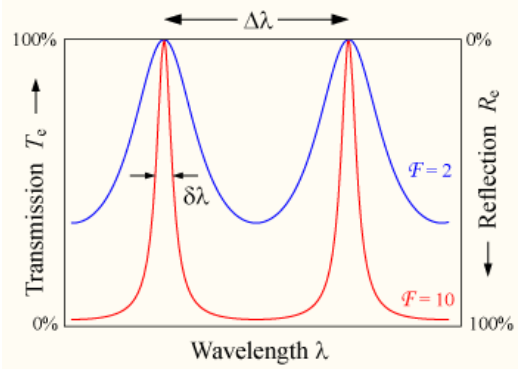
- Tuneable laser source and reference spectrometer
- Spectral correlation



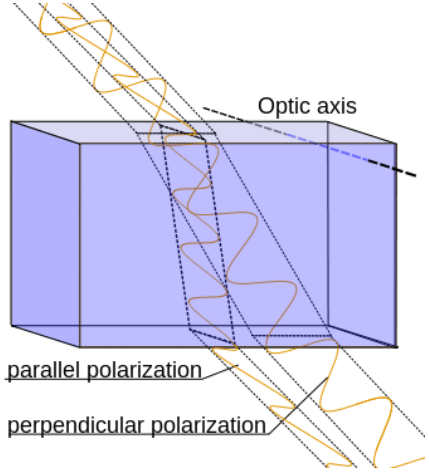
Alternative characterisation methods (2)

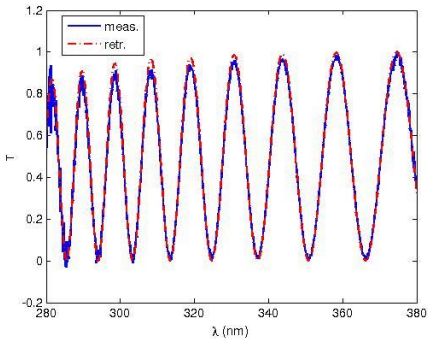
Fabry Perot Etalon Devices
-> Interference





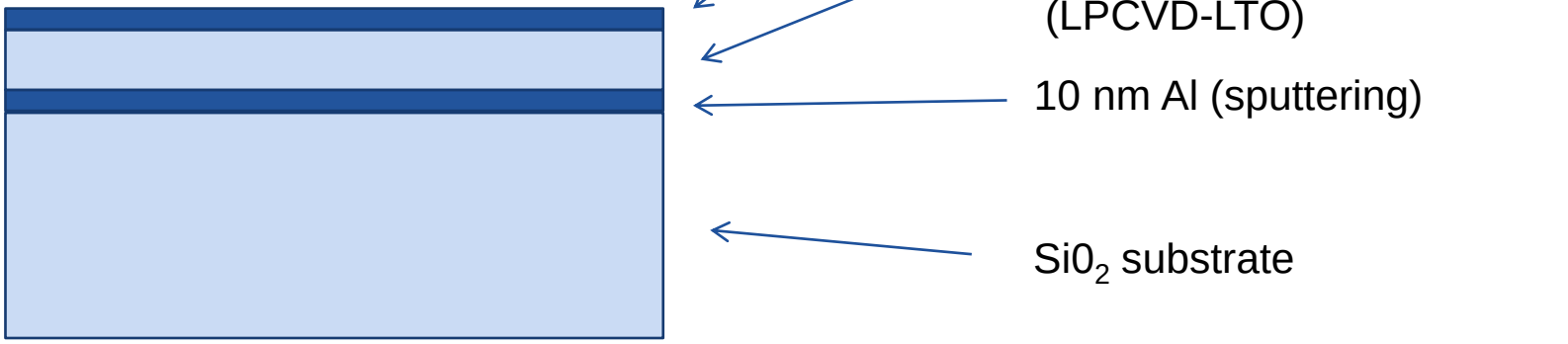
One Stage Lyot Filter
-> Birefringence





Realization of $Si0_2$ micro Fabry-Perot

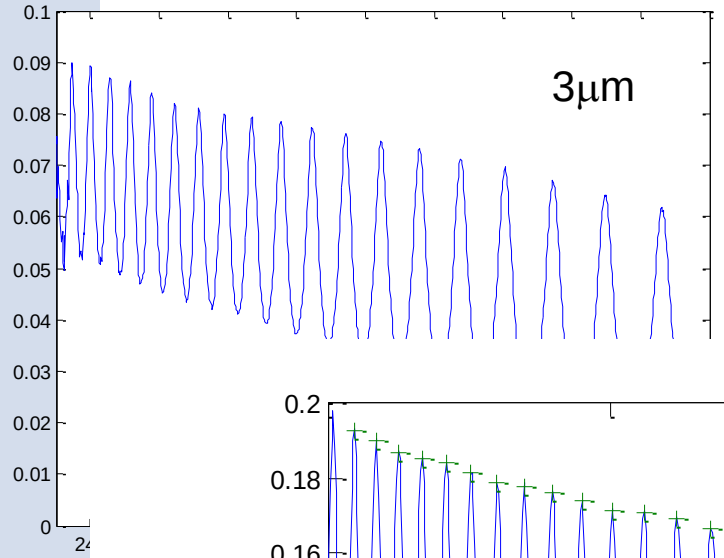
Center of Micronanotechnology, EPFL, CH

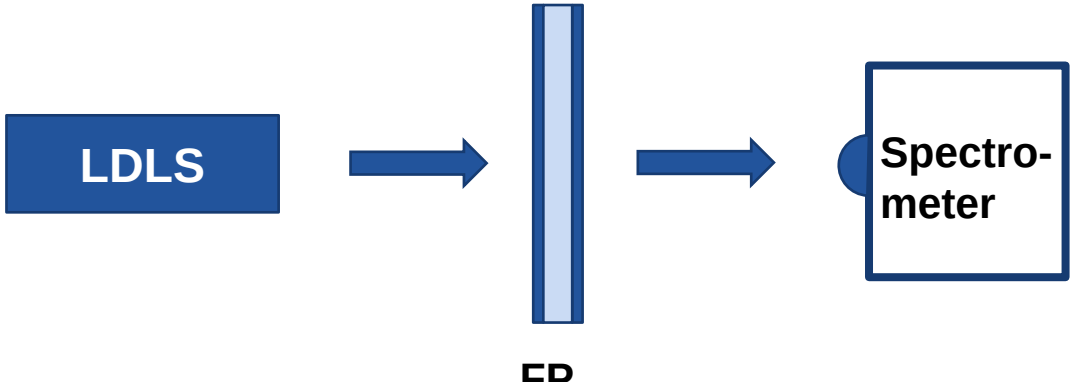


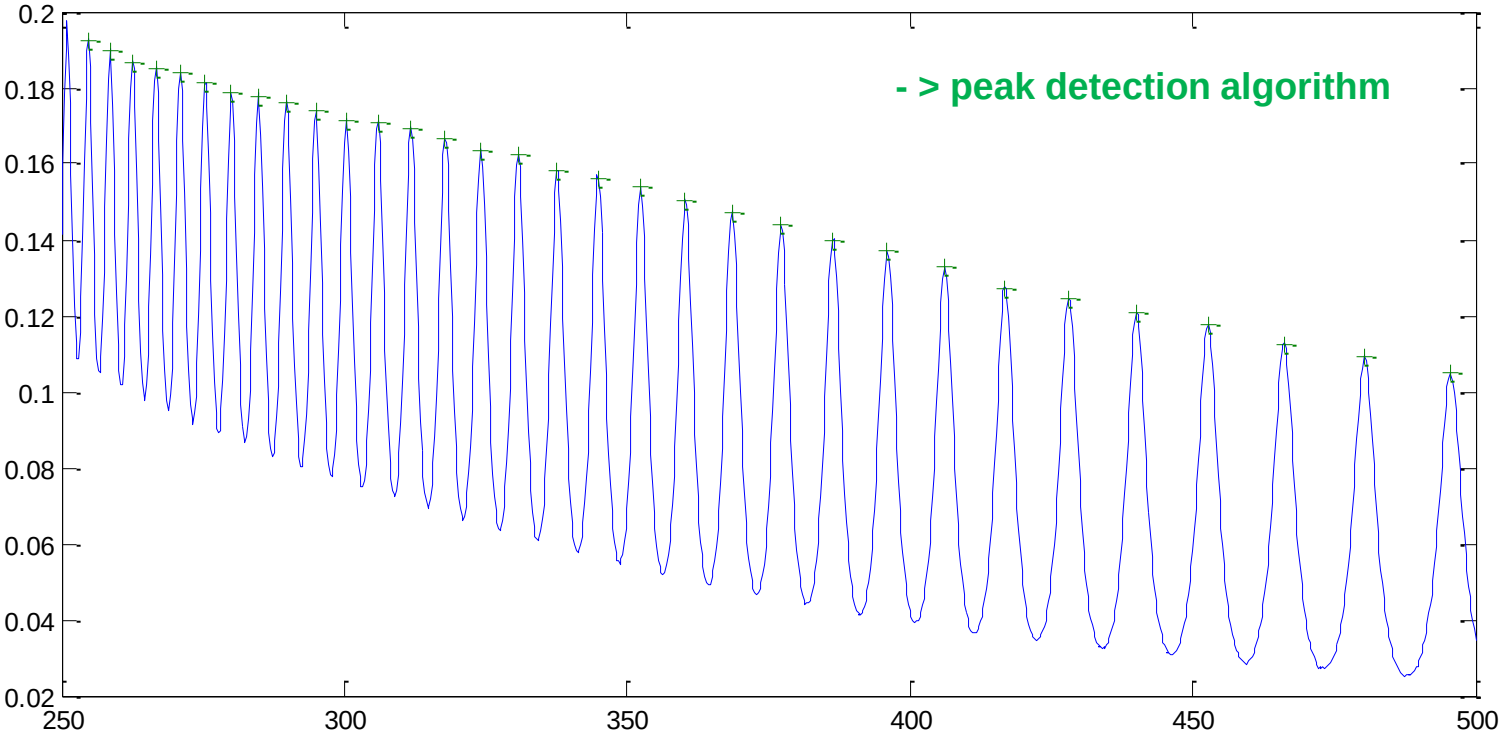
LPCVD-LTO : Low Pressure Chemical Vapor Deposition at Low Temperature Oxide

- Deposition rate: 3h / μm of SiO_2

Measurement of the transmittance

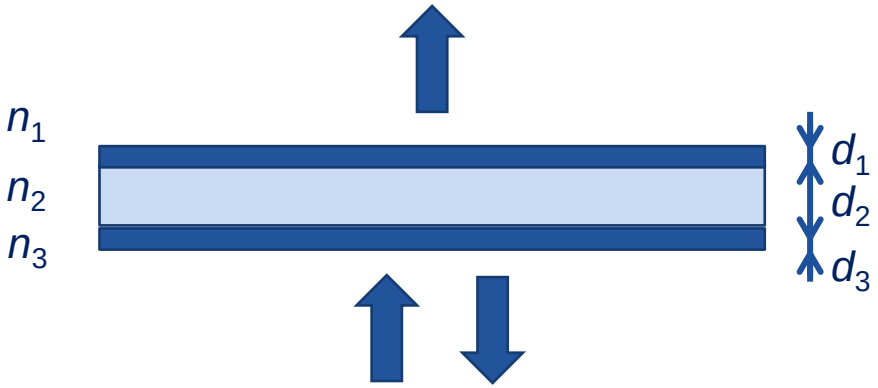


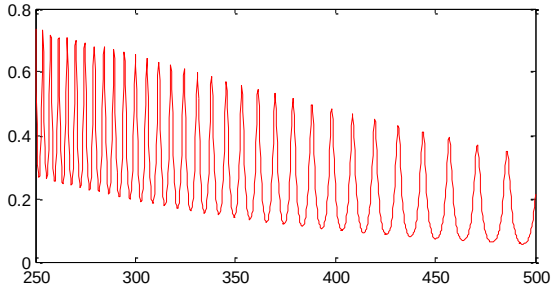




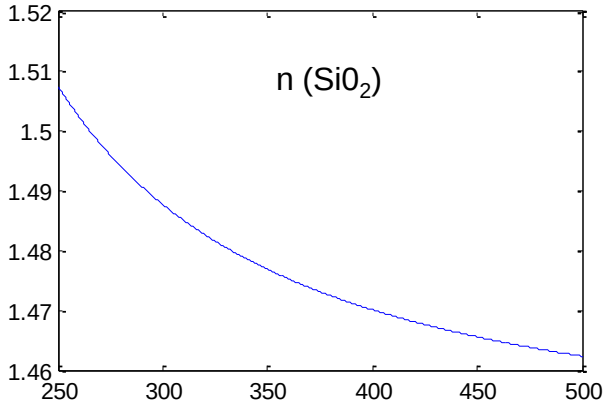
Rigorous Model of the transmittance of a Fabry-Perot

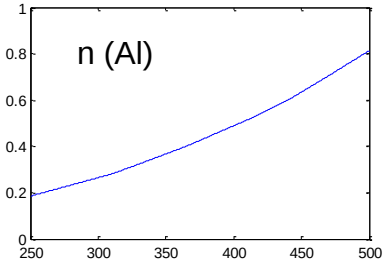
Moharam et al. JOSA Vol 12 No 5, May 1995 p 1077-1086

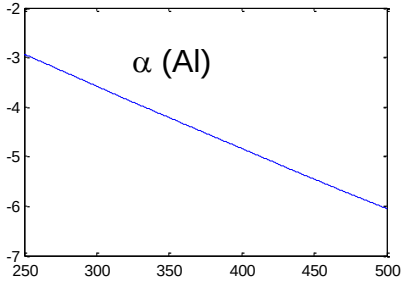




Refractive Indices: given by literature

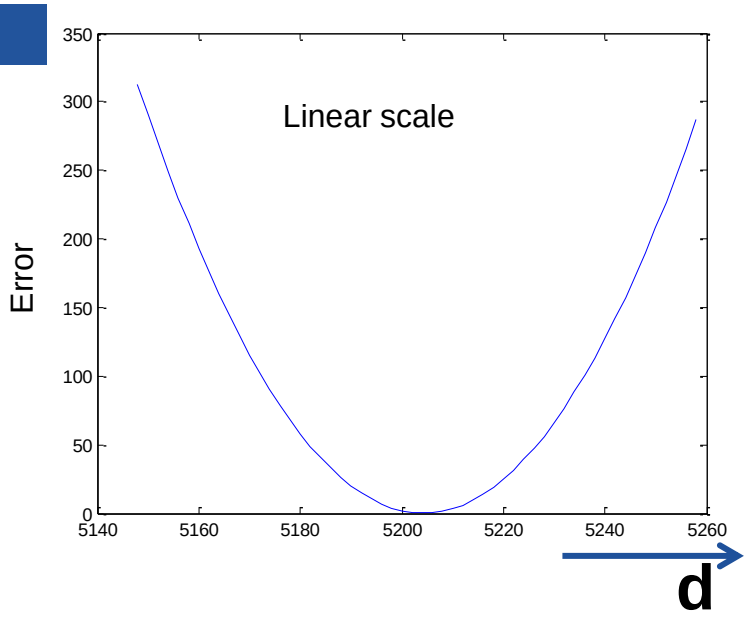


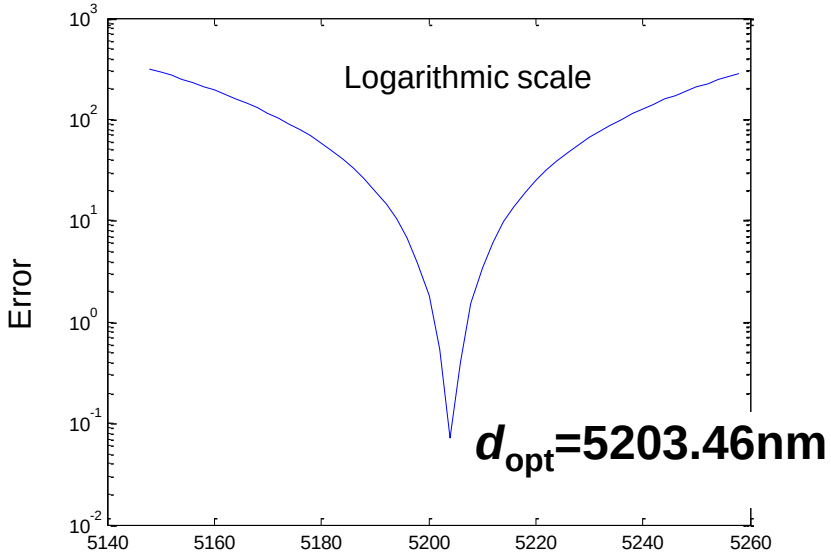


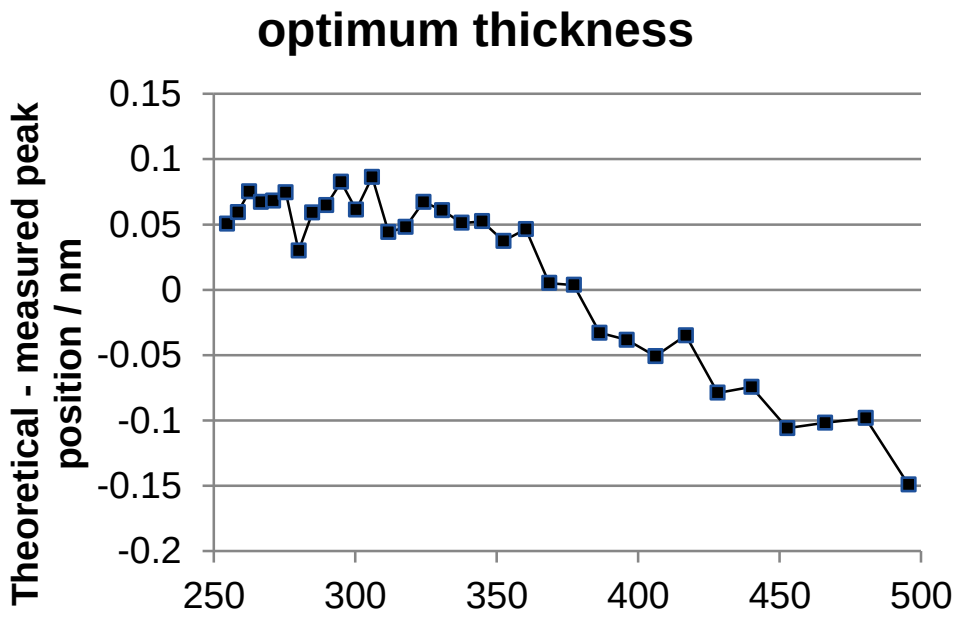


- **A priori unknown parameters: thicknesses of the layers**
- **Optimization algorithm:**
  - **χ^2: difference of measured and calculated peak wavelengths**

χ^2 of fit



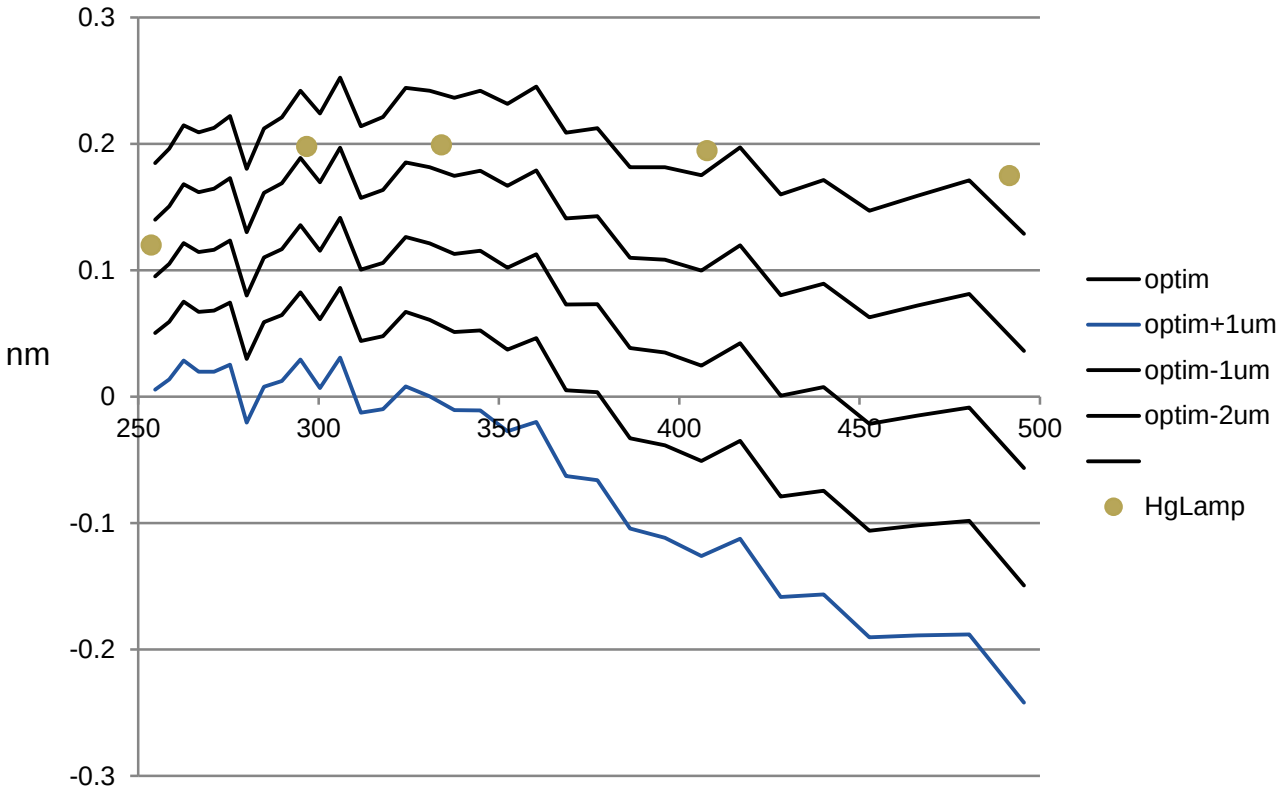




All fine?

No!!!
We don't know if the DUT is perfect!!!

Comparison with reference wavelengths generated by a Hg(Ar)-Lamp



Modelling of the dispersion function of the DUT

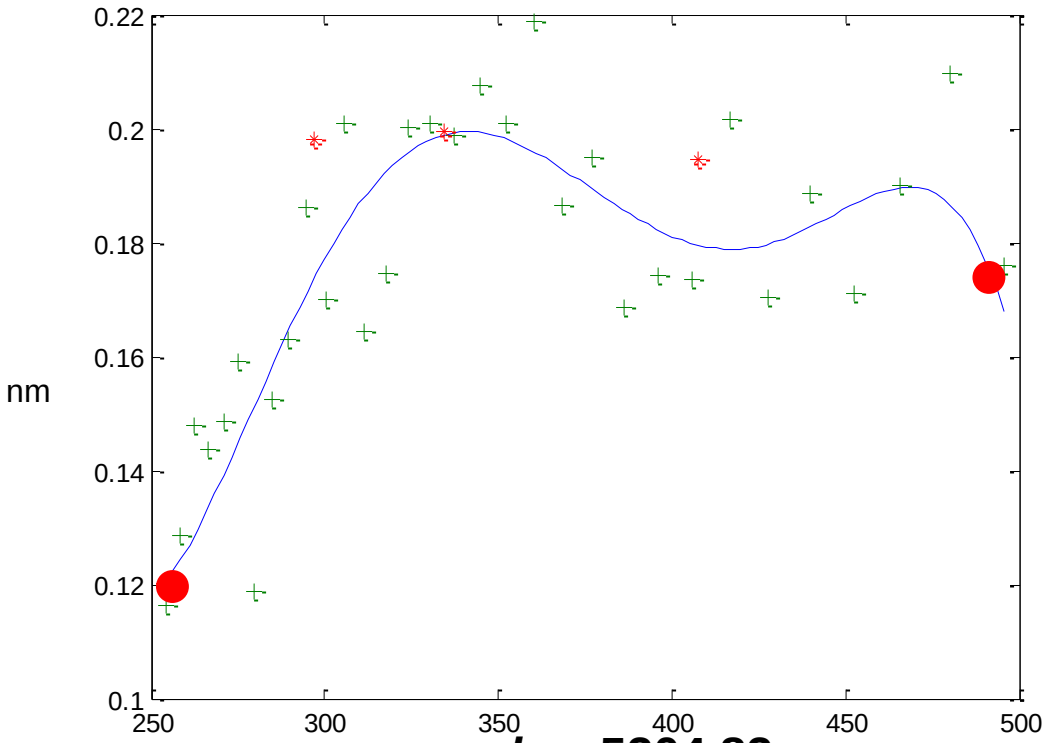
Polynom:

$$\lambda_{\text{corrected}} = \sum_{i=0}^{N} p_i \cdot \left(\lambda_{\text{DUT}}\right)^i$$

Weighted polynom fit

$$\chi^2 = \sum_{k=0}^{M} w_k \cdot \left(\lambda_{\text{meas,k}} - \lambda_{\text{model,k}}\right)^2$$

w_k = 1 : FP peaks
w_k = 50 : Hg peaks

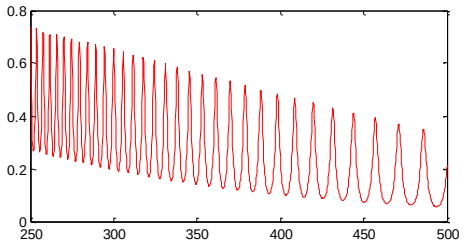


d_{opt}=5204.82nm

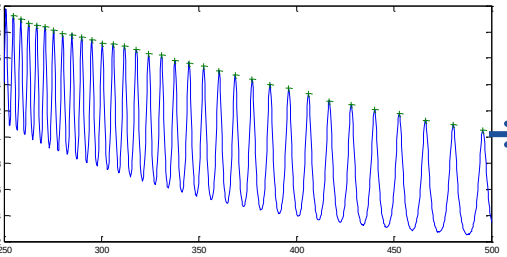
Algorithm

Refractive indices of Al and SiO_2

Initial estimation of the thicknesses



Measured peak transmittance of FP



1. Calculated theoretical model of FP transmittance

2. Calculated difference of theoretical peak position and measured peak position of FP

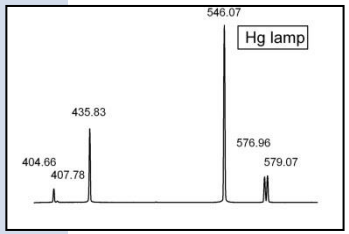
3. Calculated difference of theoretical Hg line position and measured Hg line position of FP

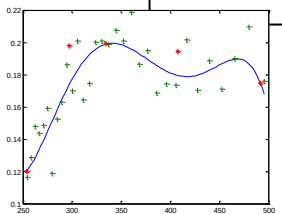
4. Weighted polynom fit (50 for Hg lines and 1 for FP peaks)

5. Determine χ^2 of polynom fit

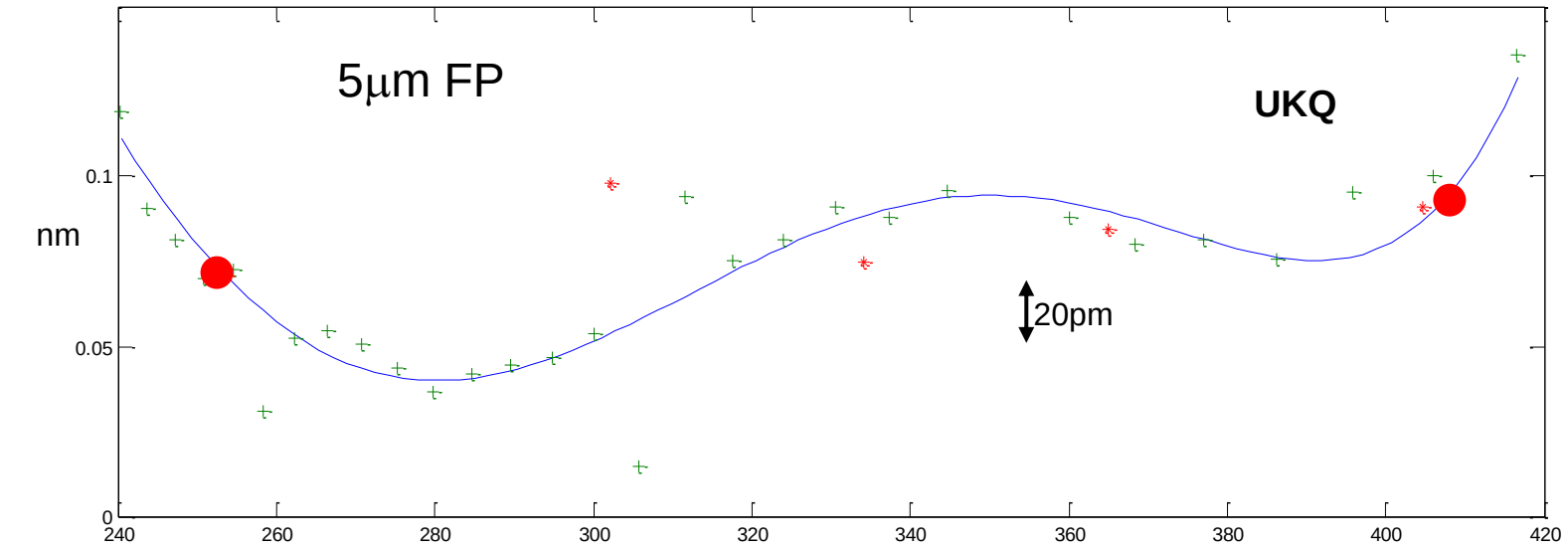
Optimize thicknesses

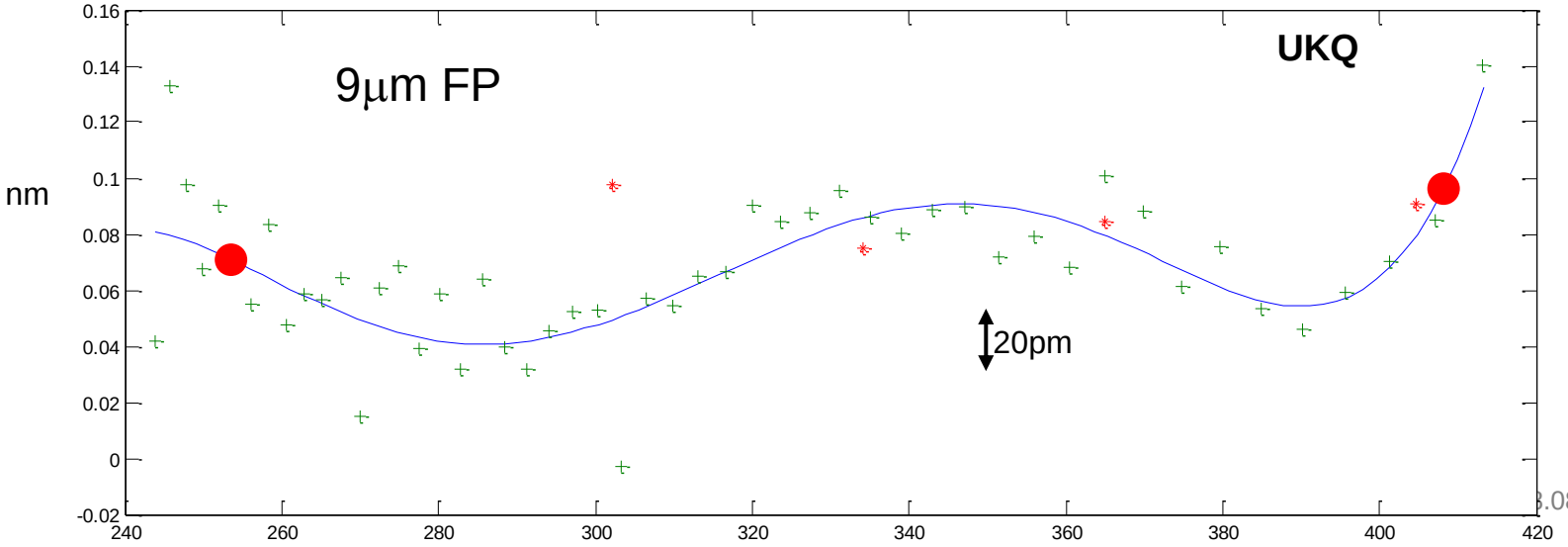
2 Hg line Measurements

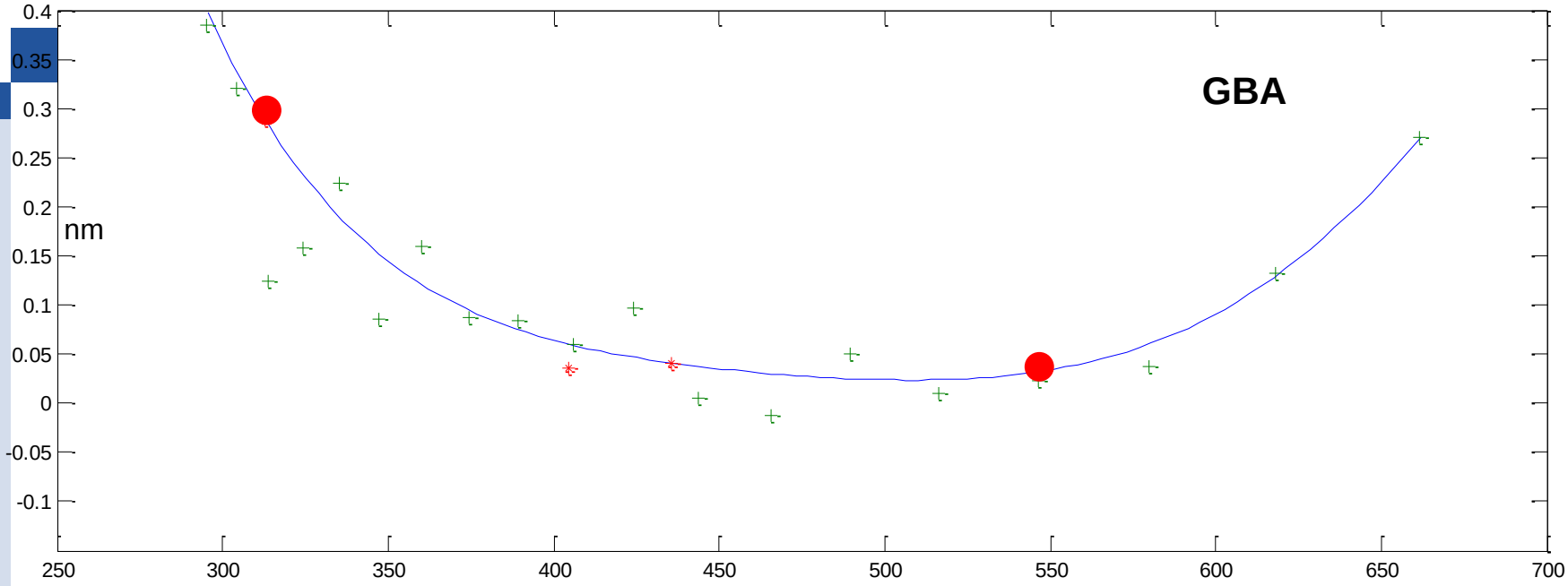


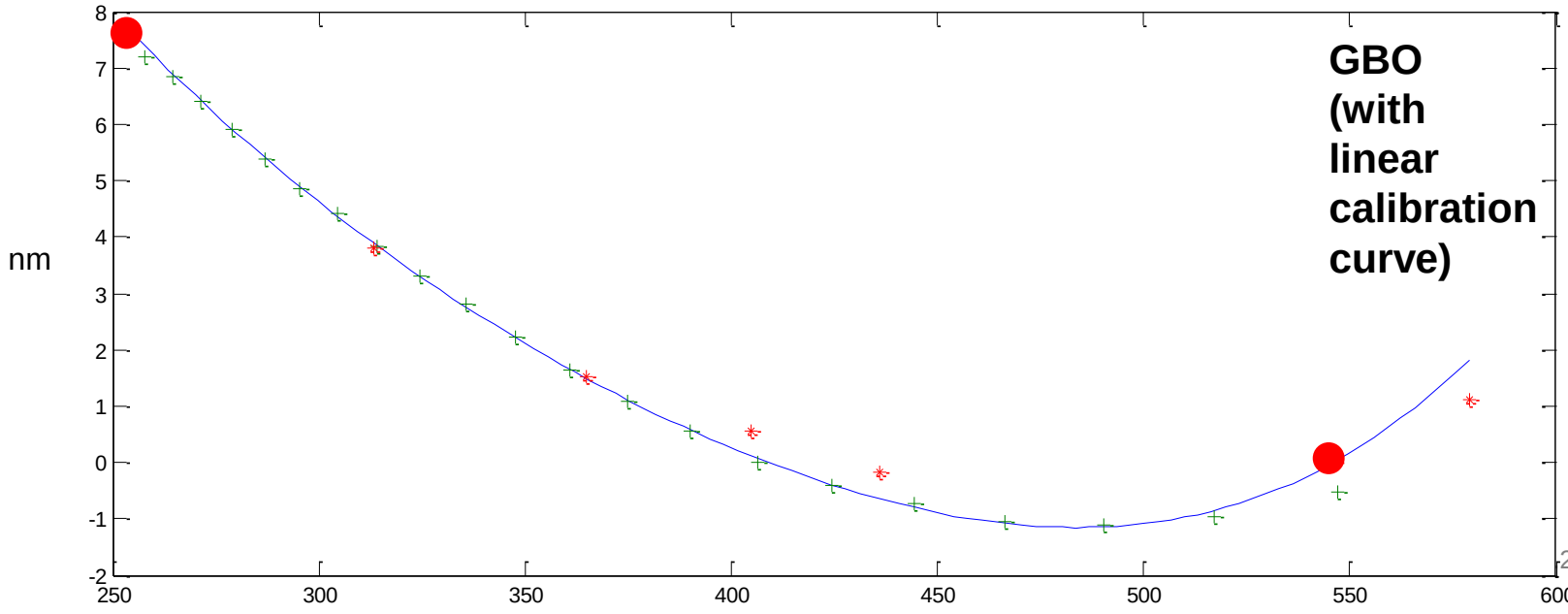


Some results: spectrometer UKQ



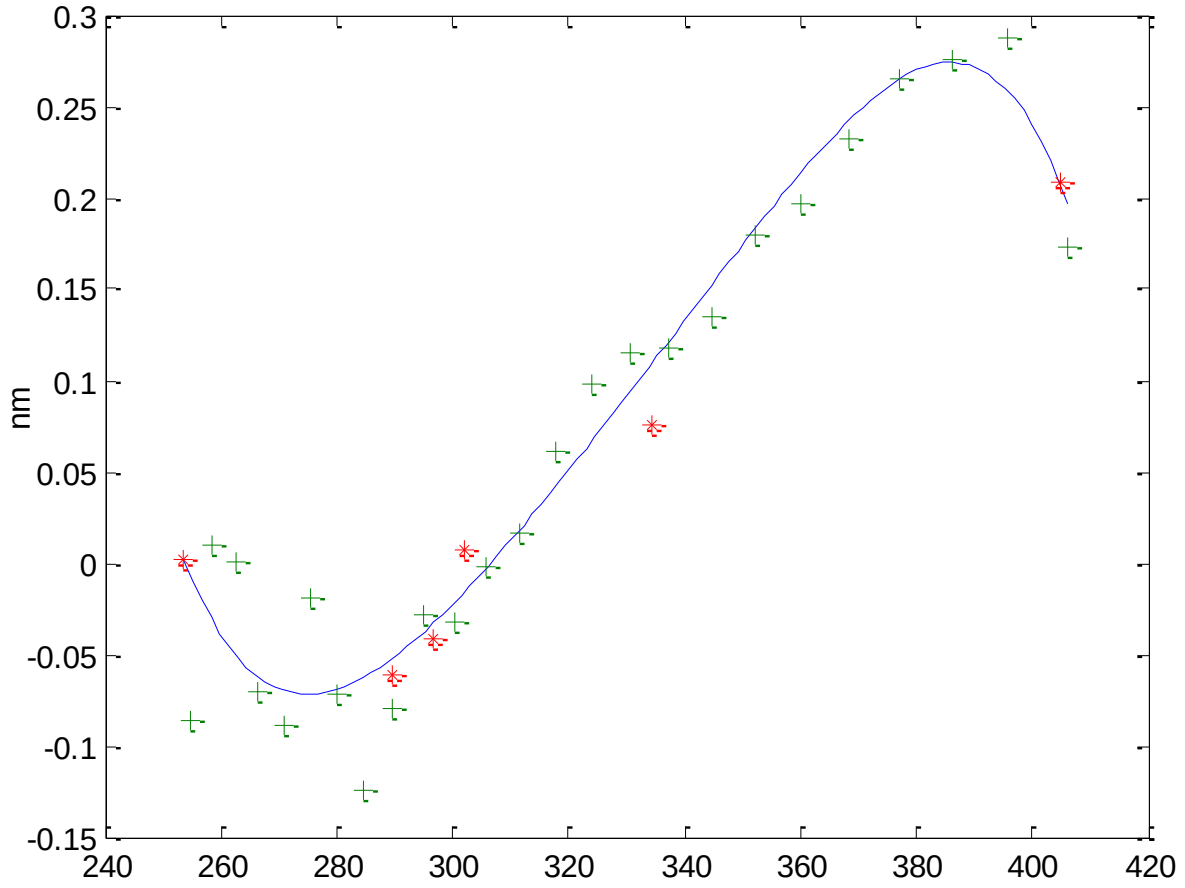



GBA
nm
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
250
300
350
400
450
500
550
600
650
700


GBO
(with
linear
calibration
curve)
nm
8
7
6
5
4
3
2
1
0
-1
-2
250
300
350
400
450
500
550
600

Is the FP an “absolute” device?
i.e. is it sufficient to know the thicknesses?

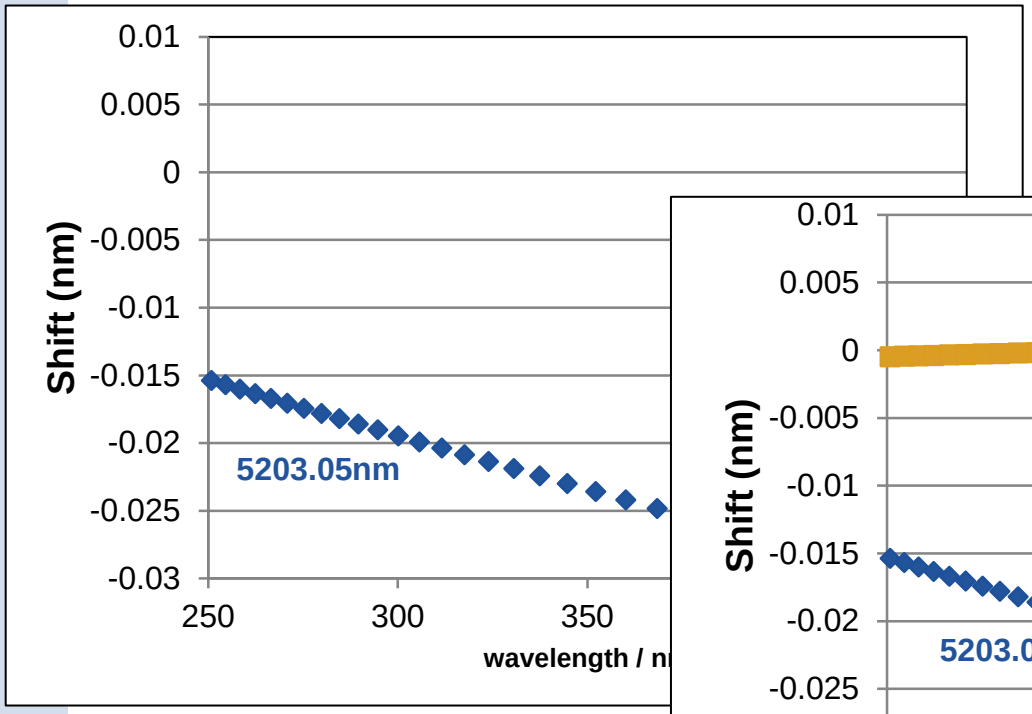
Yes!! Example: Determination of dispersion of spectrometer UKG based on the thicknesses obtained with the spectrometer UKQ



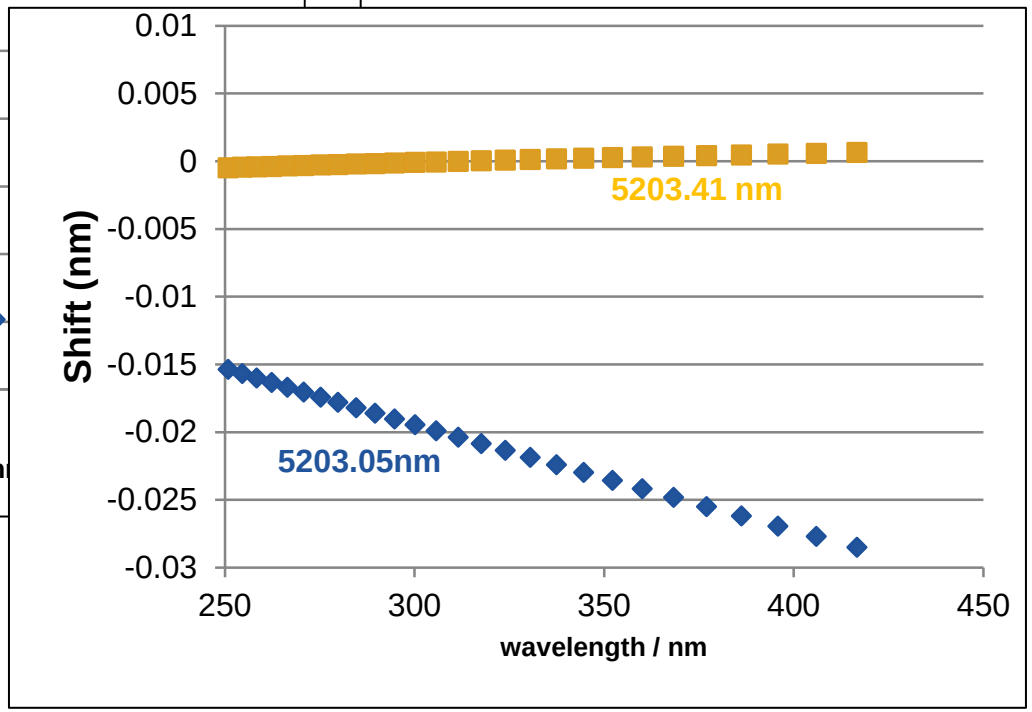
BUT: alignment and beam collimation is important if the devices is used in as absolute device

Influence of angular misalignment

Tilt of 1°



Tilt of 1°
& new optimized thickness using 2 Hg lines

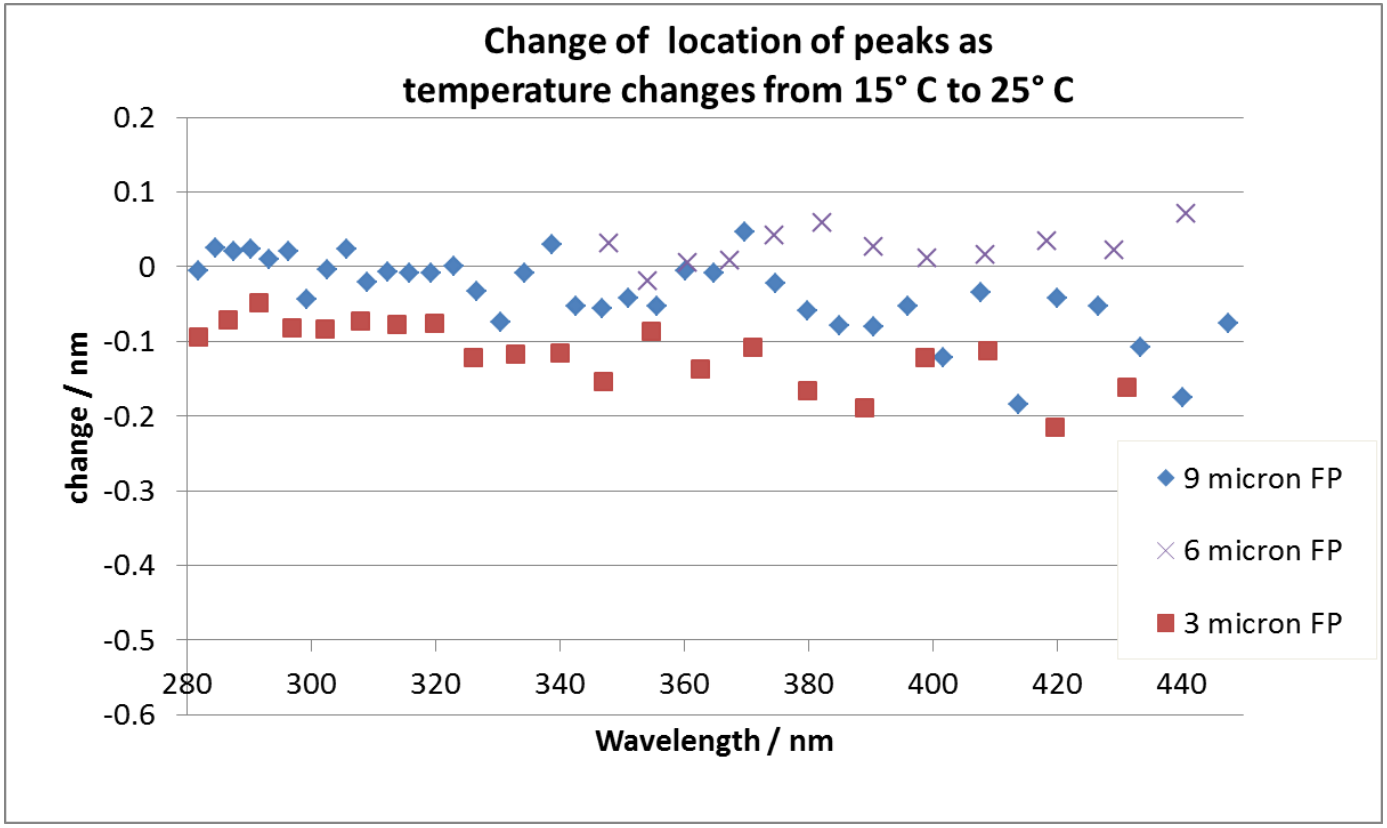


Sensitivity to temperature

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

Discussion / Conclusions

- Fabry Perot are very promising devices for the characterization of the wavelength scale of spectrometers
- < 0.02 nm uncertainties has been demonstrated
- FP can be used as **absolute** devices if the critical parameters are controlled:
  - angular alignment (or divergence of source/detector): < 0.5°
  - temperature (variation < 3°C)
- If these requirements are not met the devices can be used as **relative** scales in combination with two known absolute spectral lines

Thank you for your attention