Optical Characterisation of Coatings

Principles of Optics for Reflectometry

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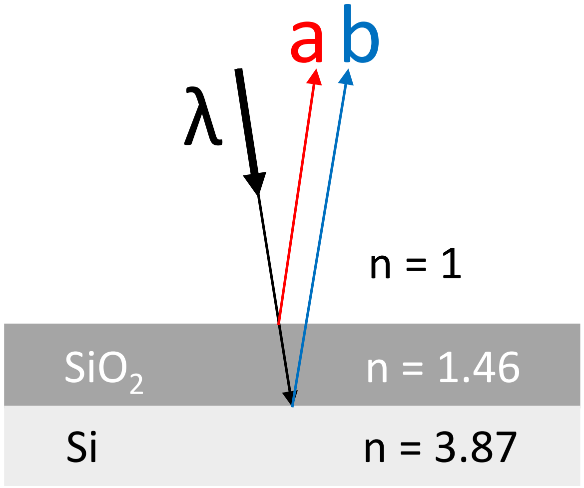
Reflectometry

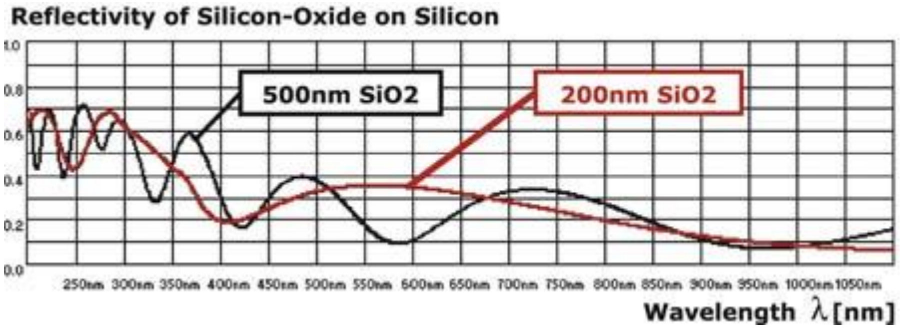

λ

a b

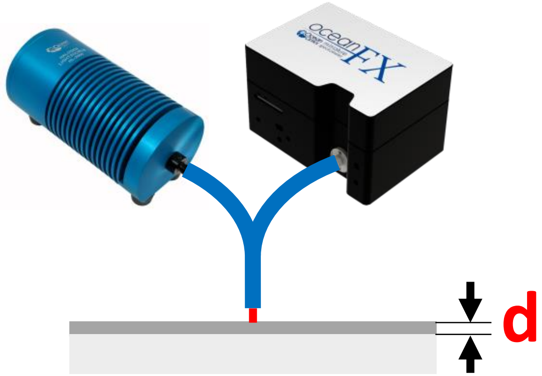
n = 1

SiO_2 n = 1.46

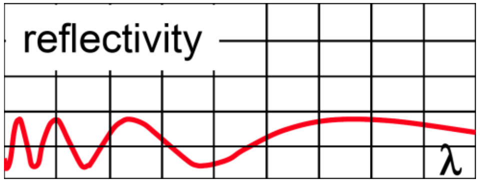
Si n = 3.87


Reflectivity of Silicon-Oxide on Silicon

Approach



reference or calibration



mathematical model

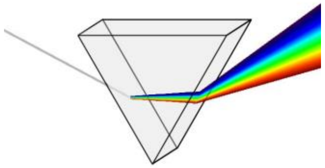
thickness d (+ optical properties)

Material properties

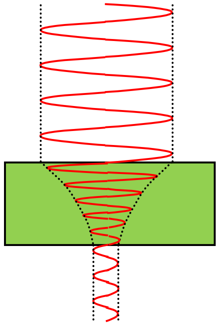
Refractive index

n(BK7 – glass) = 1.5
n(Si) = 3.18 k = -0.8

Dispersion

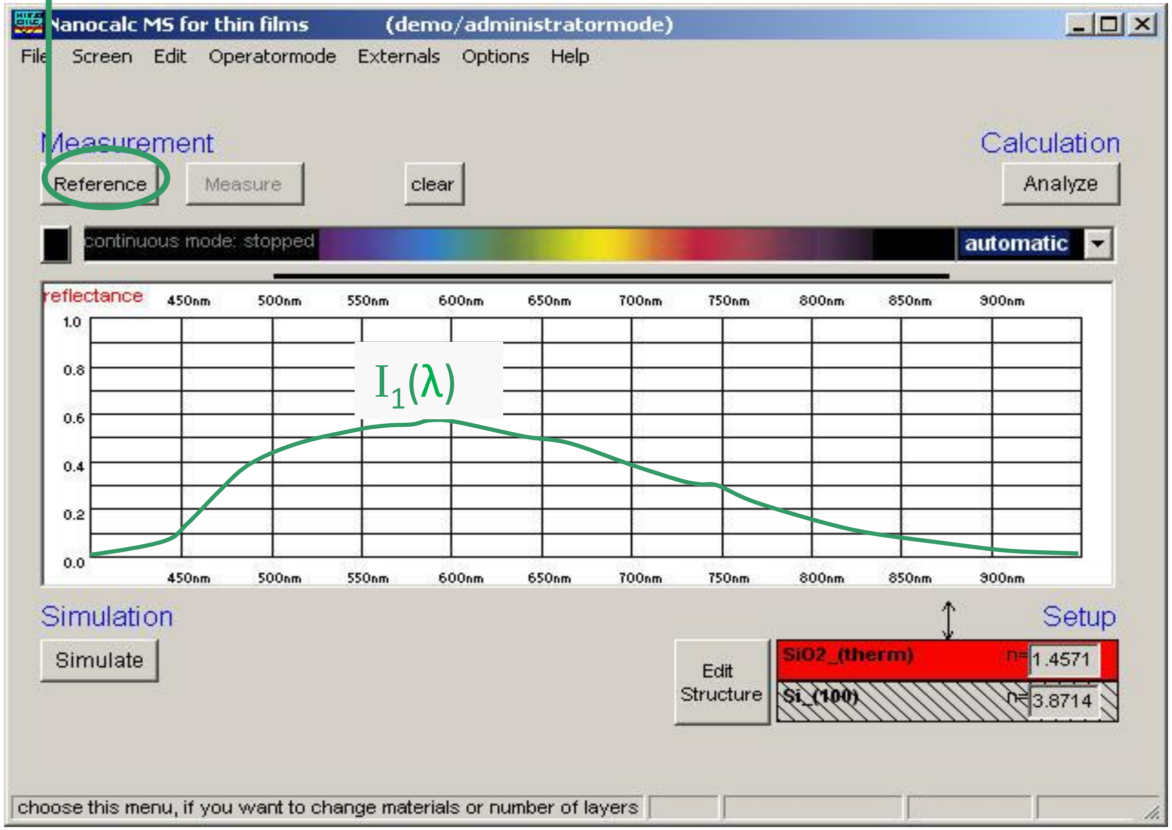


Absorption



Measurement principle - I

1. reference



continuous mode: stopped

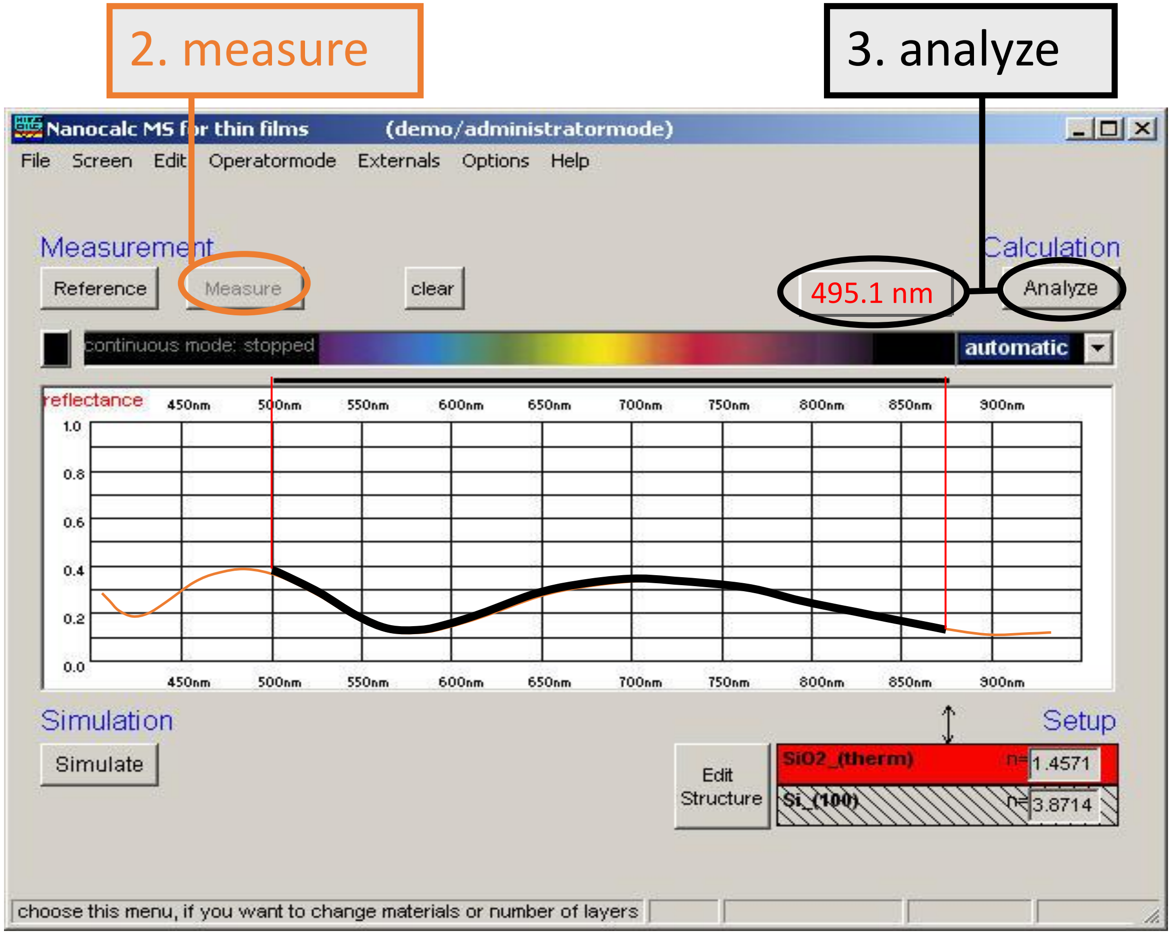
automatic

SiO2_(therm) n= 1.4571

Si_(100) n= 3.8714

choose this menu, if you want to change materials or number of layers

Measurement principle - II



2. measure

3. analyze

Nanocalc MS for thin films (demo/administratormode)

495.1 nm

continuous mode: stopped

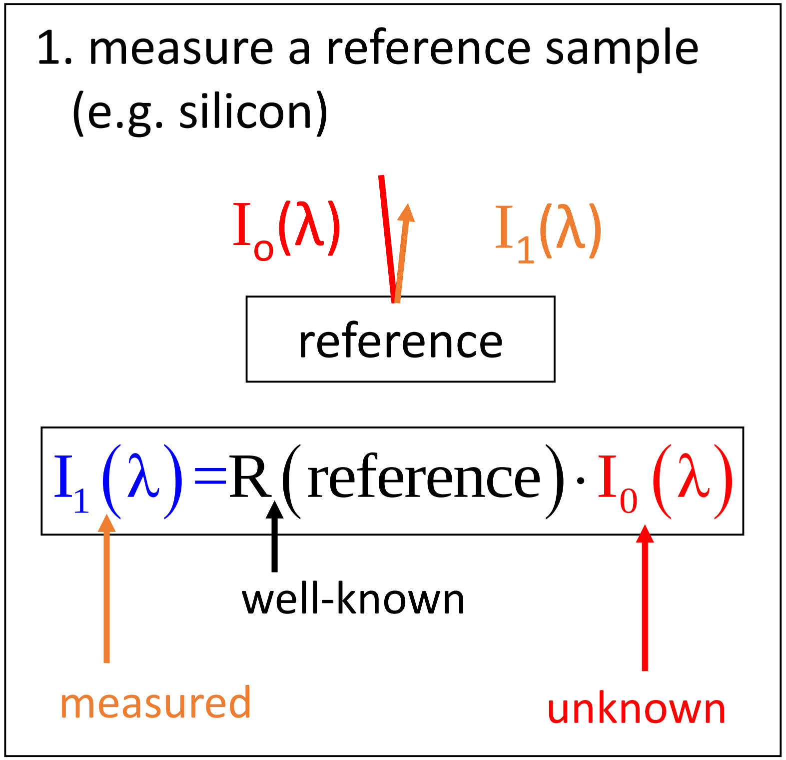
automatic

SiO2_(therm) n=1.4571

Si_(100) n=3.8714

choose this menu, if you want to change materials or number of layers

Measurement principle - reflection



1. measure a reference sample (e.g. silicon)

$I_o(\lambda)$

$I_1(\lambda)$

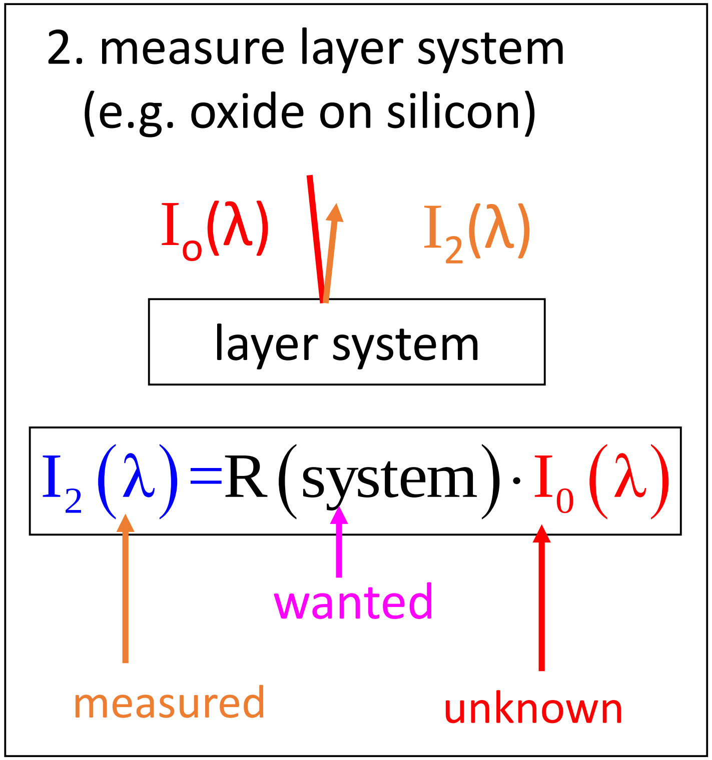
reference

$$I_1(\lambda) = R(\text{reference}) \cdot I_0(\lambda)$$

well-known

measured

unknown



2. measure layer system (e.g. oxide on silicon)

$I_o(\lambda)$

$I_2(\lambda)$

layer system

$$I_2(\lambda) = R(\text{system}) \cdot I_0(\lambda)$$

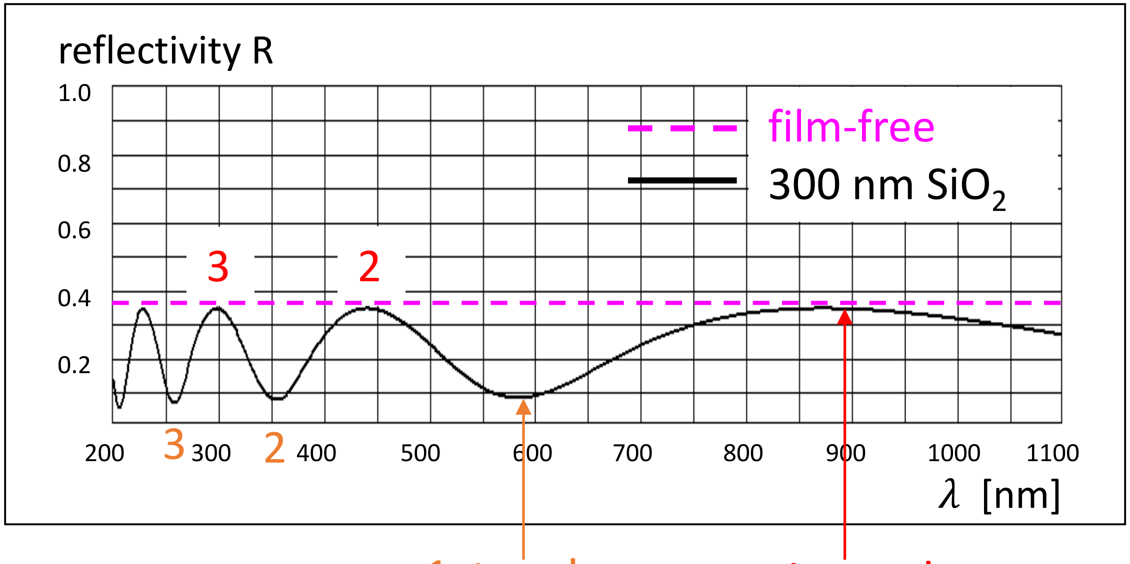
wanted

measured

unknown

$$R(\text{system}) = \frac{I_2(\lambda)}{I_1(\lambda)} \cdot R(\text{reference})$$

Anatomy of a reflectance spectrum



1st-order minimum

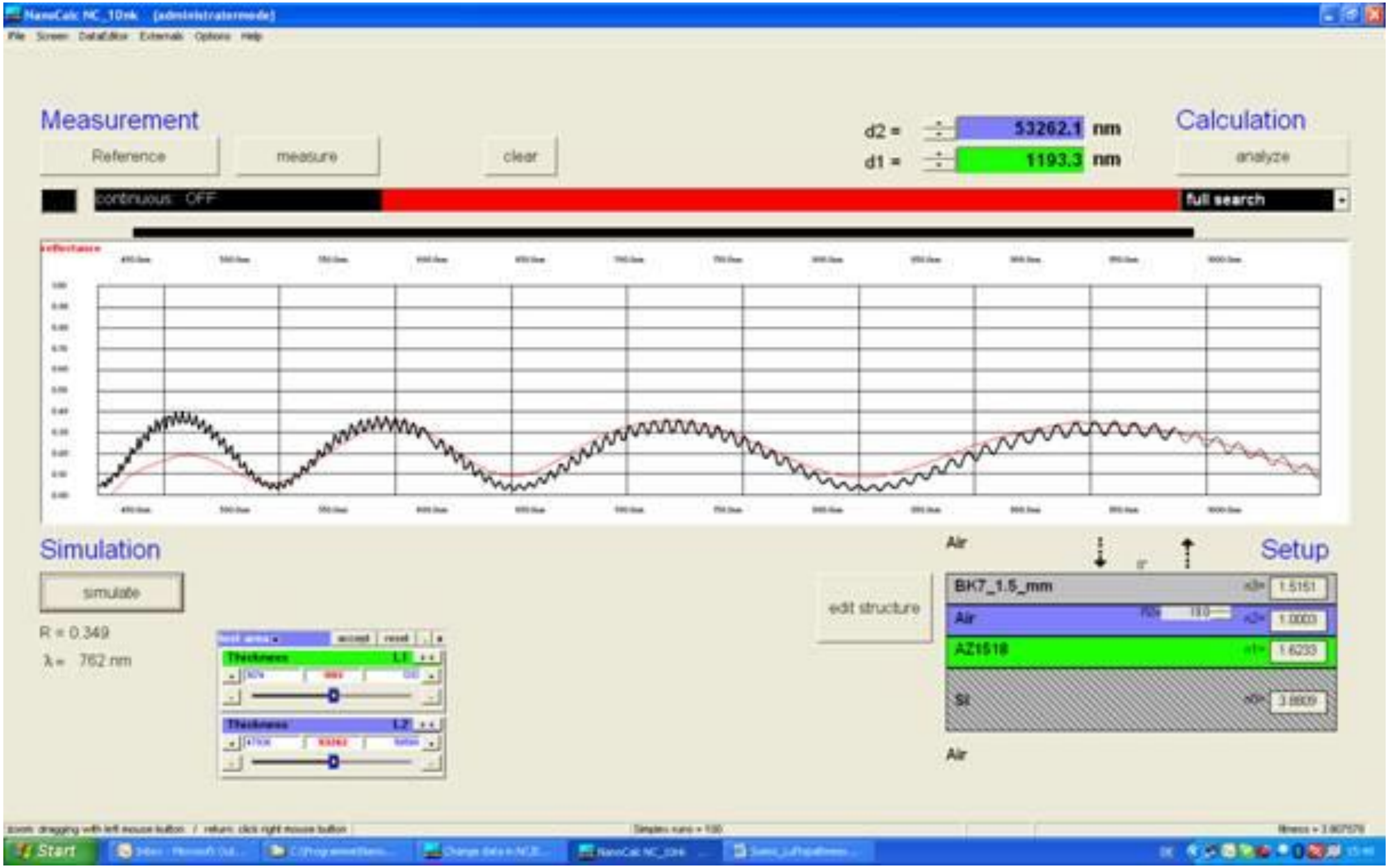
1st-order maximum

$$d = (2m+1)\cdot\frac{\lambda}{4n}$$

$$d = (2m)\cdot\frac{\lambda}{4n}$$

M=1: d=3·584 nm /4·1,46= 300 nm

Measurement examples – multiple layers



NanoCalc NC_10nk (administratormode)

d2 = 53262.1 nm

d1 = 1193.3 nm

continuous: OFF

full search

R = 0.349

λ = 762 nm

Air

BK7_1.5_mm n3= 1.5151

Air n2= 1.0003

AZ1518 n1= 1.6233

Si n0= 3.8809

Air

properties of reflectometry

- measurement property: thickness of transparent and semi-transparent layers
- in some cases also measurement of dispersion (n&k) using Cauchy or Scout models
- **very fast** and **non destructive**
- **small measurement spot** (1 um – 400 um)
- single layer or multilayer (up to 10 layers)
- thin layers (1nm -100nm): UV range

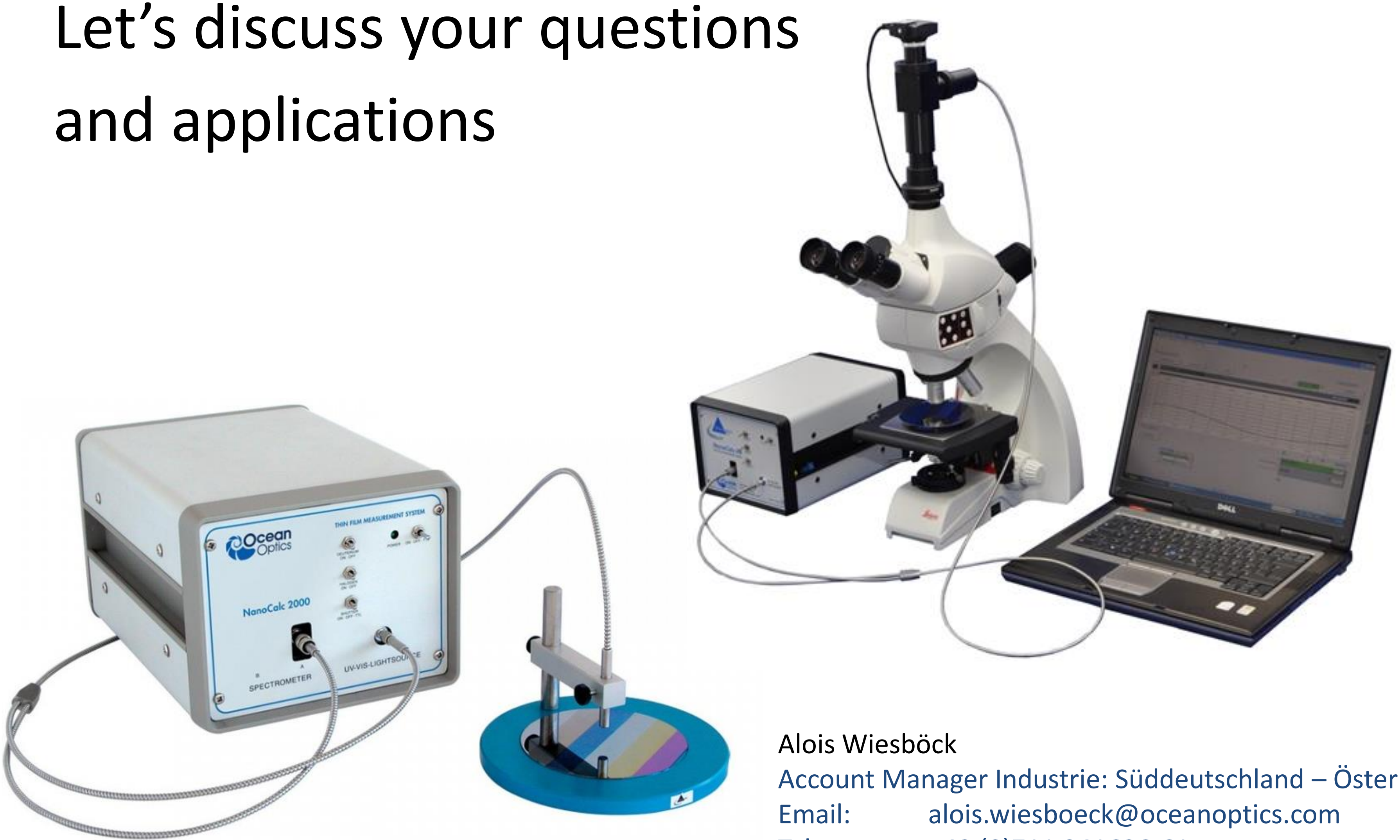
  (Please discuss layers below 20 nm with us. Maybe an ellipsometer is needed)
- thick layers (up to 250µm): VIS to NIR range

Application examples

- Semiconductor industry: Lithography (Resist)
- PECVD: SiO2, SixNy ;or Poly, amorph Si, Si
- Glass/Integrated optics: ARCs und HC; SiO2, TiO2, ZrO2…
- Tribology (friction, lubrication and wear)
- PV Industry, ARCs , SixNy, TCOs: ZnO, ITO
- OLEDS, most semitransparent layers
- Anti corrosion (PECVD): most SiO2
- Plastic industry, HC on PC, PET, PMMA, etc.
- Medical technology: coating of syringes, Parylene on heart stents, Balloon cardiac catheter(wall thickness)

- Si membranes (thin-etched or ground) 20µm to 200µm (InGaAs)
- DLC, depending on the production, transparent from 600nm or in the NIR (InGaAs)
- coatings on mech. Components (watches) - microscope application
- Wafer with structure, µm spot down to 1µm, microscope
- Air gap in mask technology, (10µm – 200µm) NIR

Let’s discuss your questions and applications



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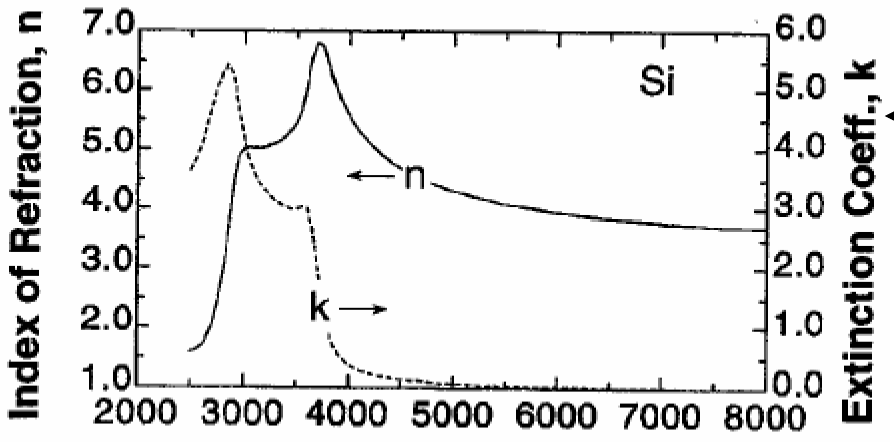
Measurement principle - III



$$R(Si) = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}$$

„well-known“

$$R(system) = \frac{I_2(\lambda)}{I_1(\lambda)} R(reference)$$

measured

mathematical models

layer thickness / refraction indices

Refractive index

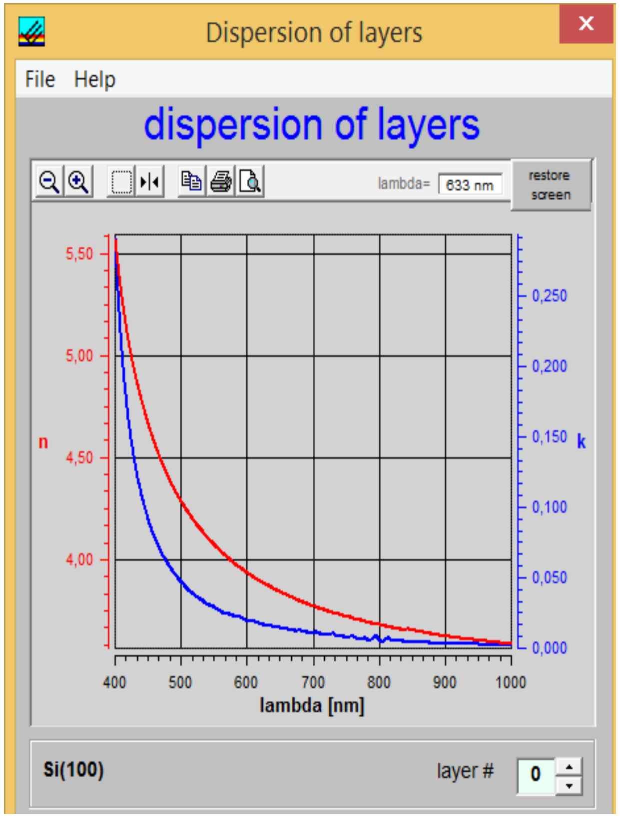
C_0 = speed of light in vacuum ~ 300000 km/s

Refraction index $\mathrm{n} = \frac{c(vacuum)}{c(matter)} = \frac{c_0}{c}$

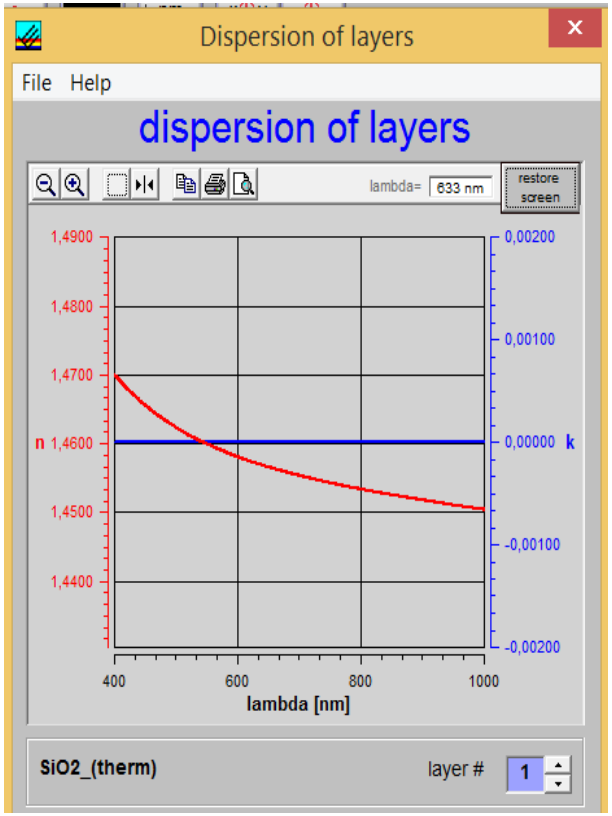
Examples: n(BK7 – glass) = 1.5
n(Si) = 3.18 k = -0.8

The refractive index is a complex number with a real part and an imaginary part. Both are depending on λ, so they show dispersion. And k = absorption

Dispersion of Si and a SiO2 layer



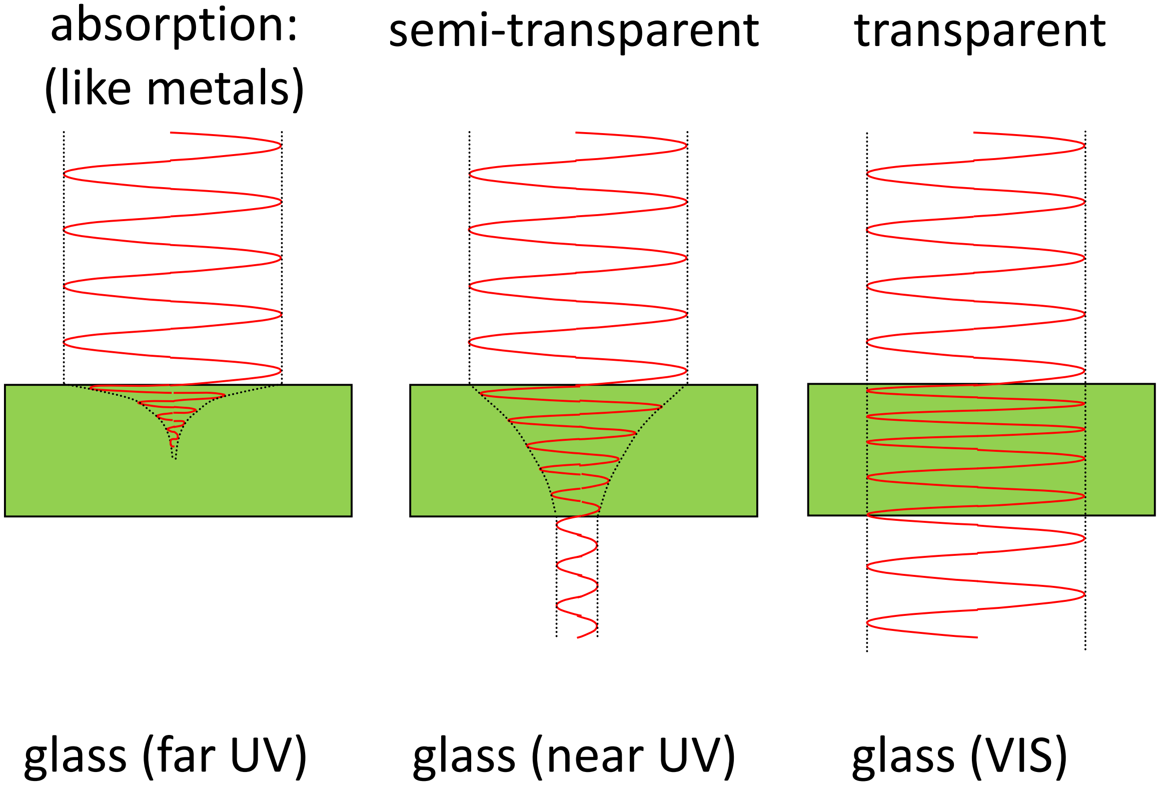
Si(100)



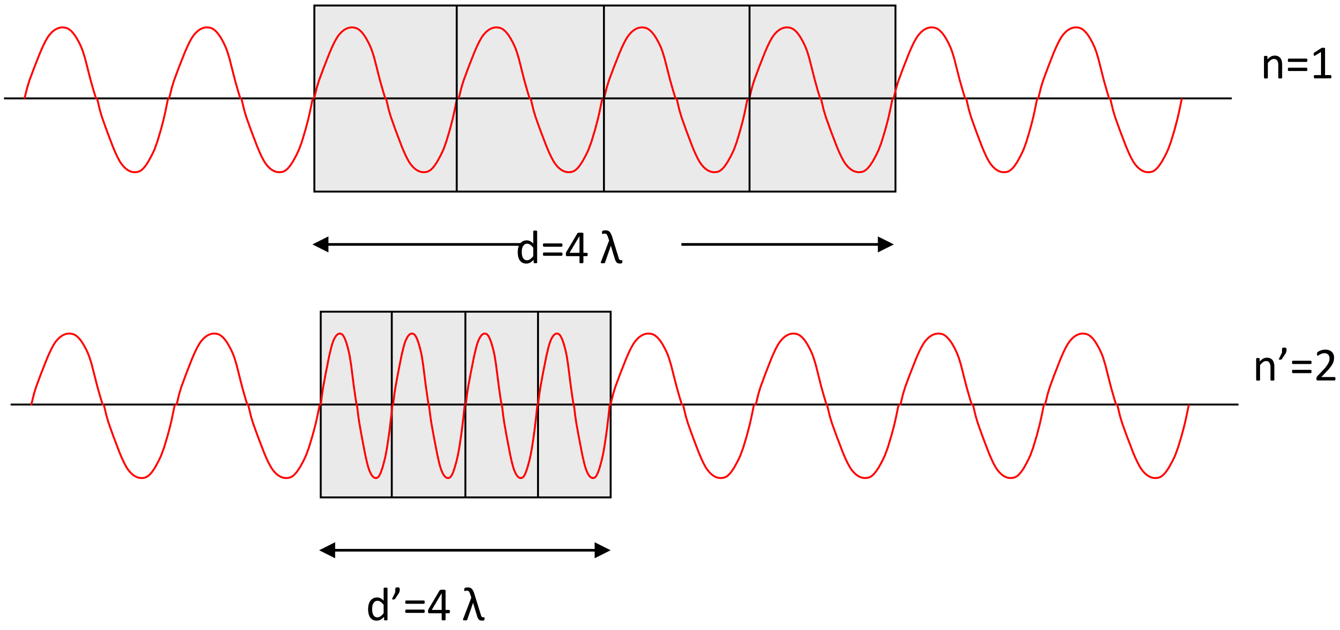
SiO2_(therm)

Absorption

We can measure only transparent and semitransparent layers



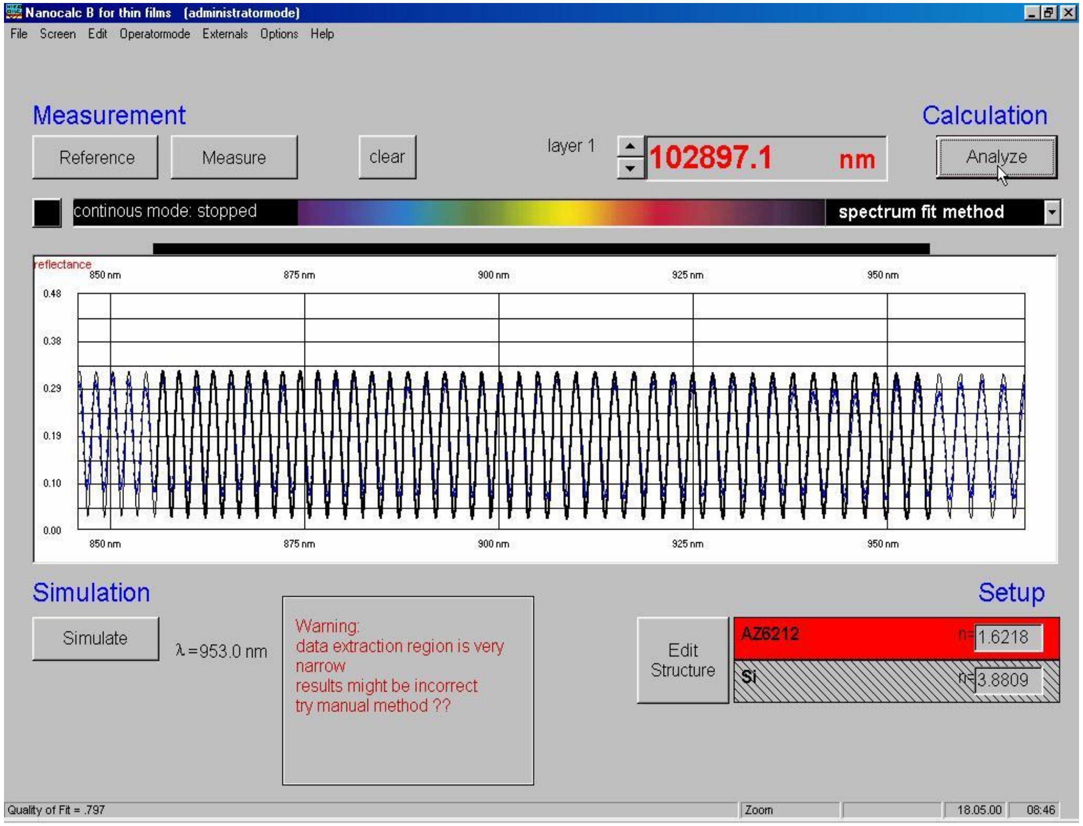
optical length



product   d·n = d’·n’ = const !! (= same number of wavelengths)

optical length = geometrical length · refractive index

Measurement examples – very thick thin films



Nanocalc B for thin films (administratormode)

layer 1 102897.1 nm

continous mode: stopped

spectrum fit method

λ=953.0 nm

Warning:
data extraction region is very narrow
results might be incorrect
try manual method ??

AZ6212 n=1.6218

Si n=3.8809

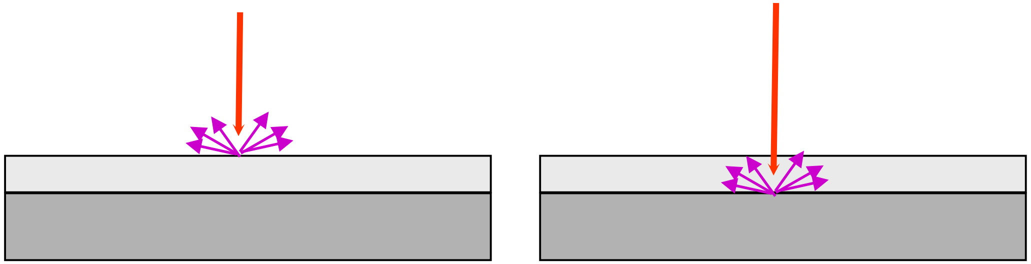
Quality of Fit = .797

18.05.00 08:46

an example with 103 μm of photoresist on silicon

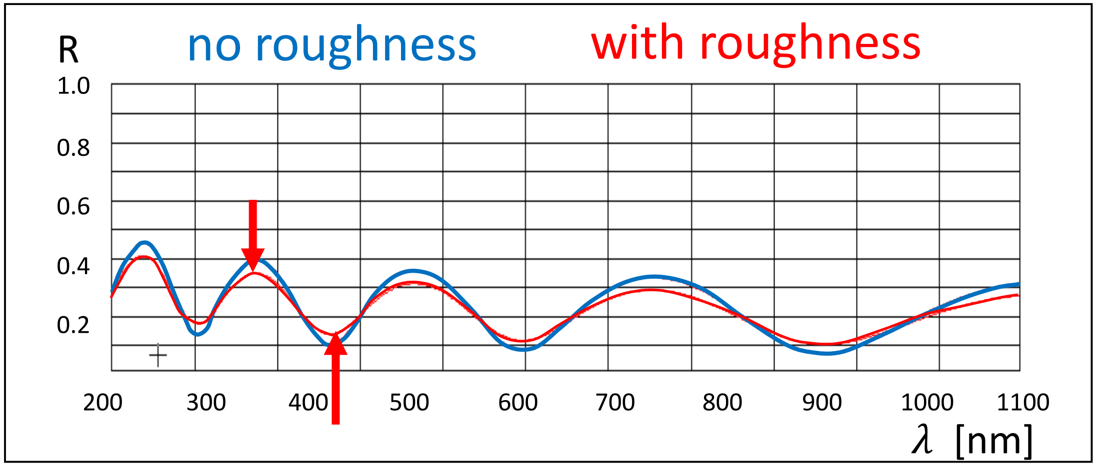
Measurement examples – rough films

parts of the incoming light is lost at the outer and inner surface



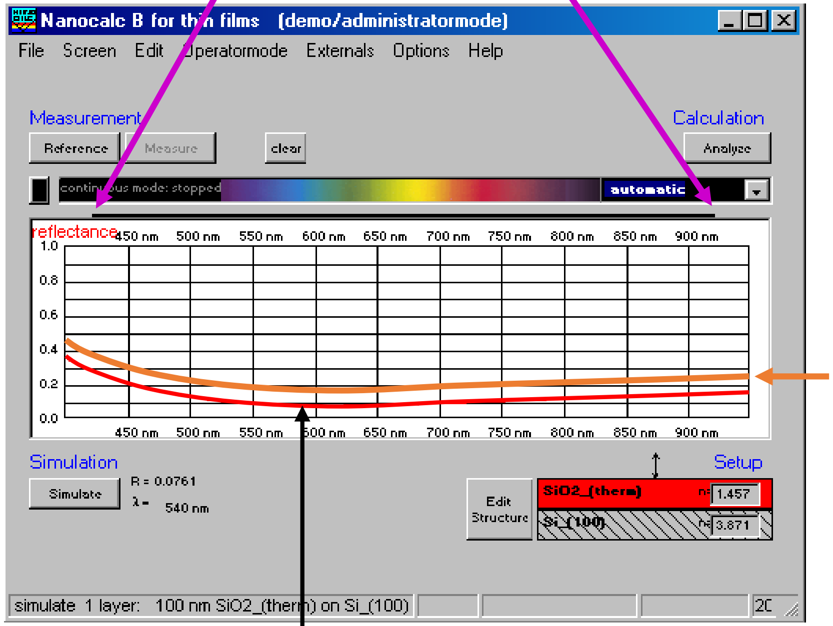
mathematically hard to describe as surface structure is unknown

- position of extrema remains the same
- amplitude vanishes



Measurement examples – very thin films

sensitive to narrow extraction region



R = 0.0761

λ = 540 nm

SiO2_(therm) n= 1.457

Si_(100) n= 3.871

simulate 1 layer: 100 nm SiO2_(therm) on Si_(100)

no wiggles

sensitive to intensity variations

1st order minimum is hard to identify