ALIGNMENT SYSTEM FOR SILICON TRACKING

IFCA SiLC (a.o.):
Marcos Fernández, Javier González,
Sven Heinemeyer, Richard Jaramillo,
Amparo López, Celso Martínez,
Alberto Ruiz, Ivan Vila

CNM SiLC (a.o.):
Manuel Lozano, Giullio Pellegrini,
Enric Cabruja

Presented by:
Alberto Ruiz-Jimeno
(IFCA)

(Special thanks to Marcos Fernandez
for the slides preparation)

Outline

Introduction

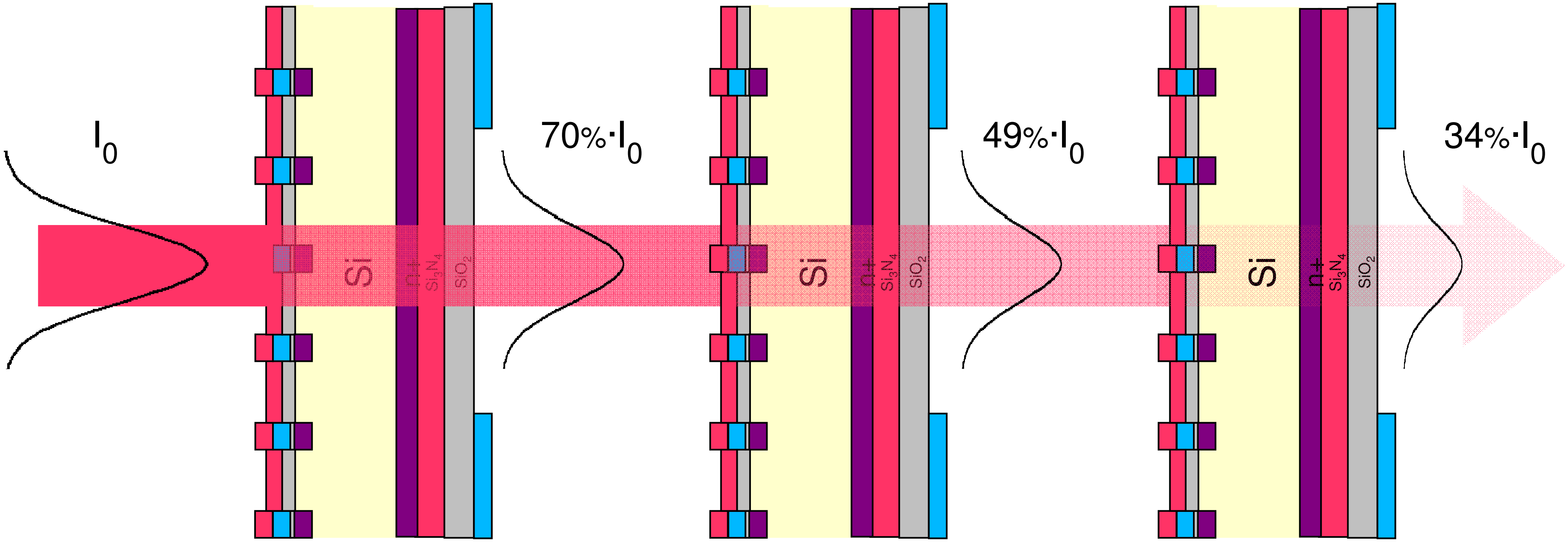
Hybrid alignment systems in HEP experiments

“Ideal Sensor” optical simulation

“Real Sensor” optical full simulation

Further details on the results shown can be found at Eudet-memo-2007-032-1

Nutshell



T=70% with Al strips

T=75-80% with ITO strips

Si µ-strip “fotosensors”? Advantages

Si is almost transparent to IR light. Still, its (slight) absorption is enough to produce a measurable signal

— Beam position across several sensors can thus be measured.

— Remaining sensors are reconstructed using tracks in overlap region.

— Subsequent track alignment improves precision by 1 order of magnitude.

Advantages of this approach:

— Sensors under study are their own alignment system ⇒ **No** mechanical **transfer errors** between fiducial marks and the modules

— Minimum impact on system integration, **no cost in extra material budget**

— Straightforward DAQ integration ⇒ Alignment data is read out using Si DAQ

— Alignment system does not compromise tracker design: changes in geometry of the modules have no impact in system precision

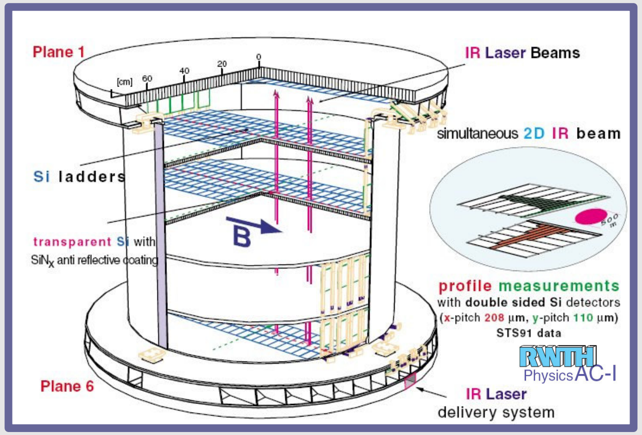
Requirements of this approach:

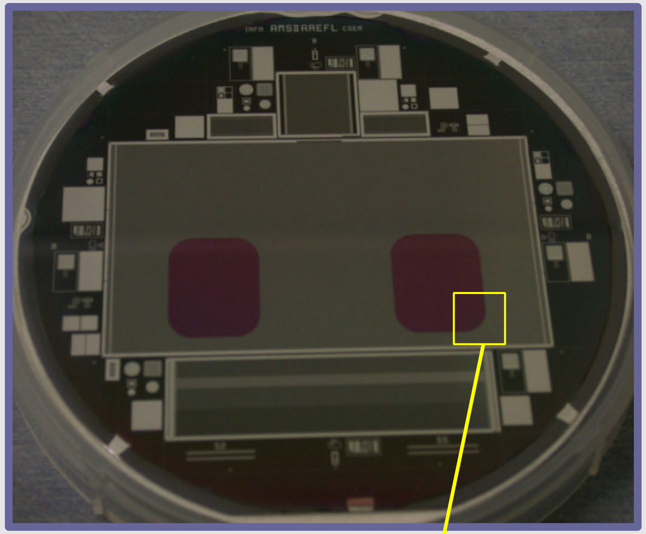
— Alignment system must be taken into account from the design phase of the sensor

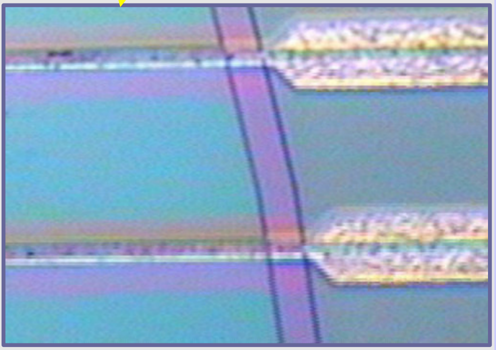
— Modifications of the sensor needed in a ~10 mm (*) diameter optical window: **removal of aluminum backelectrode locally**

(*) This number needs to be optimized

Successful predecessors ..







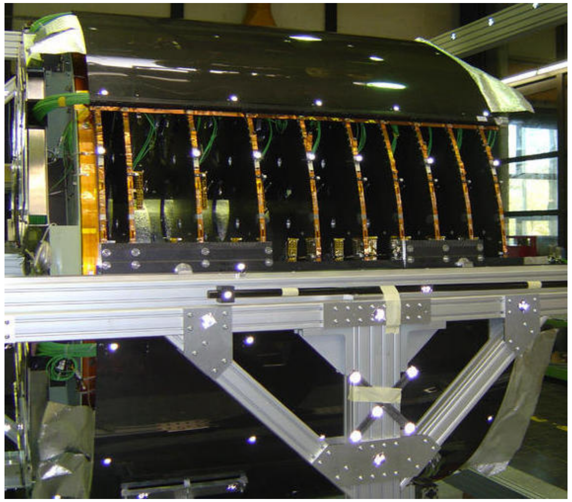
AMS-01 innovation (W. Wallraff)
λ = 1082 nm

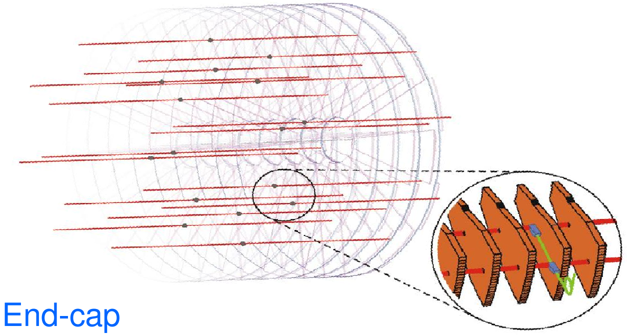
IR “pseudotracks”

1-2 µm accuracy obtained

Transmittance~ 50%

Up to 4 ladders traversed





CMS Tracker End-cap

λ = 1075 nm

- Optimization of sensors not included from beginning of sensor design ⇒ **lower transmittance** achieved~20%
- 180 deg beam splitters in the middle of the tracker produce back to back beams measured by modules
- Laser spot reconstructed with 10 µm resolution (1st sensor)

9 TEC disks (18 petals) reconstructed using 2 beams with 50 µm accuracy (100 µm required in CMS)

ILC: 2-fold approach

AMS-like approach:

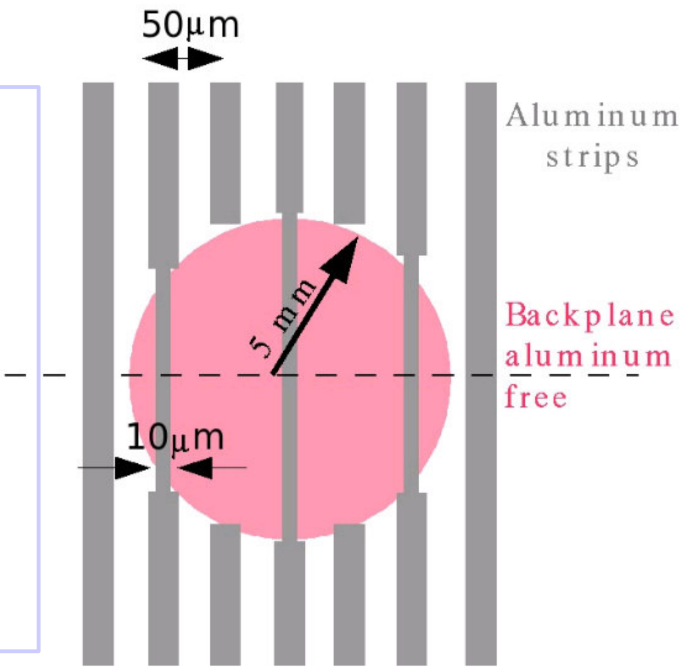
Baseline version: Minimum set of changes for any SiLC sensors. For instance, for the new HPK sensors

Implemented:

- ∅~10 mm window where Al back-metalization has been removed

Suggested:

- Strip width reduction (in alignment window)
- Alternate strip removal (in alignment window)



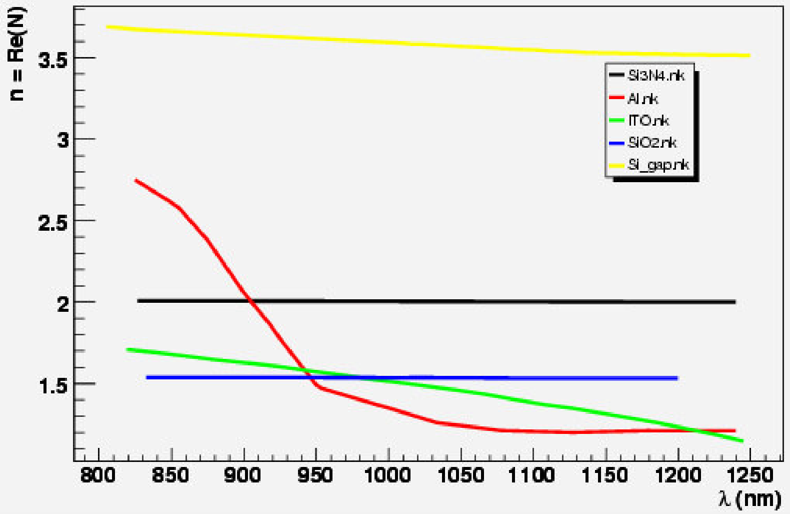
R&D on transparent Silicon μstrip sensors:

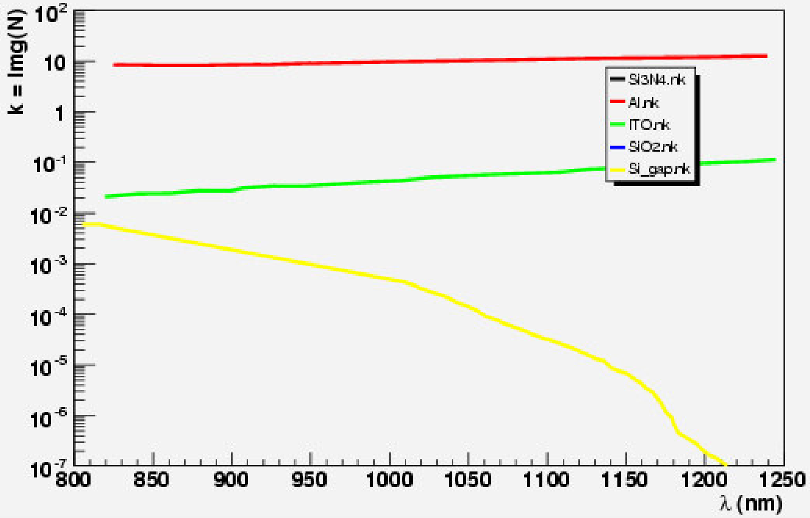
- Together with IMB-CNM (Barcelona) design, build and test new IR-transparent Silicon microstrip detectors.
- Consider option of aluminum electrodes or transparent electrodes

Optical figures for common Si µstrip materials

- Refraction index is responsible for optical behaviour of materials. Function of wavelength: N=n(λ)+ik(λ)

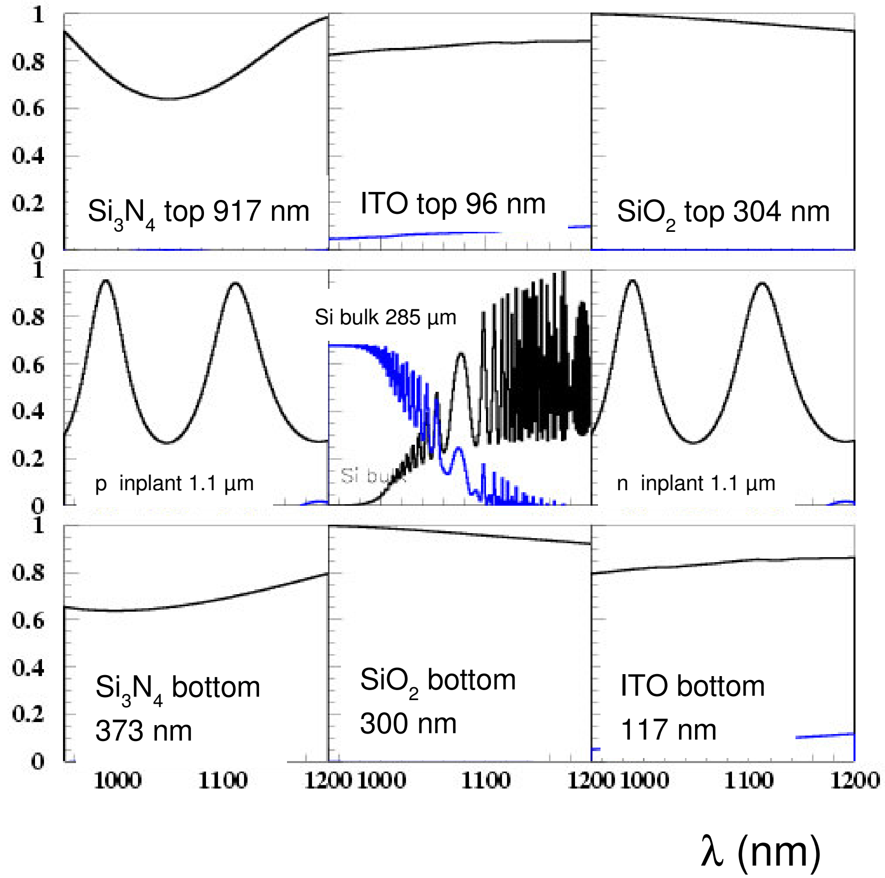
n=related to energy balance
k=related to optical absorption $\frac{1}{\alpha} = \frac{\lambda}{4\pi k}$





- Typical absorption for Silicon [200-320] µm thick for λ in IR: A~5-10% ⇔ 40-2000 MIPs

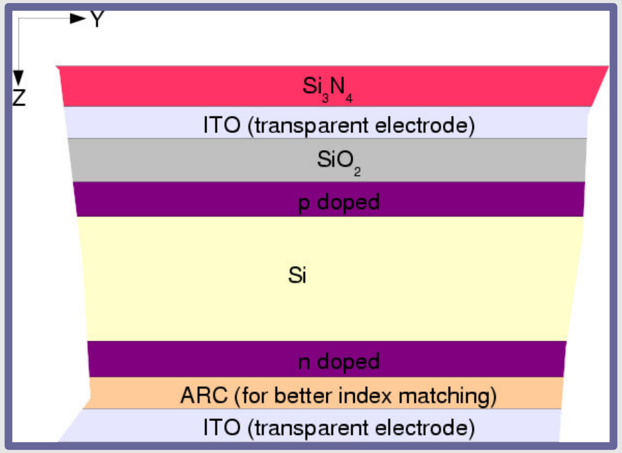
- Transmittance calculated for typical thickness



Optical Simulation of Si µ-strip sensors

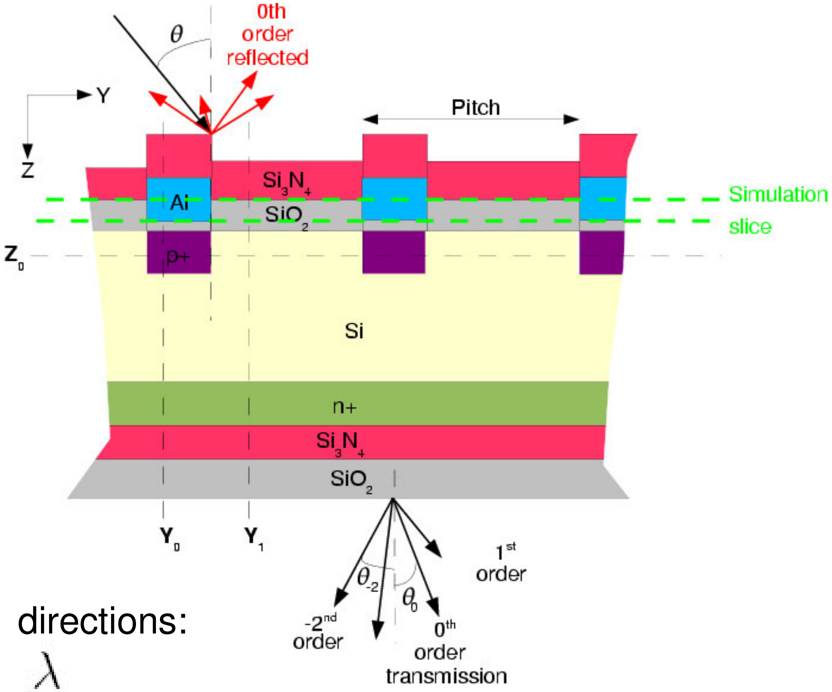
- First calculations assumed an **ideal sensor** scenario:

  Planoparallel layer surfaces (bordless)
  Continuous implantations
  Front and back polished
  Al substituted by transparent electrodes



- Now we studied a **realistic sensor**:

  Upper layers are periodically segmented
  Strips=linea diffraction grating



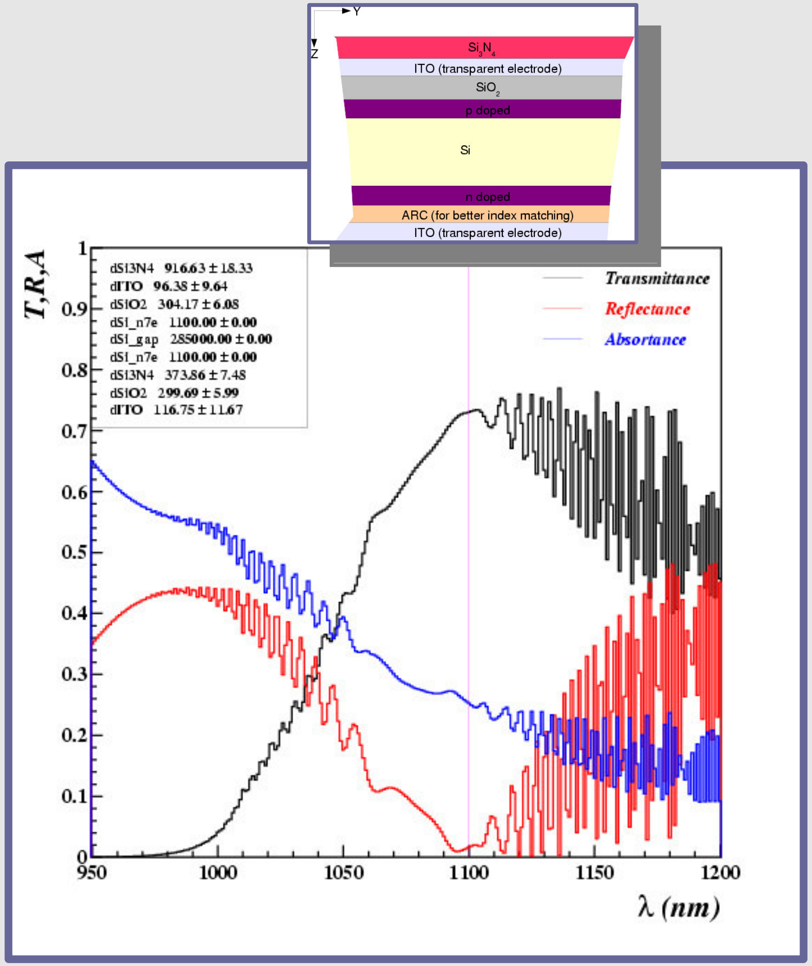
- Incoming wave splits in a series of waves with discrete propagation directions:

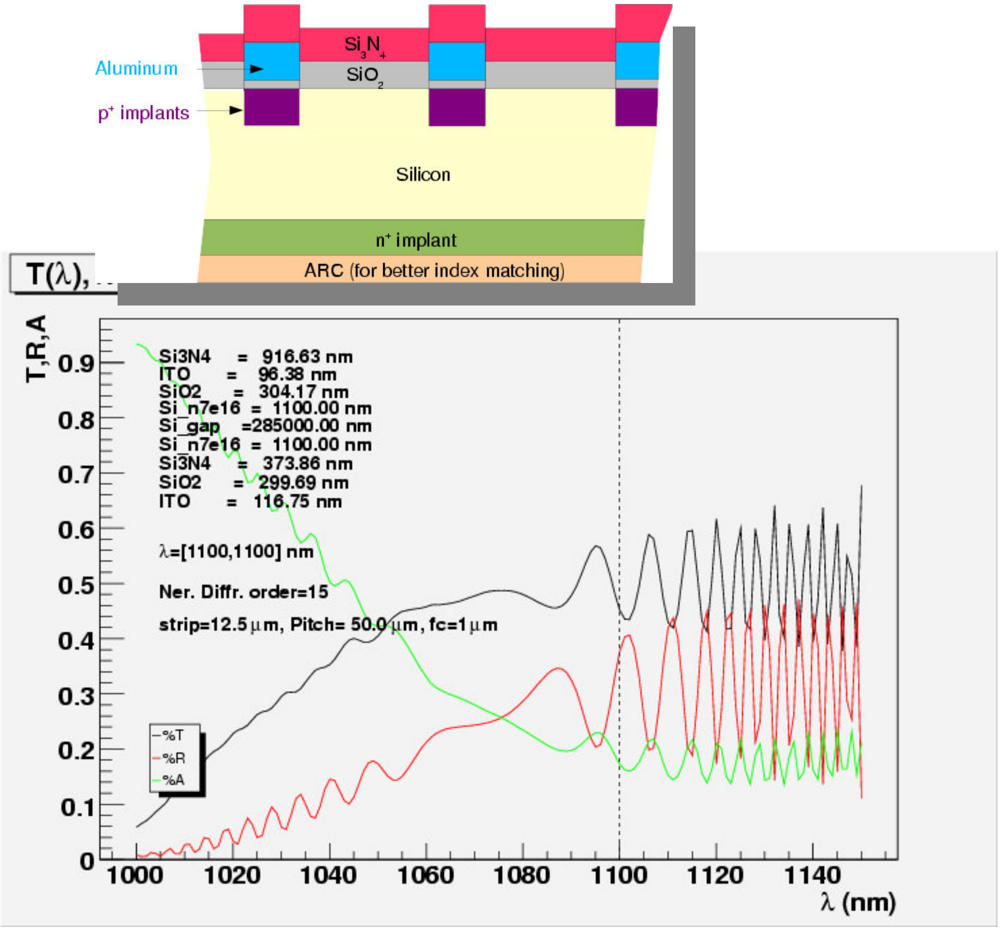
$$\sin\theta_m = \sin\theta + m\frac{\lambda}{d}$$

- Transmitted and reflected fields are mathematically expressed as series of plane waves with discrete propagating directions, satisfying boundary conditions.

- Needed a 2D vectorial (optical) simulation accounting for inhomogeneities along the layers. We have tried two methods Rigourous Coupled Wave Analysis (RODIS) and Eigenmodes method (CAMFR), with identical (good) result.

Ideal versus Real results

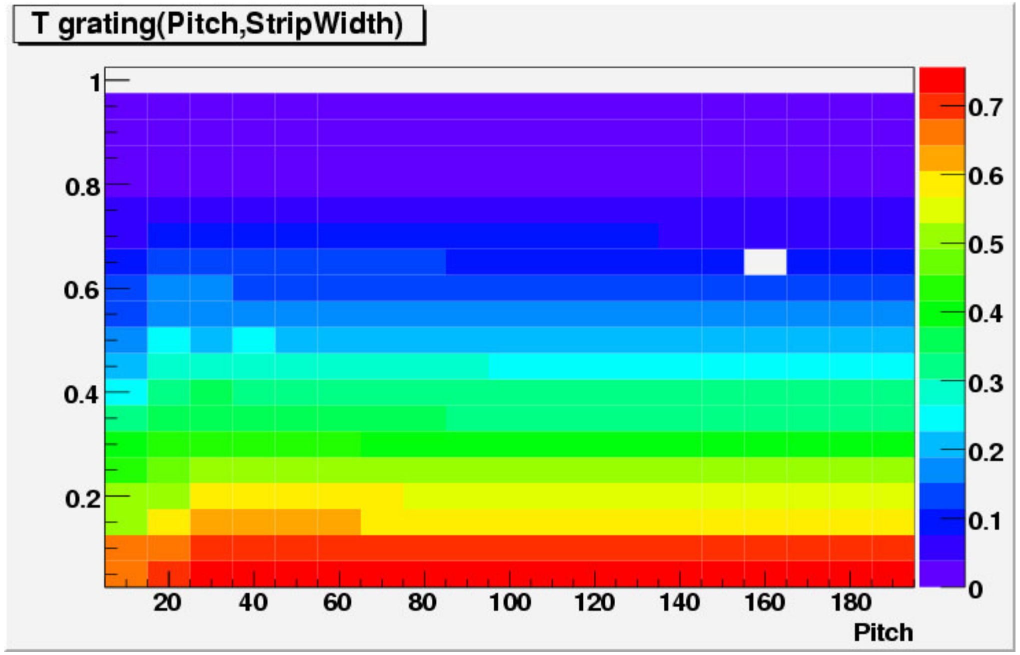




- Left plot shows a design optimised for maximum transmittance at λ=1.1 µm, using ITO for electrodes Right plot shows the same design calculated with **segmented** layers (Si_3N_4,SiO_2,ITO, implants)
- Differences are important. But this doesn't mean that transmittance with segmented electrodes is lower. It just means that **a good design calculated with ideal sensor is not a good design calculated with a real sensor**.

Optimization of real sensors (I)

- Grating parameters (width, pitch) and then thicknesses
- T(pitch,strip_width), with strip_width expressed as percentage of the pitch
  Using Al strips:

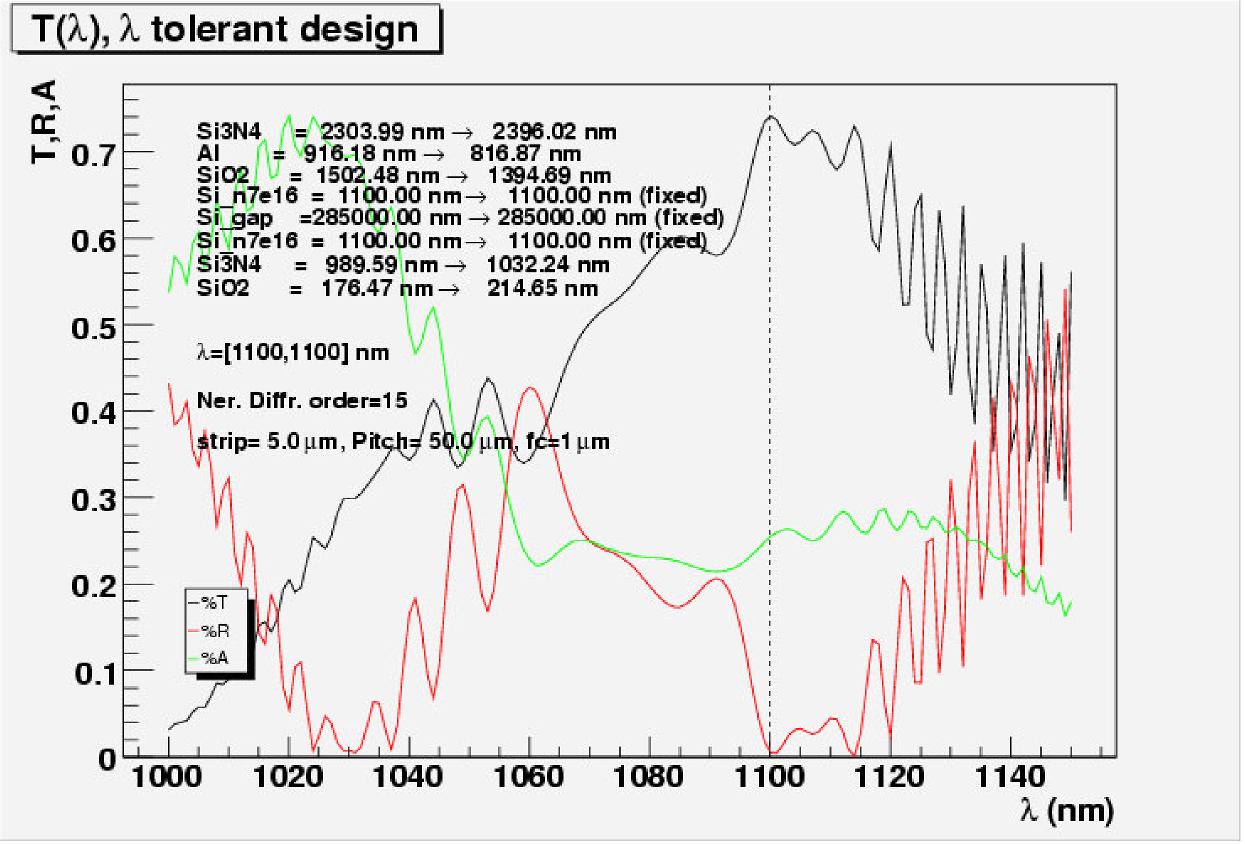


- The less Al, the more transmittance. Good compromise: **strip_width = 10% · Pitch**

Optimization of real sensors (II)

- Once strip_width/pitch is optimum, we maximize transmittance using the following χ^2

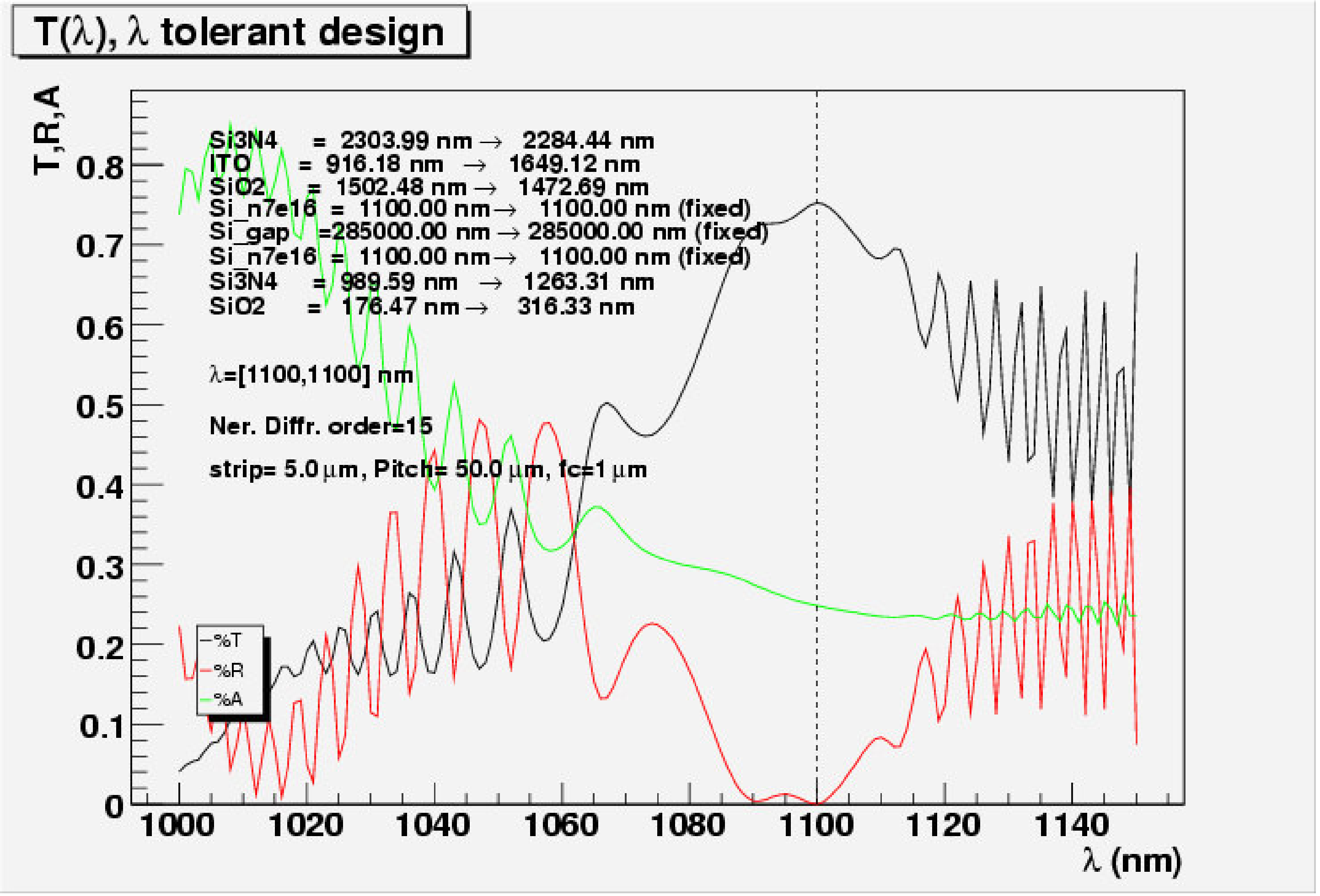
$$\chi^2 = \underbrace{\sum_{\lambda=1100\pm\Delta\lambda} \sum_{d_i} \underbrace{\left(T(\vec{d_i},\lambda) - T_{max}\right)^2}_{\text{Maximize T varying thicknesses}} + \underbrace{R(\vec{d_i},\lambda)}_{\text{Minimize R}}}_{\text{Laser spectral width}}$$



- Al strips
- Pitch=50 μm
- Strip Width=5 μm
- p,n implants 7×10^{16} cm^{-3}

Transparent electrodes

- 5% increase (T~75%) if thick ITO layers (>500 nm) are used.



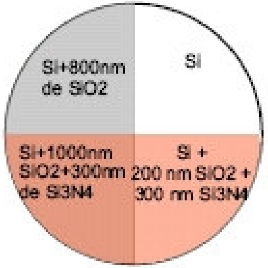
- Note: There is a 10% increase (T~80%) if thin layers ITO layers (≤100 nm) are used (technologically challenging)

IMB-CNM prototypes

- New wafers from **TOPSIL**, (high resistivity, double polished, 285 µm thick) arrived to CNM on **Dec. 4th.**
- First run = 4 wafers to extract refraction indexes and doping level
  1 wafer with Al strips to crosscheck simulation

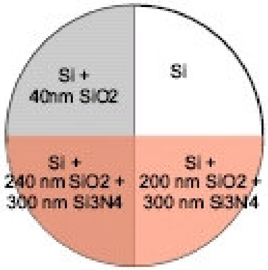
Wafer #1

Without junction implant



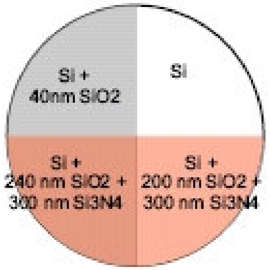
Wafer #2

All wafer surface is doped with Boron. C=1e16 cm-3



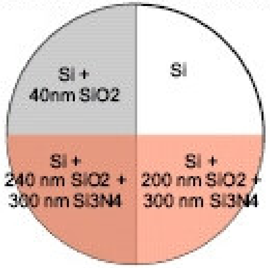
Wafer #3

All wafer surface is doped with Boron. C=1e17 cm-3



Wafer #4

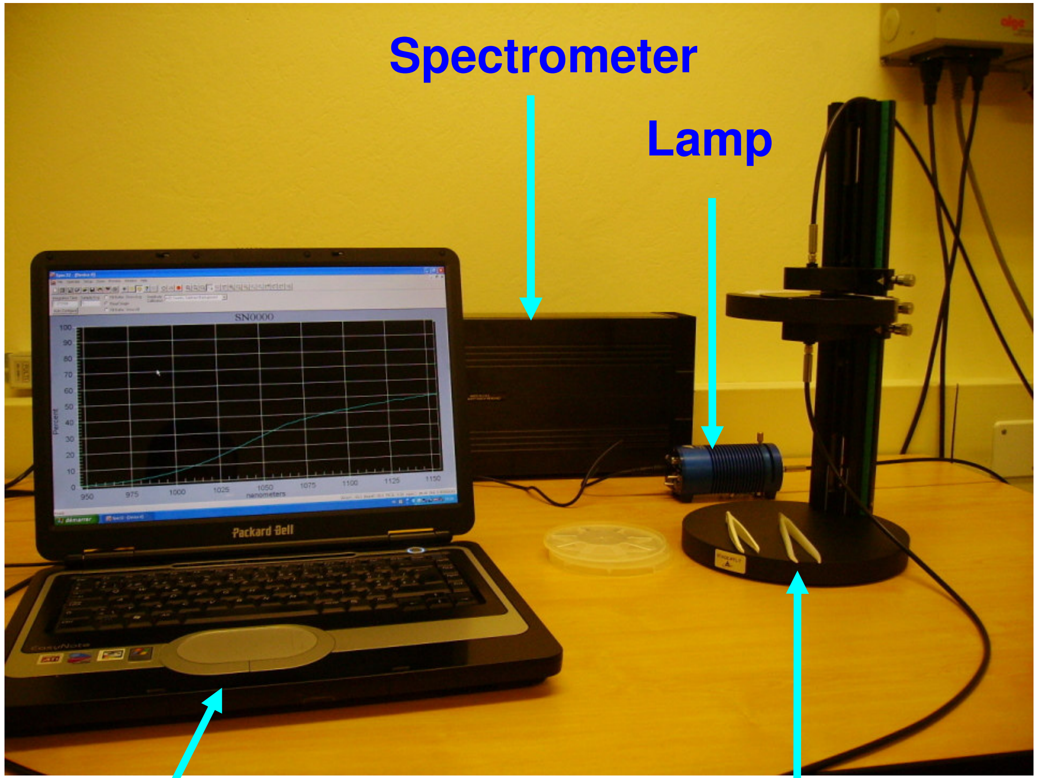
All wafer surface is doped
Top surface with Boron. C=1e16 cm-3
Back surface with Phosphorus, C=1e17 cm-3



Wafer #5

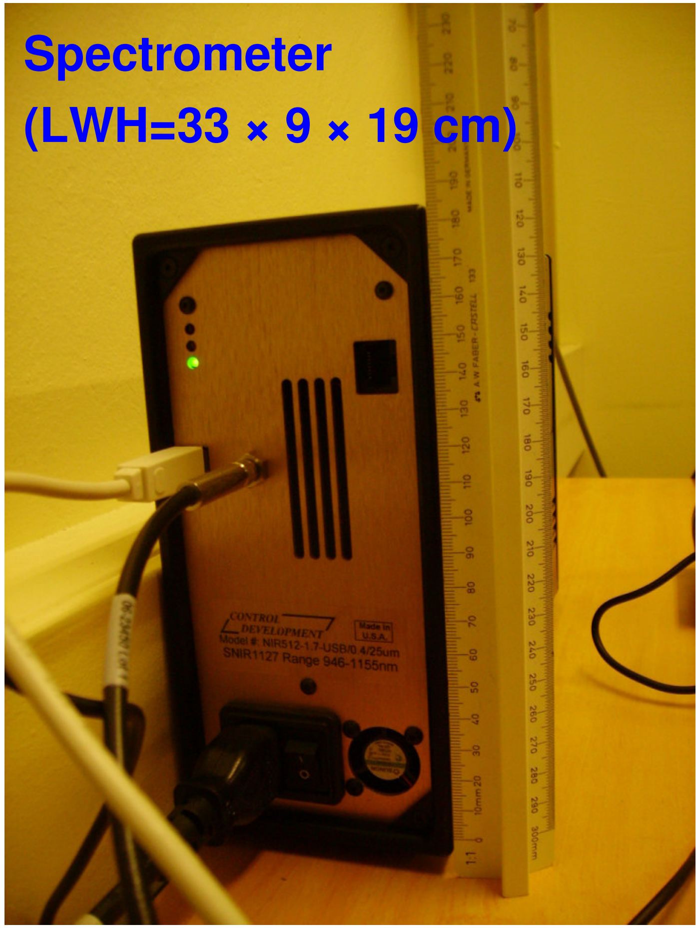
- Custom designed grating spectrometer optimized in λ=[950,1150] nm with 1 nm spectral resolution, able to measure %T and %R acquired. First measurements happened in February

IFCA NIR spectrometer



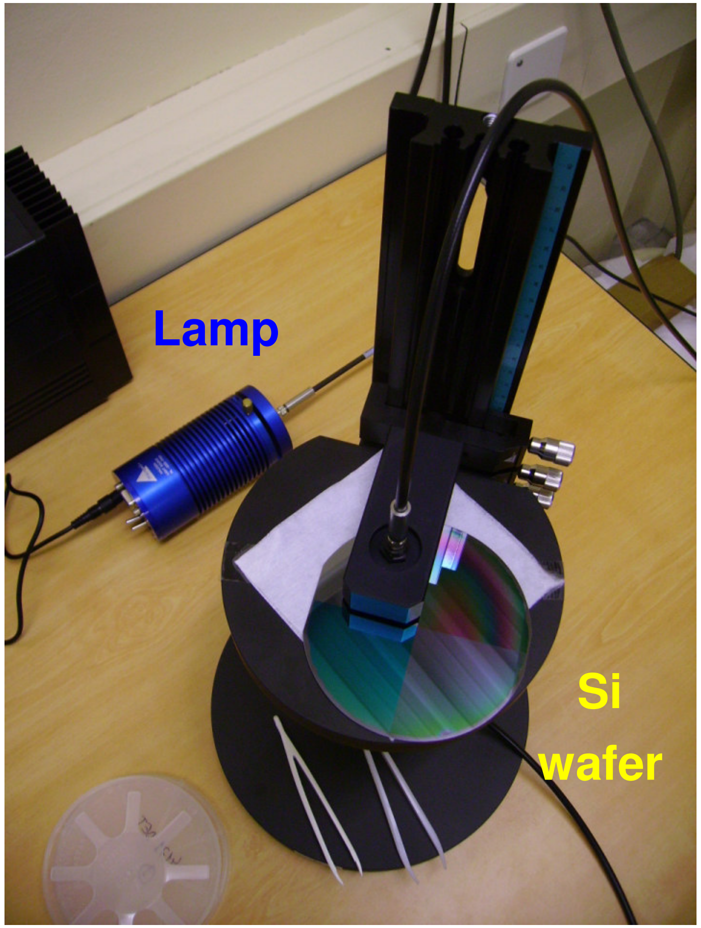
CDISpec32
(sw provided by
manufacturer)

RT Stage
setup for
%T



Working λ=950-1150 nm
1.2 nm spectral resolution

IFCA NIR spectrometer (II)



First hands-on by Monday 28th January

Measurements can be done with light on

Quick measurements (<1 s/spectrum)

Average of measurements is also possible

Measurement process:

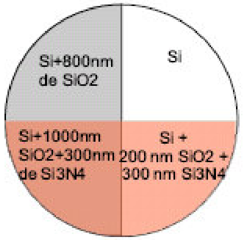
- Background reference (lamp shutter ON)
- 100% reference (lamp shutter OFF)
- Wafer measuremet

First measurements of CNM wafers

N-type wafer
Resistivity 10 kohm
Doping concentration 4e11 cm-3
Two sides polished

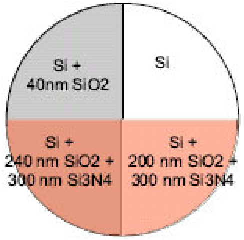
Wafer #1

Without junction implant



Wafer #2

All wafer surface is doped with Boron. C=1e16 cm-3



Wafer #3

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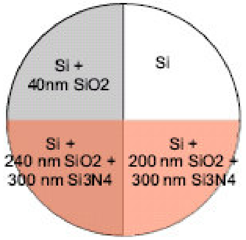
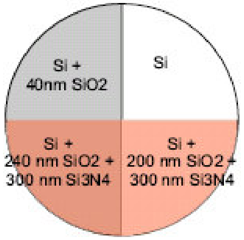
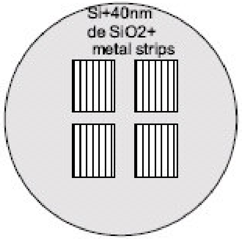


Wafer #4

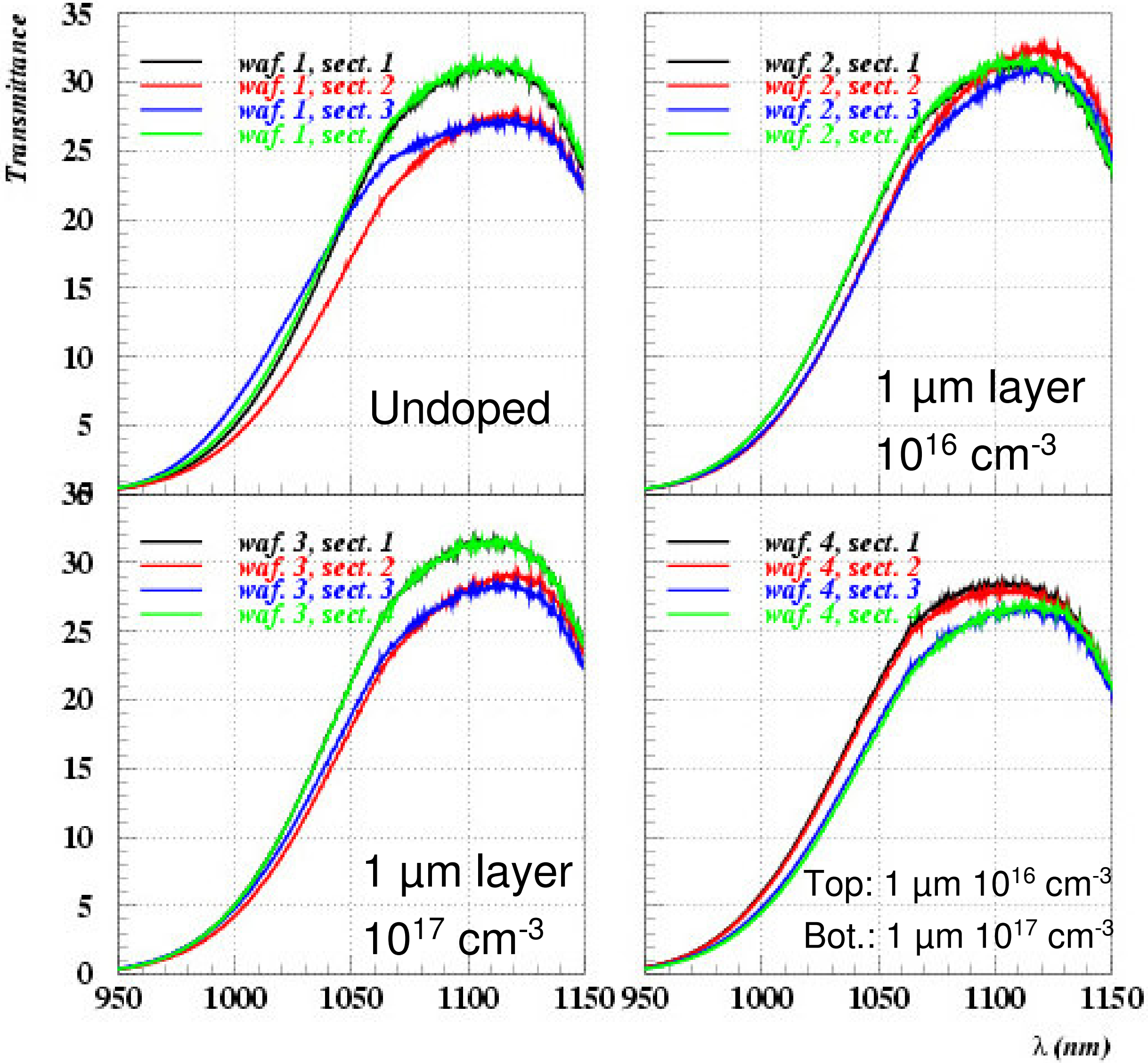
All wafer surface is doped
Top surface with Boron. C=1e16 cm-3
Back surface with Phosphorus, C=1e17 cm-3



Wafer #5



All wafers, all sectors

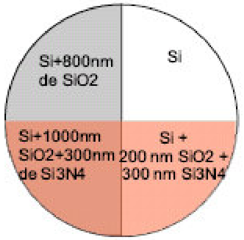


First measurements of CNM wafers

N-type wafer
Resistivity 10 kohm
Doping concentration 4e11 cm-3
Two sides polished

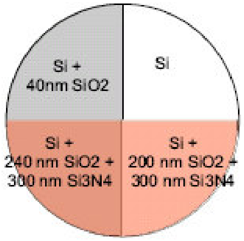
Wafer #1

Without junction implant



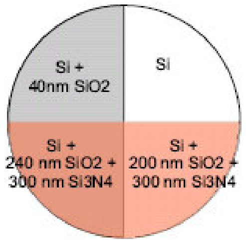
Wafer #2

All wafer surface is doped with Boron. C=1e16 cm-3



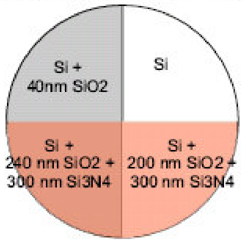
Wafer #3

All wafer surface is doped with Boron. C=1e17 cm-3

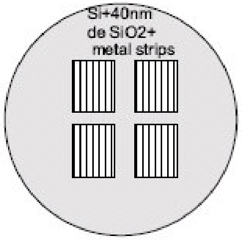


Wafer #4

All wafer surface is doped
Top surface with Boron. C=1e16 cm-3
Back surface with Phosphorus, C=1e17 cm-3

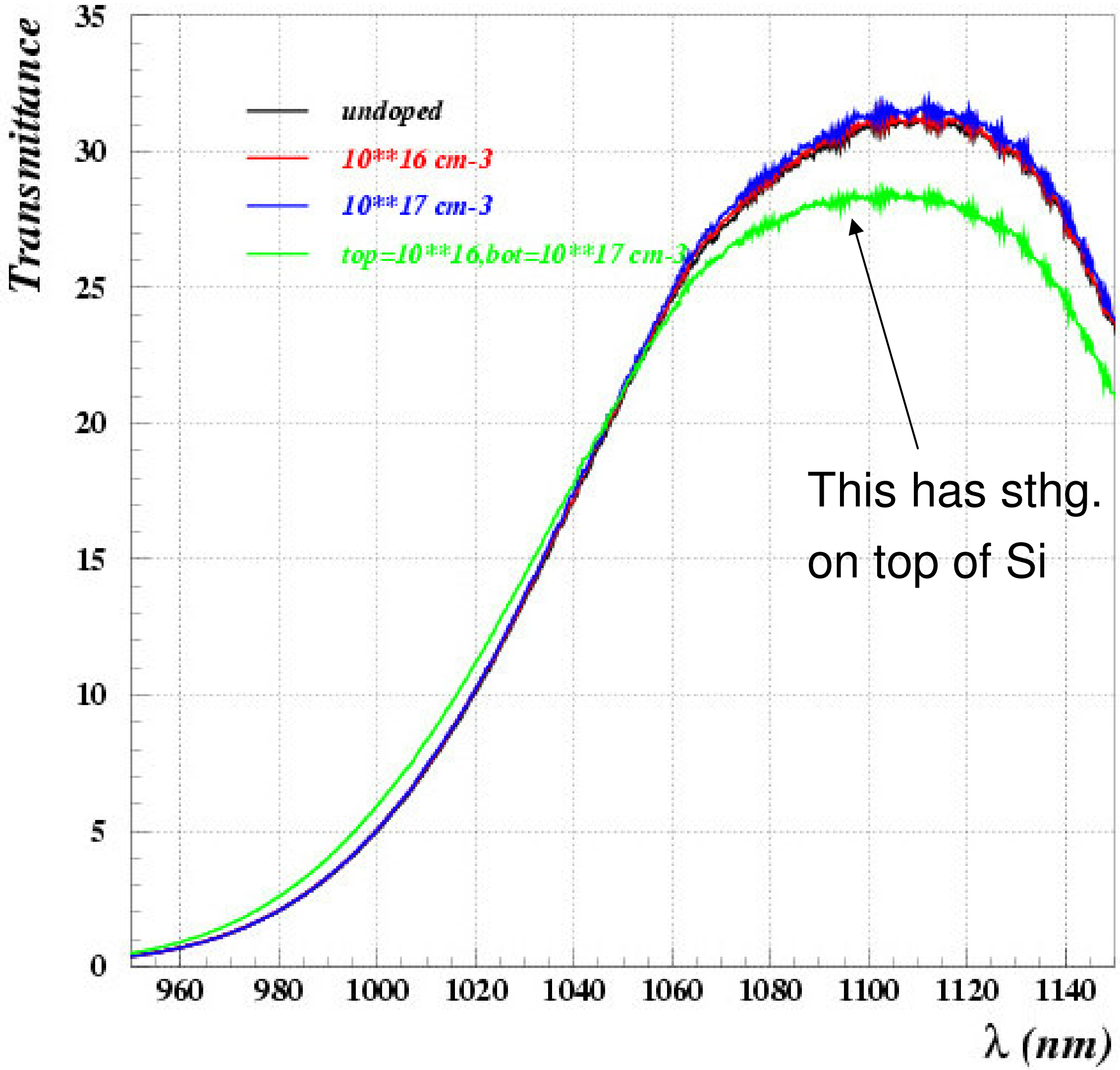


Wafer #5



All wafers, only 1st sector

(~Si of different doping levels)



This has sthg. on top of Si

First observations...

— We cannot conclude anything yet

— It seems that the doping level is still too low to see any change in the transmittance (this is not expected from the bibliography we used)

— No interferential waves due to the used combination of binning and spectral resolution.

— I measured using another spectrometer one of the CMS sensors

I could not record exactly where the measurement was taken

Scanning the CMS sensor area with our SPM, I can reproduce that measurement

ToDo & Summary

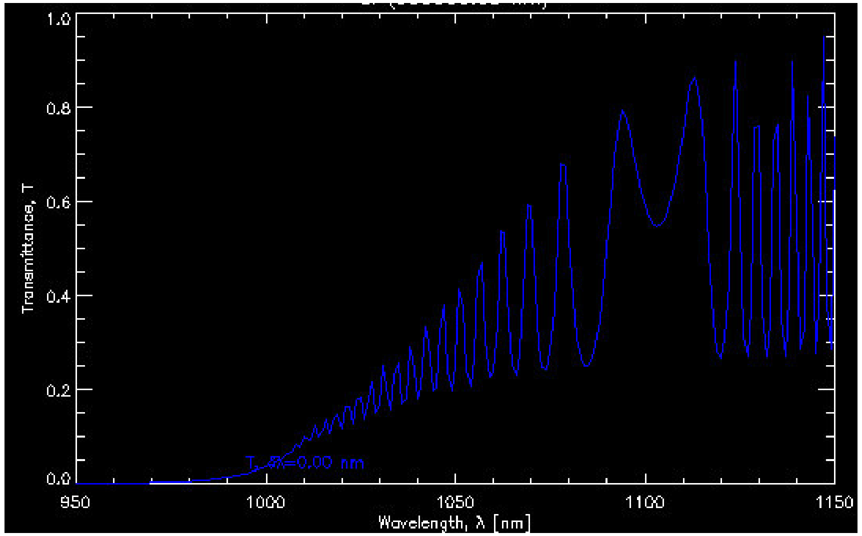
- Presented R&D activity developed within SiLC Collaboration and EuDET project
- Alignment of Si µstrip sensors is eased using IR beams (pseudotracks).
  - No need for external monitoring systems
  - No impact on system integration and Si-DAQ
  - No extra material budget
- 5 new HPK sensors modified for IR alignment
- Rigorous treatment of diffraction in the microstrips done for first time
  - Ideal layers do not describe a real sensor
  - We have a simulation able to cope with diffraction effects and material optical absorption
  - Design optimized using Al strips yields 70% transmittance
  - Up to 10% higher if ITO is used
- CNM preparing samples of each layer. Measurements using a new spectrometer have started. We are analyzing the results
- We will still simulate gaussian beams, non squared strip boundaries, angular incidence and order of incidence

BACKUP

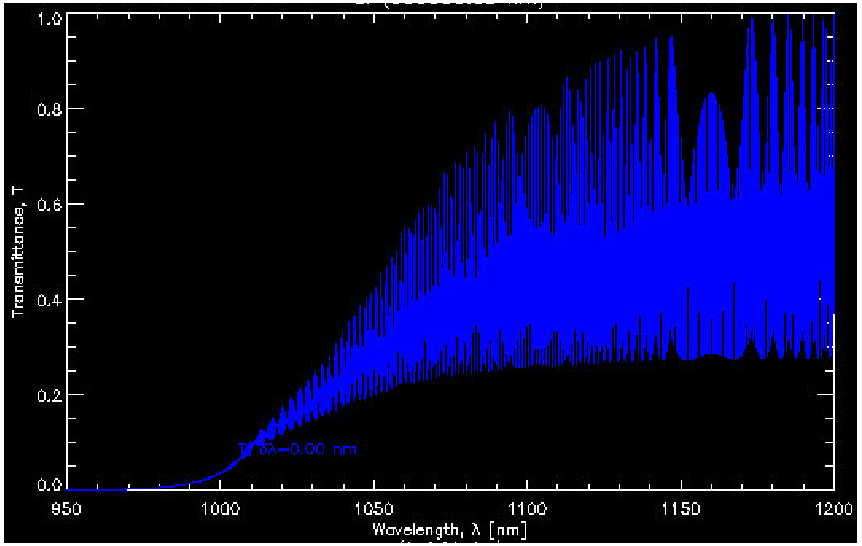
Plotting interference (visibility)

$$300\ \mu m\ \text{Si} \Rightarrow 2\pi n d = m\lambda/2;\ m \sim O(10^4)$$

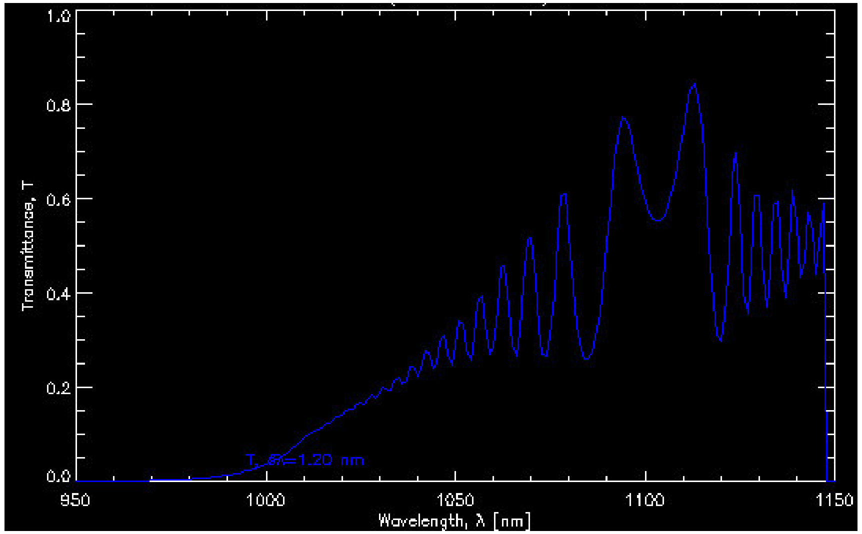
Bin $\Delta\lambda$=1 nm, no spectral resolution (σ_λ=1.2 nm)



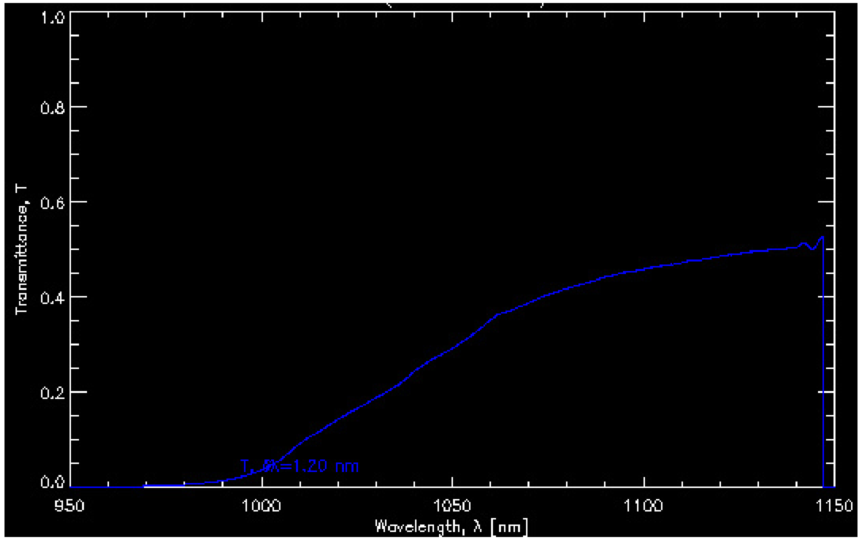
Bin $\Delta\lambda$=0.2 nm, no spectral resolution (σ_λ=1.2 nm)



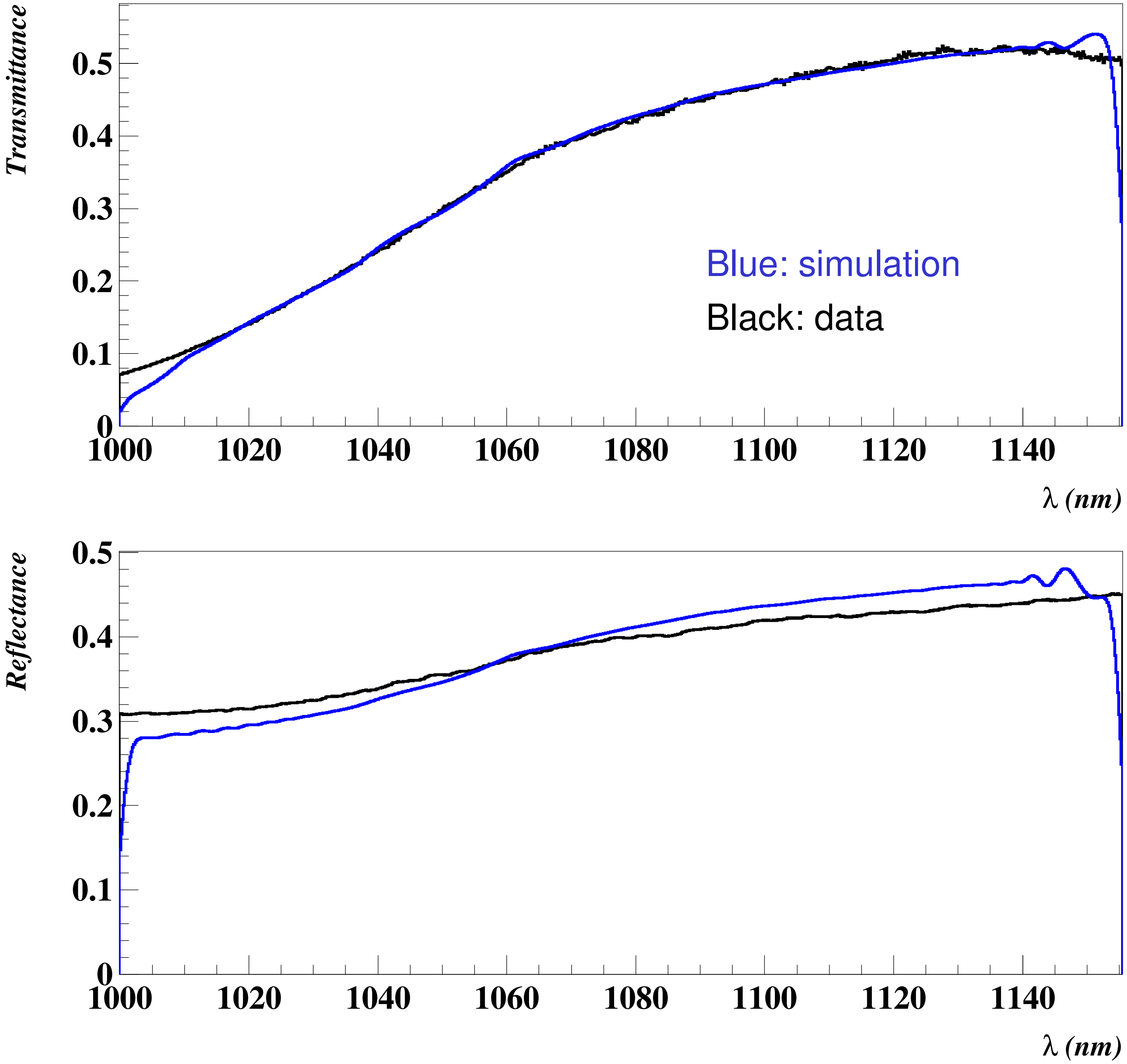
Bin $\Delta\lambda$=1 nm, spectral resolution (σ_λ=0)



Bin $\Delta\lambda$=0.2 nm, spectral resolution (σ_λ=0)



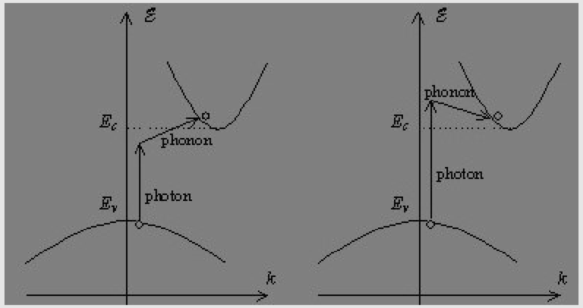
Preliminar!

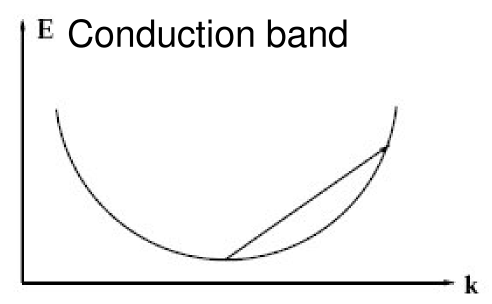

Transmittance
0.5
0.4
0.3
0.2
0.1
0
1000
1020
1040
1060
1080
1100
1120
1140
λ (nm)
Blue: simulation
Black: data
Reflectance
0.5
0.4
0.3
0.2
0.1
0
1000
1020
1040
1060
1080
1100
1120
1140
λ (nm)

Absorption in doped Si

The 2 main optical absorption mechanisms in intrinsic-Si:

Photon **absorption** assisted **by phonons** (dominates at λ <bandgap)

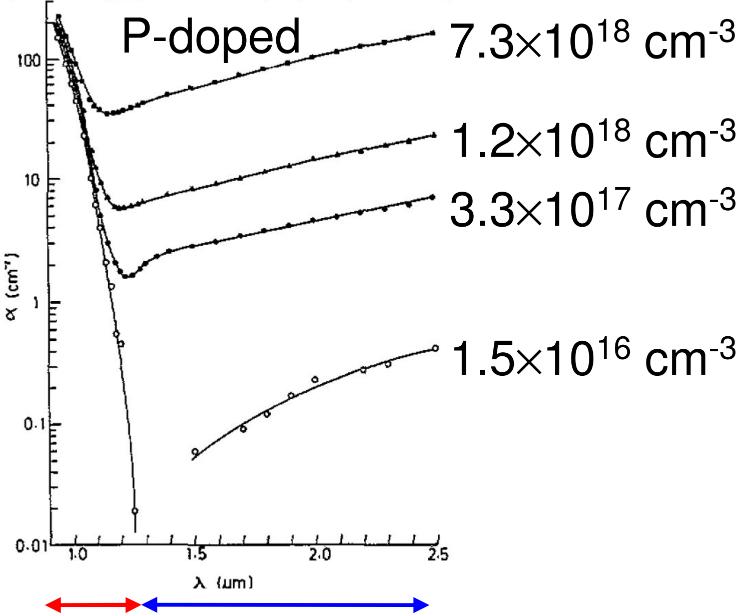




Free carrier absorption (dominant at λ>bandgap)

Doping of Si narrows bandgap. Lower photon energy needed ⇒ higher absorption for same energy photons

S. E. Aw et al, J. Phy. Condens. Matter 3 (1991) 8213-8223



Phonon assisted absorption

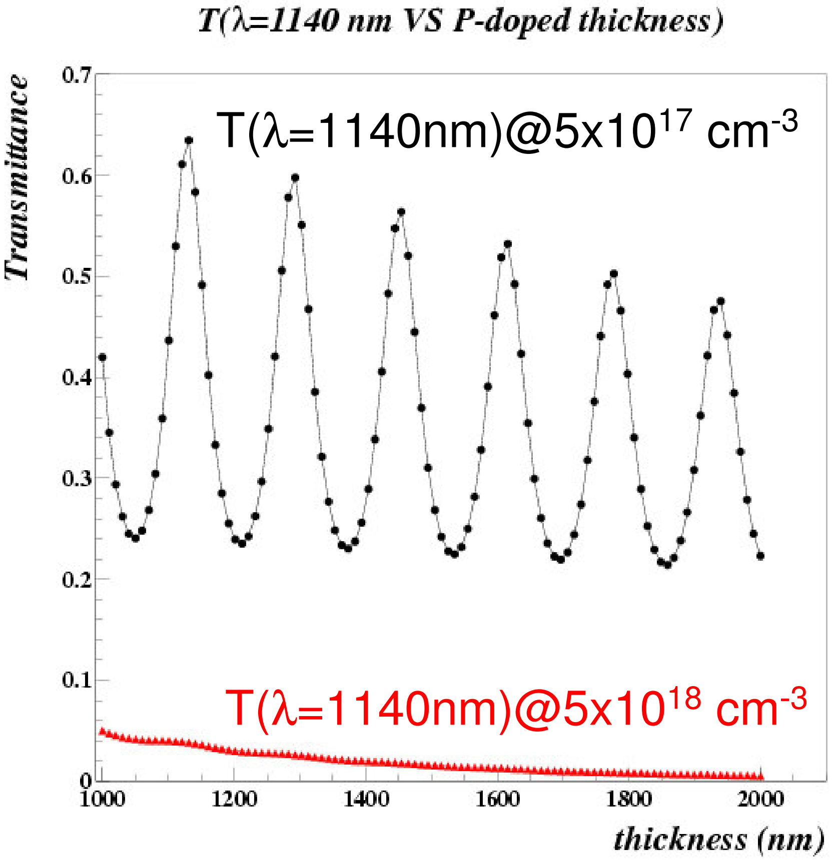
Free carrier absorption

Free carrier absorption begins to dominate at wavelengths > 1100 nm (roughly)

Note that doping increases absorption orders of magnitude !!

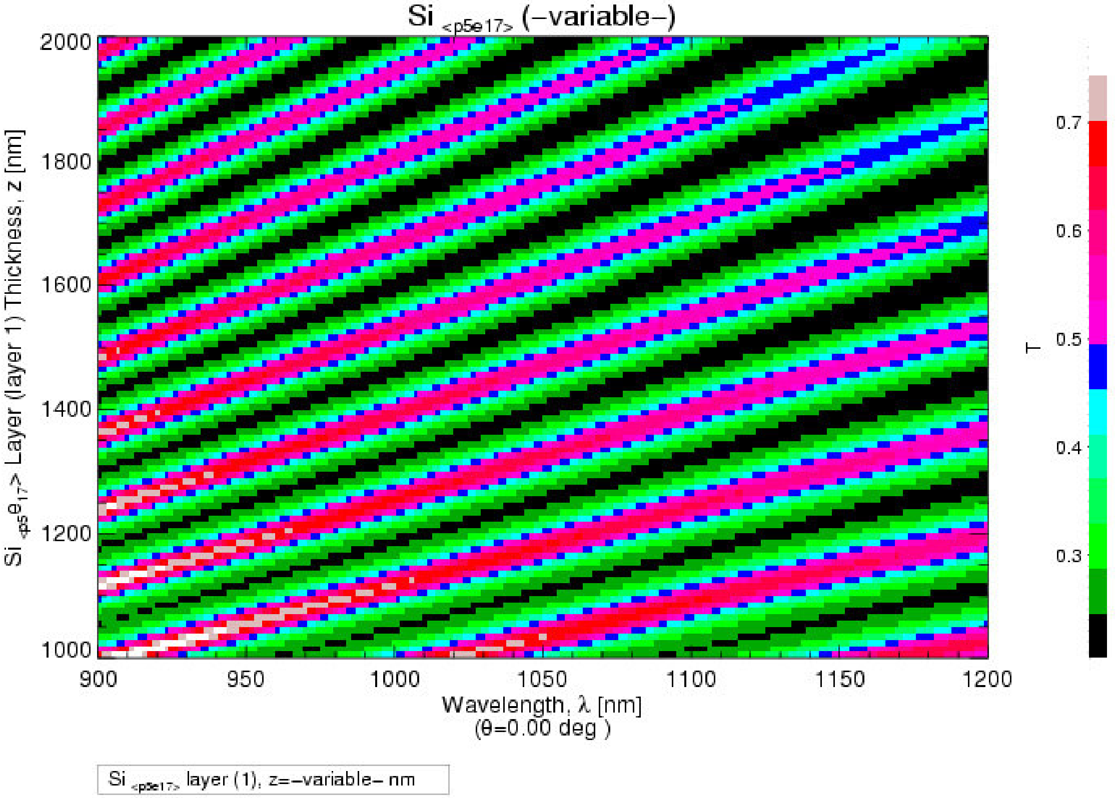
Transmittance vs doping

Are implants transparent? Only if dopant level below ~$5x10^{17}$ cm^{-3}



T(λ=1140nm)@$5x10^{17}$ cm^{-3}

T(λ=1140nm)@$5x10^{18}$ cm^{-3}



CMS (HPK sensors) p+ implant resitivity=140 kΩ/sq.

For 2 µm implant depth ⇒ 0.28 Ω.cm⇔$7x10^{16}$ cm^{-3} ⇒ CMS Implants are transparent