New technologies for structural and environmental monitoring of tracker and vertex systems

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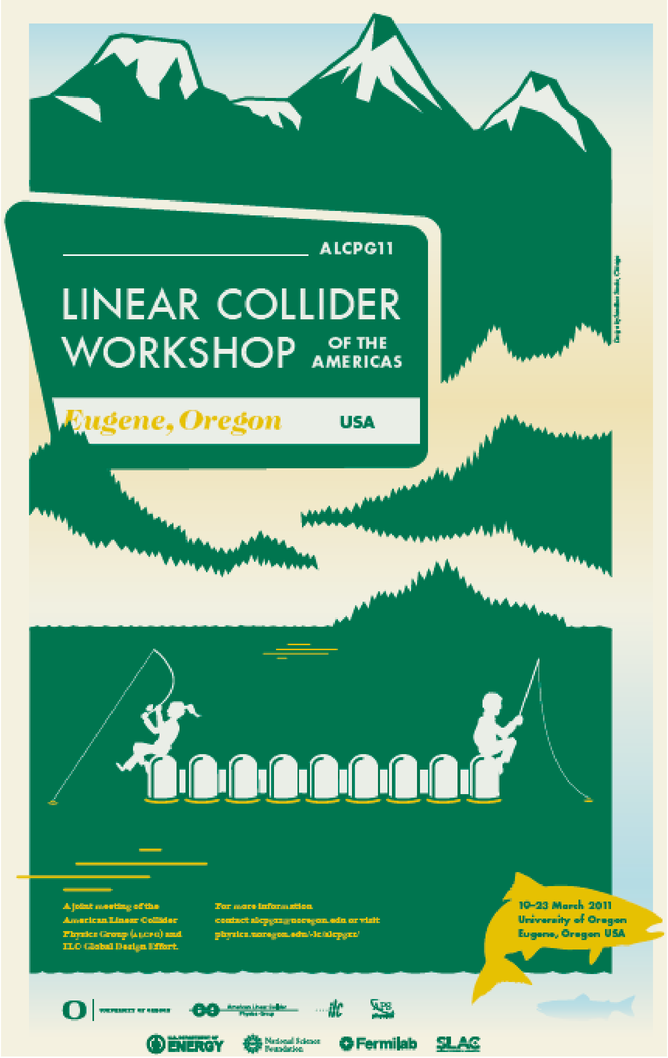

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“New technologies” means they are well settled in other fields but their usage in HEP is very recent/new.

- Structural monitoring of silicon tracker systems:

  — Using IR-transparent microstrips for tracker alignment → not new
  — Method to improve their IR-transparency → new

- Struct.&environmental monitoring of tracker & vertex systems:

  — Using integrated fiber optic sensors (FOS) as monitors → not new
  — Embedding FOS in the tracking sensor itself → new

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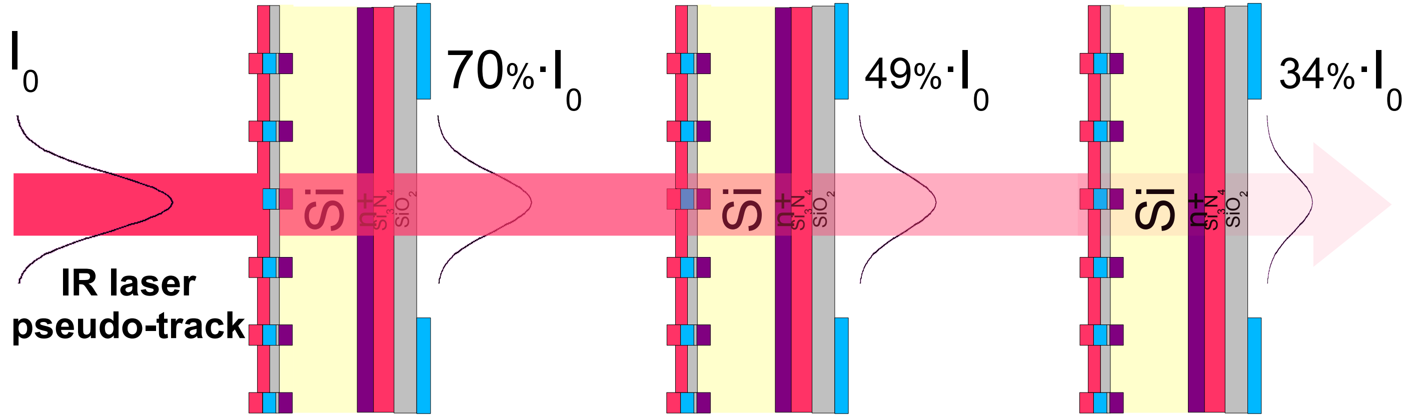
Structural monitoring of silicon tracker systems

Microstrips as semitransparent light detectors

- Laser tracks can be used by a hardware system to align the tracker



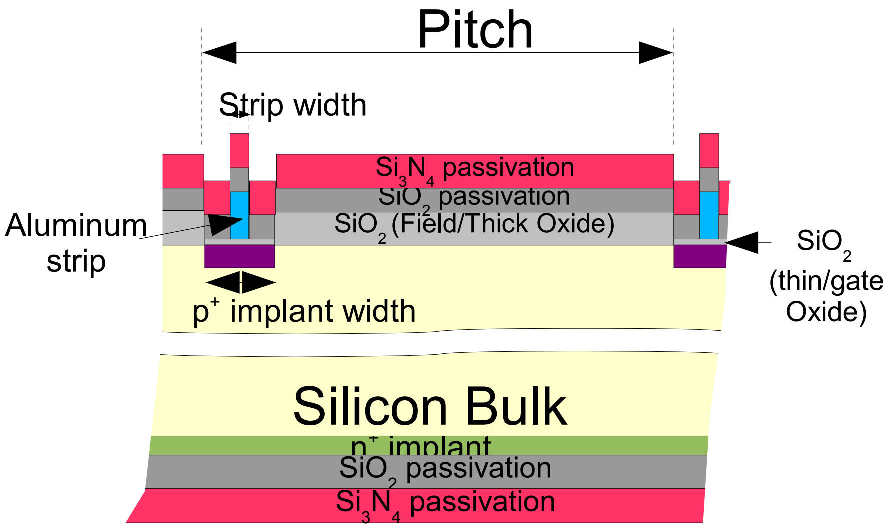
%T	#
90	30
80	15
70	10
60	7
50	5
40	4

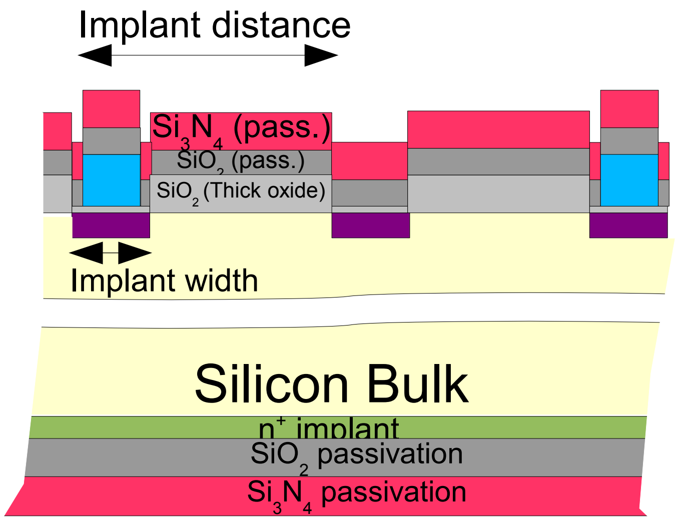
- First implemented by AMS I, then AMS II and CMS.
Envisaged for sLHC and ILD's FTD

- Goal: improve transmittance to infrared light of microstrip detectors without altering the standard production process

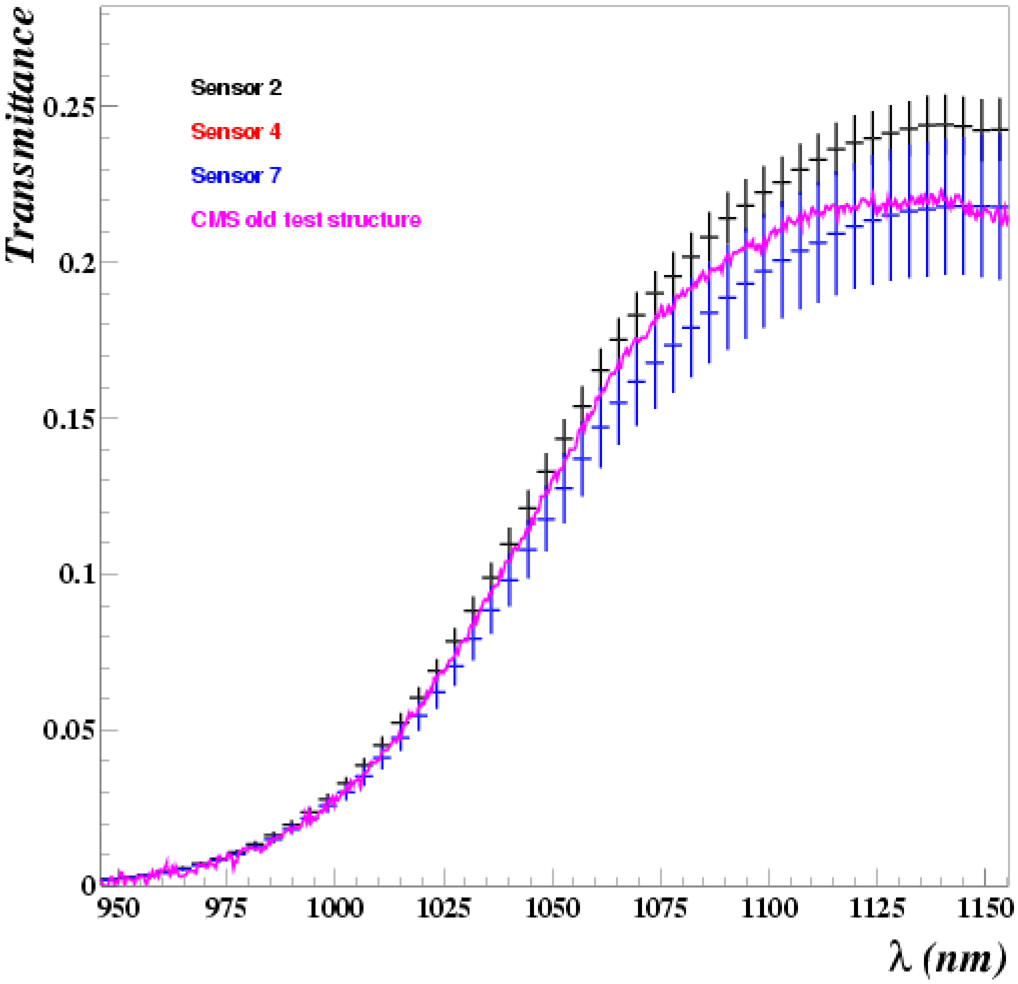
- R&D done at IFCA+CNM (Spain), then know-how transfer to larger producer

- Generic sensor to optimize:
  - 50 µm pitch sensors, both with/out intermediate strips
  - Implant width=12.5-17,5 µm, Strip width 3-15 µm
  - $T_{\text{Hamamatsu}}(\lambda=1085\text{ nm})=20\%$





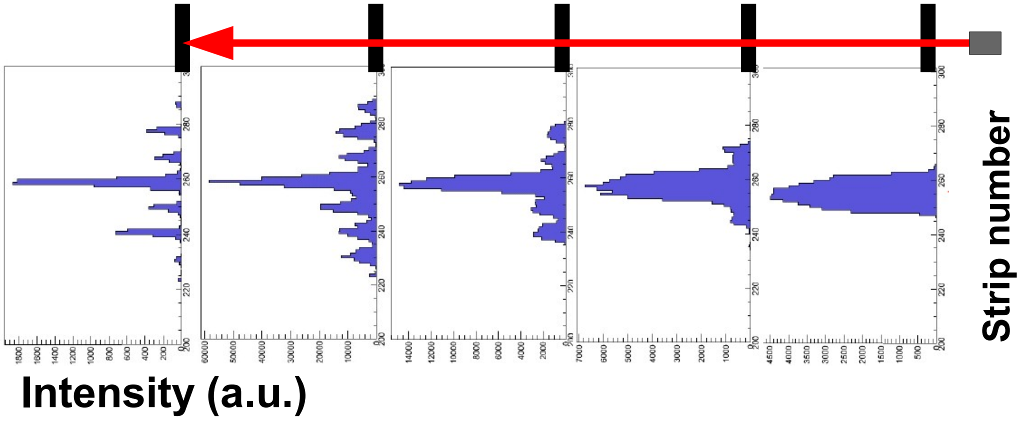
Hamamatsu sensor measurements T(λ) for sensors with 50 µm pitch



Optical simulation of microstrips

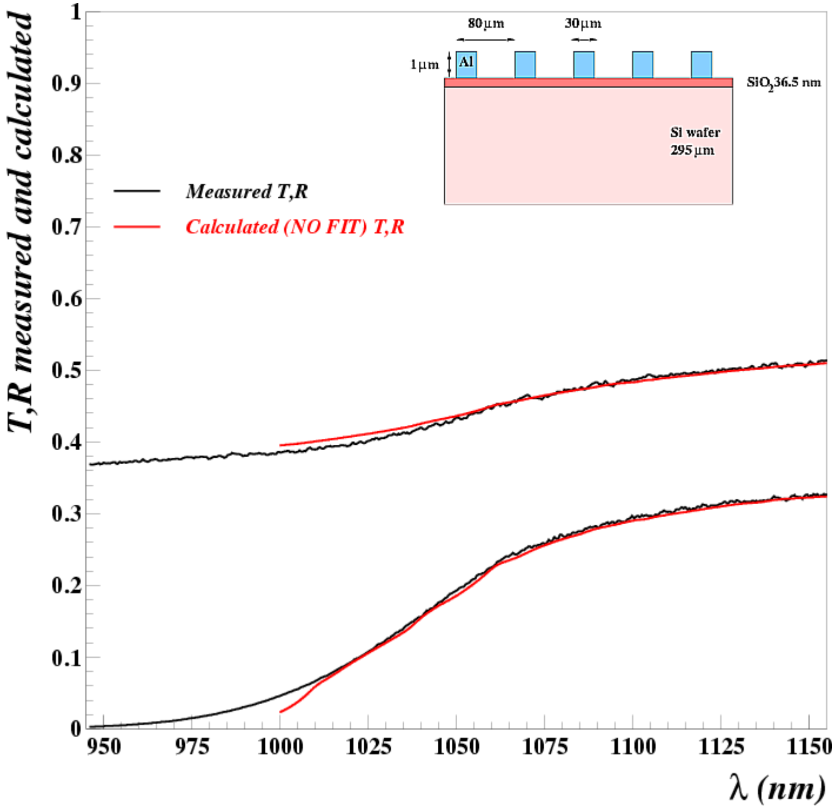
- Optimization of detector for maximum transmittance (%T) requires simulation of diffraction by strips

CMS hw alignment system data



- Simulation done. First (and only) optical simulation in HEP of microstrips to include this level of detail

- Validated against published data, measurements of simple gratings... and against the own sensors we are trying to optimize



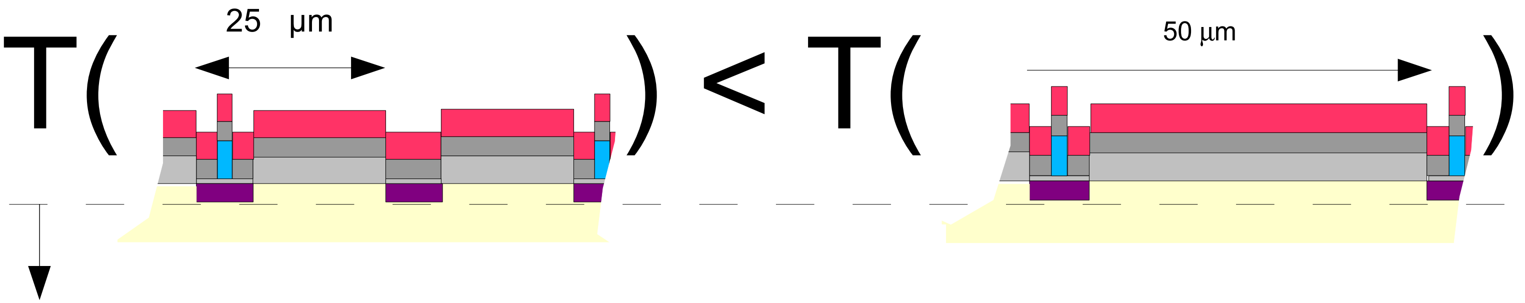
Main conclusions from full simulation (I)

See for instance: Eudet-Memo-2009-23

— Strip width increase (mirror effect):
→ increases reflectance (1st order), reduces transmittance (2nd order).

— Pitch reduction (=closer strips):
→ decreases transmittance (1st order effect), increases reflectance (2nd order).

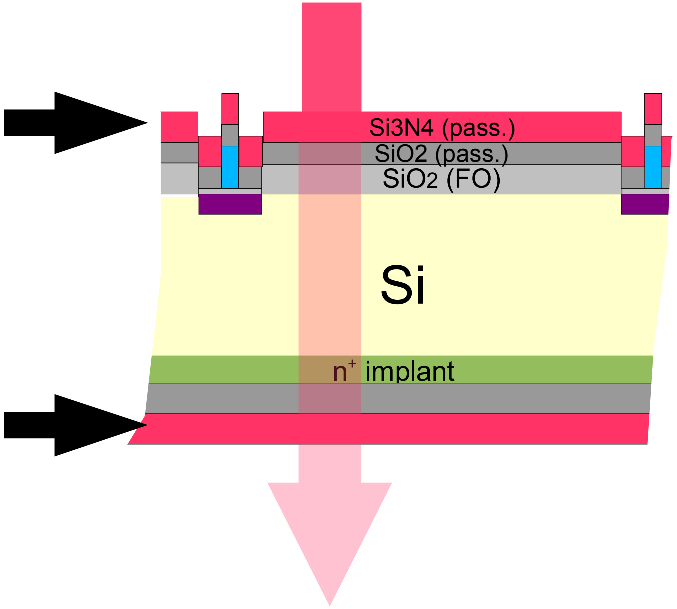
— Strips having metal or not (i.e. intermediate strips) behave as a diffraction grating. Busier pitch ⇒ lower transmittance



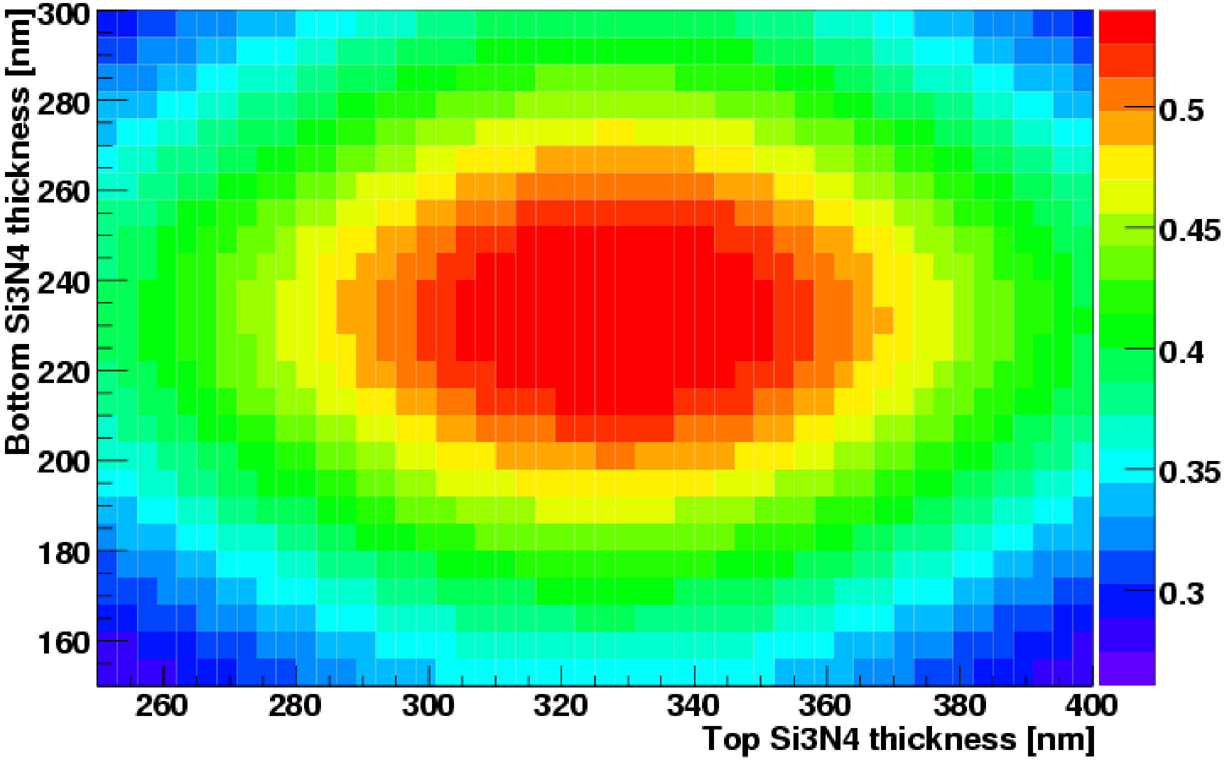
(Below this line, both types of sensors are the same)

Main conclusions from full simulation (II)

— Top and bottom **nitride** layers behave as an **A**nti**R**eflection **C**oating (ARC)

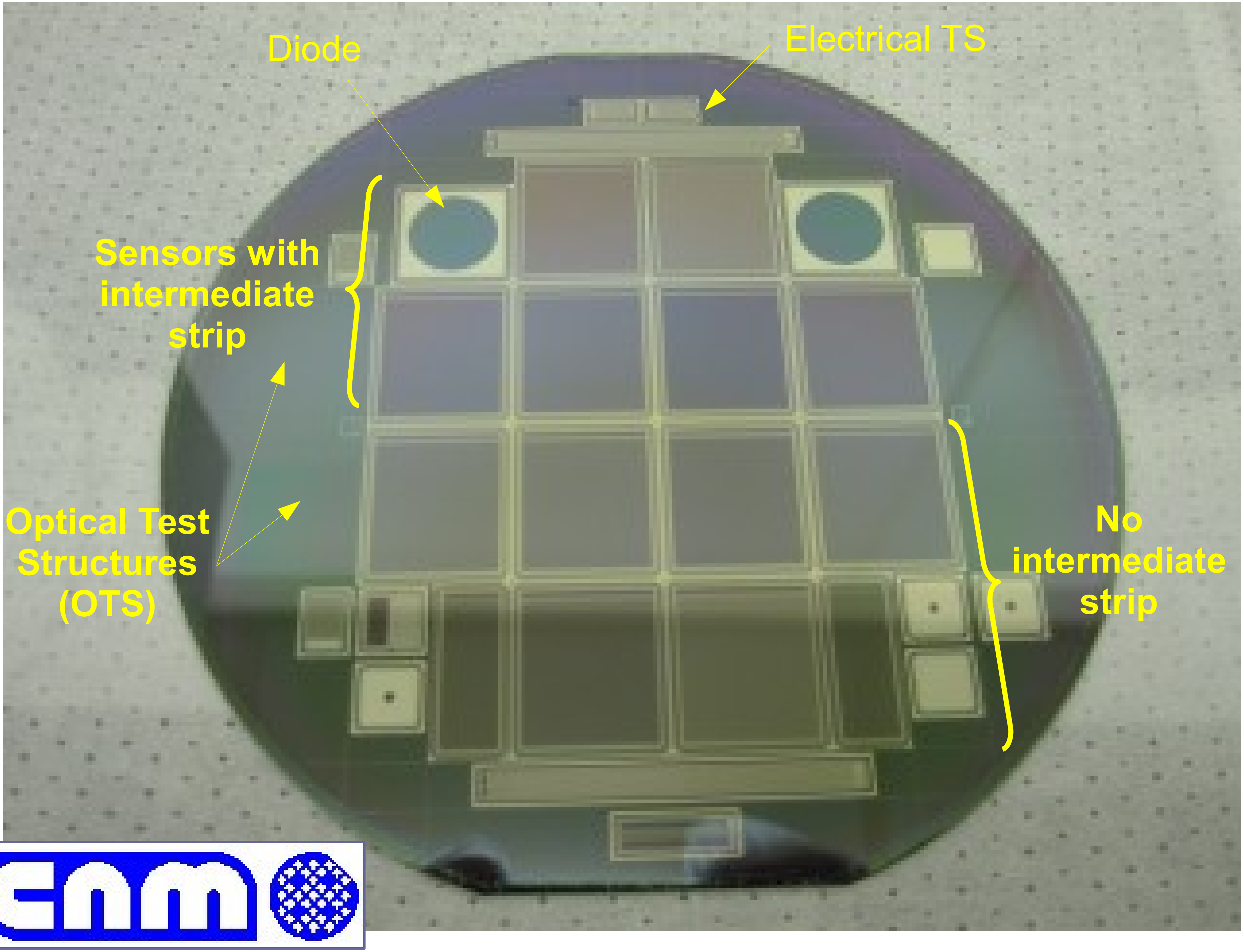


T=T(top,bottom passivation thickness)
Periodical ~ 250-300 nm

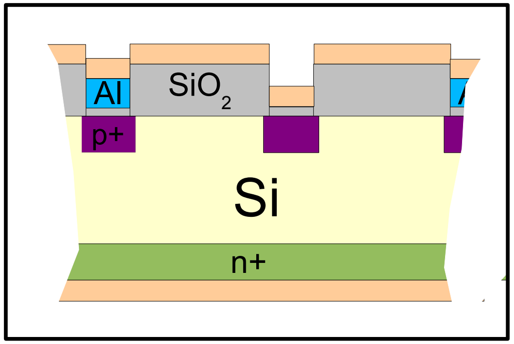


— Even if T=T(9 thickness), we can optimize T_{opt}=T(2 thickness)

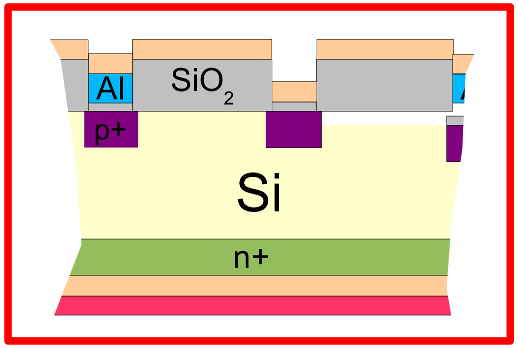
5+1 wafers done at CNM-Barcelona
12 multigeometry strip sensors/wafer+optical test structures+electrical test structures



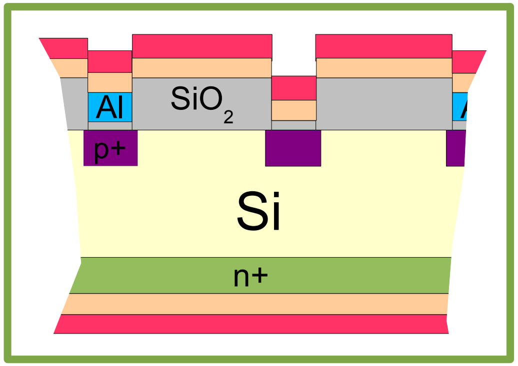
LEGEND



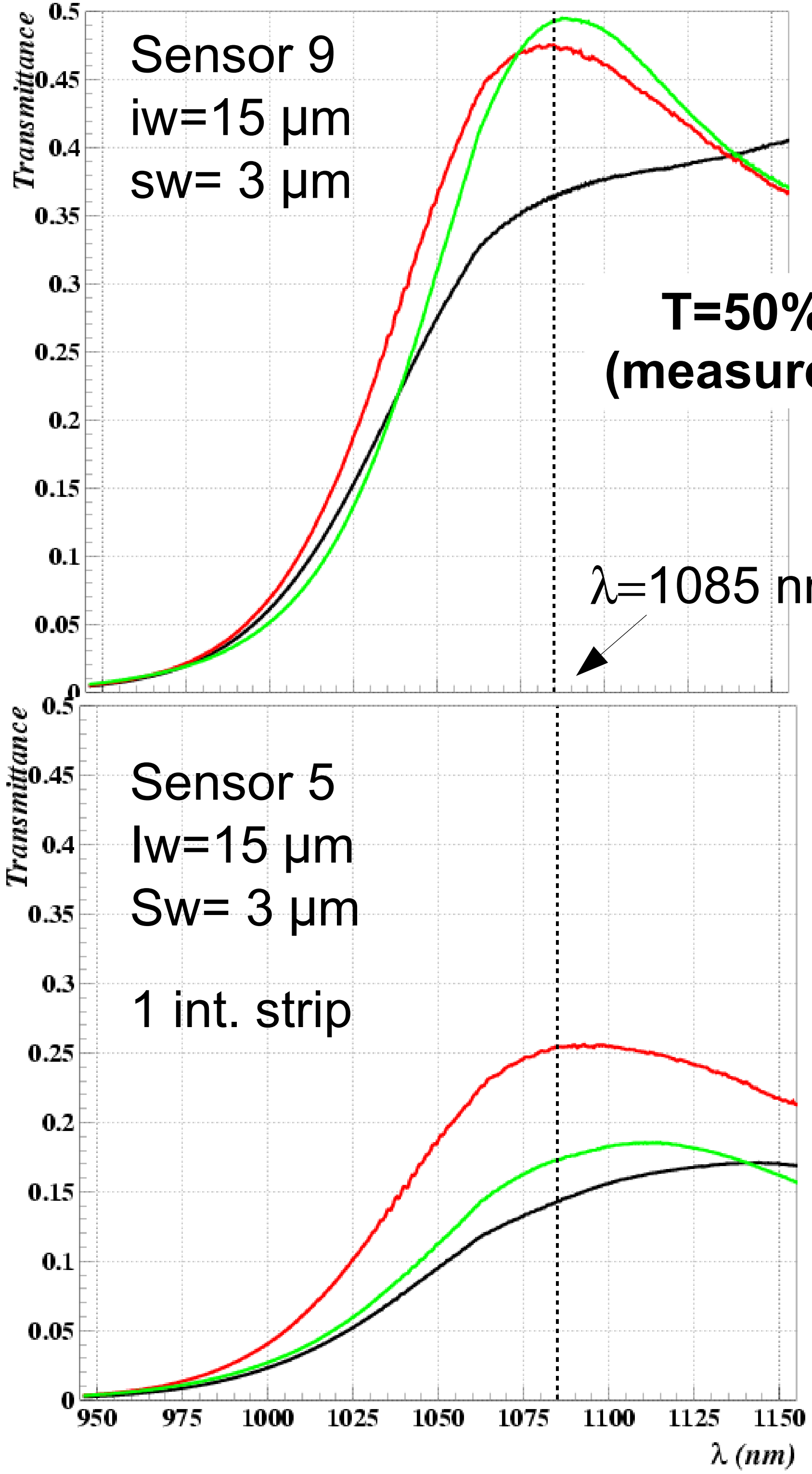
Step 1
SiO2 on top
and below.
(No nitride)



Step 2
Nitride
below



Step 3
Nitride
on top
and below



Sensor 9
iw=15 µm
sw= 3 µm

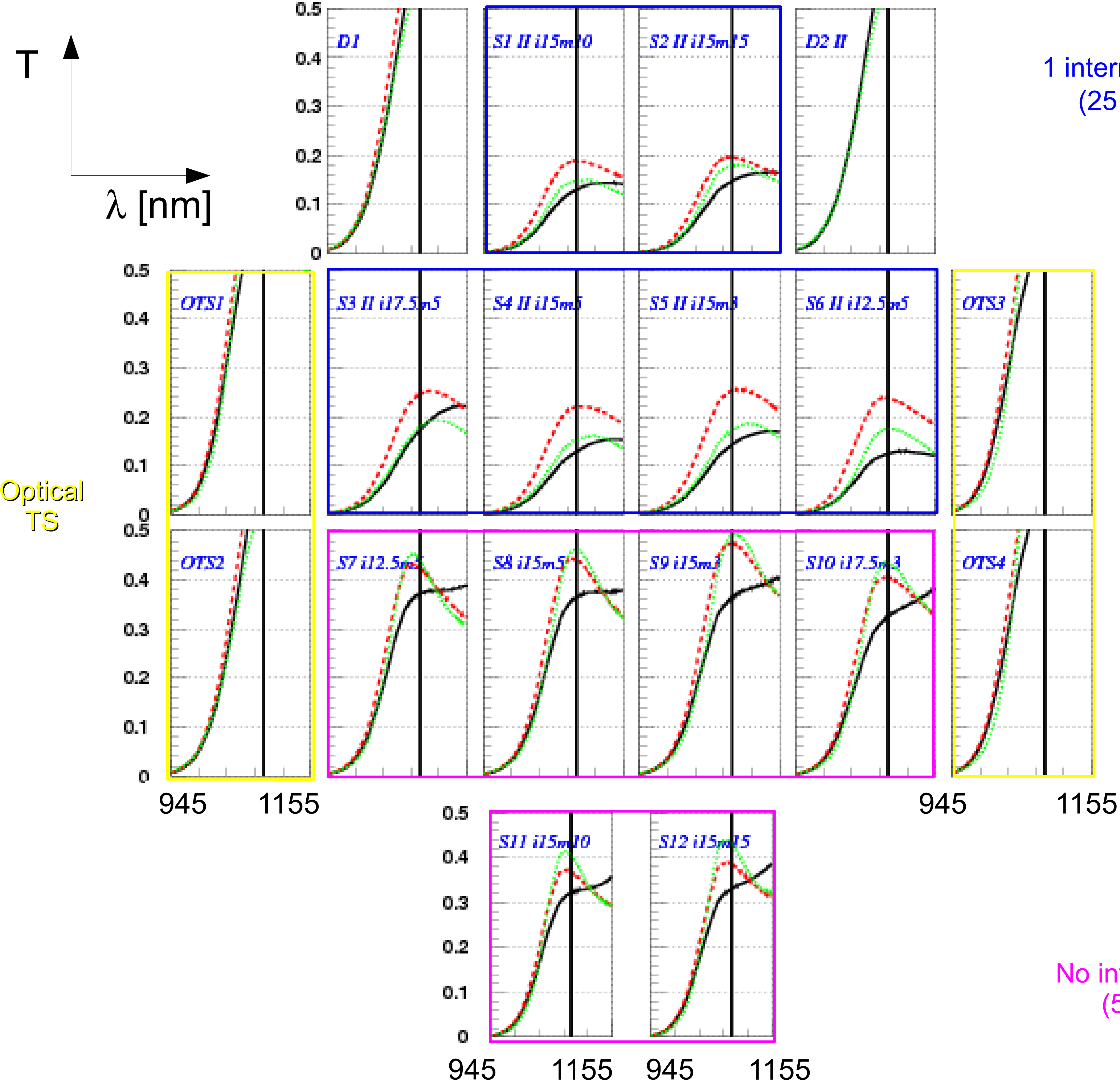
T=50%
(measured)

λ=1085 nm

Sensor 5
Iw=15 µm
Sw= 3 µm

1 int. strip

OPTIMIZED WAFER



Optical
TS

Optical
TS

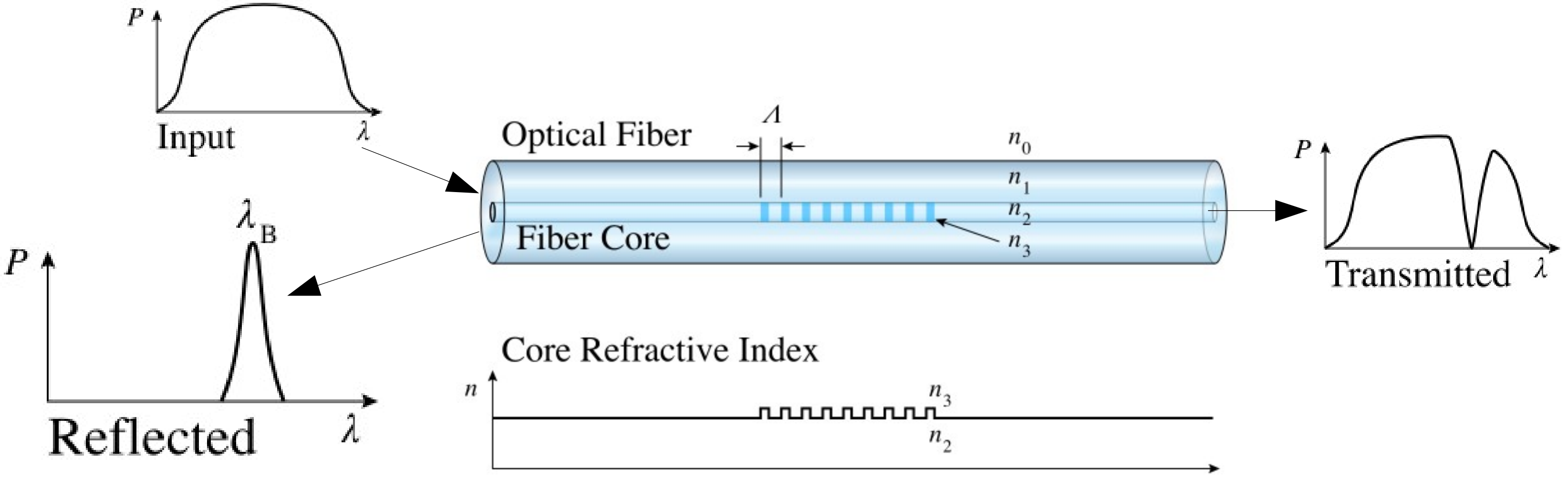
1 intermediate strip
(25 µm pitch)

No intermediate strip
(50 µm pitch)

Structural and environmental monitoring of vertex (and tracker) systems

Introduction to Fiber Grating Optical Sensors (I)

- Gratings can be used as “single wave reflectors” *aka* Bragg reflectors



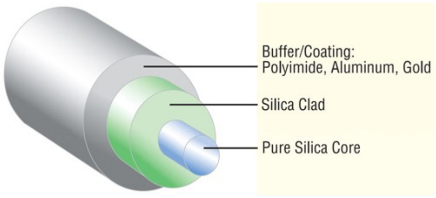
$$\lambda_B = 2\, n_{eff}\, \Lambda$$

- λ_B is sensitive to strain and T:

$$\left[\frac{\Delta\lambda_B}{\lambda_B}\right] = C_S\epsilon + C_T\Delta T \quad \begin{cases} \sim 10 \text{ pm/K} \\ \sim 1 \text{ pm}/\mu\varepsilon \end{cases}$$

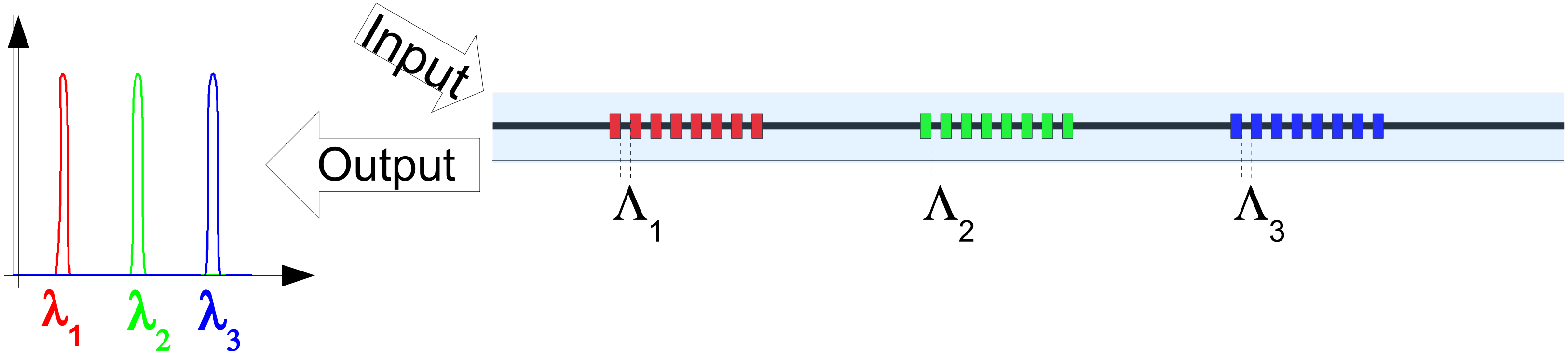
- Bragg reflectors can then be used as sensing elements in optical fibers

- Other quantities (humidity, %CO2, magnetic field,...) can be measured using coatings sensitive to these measurands.



Introduction to Fiber Grating Optical Sensors (II)

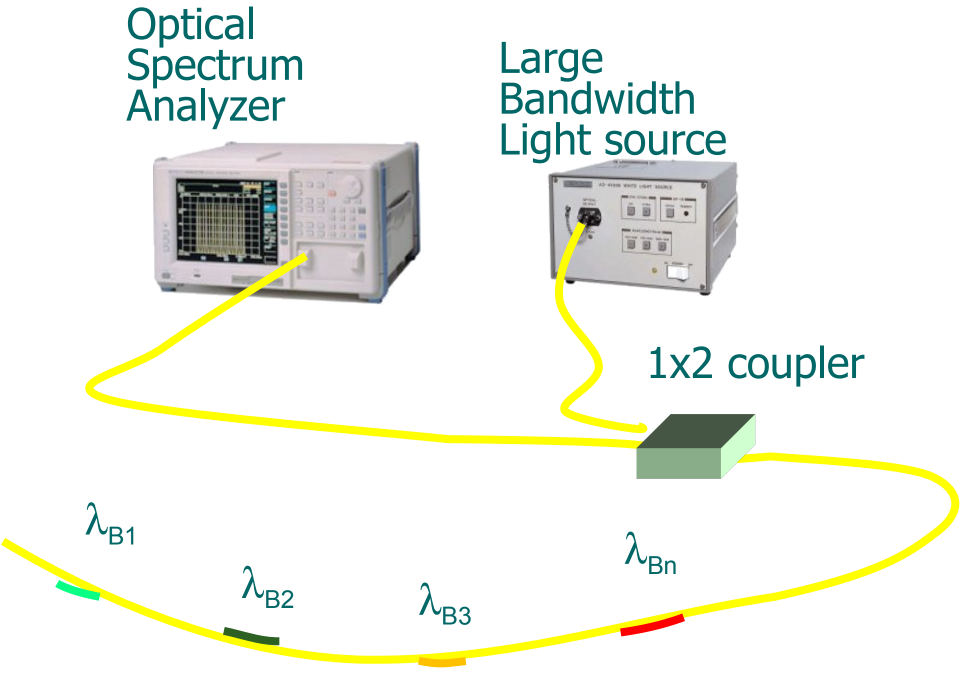
- Gratings for different wavelengths can be recorded in the same fiber: measurand mapping capability



- Optical fibers can be embedded in materials

We have then *smart structures* capable of self-monitoring

- Light source and analyzer can be up to km away from the sensor itself



Monitoring requirements for trackers and vtx systems

- FOS are light-weight, miniaturised, flexible, inmune against em fields, HV. They work in a wide range of T (4... 900 K)

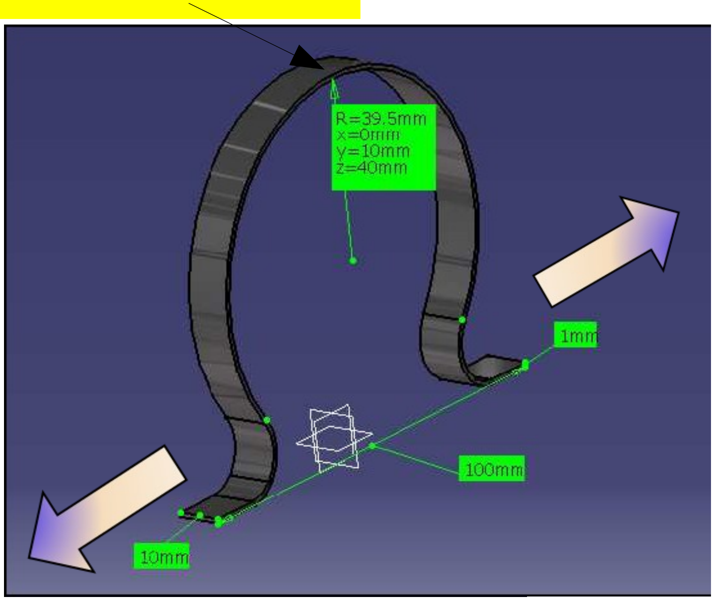
- No copper and powering lines (much less noise picked-up & induced)

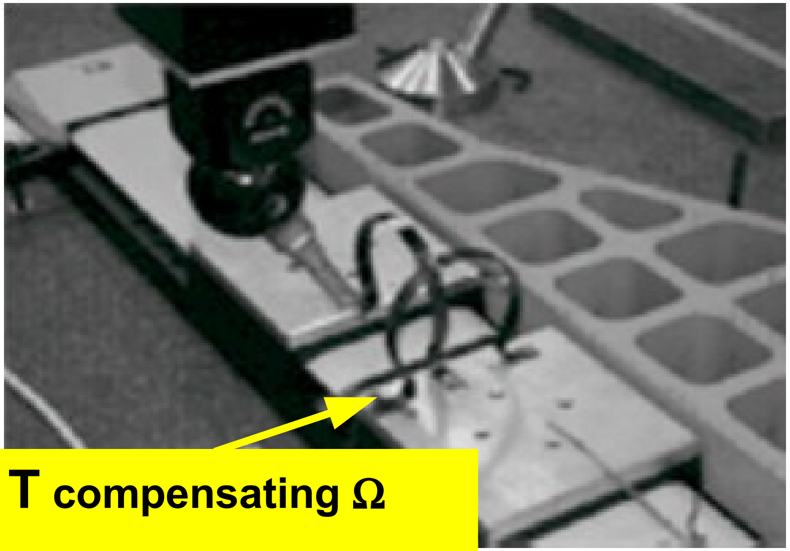
- These features match very well current and future silicon systems needs for:
  - Real-time monitoring of environment variables (T, humidity, B field...)
  - Real time structural monitoring: deformations, vibrations (push & pull operation), movements.

Predecessors in HEP:
Omega-like gauge

Mechanical displacement: Original idea from the late BTeV vertex detector

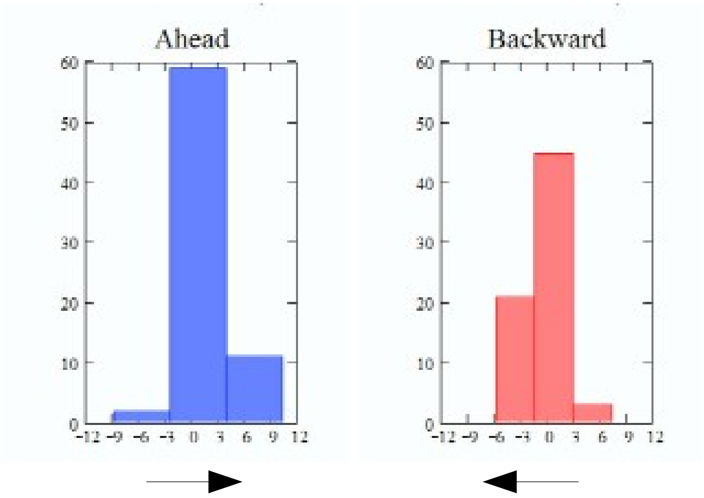
Strain FBG sensor on the tip





T compensating Ω

Residuals

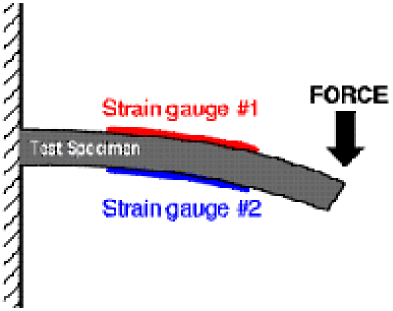


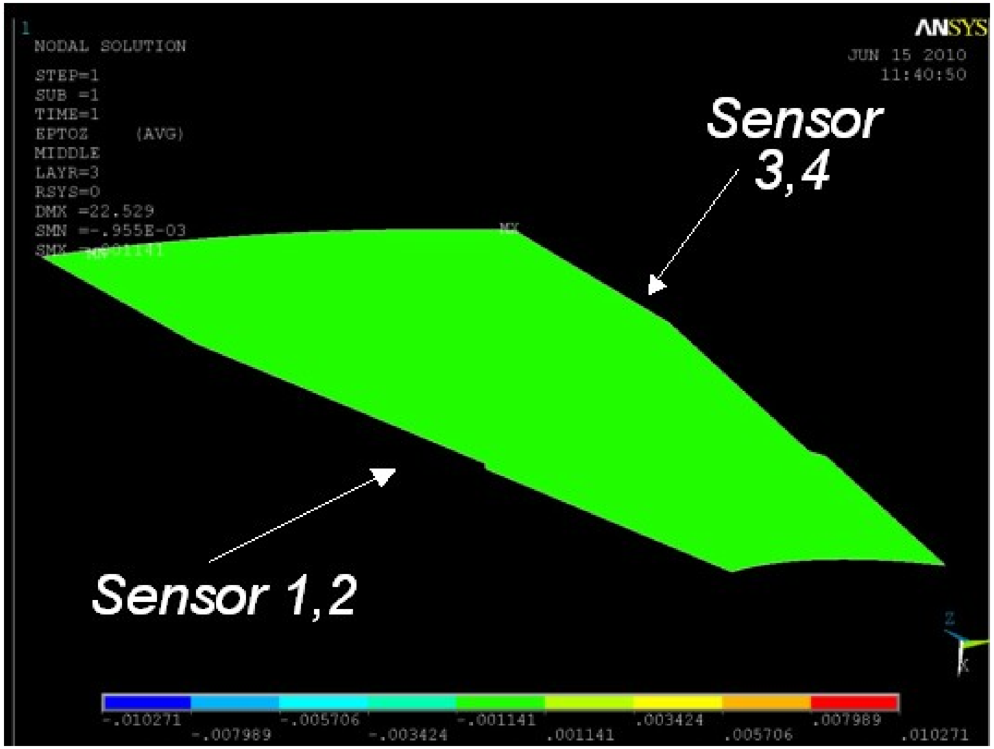
IFCA: Current R&D activities with FOS

- Embedding of fibers into CF composites
- Bonding of fibers to sensors
- Radiation resistance
- A displacement sensor based on FBG

Embedding of fibers into CF composites

- A possible application in HEP: embedding of FBG sensors in carbon fiber composite to monitor deformations and vibrations

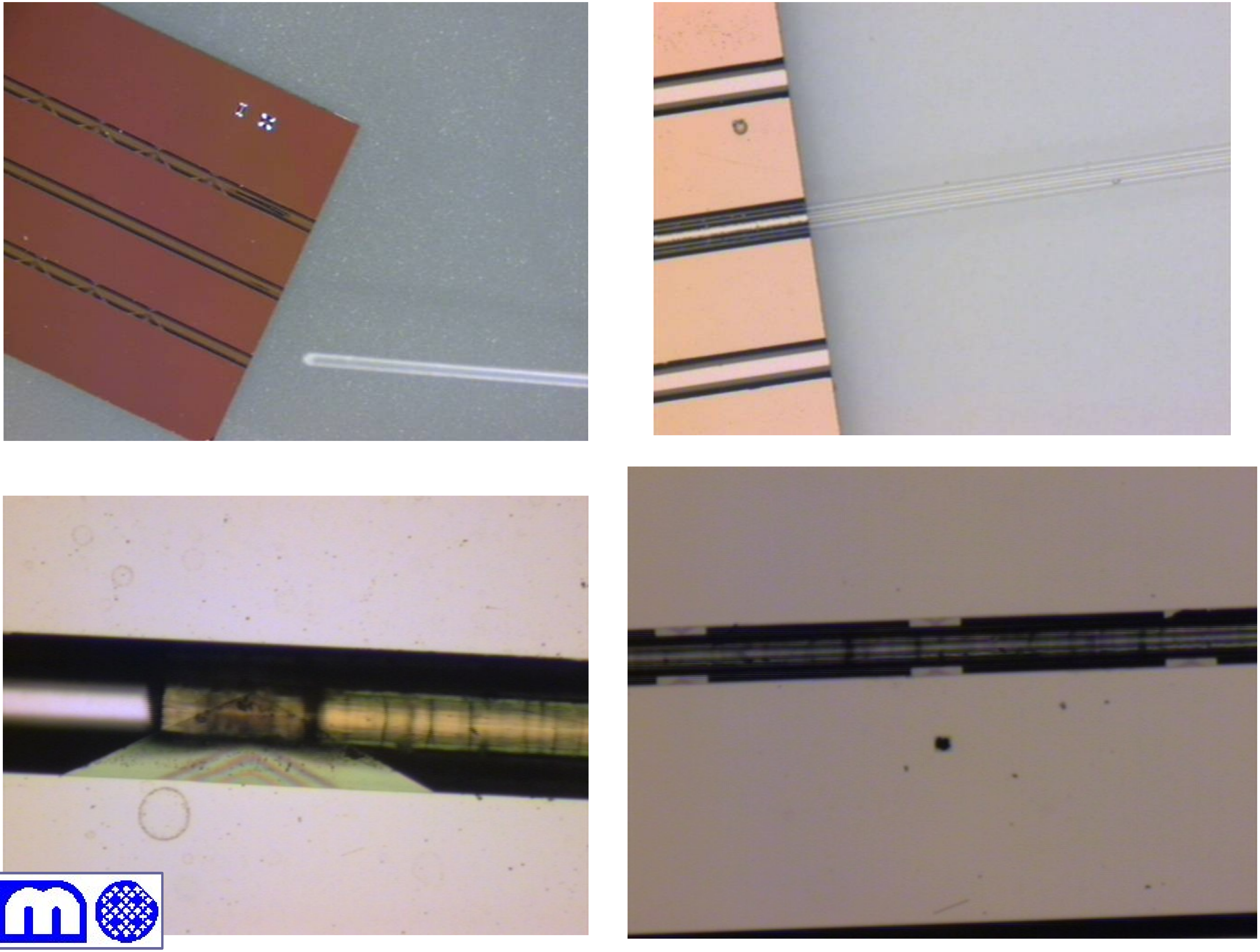




- Currently working collaboration agreement between IFCA and Spanish Aerospace Agency (INTA)

Design of micromechanical fixations for **bonding of fibers to silicon sensors**

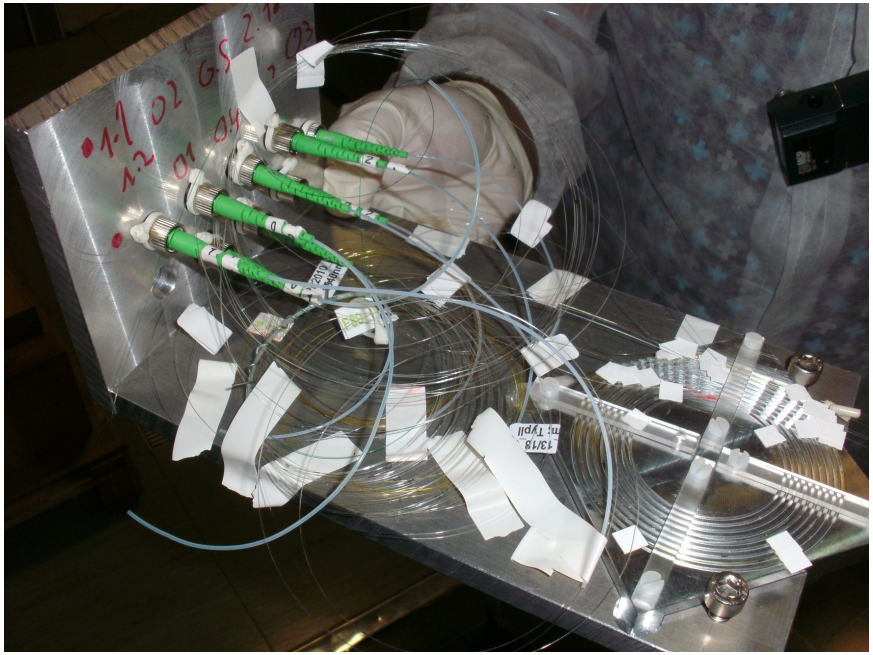
Wafer with machined groove done at CNM-Barcelona



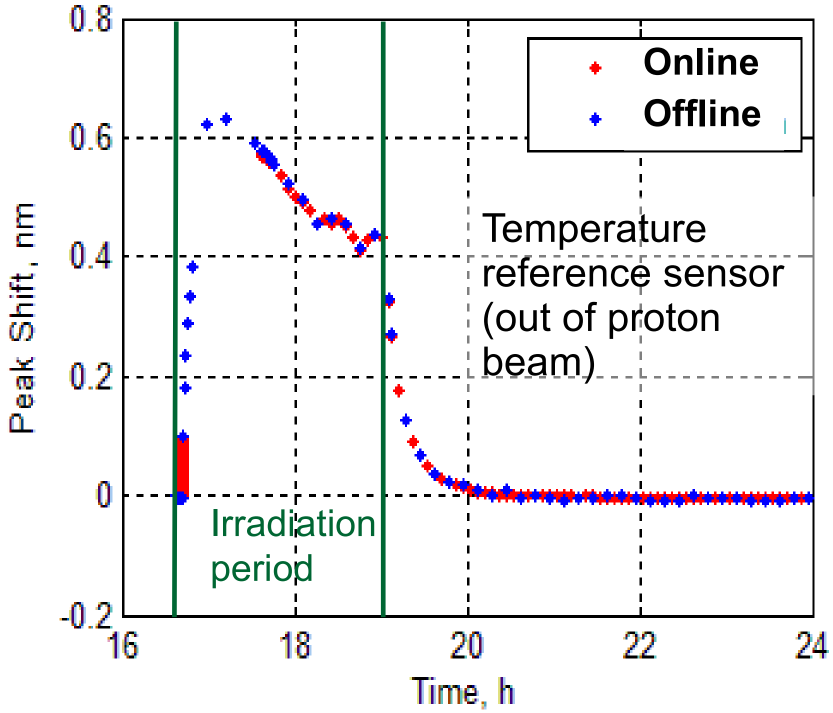
Rad-Hard Qualification of FOS

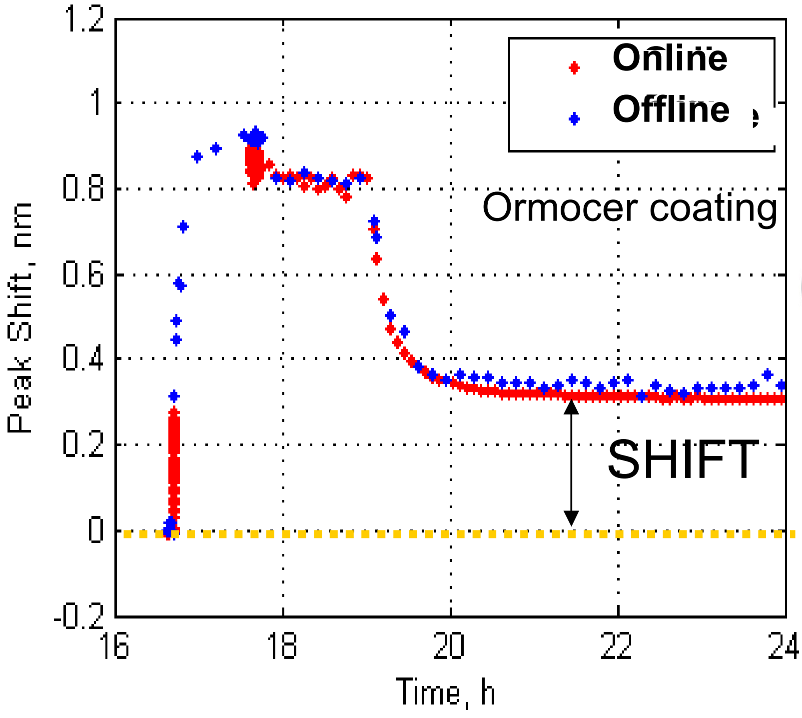
- We need to proof radiation hardness of the sensor in the fiber and of the fiber embedded in hosting material (CF laminate)

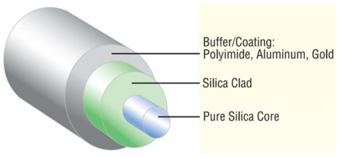
- Irradiation campaign at Spanish National Centre for Accelerators (CNA-CSIC)
- New Cyclotron facility (18MeV protons), here 15.5 MeV protons
- 9 fibers, 3 different coatings, 2 different sensors irradiated



Irradiation Campaign: Effect on the fiber

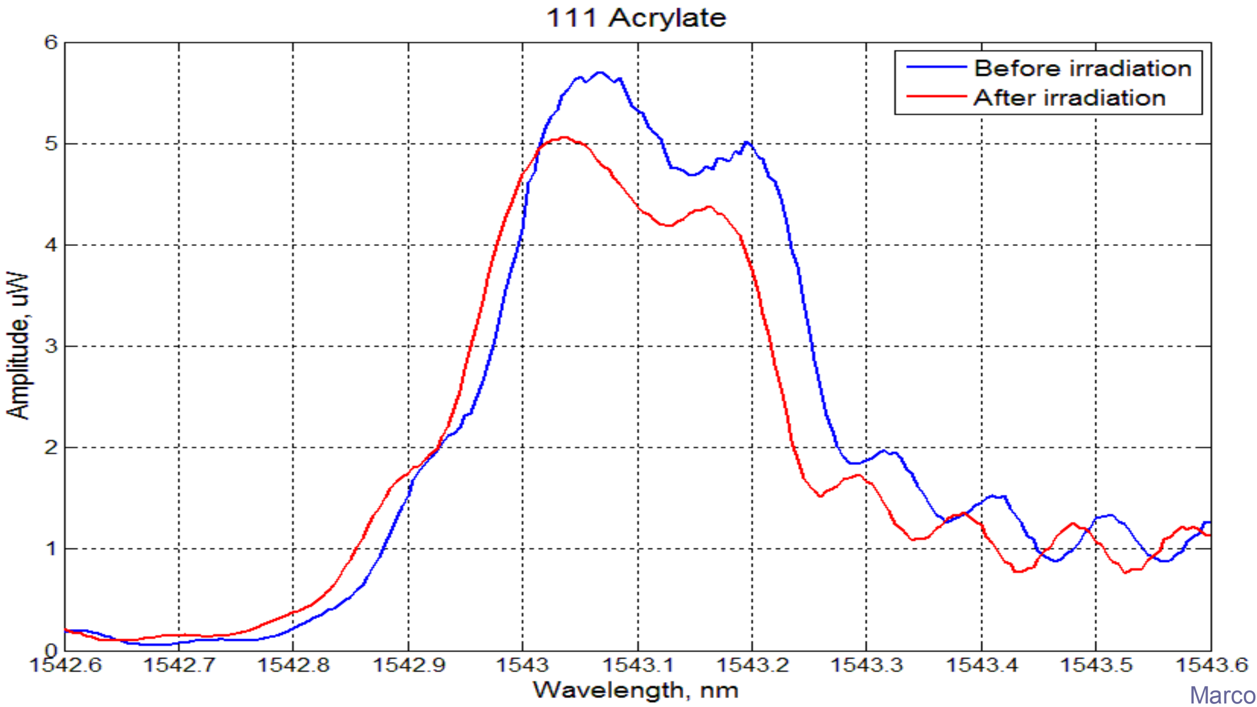




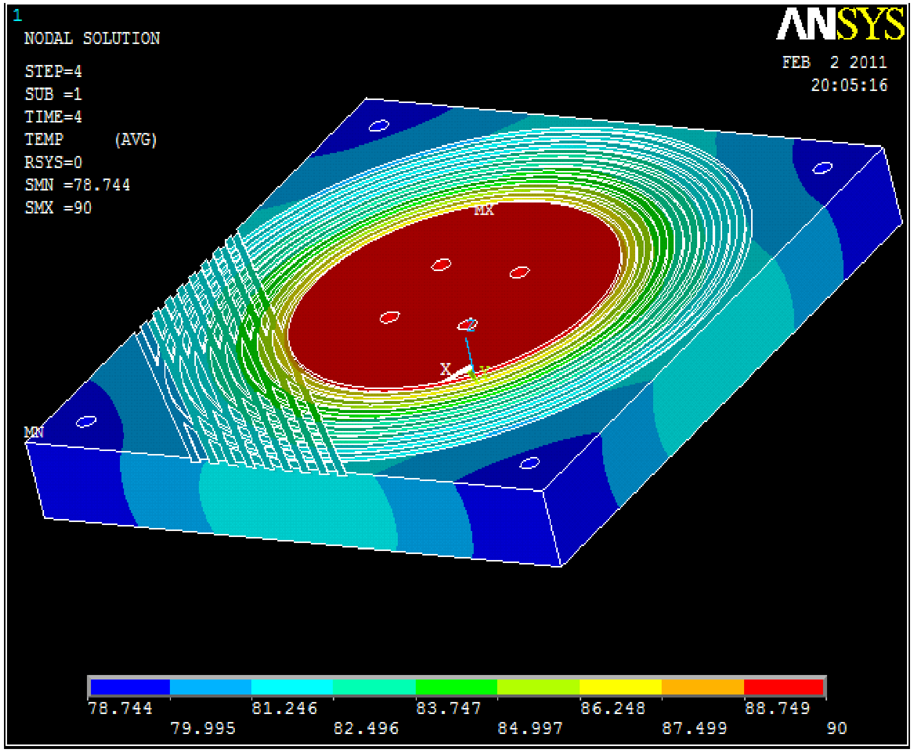


Most resistant sensor to irradiation: acrylate

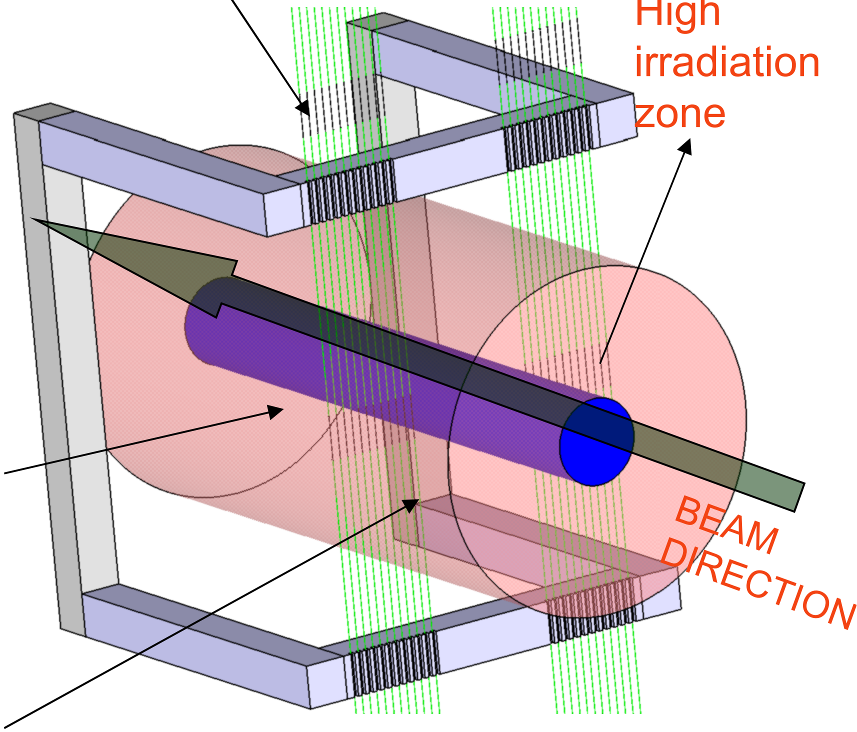
Peak shift:*O(pm)*



New irradiation campaign



First campaign: ΔT=12C



Reference FBG sensors outside irradiation zone

High irradiation zone

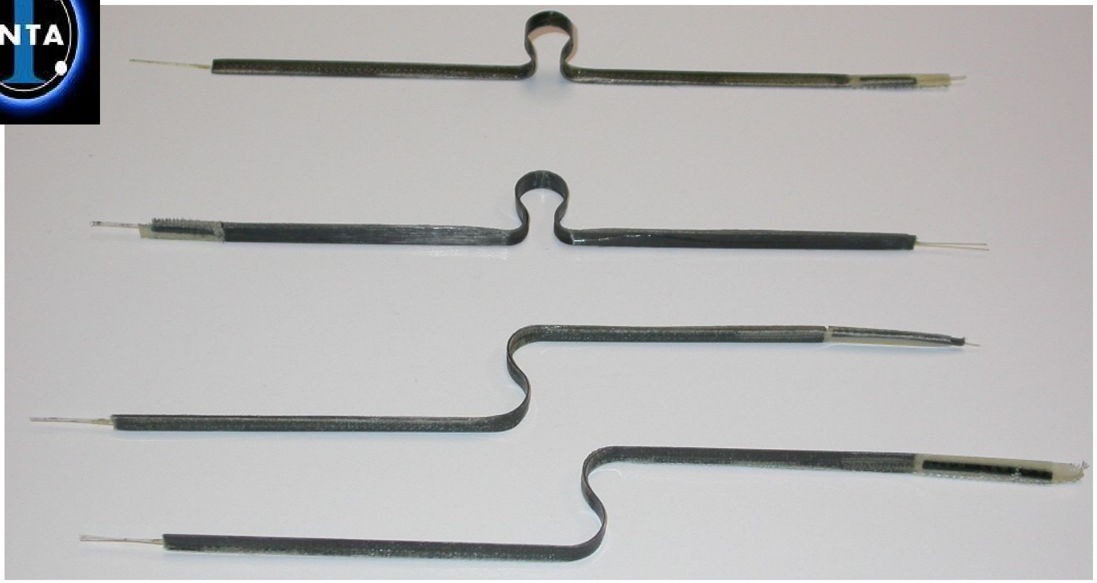
Irradiated FBGs

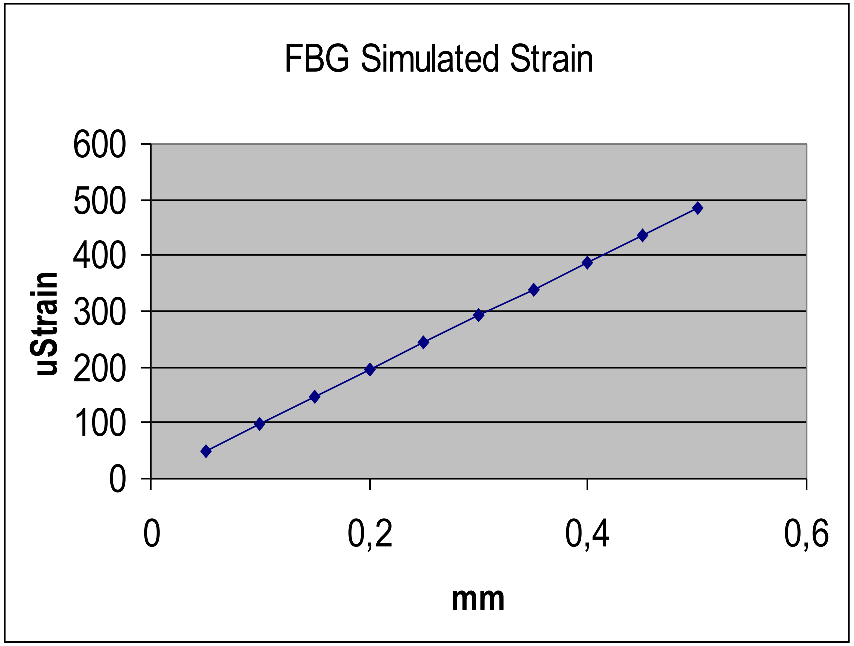
Uniform irradiation zone

New fiber support for next irradiationcampaign

Omega shape manufacture

- The first four mechanical dummies manufactured in INTA to evaluate manufacturing procedure (2 omega shape and 2 S-shape)
- They are going to be tested in an Universal Tension tester
  - The Reaction / displacement curve
  - Compare results with FEA simulations.





Slope ~ 1 με / μm

Resolution ~1 μm

Conclusions

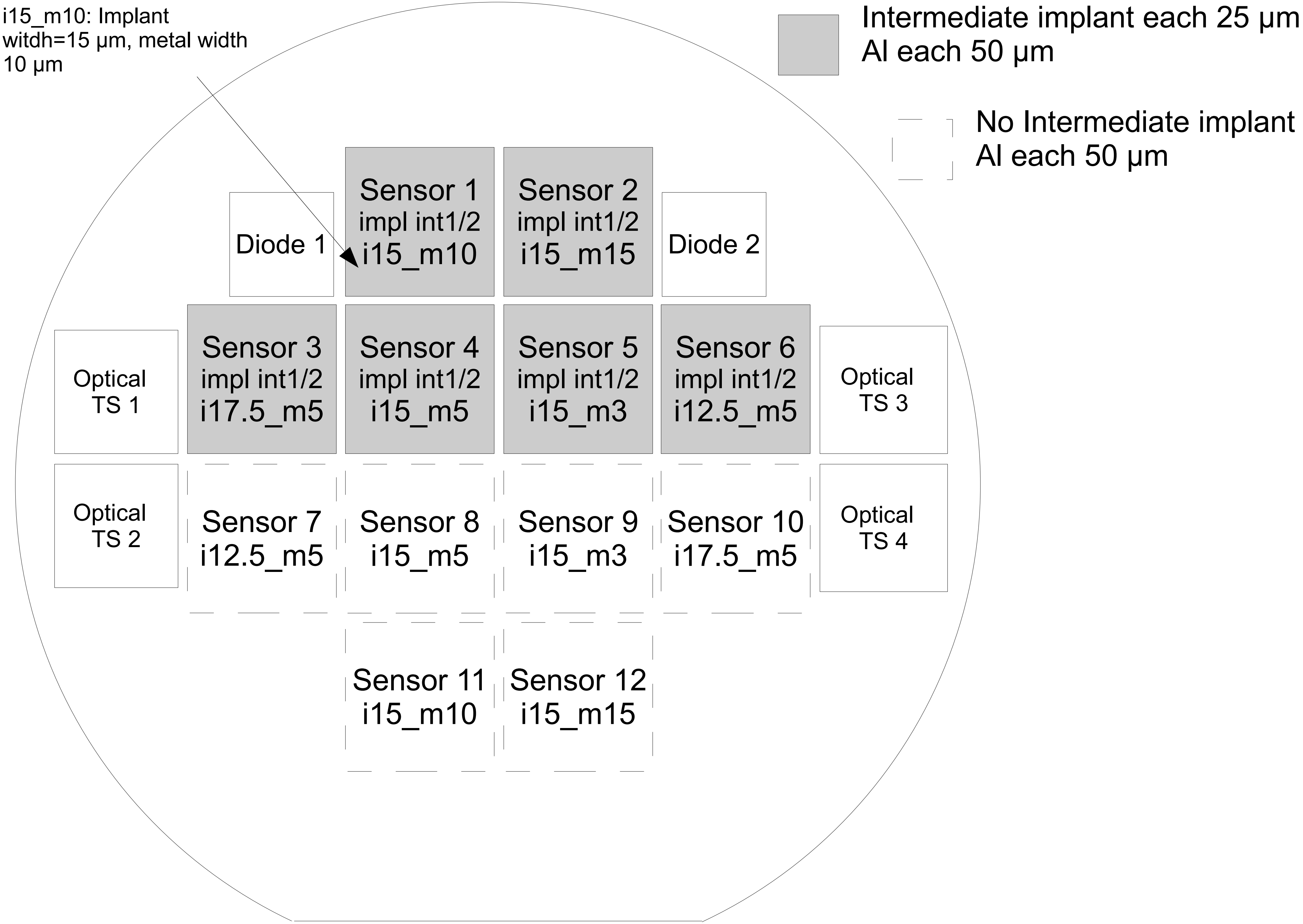
- We have presented some new solutions for hardware alignment problems

- Alignment of Si trackers will benefit of more transparent microstrip sensors
  Minimal cost in production: tune thickness of top and bottom nitride

- Fiber Optical Sensors are proposed for structural and environmental monitoring of Si vtx+trackers:

  - Well stablished technology in aeronautics and civil engineering
  - Distributed and remote sensing, lightweight and noiseless
  - Testing rad-hardness of different fiber coating materials
  - Displacement prototypes under production

BACKUP


i15_m10: Implant witdh=15 µm, metal width 10 µm
Intermediate implant each 25 µm
Al each 50 µm
No Intermediate implant
Al each 50 µm
Diode 1
Sensor 1
impl int1/2
i15_m10
Sensor 2
impl int1/2
i15_m15
Diode 2
Optical TS 1
Sensor 3
impl int1/2
i17.5_m5
Sensor 4
impl int1/2
i15_m5
Sensor 5
impl int1/2
i15_m3
Sensor 6
impl int1/2
i12.5_m5
Optical TS 3
Optical TS 2
Sensor 7
i12.5_m5
Sensor 8
i15_m5
Sensor 9
i15_m3
Sensor 10
i17.5_m5
Optical TS 4
Sensor 11
i15_m10
Sensor 12
i15_m15

Wafer 3: Sequential deposition of Si3N4 (using measured thickness)

$T=T($ top Si_3N_4 thickness , bottom Si_3N_4 thickness $)$ for the 12 sensors