ICTR-PHE 2014

Detection of ionizing radiation by intrinsic optical fiber sensors: preliminary results

L. Cella, G. Gagliardi, S. Avino, V. D'Avino, A. Giorgini, R. Liuzzi, P. De Natale, R. Pacelli

CNR-IBB, Istituto di Biostrutture e Bioimmagini, Napoli, Italy
CNR-INO, Istituto Nazionale di Ottica , Napoli, Italy
Università degli Studi di Napoli Federico II, Italy

IBB

Purpose

- To develop a totally passive miniature radiation sensor based on optical fiber resonant cavity
- Basic idea: radiation-induced effect on fiber material (SiO_2) → refractive index variations → prospectively absorbed dose measurements

Background

"Radiation domain"

- Recent technological advances in RT have increased the use of small fields (<4 cm x 4 cm) reinforcing the demand for novel dosimeter technology
  - ✓ R. Alfonso et al , Med. Phys. 2008
- Among the available dosimetry systems none of them have the characteristics of an ideal dosimeter
  - ✓ J. Andersson et al, Med. Phys. 2012

"Optical fiber domain"

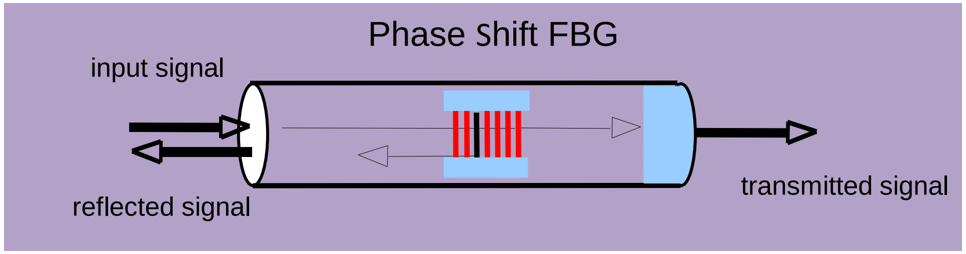
- Optical fiber detectors as extrinsic sensors (transmission of light)
  - ✓ S. O'Keeffe et al Sens. Rev. 2008, A. L. Huston et al Nucl. Instrum. Methods Phys. Res. 2001
- Radioluminescent dosimeters based on doped SiO_2 optical fiber as active sensors (light-emitting fibers) but some limitations are present (i.e. "stem effect" for MV photons)
  - ✓ E. Mones et al Radiat. Meas. 2008, M. Aznar et al Phys. Med. Biol. 2004, I. Veronese et al Rad. Meas. 2010

Theories

- Different theories on Ge-doped silica refractive index variations after exposure to IRs:
  - "color center model" → creation of defect centers by interaction of high-energy photons with OH radicals and Ge, naturally present in silica fibers, or with added dopants
      - » Skuja L. et al, J. Non-Cryst. Solids 1998
  - "compaction effect" → a radiation induced densification process
      - » Buscarino G. et al, J. Phys. Condens. Matter 2010
  - A combination of the above theories
      - » Takshashi M. et al J. App. Phys. 2002

Materials and methods

- We employed totally passive $Ge_{6\%mol}$-doped optical fiber sensors based on special Bragg-grating (FBG) cavity reflectors.



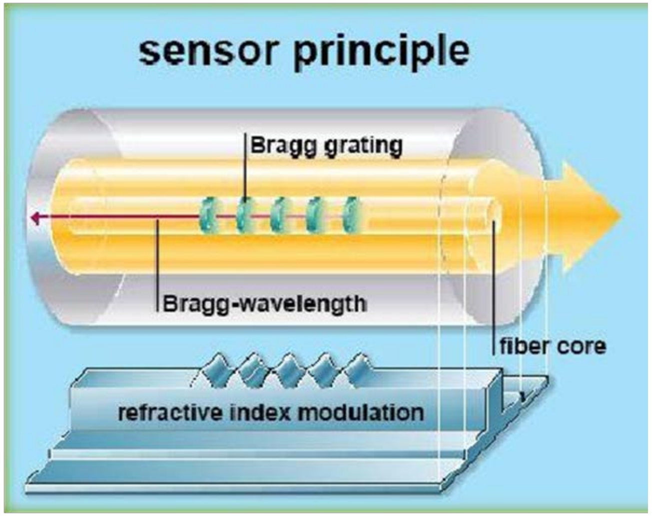
Bragg
Peak reflectivity

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

$\Lambda =$ Grating pitch

Any change in the grating pitch and/or refractive index results in a shift of λB

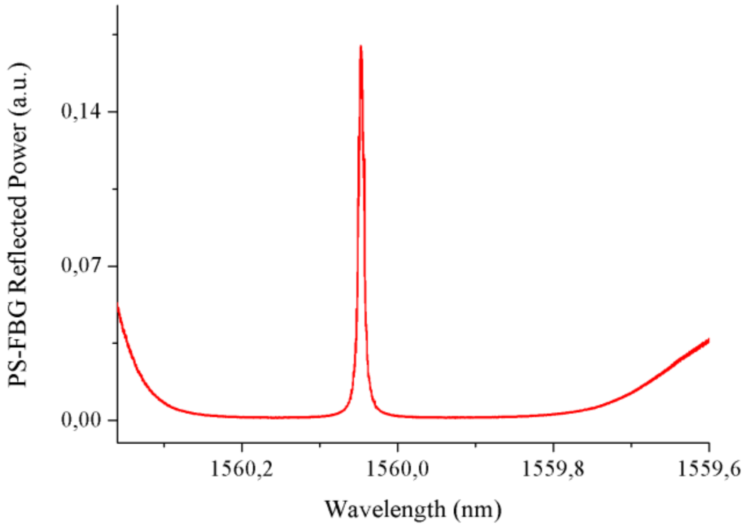
Sensors characteristics (1)



- The effective interaction volume of the sensor

  $= 6 \times 10^{-4}$ mm^3

- Transmission and reflection spectrum with only one narrow mode at the center of Bragg curve



Experimental apparatus: FBG irradiation

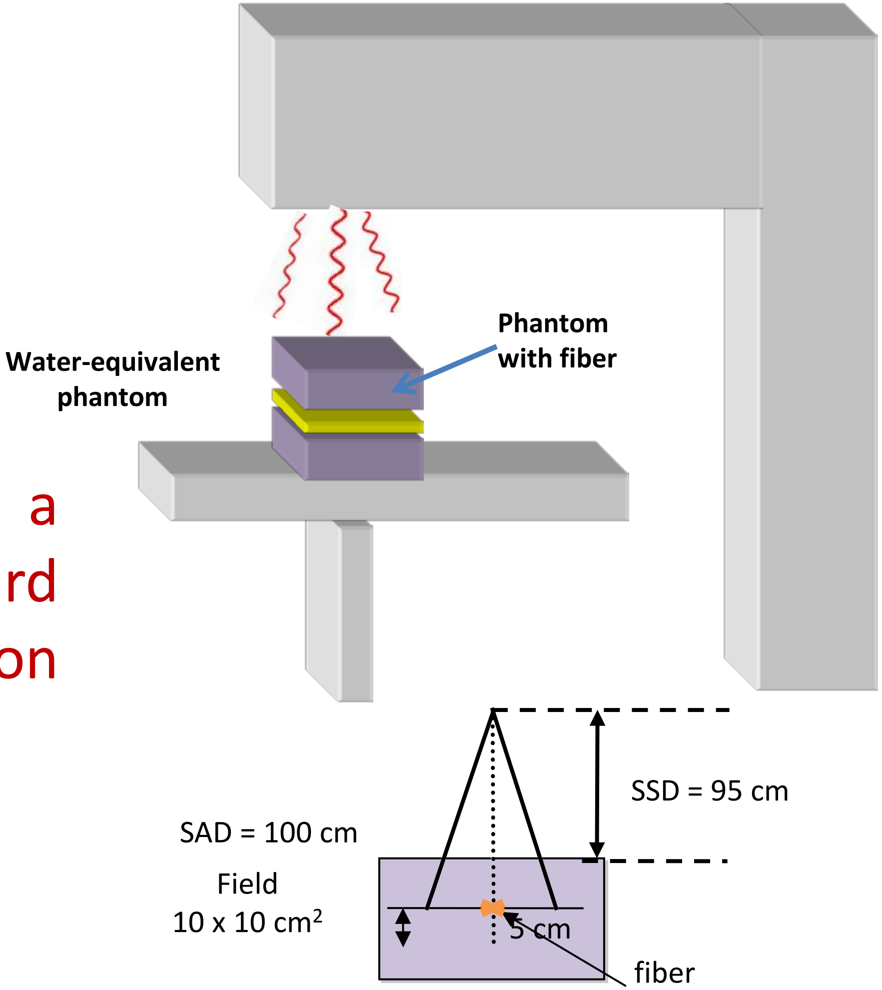
2 sensors with different spectral features:

- ✓ FBG1
- ✓ FBG2 (higher reflectivity)

The FBGs were inserted into a phantom irradiated in standard conditions by a 6MV linac photon beam

2 dose steps:

- ✓ FBG1 with 10 Gy increments up to 30 Gy
- ✓ FBG2 with 1 Gy and 2 Gy



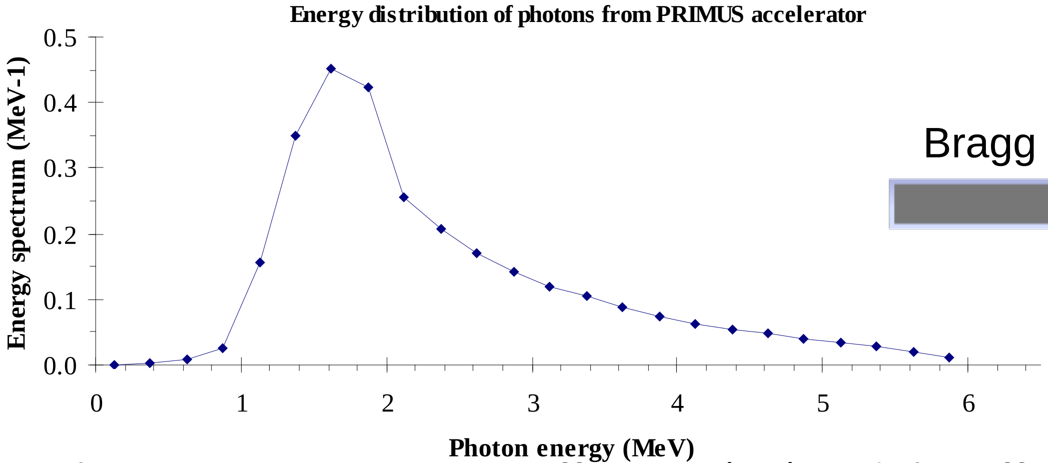
Sensors characteristics (2)

d core=8 µm Ge-doped (6% mol) SiO_2

d cladding =125 µm SiO_2

core	cladding
w_{Si}=43.4%	w_{Si}=46.7%
w_{Ge}=7.2%	w_O=53.3%
w_O=49.4%	

	Z	**Z/A**	**I (eV)**	**ρ (g/cm³)**	**M (molar mass) (g/mol)**
Si	14	0.49848	173.0	2.330	28.086
Ge	32	0.44071	350.0	5.323	72.63
O	16	0.50002	95.0	1.332×10^{-3}	15.999
SiO_2				2.63	60.08



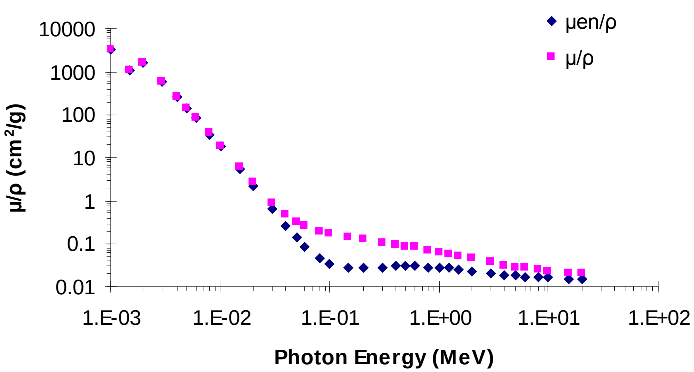
Bragg 's rule

$$\left(\frac{\mu_{en}}{\rho}\right)_{mixture} = \sum_i w_i \left(\frac{\mu_{en}}{\rho}\right)_i$$

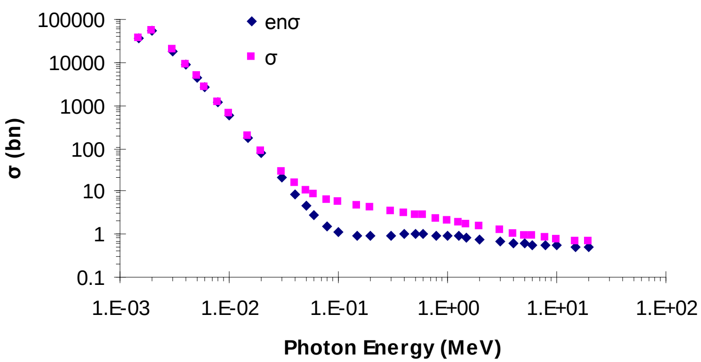
The mass attenuation coefficients (μ_m) and the effective atomic number (Z_{eff}) of the sensors were calculated as function of the photon energy in the range 1-6 MeV

Interaction mechanisms of radiation within the sensor material

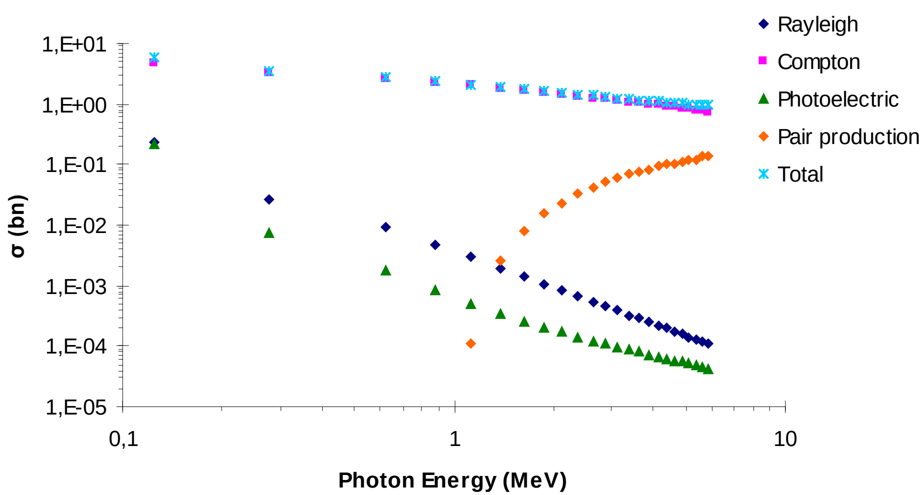
Mass attenuation and the mass energy absorption coefficients vs photon energy



Attenuation and energy-absorption cross sections vs photon energy

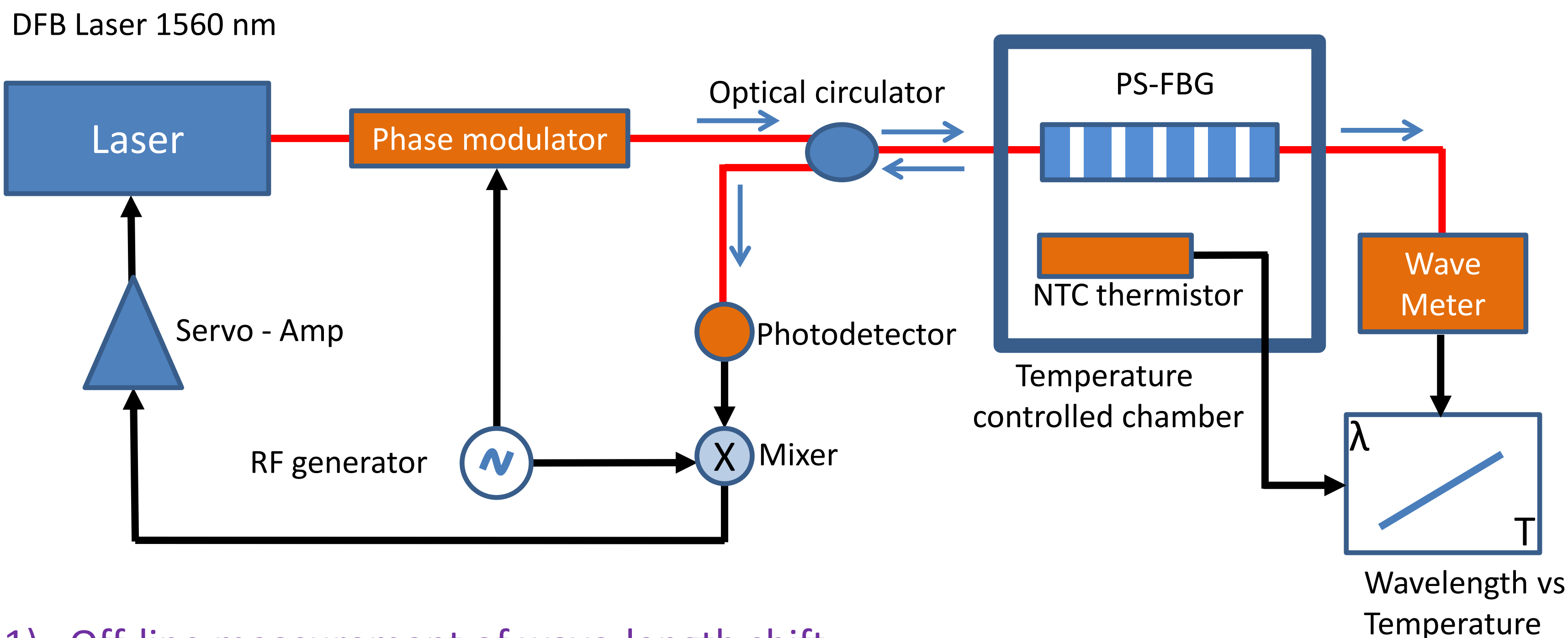


Attenuation cross sections vs photon energy for each interaction process



- The weighted average μ_m = 0.044 cm^2/g (1-6 Mev)
- The weighted average Z_{eff} = 10.04 (1-6 Mev), “nearly water equivalent” (Z_{eff} = 7,42)

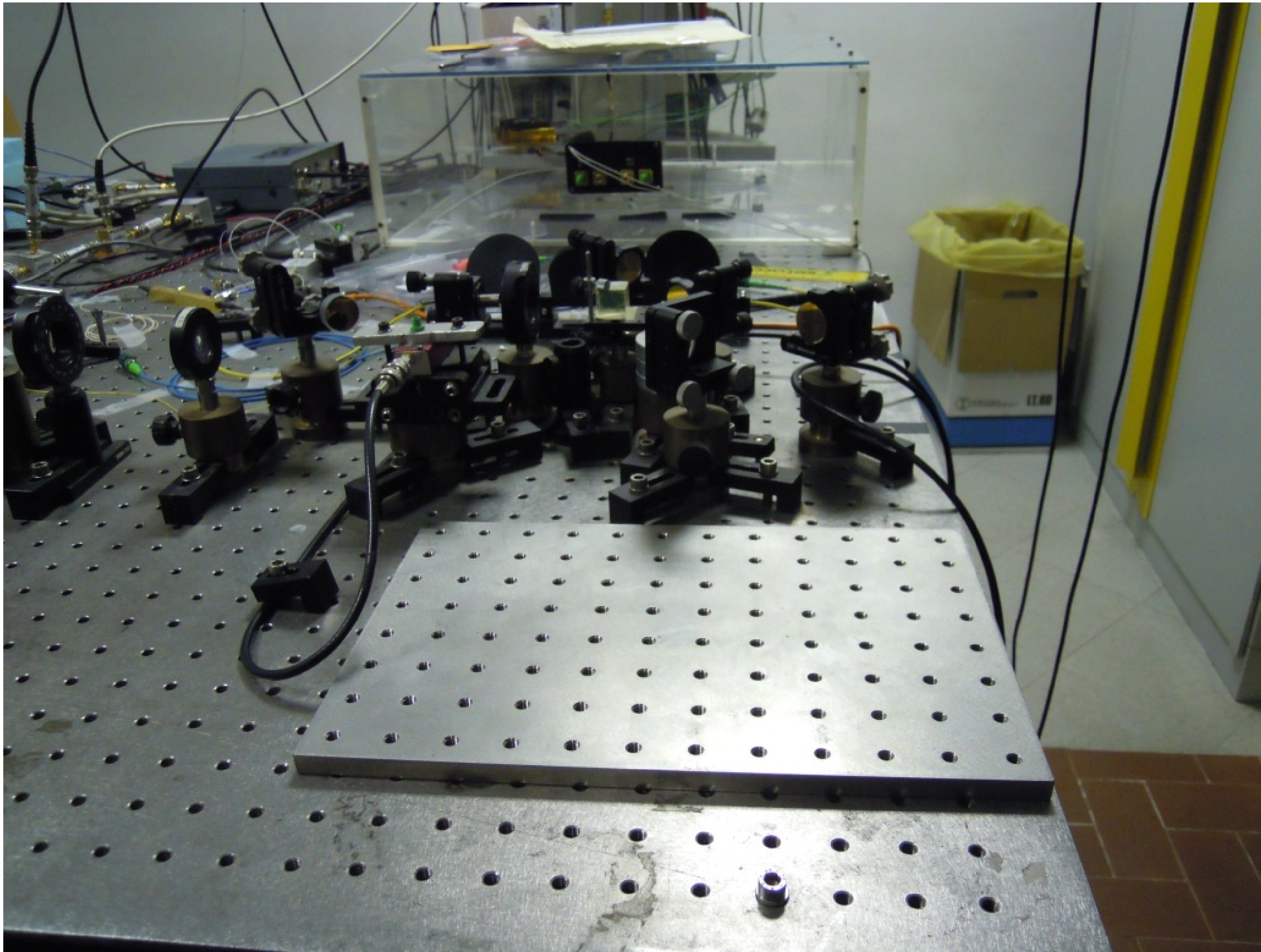
Experimental apparatus: high sensitivity interrogation scheme



1) Off-line measurement of wave-length shift

2) The FBG is placed in a temperature controlled chamber (negative temperature coeff thermistor, 1 mK)

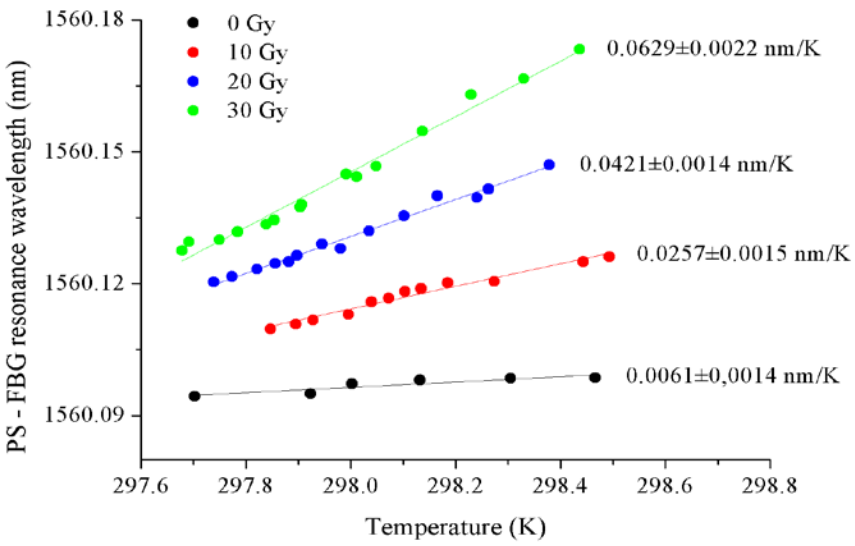
3) To check if λ-shift were due to thermal shift, the temperature is scanned and the thermo-optic response (λ_B *vs* T) measured (uncertainty on thermoptic response≈ 1pm/k)



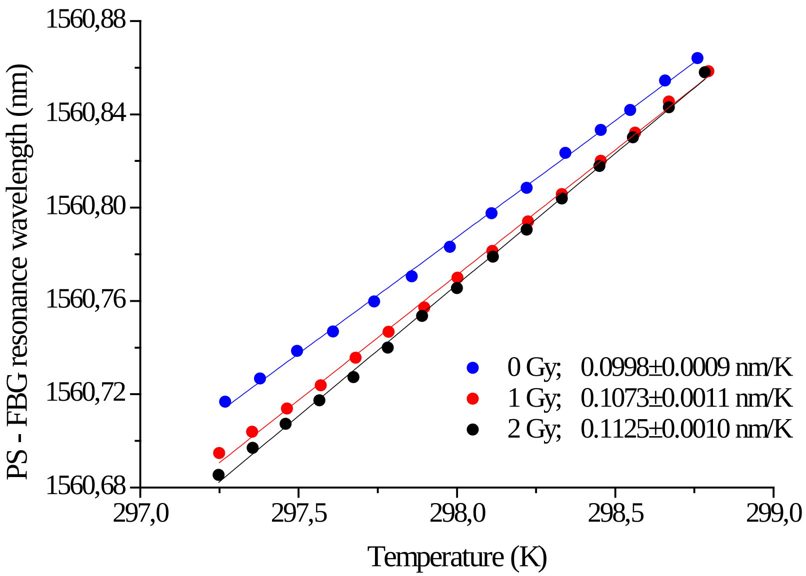
RESULTS

A net **wavelength shift** was measured after each irradiation

FBG-1

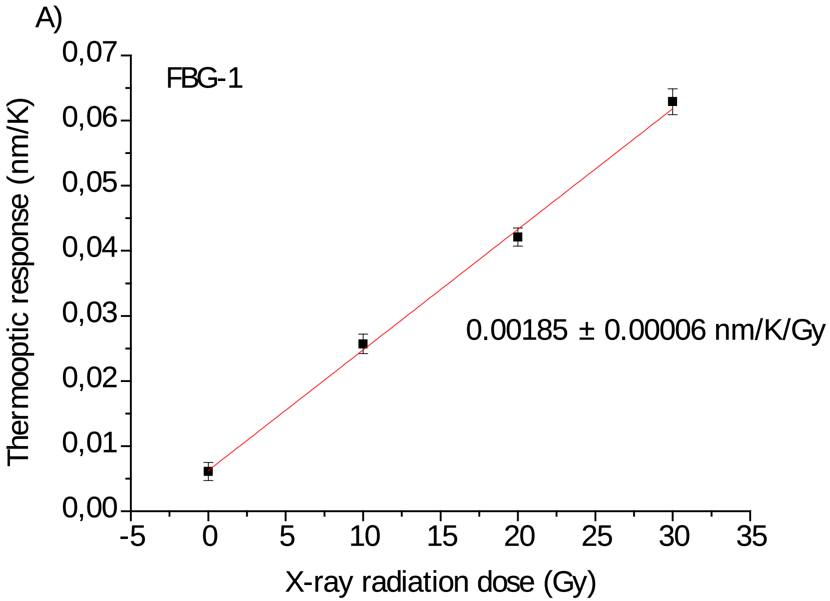


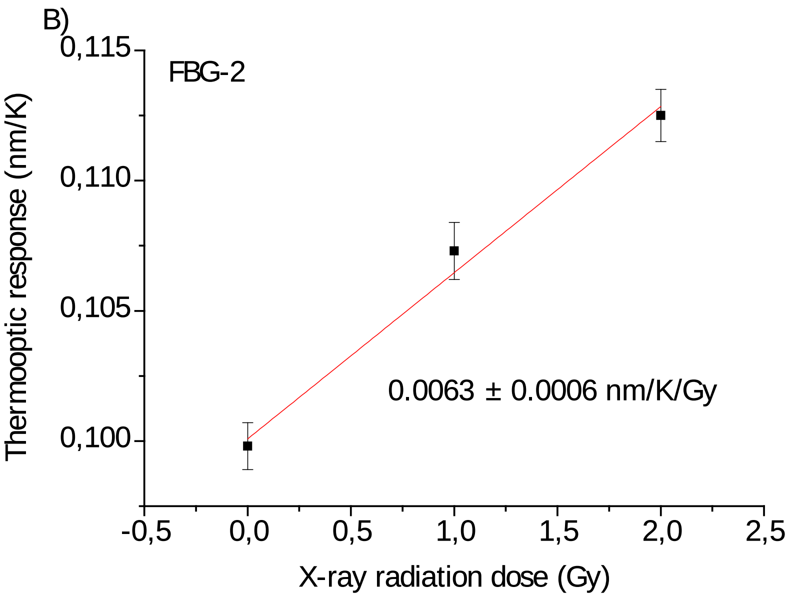
FBG-2



RESULTS

Additional phenomenon: a radio-induced change of the fiber **thermo-optic response** measured by tuning the resonant mode wavelengths with temperature

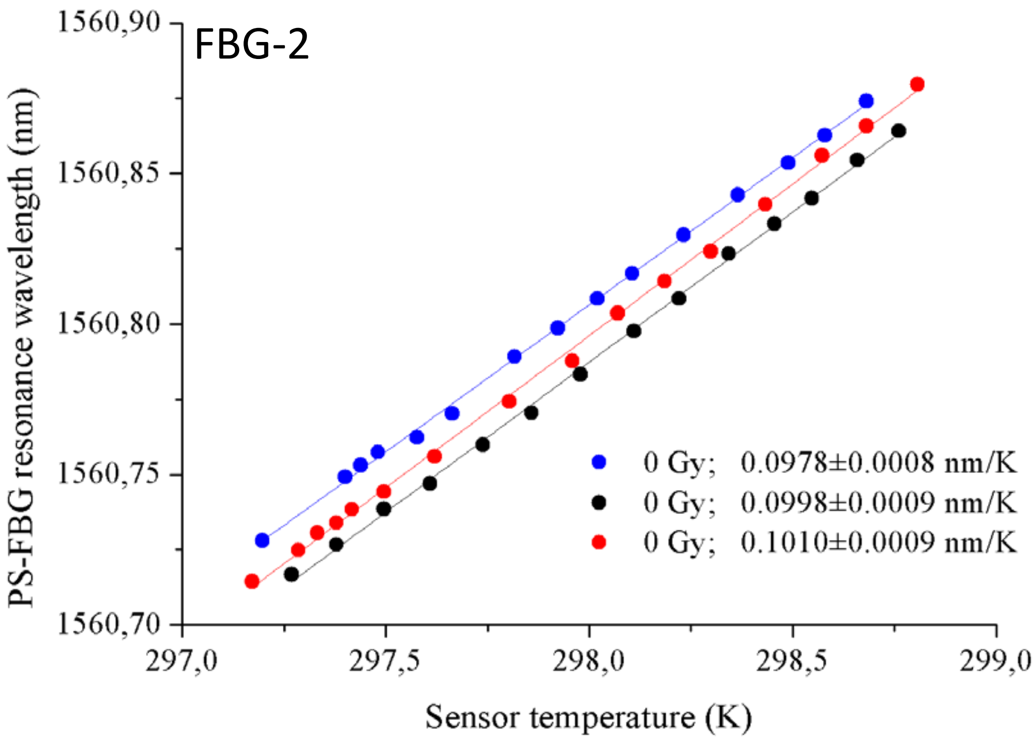




Dividing the dose response coefficient (FBG-2) by the average value of the uncertainty on the single measurement of the thermo-optic response (1 pm/K) we obtain a final resolution of 0.16 Gy.

Reproducibility

Reproducibility test: repeated measurement of the thermo-optic response before irradiation



Reproducibility ~ 2 %

Conclusion

"To function as a radiation dosimeter, a sensor must possess at least one physical property that is a function of the measured dosimetric quantity and that can be used for radiation dosimetry with proper calibration"

The observed effect of IRs delivered to the FBG sensor is two-fold :

1) **A wavelength shift**

2) **A change of the fiber thermo-optic response**

It could work!!!!!!!!!!!

Thank you for your attention

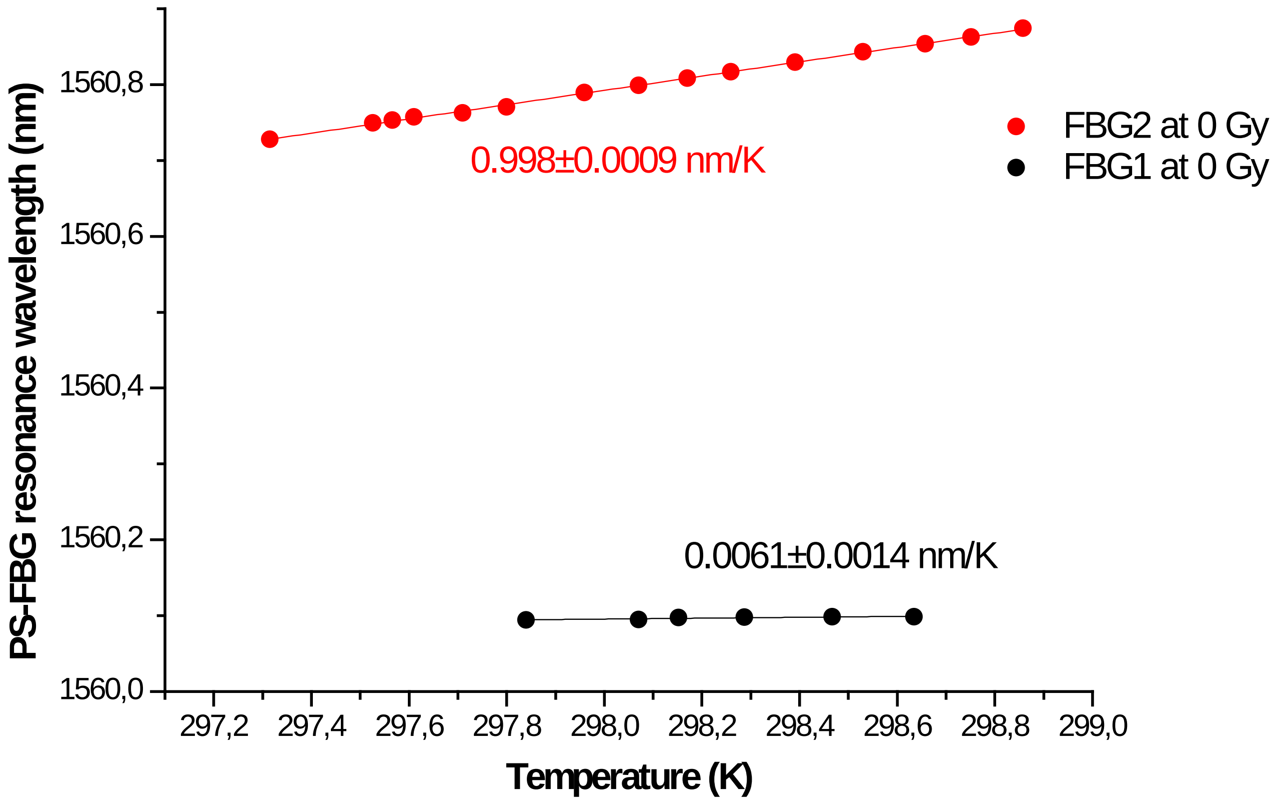
This research is supported by Italian Ministry for Education and Research (MIUR) with the project FIRB - RBFR10Q0PT_001 “DROPS.”

1) wavelength shift : undesired effects of mechanical strains and temperature fluctuations on the fiber that may reduce the accuracy and even mask the desired information at small doses

2) thermo-optic response : substantially immune to environmental conditions.

FBG1 vs FBG2:

higher reflectivity of FBG-2



higher resolution of FBG-2