Physical effects of ionizing gamma radiations on IR optical fibers and IR sources for the TRIS project.

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Introduction: Based on the heritage of Ma_MISS (Mars Multispectral Imager for Subsurface Studies) onboard Rosalind Franklin rover mission, TRIS is a Research and Development (R&D) program to increase the TRL (Technology Readiness Level) of transmissions (optical fibers) and illuminations systems, currently operating in the visible and near-infrared. The main goal is to extend toward the IR spectral range the sensitivity of a Ma_MISS like spectrometer [1-4].

To survive in space environment, optical component must be able to withstand various types of stress. These include thermal-vacuum and radiation stress. Here we report the results of optical performance tests of fibers after being subjected to ionizing radiation.

Optical element description and Irradiation Facility: The main optical elements of TRIS are IR sources and fiber optics.

The IR sources are constituted by a thin film resistor of diamond-like nanostructured amorphous carbon. The active area is 1.7 mm x 1.7 mm, with an emissivity of 0.8 in the spectral range 1 ÷ 20 µm. The operating temperature is adjustable by changing the voltage and amperage values. To find the best solution for our purposes, we studied IR sources coupled with four different optical solutions: a reflectorless source, two with different parabolic optics, and one coupled to an elliptical reflector (see Fig.1, bottom panel).

The fibers are characterized by an Indium Fluoride Glass (IFG-InF_3) with core/cladding diameter of 200/260 µm. The numerical aperture is 0.2, external coating is in peek. The transmission wavelength range is 0.3 – 5.5 µm.

The initial detailed characterization of optical performances of both fibers and IR sources together with the used setups is described in [5].

We performed irradiation experiments on fibers and IR sources by means of ionizing (gamma-rays) radiation, thanks to the Calliope Facility at ENEA-Casaccia [6] premises. Fibers and sources were subject to irradiation separately and in different times during the period March to October 2023.

The irradiation source is given by ^{60}Co the emitted photons have energies 1.17 and 1.33 MeV. The elements to be irradiated were placed inside lead bunkers to partially shield the source and reduce the dose rate. The specific dose was monitored by specially calibrated dosimeters placed in the vicinity of the tested optical components. According to the project requirements, the fibers and IR sources were irradiated with a total dose of 250 Gy. Two further experiments were performed with half a dose (125 Gy) and one and half a dose (375 Gy). In the case of fibers, because transient physical effects could have been expected, we decided to irradiate three separate batches of fibers, at the three fixed doses, to do not have interruptions. In the case of the IR sources, the dose was additive. To get a truer estimate of the effects of radiation on the emitters, they were irradiated while they were powered via dedicated power supply.

Results: Both fibers and sources performances (in terms of transmittance and emitted spectral radiance) were characterized by means of two setups after the various dose steps. Concerning the fibers, measurements were performed after 1h at Calliope, by means of FieldSpec and QTH lamp, in the restricted VNIR range 0.35-2.5 µm, with the aim of investigating on putative transient effects. Subsequent measurements were performed at our lab (C-Lab at IAPS/ INAF) with both FieldSpec and Bruker-FTIR (1-6 µm) at various times. The last measurements were done after 8 months from the irradition. Concerning the IR sources, the characterization after irradiation was only carried out by means of FTIR.

Optical fibers:

The irradiated fibers show a notable decrease in the transmission of light at blue frequencies (the light appears more "yellow" (fig1). This corresponds in the VNIR spectra to the appearance of the strong absorption band centered at about 440-470 nm (fig.2).

Thus, the transmission of light near blue wavelengths is almost completely suppressed. Moreover, the spectral slope of the transmission increases in the spectral range up to about 1.5 µm. The overall transmittance at wavelengths < 1.5 µm remains lesser than the initial transmittance (before irradiation), while above 1.5 µm there are no substantial or observable effects on fiber transmittance, and data show a perfect match with the starting measurements (fig.3).

IR sources:

For what concerns the IR sources, the emitted spectral radiance measured before and after the irradiation at different doses does not show substantial variations in spectral shape and nor in intensity.

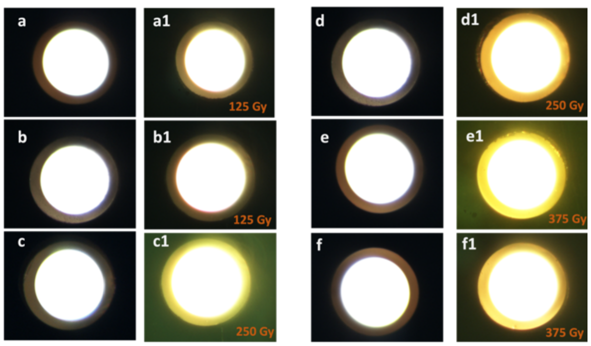

Figure 1: Microscope photographs of the optical fibers after irradiation with 125 Gy (a,b), 250 Gy (c,d) and 375 Gy (e,f). For each letter, the left image corresponds to the fiber before irradiation, while the right image corresponds to the fiber after irradiation. Each fiber was connected to the exit collimator of the QTH lamp in order to visually evaluate the exiting light.

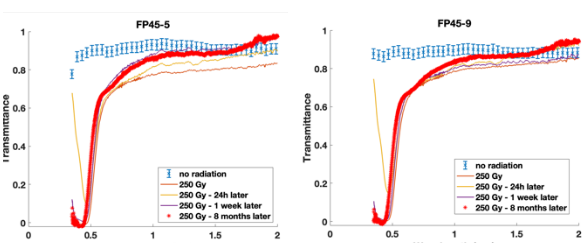

Figure 2: Transmission of two fibers measured in the VNIR (Fieldspec) before and after the irradiation at 250 Gy. Measurements "after" were performed at several times since 1h until 8 months. The blue points with error bars correspond to the initial measurements. The red curve is the last measured (after 8 months).

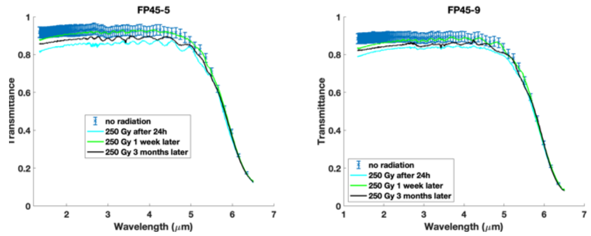

Figure 3: Transmission of two fibers measured in the IR (FTIR) before and after the irradiation at 250 Gy. Measurements "after" were performed at several times since 1h until 8 months. The blue points with error bars correspond to the initial measurements. The black curve is the last measured (after 8 months).

Conclusions: TRIS optical elements were irradiated with γ radiations and tested. In the analysis carried out at the end of the irradiation process, no damage was found in IR sources or on the external coating of the fibers (nor in the ferrules).Thus, the sources passed the radiation test.

The most evident effect of radiation is the appearance of an absorption band in fiber transmission in the visible region, around 440 nm (blue). Variation in the optical performance above 1 micron is almost negligible and is within the statistical error. As a consequence, we can conclude that for the range of interest of the TRIS project (1-5.5 microns), the fibers passed the radiation test.

References: [1] De Sanctis, M. C., et al. *The Planetary Science Journal* 3.6 (2022): 142. [2] De Sanctis M.C. et al. (2017), *Astrobiology* 17, 6-7, 612-620. [3] Vago J. et al., et al.: (2017) *Astrobiology*, 17, 6-7, 471-510. [4] De Sanctis, M. C., et al. *Nature* 528.7581 (2015): 241-244. [5] La Francesca E., et al., *Congresso Nazionale Scienze Planetarie,* Perugia-Italy (2023). [6] Baccaro, S.; Cemmi, A.; Di Sarcina, I.; Ferrara, G. Gamma Irradiation Calliope Facility at ENEA—Casaccia Research Centre: Rome,Italy. In ENEA Technical Report; RT/2019/4/ENEA; Fusion and Technology for Nuclear Safety and Security Department Casaccia Research Centre: Rome, Italy, 2019; ISSN 0393-3016.**Acknowledgements:** TRIS instrument development and scientific activities are funded by the Italian Space Agency (ASI) grant ASI-INAF n. 2021-3-HH.0.