

GAMMA AND PROTON IRRADIATION EFFECTS ON OPTICAL TRANSMISSION MATERIALS FOR PLASMA DIAGNOSTICS IN NUCLEAR FUSION REACTOR*

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Abstract

Optical transmission materials will play very important roles in fusion reactors, where they will be used under heavy irradiation environments. Our goal is to assess the suitability of SiO₂ and Al₂O₃ based materials for both diagnostic and remote handling application, focusing on comparison of the ionization and displacement induced damage (influence on the UV and visible optical transmission properties). The irradiation facilities are: IRASM – 200 kCi ⁶⁰Co source, minimum 2kGy/h, ethanol chlorine benzene and ESR dosimetry; HVEC 8 MV TANDEM – protons up to 16 MeV and 200 nA. The gamma and proton irradiation chambers characteristics and some preliminary results on alumina pellets are presented.

Introduction

Optical transmission materials will play important roles in nuclear fusion reactors, where they will be used under heavy irradiation environments -neutrons, gamma-rays, protons, helium and other ions- [1, 2]. Among the important applications of fiber optics are light pipes for monitoring Tokamak fusion reactor plasma conditions. These applications will make unprecedented demands for hardness against optical attenuation induced by moderate to very high doses of gamma rays and neutrons [3, 4]. We started a program on gamma and proton induced degradation in ceramic windows and optical fibres. Our project focuses on the comparison of the ionization and displacement induced damage in SiO₂ and Al₂O₃ based materials and the influence on the UV and visible optical transmission properties.

The main characteristics of Bucharest irradiation facilities are:

- IRASM IRRADIATOR: 200 kCi ^{60}Co “swimming pool” source, minimum 2 kGy/h with an isotropic dose rate up to 1 Gy/s, ethanol chlorine benzene dosimetry, ESR dosimetry
- HVEC 8 MV FN TANDEM: protons up to 16 MeV and 200 nA, alpha particles up to 21 MeV and 50 nA, O, C, N ions approximately 100 MeV up to 50 nA.

Experimental

The following main milestones for this project have been achieved up to now:

- Realizing a gamma irradiation chamber, acting underwater, allowing various temperatures (20-300° C) on the sample, with adequate oven for 20-300° C on ceramics samples, distance commanded, thermocouples sending the information at distance, and adequate high dose gamma rays dosimetric system; we used ethanol-chloride benzene vials dosimeters, tested in the range of 2-11 Mrad (20-110 kGy).
- Realizing a proton irradiation chamber, acting in vacuum, allowing various temperatures on the sample in the presence of irradiation heating (1 mA \times 1 MeV = 1 W), with adequate oven for 20-300° C, distance commanded, adequate thermocouples sending and possibility to apply an electric field during heating.

Results

As irradiations on different samples, we performed until now:

- Semiconductor lasers from 2 to 11 Mrad (20 to 110 kGy) gamma irradiation;
- Alumina pellets (Merck) 2 and 4 Mrad (20 and 40 kGy) gamma irradiation;

As post-irradiation studies we can mention up to now optical absorption measurements in the range of UV-VIS range of gamma irradiated alumina pellets, performed at room temperature by means of a Cary 5 (Varian) double beam spectrophotometer. The spectral bandwidth was kept to 1 nm. Some preliminary results are shown in figures 1 and 2, where the diminution of the transmission caused by the gamma irradiation is clearly displayed.

Concerning the 15 MeV proton irradiation, the main problem is the induced radioactivity in the sample. For example, in the case of iron and copper (two main components or impurities in our types of samples), our conclusions are:

- for iron: the main radioactivity is from (91.72%) $^{56}\text{Fe}(p,n)^{56}\text{Co}$ ($T_{1/2} = 77.4$ d): 10 $\mu\text{Ci}/\mu\text{A}\times\text{h}$, which means for 100 ppm Fe at 10^{17} protons 5 nCi and at 10^{18} protons 50 nCi.

Under the level of 100 nCi for Co-56 (low level radioactivity), the handling rules are not severe, but higher than 100 nCi the safety regulations become more complicated.

- for copper: the main radioactivity is from (30.9%)⁶⁵Cu(p,n)⁶⁵Zn ($T_{1/2} = 245$ d): $2.5 \mu\text{Ci}/\mu\text{A}\times\text{h}$, which means for 100 ppm Cu at 10^{17} protons 1.25 nCi and at 10^{18} protons 12.5 nCi. The conclusions for iron (100 nCi level) are valid for copper too.

The main problem is the sample's radioactivity influence on luminescence and absorption measurements. For optical fibers metal jacketed, the presence of Fe, Cu, Ni generates problems and for semiconductor lasers, the presence of a relatively thick metallic jacket (Fe, Ni, etc) must be considered as an important impediment for our experiment.

As a preliminary test two alumina pellets (Merck) were 5×10^{15} and 10^{16} proton implanted at 15 MeV; the residual radioactivity measured after 48 hours was approximately 30 μGy at the surface. We waited for six weeks for a diminution to 3 μGy to start the post-irradiation experiments in good radioactivity conditions for the samples, using the same Cary 5 spectrophotometer. The results presented in figure 3 clearly indicated a diminution in transmission, very similar to gamma irradiation case, which could be explained if we consider the strong gamma field accompanying the 15 MeV proton irradiation in a light elements structure and the limited proton range in our samples (less than 0.5 mm).

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Figure 1

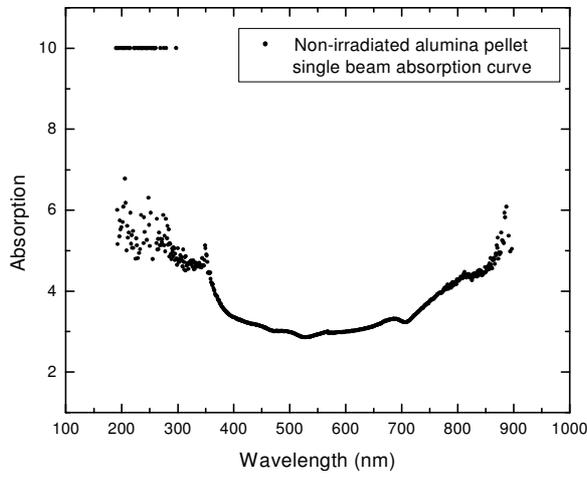


Figure 2

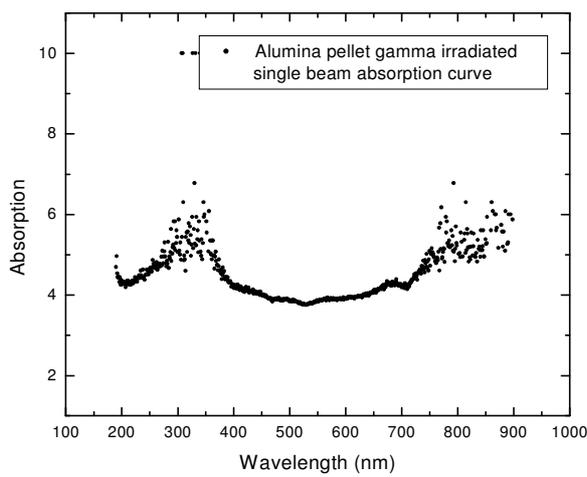


Figure 3

