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Improved extrinsic polymer optical fiber sensors for gamma-ray monitoring in radioprotection applications

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ABSTRACT

Gamma radiation detection in the range of 662 keV, the reference for environmental protection, is done through extrinsic optical fiber sensors. The fluorescence rendered by an inorganic scintillator when irradiated with such gamma rays is gathered by a modified polymer optical fiber tip. This modification increases the recorded signal when compared with plain unaltered fiber. Two fiber tip modification are then compared in terms of light gathering capability. A chemically etched fiber, in which the cladding and part of the core are removed, and a tapered fiber in which the core-cladding structure is kept. Both structures are comparable in length and final diameter, and show linear response in the tested range up to 2 Gy/h air Kerma rate. The etched fiber shows a higher slope than the tapered one, although both improve the signal gathered by a plain fiber tip. The easy fabrication and handling of the reported transducers, together with the improved signal gathering, allow to reduce the overall system budget with the use of low-cost optoelectronics in the detection stage. This offers a significant improvement for surveillance systems in radioprotection applications, in which presence of gamma radiation coming out accidental leakage or spurious sources activity is the main target.

1. Introduction

The use of optical fiber sensors is widely spread nowadays [1]. A recent novelty is the use of polymer optical fibers (POF) is such field [2,3], which adds both easy handling and interconnection to the well-known advantages of optical fiber, namely small size and weight, immunity to electromagnetic interferences, multiplexing capabilities, etc. All these features have permitted the use of fiber optic sensors for both in situ and on line monitoring of a variety of parameters, even in either difficult access areas or harsh environments.

An example of such harsh environment application is the detection and measurement of ionizing radiation. Two POF sensor types have been reported in literature, either intrinsic or extrinsic [4]. The first one is based in the so called Radiation Induced Attenuation (RIA), in which the attenuation of the fiber is measured as a function of the cumulative radiation dose. The extrinsic scheme relies in the transduction from ionizing to visible radiation through inorganic scintillators.

While intrinsic sensors have been mainly reported for both industrial applications and radioactive environments, extrinsic sensors have been essentially applied to clinic dosimetry, in which the interest relies mainly in measuring the absorbed dose of either X-ray or gamma ray by a body. This difference is also seen in the energy ranges with which each application operates. Thus, intrinsic sensors measure cumulative total dose in the range of hundreds of kGy [5,6], with energies of the photons irradiating a long fiber path lying in the range of tens to hundreds of keV. On the other side, extrinsic sensors measure the fluorescence induced in a scintillator by irradiating it, which is then gathered by an optical fiber. A variety of transducing schemes have been reported in literature. All of them coincident in attaching a POF to either a scintillating crystal [7], a scintillating powder [8] or a scintillating powder dissolved into a suitable matrix, usually an epoxy resin [9–11]. This later example has also lead to the use of specialty fabricated fluorescent fibers with different matrices [12–14]. In this case, the photons irradiating the reported transducers have higher energy than the reported for intrinsic applications. Actually, these photons are released either by radioactive isotopes (^{60}Co, ^{125}I, ^{193}Ir, etc.) or linear accelerators (LINAC) with energies ranging from 6 to 15 MeV and with dose rates around 2 Gy/h.

Another difference is that intrinsic sensors require a long fiber path and a measurement setup including a light source and a

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0030-3992/

Table 1
Data of the prepared samples for gamma radiation measurements.

	Length (mm)	Final diameter (μm)	Profile
Sample 1	20	1000	Uniform
Sample 2	15–18	680	Uniform
Sample 3	20	680	Exponential

spectrometric detector, while extrinsic sensors just need a photodetector at the detection stage. However, fluorescent measurements are more difficult due to the signal weakness. Therefore, either scientific grade photon counters or cooled spectrometers are needed. A further limitation of these extrinsic sensors is that the light is collected by the fiber tip, which restricts the effective collection volume to the limited by the numerical aperture of the fiber (0.5 for PMMA based optical fibers).

In this work, the focus is put on the radioprotection field. Thus, the interest is in monitoring either processing and storage facilities for radioisotopes or radioactive waste containers. Therefore, detection of both occasionally medium and high radiation levels, caused by any leakage or by spurious radioactive sources activity, is intended. The objective is therefore, to give an early alarm of the presence of gamma radiation instead of giving a precise lecture of the released dose rate or cumulative dose for gamma rays.

For this purpose, extrinsic sensors are best suited, due to their reduced size probe, what combined with its flexibility allows its deployment in thigh areas in radioactive facilities. However, extrinsic sensors have not been reported for energy ranges belonging to the gamma rays around 662 keV, like the released by the ^{137}Cs isotope, the reference for environmental protection due to its energy spectrum. This value is much lower than the usual one for this kind of transducers.

These kind of sensors require high performance photodetectors, which represent an increase in the system budget. Therefore, an increase in sensitivity is highly desirable in order to reduce the overall cost of the system by allowing the use of low-cost optoelectronics. Recently, a method to improve the fluorescence signal for gamma ray detection has been presented by the authors [15]. The main improvement of such approach is the increase of the effective collection area by removing the cladding and part of the core of the fiber tip. However, there is another method to increase the effective collection area that could be advantageous for the development of extrinsic transducers, since keeps the core-cladding structure of the fiber [16,17].

Here, we demonstrate the suitability of using modified polymer fiber tip for increase the fluorescence signal and thus the gamma ray detection. For this, we compare the fluorescence signal gathered by both a plain unmodified and chemically etched fiber tip. Afterwards, two methods of fiber tip modification are also compared in terms of fluorescence collection when irradiated with 662 keV photons released by a ^{137}Cs source with variable air Kerma rate ranging from 0.5 to 2 Gy/h. This means we are intended to detect a gamma radiation field in air. The obtained results show that both methods are suitable to increase the fluorescence signal. This permit to relax the constraints of the optoelectronic detection stage, since a commercial grade spectrometer can be used while keeping a signal-to-noise ratio (SNR) good enough for radioprotection purposes.

2. Transducers fabrication and experimental setup

As said before, the improvement in the SNR of the fluorescent signal has been afforded by modifying a section of the polymer optical fiber distal end. The proposed devices are based in PMMA optical fiber 1 mm diameter. The usual device reported in literature, simply strips the outer jacket off [18–21], followed by a grinding and polishing the fiber tip. Here, the fiber has been further narrowed by two different methods. The first one is based on a chemical etching that allows the removal of the cladding and part of the fiber core. The procedure is essentially depicted in [17] and involves the immersion of the fiber length to be narrowed into

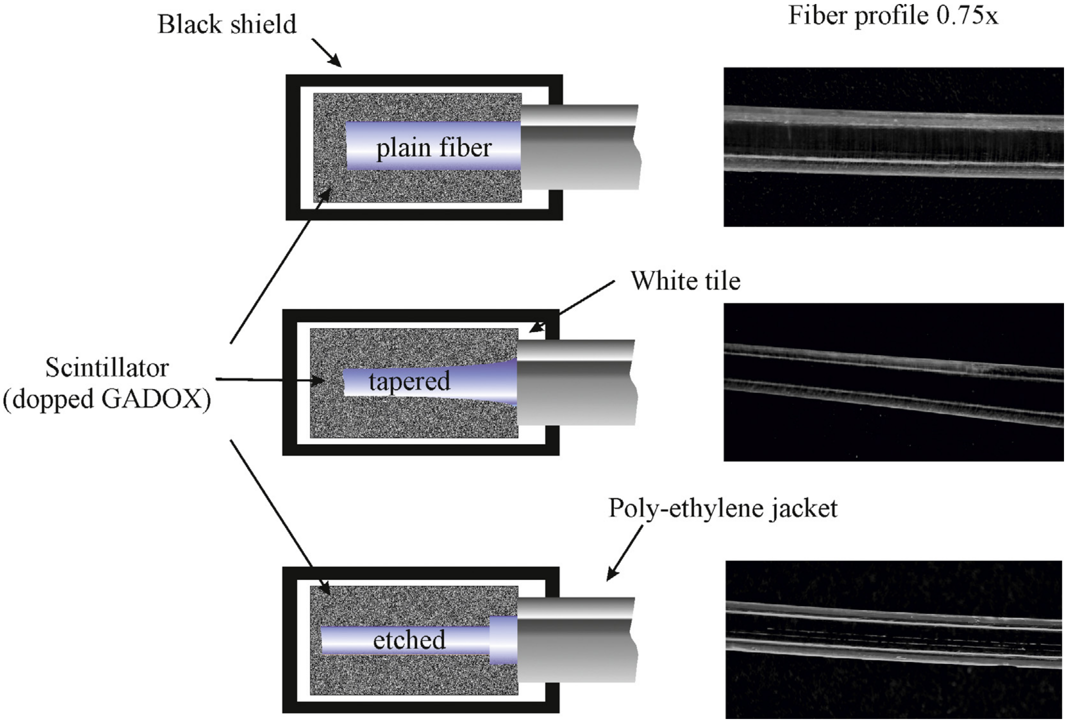

Fig. 1. Schematic draw of the fabricated transducers, with either a plain fiber tip, an etched fiber tip or a tapered one inside a microtube containing about 1 g of GADOX. Microtubes are coated internally with a white tile and black shielded externally. A picture of the fiber profile, taken with 0.75× magnification, is included for each device.