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Test of a Fiber Optic-Based LYSO Scintillator Dosimeter in a ^{60}Co Irradiation Chamber

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1. Introduction

Due to its excellent remote measurability and high spatial resolution, the fiber optic-based radiation dosimeter has been extensively explored for its usability in medical applications by several researchers [1-2]. In the previous work [3,4], we reported the result of our investigation on feasibility of a photon dosimeter constructed with a BGO($Bi_4Ge_3O_{12}$) or GSO(Gd_2SiO_5) scintillator piece coupled to a plastic optical fiber. The plastic optical fiber had a diameter of 3mm and the scintillator piece was in a cylindrical form with 5mm diameter. The size of the scitillator piece as well as the fiber should be as small as possible for higher spatial resolution, and the radiation hardness should be high enough for stable operation in strong radiation fields. Recently, LYSO(Cerium-doped Lutetium Yttrium Orthosilicate) scintillators, which have much higher light yield and radiation hardness than BGO and GSO, have been commercially available. This paper reports the result of our investigation on dosimetric characteristics of a fiber optic-based dosimeter employing a smaller LYSO scintillator piece with 2mm diameter coupled to a silica optical fiber with 1mm core diameter.

2. Materials and Experimental Methods

2.1 Dosimeter Model

As shown in Fig. 1, the dosimeter model is basically composed of a scintillator piece, a light guiding optical fiber, a current-type PMT, a dual channel picoammeter, and a PC. The scintillator is a Cerium-doped LYSO single crystal produced by Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT). It was purchased as polished in a cylindrical form of 2mm x 10mm. The optical fiber is a product (FVA100010501250) of Polymicro Technologies. The fiber is composed of silica core, doped silica clad and polyimide buffer. The core diameter is 1mm and the outer diameter is 1.25mm.

The fiber is enclosed in a fiber jacket to block off the ambient light and its ends are terminated with male SMA-type connectors. The scintillator is enlosed in a black heat shrinkable tube and attached to one end of the fiber. In order to eliminate the effect of the Cerenkov light generated in the fiber core, a second dummy fiber of the same kind but without the scintillator piece is used. Both fibers are bound together so that they can be exposed to the same amount of radiation.

The other end of each fiber is coupled to a current-type PMT with an SMA type adaptor. The PMT is a product (H6780-4) of Hamamatsu Photonics. The PMT gain is controlled between 10^2 and 10^6 by adjusting the anode control voltage between 0.25 and 0.9 V. The PMT currents from both trains are simultaneously measured with the dual channel picoammeter (Keithley 2502). The picoameter has a variable voltage source in each channel so that it can be used as the gain control voltage of the PMT. The output currents from the picoammeter are sent through an GPIB cable (KUSB-488A, Keithley) to the PC, where the net PMT current is calculated by subtracting the dummy fiber current from the sensor fiber current in LabVIEW program. This net PMT current is taken as the dosimeter current.

For the purpose of evaluating our dosimeter model, a Farmer-type ionization chamber (PTW 30-351) with a sensitive volume of 0.6cc is used as a reference dosimeter. The dosimeter has been calibrated to measure the air kerma dose rate.

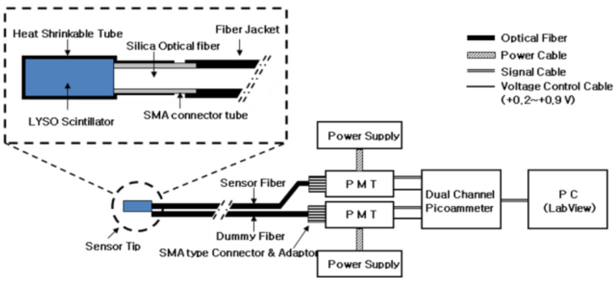

Fig. 1. Schematic diagram of the dosimeter model

2.2 Experimental Methods

Test of our dosimeter is carried out in a ^{60}Co irradiation room loaded with a source activity of 171 TBq. The PMT currents are measured at 10, 15, 20, 25, 30, 35, 40, 60, 80, 100, 120, 140, 160, 180, 200cm from the source along a straight radial line. The measuring time is 2 minutes at each point. 5 measurements are made at each point and the average of them is used for evaluation. The air kerma dose rates are also measured at the same points with the Farmer type ionization chamber and these values are taken as reference dose rates. The reference dose rate varies from 13Gy/h (at 200cm) to 1616 Gy/h (at 10cm).

The background currents (the currents without the source) from both fiber trains were slightly different from each other even at the same PMT control voltage.

We assume this should result from differences in the intrinsic characteristic of both PMTs. In order to have the same background current, we adjusted the anode control voltage of both PMTs to 0.7V for the sensor fiber train and 0.74V for the dummy fiber train.

2. Results and Discussion

Fig. 2 shows variation of the dosimeter current with respect to the reference dose rate. The solid line represents a linear fitting of the dosimeter current data to the reference dose rates. The fit function obtained by ORIGIN 6.1 graphing program is expressed as I=a*D + b, where I is the dosimeter current (A), D is the reference dose rate (Gy/h), and a and b are fitting constants obtained as $4.75x10^{-8}$ and $3.68x10^{-7}$, respectively. The correlation constant and standard deviation of the linear fitting were given as 0.99995 and 2.26466E-7, respectively. As the correlation constant approaches unity, better linearity is attained and the standard deviation decreases. In order for a dosimeter to work properly, its reading should be proportional to the true dose. From the correlation constant of almost unity and the very small standard deviation, we find that the reading of our dosimeter model is almost proportional to the reference dose rate in the considered dose rate range, about 10~1600Gy/h.

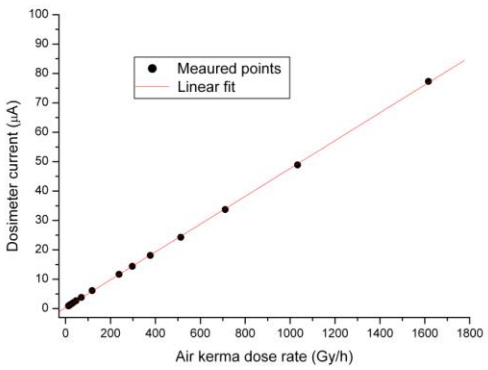

Fig. 2. Linear fitting of dosimeter current with respect to the reference air kerma dose rate measured with a Farmer type dosimeter

For the purpose of evaluating the accuracy of our dosimeter model, we derive a calibration function to be used for the conversion of the dosimeter current into the air kerma dose rate. The calibration function is obtained from the fit function by a simple transformation to the form $D=\alpha * I + \beta$, where α and β are calibration constants, computed to be $2.105x10^{7}$ and -7.74, respectively. Using this calibration function, we converted the dosimeter currents into the dose rates at all points. Table I. compares the dose rates measured with the ionization chamber (reference) and our dosimeter model (converted). The relative errors shown are estimated by the formula: $Error(\%) = \frac{D - D^*}{D^*} \times 100$, where D and D* represent the converted and reference dose rates, respectively. The errors are less than ±7%. Considering that a single linear calibration function has been used for the whole dose rate range, the errors are within acceptable range.

Table I. Comparison of the reference and converted dose rates

Position (cm)	Reference Dose rate (Gy/h)	Converted dose rate (Gy/h)	Relative Error (%)
10	1616	1621	0.60
15	1033	1023	-0.73
20	711	701	1.07
25	513	505	1.26
30	377	374	0.68
35	297	295	0.08
40	238	240	1.13
60	118	122	3.45
80	70	73	5.17
100	46	49	5.35
120	33	35	4.48
140	25	26	2.90
160	19	19	0.38
180	16	15	3.41
200	13	12	-6.78

3. Conclusions

A fiber optic-based LYSO scintillator dosimeter model has been constructed and calibrated in a ^{60}Co irradiation room using a commercial Farmer type ionization as reference. A single linear calibration function has been obtained in the air kerma dose rate range, about 10~1600Gy/h. Using this calibration function, the dosimeter model shows acceptable deviation from the commercial dosimeter. It is concluded that the dosimeter can be used as a gamma ray dosimeter in the considered dose range.

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