Nuclear Instruments and Methods in Physics Research A 773 (2015) 72–80

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical Notes

A SiPM based real time dosimeter for radiotherapic beams

A. Berra [a,*], V. Conti [b], D. Lietti [a], L. Milan [a], C. Novati [a], A. Ostinelli [b], M. Prest [a], C. Romanó [a], E. Vallazza [c]

[a] Università degli Studi dell'Insubria e INFN sezione di Milano Bicocca, Via Valleggio, 11 22100 Como, Italy
[b] Ospedale Sant'Anna, Servizio di Fisica Sanitaria, Como, Italy
[c] INFN sezione di Trieste, Italy

ARTICLE INFO

Article history:
Received 30 July 2014
Received in revised form
28 October 2014
Accepted 1 November 2014
Available online 7 November 2014

Keywords:
Radiation dosimetry
Silicon PhotoMultipliers
Scintillator

ABSTRACT

This paper describes the development of a scintillator dosimeter prototype for radiotherapic applications based on plastic scintillating fibers readout by Silicon PhotoMultipliers. The dosimeter, whose probes are water equivalent, could be used for quality control measurements, beam characterization and in vivo dosimetry, allowing a real time measurement of the dose spatial distribution. This paper describes the preliminary percentual depth dose scan performed with clinical 6 and 18 MV photon beams, comparing the results with a reference curve. The measurements were performed using a Varian Clinac iX linear accelerator at the Radiotherapy Department of the St. Anna Hospital in Como (IT). The prototype has given promising results, allowing real time measurements of relative dose without applying any correction factors.

1. Introduction

Modern radiotherapy heavily increased the use of complex radiation fields. Intensity-modulated radiotherapy (IMRT) [1,2], helical Tomotherapy [3], CyberKnife robotic radiosurgery [4,5] and stereotactic radiosurgery [6,7] use sequences of high modulated and/or small fields whose dosimetry is not trivial.

Care should be taken in selecting the correct dosimeter. Too large dosimeters can suffer from loss of electronic equilibrium, may cause a local fluence perturbation and produce a dose-averaging response. Sometimes, a beam control during the treatment delivery may also be useful, requiring a tissue equivalent dosimeter not perturbing the treatment itself. An ideal dosimeter should be easy to use, small, possibly real time and water-equivalent.

The need for new types of dosimeters is thus becoming increasingly important taking into account also the necessity of reliable and time sparing quality assurance (QA) protocols. This paper describes the development of a small scintillating fiber dosimeter prototype, able to provide water equivalent and real time measurements of the clinical radiation beam.

The advantages of plastic scintillator dosimeters in comparison with standard devices are treated in Section 1. In Sections 2 and 3 the structural features of the dosimeter prototype and its readout electronics are described, paying particular attention to the description of the Silicon PhotoMultipliers (SiPMs). Section 4 presents the setup and the measurement method, while Section 5 describes the characterization with phantom measurements. Conclusions and future outlooks are treated in Section 6.

2. Why a scintillator dosimeter?

There are several dosimeters used commonly in radiotherapy, each of them presenting advantages and drawbacks [8].

Ionization chambers are accurate and precise but they have no excellent spatial resolution (their smaller sensitive volume is $\sim 10\ mm^3$) and the dose evaluation requires the application of complex conversion factors. Diodes can have a very small sensitive volume (up to $1\ mm^3$) but not well verifiable (due to the depletion zone instability). Usually, both ionization chambers and diodes, being single channel devices, have to be moved to map the radiation field. In the last years, however, arrays of ionization chambers were developed [9]; these arrays can perform two-dimensional measurements with a spatial resolution of 5 mm.

Radiographic and radiochromic films have a very good 2D resolution ($\sim 1\ \mu m$) but they need a complex and long readout procedure, resulting in non-real time devices; electronic portal imaging devices (EPIDs) are promising 2D dosimeters but they are not water equivalent and need an accurate calibration [10,11].

Thermoluminescent dosimeters (TLDs) are available in different sizes and shapes but both the preparation procedure and the readout one are very time consuming since, before the irradiation, they have to undergo an annealing cycle that requires several hours and must be repeated after each measurement.

* Corresponding author: Università degli Studi dell'Insubria, Via Valleggio, 11 - 22100 Como, Italy.
E-mail address: alessandro.berra@gmail.it (A. Berra).

http://dx.doi.org/10.1016/j.nima.2014.11.001
0168-9002/

Our prototype, based on scintillating fibers readout by SiPMs, is proposed as a competitive alternative to the traditional devices, being real time, easy to handle and operate, radiation hard, water equivalent and with a good scalability for a multichannel device; moreover, the absence of high voltage within the detector volume makes the dosimeter suitable for in vivo measurements.

The first attempts to assemble a scintillator device for dosimetric purposes were reported in the 1960s and in the 1970s [12,13]. However the first comprehensive study about the applicability of scintillators to clinical dosimetry was published in 1992 [14]. During the last dozen years, the interest about dosimeters based on scintillators has grown [15], leading several research groups to develop prototypes for different applications (for example: external radiotherapy with small beams [16], intraoperative radiotherapy [17], in vivo dosimetry [18]).

The main problem that can affect the measurement accuracy of scintillator dosimeters is the Cherenkov radiation which is emitted when charged particles cross a transparent material at a speed larger than the light speed in the same material. It is a threshold phenomenon, which occurs when $n\beta > 1$ where n is the refractive index of the transparent medium and β is the ratio of the particle and the light speed in vacuum. Cherenkov radiation is not proportional to the absorbed dose, so it has to be distinguished from scintillation light; several methods were proposed to reach this goal [19].

For our dosimeter the simplest and most reliable one was adopted: the scintillating fiber is paired with a white one of identical shape and material, in which only the Cherenkov radiation is produced; the light can be collected by a dedicated readout channel and subtracted offline.

3. The prototype characteristics

The scintillating dosimeter prototype described in this paper consists of a single probe dosimeter, whose assembly is based on the results described in [20]. The most important improvement with respect to the previous prototype is the use of SiPMs for the light readout.

SiPMs belong to the new frontier of readout systems for scintillating detectors. A SiPM consists of a matrix of silicon photo-diodes connected in parallel and operated in the Geiger–Muller regime [21,22]. The thin layer of silicon dioxide (SiO_2) placed over the p–n junction allows us to generate a very intense electric field in the junction region. In this way photons impinging on the SiPM generate electron–hole pairs in the junction causing a Geiger discharge. Even if each pixel acts as a binary device, the number of hit pixels is proportional to the number of photons (for moderate fluxes) thus providing an analog information. Silicon PhotoMultipliers present many advantages with respect to classical PhotoMultiplier Tubes (PMTs): they require a small bias voltage (~40 V), they are insensitive to magnetic fields (up to 1.5 T) and have a limited dimension and weight (a few mm^3 and a few grams with respect to tens of cm^3 and a hundred of grams for PMTs). The main drawbacks are the large dark count rate, the limited dynamic range (due to the finite number of available pixels) and the dependence on temperature of their main parameters [23].

SiPMs were previously tested as light readout devices for plastic dosimeters in [24] with good results. With respect to this paper, we preferred to use a standard approach for the Cherenkov subtraction (two parallel fibers) and the use of a charge integrating electronics instead of the counting one described in [24].

The dosimeter probe consists of a couple of fibers (a scintillating and a white one) readout by two SiPMs: while the scintillating fiber is devoted to the dose readout, the white fiber has to collect the Cherenkov radiation, whose signal is then subtracted offline from the scintillating one. Both the fibers (10 mm long and with a diameter of 1 mm) are optically glued to white 30 cm long (1 mm diameter) fibers, whose function is to carry the light to the SiPMs: plastic adapters (Fig. 1) were used to mechanically match the SiPMs to the optical fibers. A sketch of the dosimeter probe is presented in Fig. 1c.

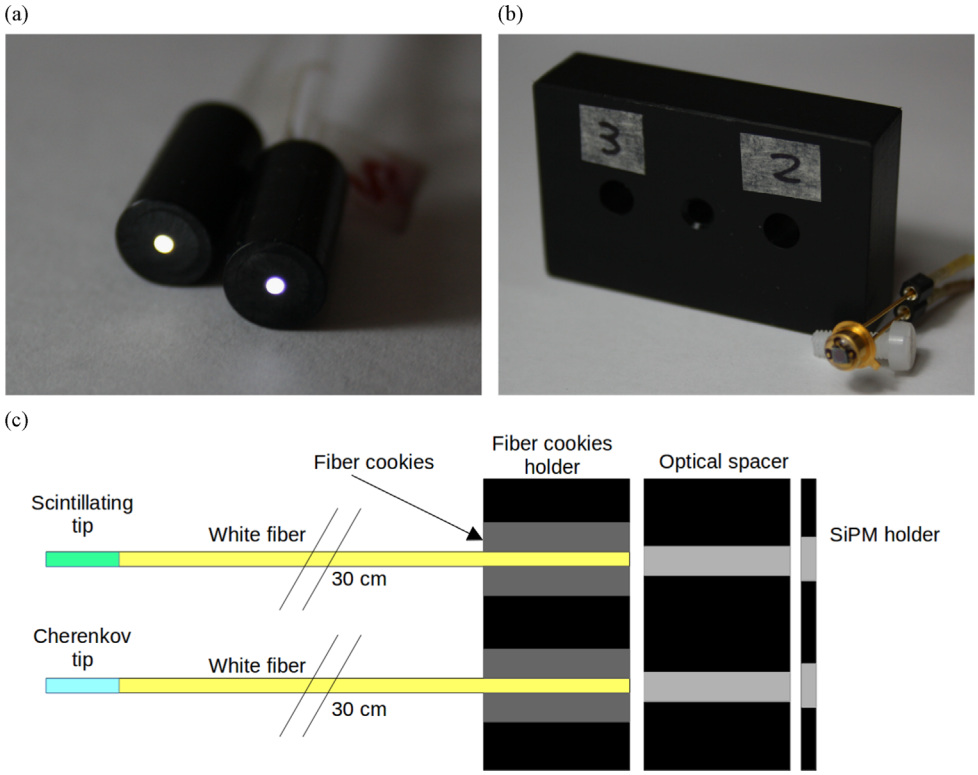

Fig. 1. Fiber cookies (a), SiPMs plastic support (b) and schematic drawing of the dosimeter probe (c); the blueish fiber on the right of (a) is the scintillating one. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)