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Feasibility study of radiation quality assessment with a monolithic silicon telescope: Irradiations with 62 AMeV carbon ions at LNS-INFN

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ABSTRACT

The Segmented Monolithic Silicon Telescope, a two-stage detector recently proposed as a solid state microdosimeter, demonstrated to be capable of measuring the microdosimetric spectra of clinical proton beams similar to those measured by reference tissue-equivalent proportional counters. This work concerns the study of the possibility of exploiting this feature for carbon beam quality assessment. To this aim, the silicon device was placed in a polymethylmetacrylate phantom and irradiated with a 62 AMeV un-modulated carbon beam at the cyclotron facility of the Laboratori Nazionali del Sud of the Italian Institute of Nuclear Physics.

The results of these preliminary measurements will be discussed in details.

1. Introduction

The microdosimetric characterization represents a useful method for the quality assessment of hadron beams (Wambersie et al., 1990; Menzel et al., 1990). The possibility of performing dosimetry and quality assessment at the same time allows a detailed picture of the physical properties of clinical beams and permits the investigation of the effectiveness of a therapeutic treatment (Menzel et al., 1990; Coutrakon et al., 1997; De Nardo et al., 2004). Efforts should be made for developing experimental techniques able to measure microdosimetric distributions in hadron beams. Standard tissue-equivalent proportional counters (TEPCs) cannot sustain the particle current of clinical hadron beams (De Nardo et al., 2004), while miniaturized TEPCs (mini-TEPCs) are fairly complex and difficult to use.

Recently, an alternative solid state detector, easy-of-use and transportable, was proposed and studied by Agosteo et al. (2010) for the microdosimetric characterization of clinical proton beams. In particular, a segmented silicon device based on the monolithic silicon telescope technology (Segmented Monolithic Silicon Telescope, SMST) was irradiated with a modulated beam at the CATANA proton therapy facility (Catania, Italy) and results were compared with those obtained with a reference TEPC. The agreement was satisfactory.

This work describes the study carried out to investigate the possibility of using the SMST for performing microdosimetric measurements of ^{12}C ion beams.

2. Materials and methods

The SMST was designed and developed in collaboration with ST-Microelectronics (Catania, Italy) (Tudisco et al., 1996; Agosteo et al., 2005). As sketched in Fig. 1a, the device consists of a thin surface detector ΔE, about 2 μm in thickness, and a deep detector E, about 500 μm in thickness, made out of a single silicon wafer. The two detectors, called stages, share a deep p^+ electrode (obtained through a high energy ion implantation) which acts as a "water-shed" for the collection processes. The SMST is characterized by a ΔE detector geometrically segmented in a matrix of cylindrical elements, about 9 μm in diameter and 2 μm in height (see Fig. 1b). The elements are surrounded by guard rings about 14 μm in diameter and electrically connected in parallel. The segmented ΔE detector have a total sensitive area of about 0.125 mm^2 and is coupled to a single E detector about 25 mm^2 in area.

Owing to the dimensions of its active volume, the segmented ΔE detector is in principle a microdosimeter, while the E detector can give information about the kind and the energy of the impinging particle.

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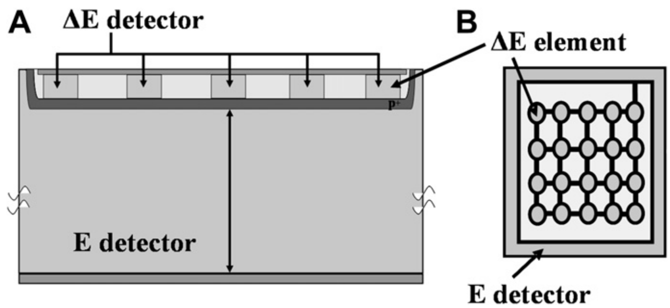

Fig. 1. Cross section (A) and front-view (B) of the SMST. This device consists of a thin surface ΔE detector coupled to a thick detector E made out of a single silicon wafer. In particular, the ΔE detector is geometrically segmented in more than 1800 cylindrical elements (about 9 μm in diameter and 2 μm in height) connected in parallel to give an effective sensitive area of about 0.125 mm^2.

The SMST was irradiated with 62 AMeV carbon ions at the cyclotron facility of the INFN-Laboratori Nazionali del Sud (LNS, Catania, Italy). In order to characterize the carbon beam, the silicon device was wrapped in a metalized mylar foil and placed in a PolyMethylMethAcrylate (PMMA) bar 1 × 1 cm^2 in cross section. This bar was inserted in a PMMA cube 12 × 12 × 12 cm^3 in volume (Fig. 2). At each measurement position, an adequate number of PMMA foils of different calibrated thickness (about 3 mm, 2.5 mm and 50 μm in thickness) were located in front of the detector in order to reproduce the desired depth. Both detector stages were biased and the associated signals were independently amplified and shaped. The pulses generated in the two stages, whose amplitudes contain information about the energy ϵ imparted per event in the silicon ΔE and E detectors, were acquired by a custom two-channel ADC in coincidence mode in order to maintain the time correlation.

3. Irradiation of the SMST with 62 AMeV carbon ions

3.1. Depth dose profile of the primary beam

The response of the SMST to carbon ions and the associated fragments was studied by acquiring and processing the distributions of the energy ϵ imparted per event in the ΔE detector versus that deposited in the E detector, referred as ΔE–E scatter plot in the following. Fig. 3 shows the depth dose distribution across the PMMA irradiation set-up resulting from Monte Carlo simulations performed with the FLUKA code (Fassò et al., 2005). Points A–L in Fig. 3 indicate the adopted measurement positions. In particular, points A–H refer to measurements across the Bragg peak, while points I–L refer to measurements beyond the Bragg peak.

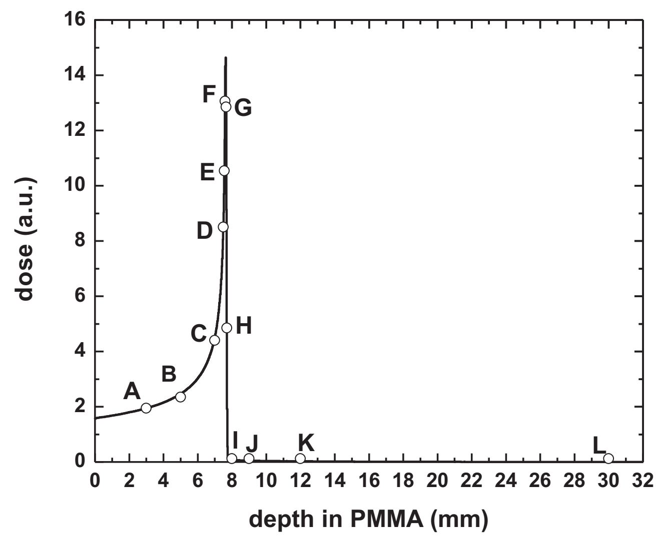

Fig. 3. Depth dose distribution across the PMMA irradiation set-up resulting from Monte Carlo simulations performed with the FLUKA code. Points A–L indicate the adopted measurement positions (3, 5, 7, 7.5, 7.55, 7.6, 7.65, 7.7, 8, 9, 12, 30 mm respectively).

The SMST was irradiated with 62 AMeV carbon ions at different PMMA depths, namely points A–H in Fig. 3. At each measurement position, the collection of the microdosimetric distribution allowed the estimate of the absorbed dose D and of the associated statistical fluctuations. In particular, D was calculated from the energy ϵ imparted per event in the silicon ΔE detector by using the following expression (ICRU, 1983):

$$D \cong N \cdot \int_{z_{\min}}^{z_{\max}} z \cdot f(z) \cdot dz \qquad (1)$$

where z is the specific energy, defined as the ratio of the ϵ and the mass m of the sensitive volume of the ΔE detector, and N is total number of collected events. In order to estimate the relative dose profile, the calculated values were normalized to monitor units acquired with a reference ionization chamber of the beam delivery system (Cirrone et al., 2004).

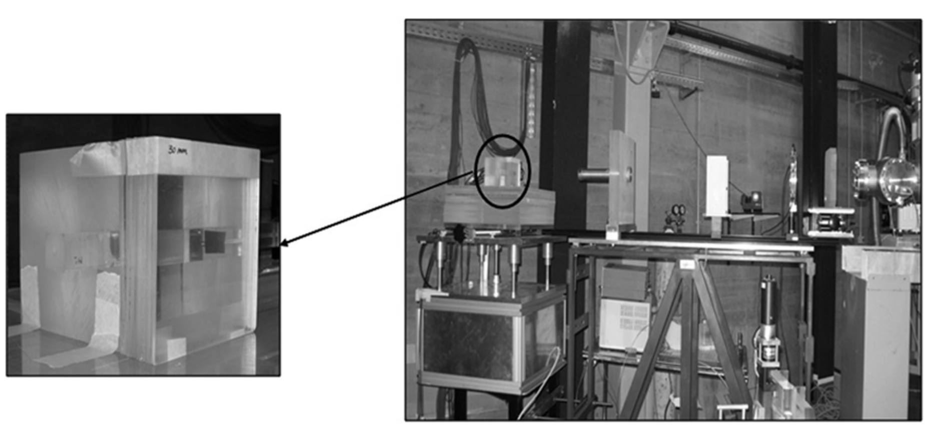

Fig. 2. Experimental set-up. The silicon device, wrapped in a mylar foil, was placed inside a PMMA bar 1 × 1 cm^2 in cross section. This bar was inserted in a groove made in a PMMA cube 12 × 12 × 12 cm^3 in volume.