A pixelated silicon telescope for solid state microdosimetry

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INTRODUCTION

A monolithic silicon telescope (consisting of a ΔE and an E stage, 2 µm and 500 µm thick, respectively) coupled to a polyethylene converter was proposed as a solid state microdosimeter [1]. The result of a comparison with a cylindrical tissue-equivalent proportional counter (TEPC) highlighted some discrepancies in the shape of the distribution of energy imparted per event, especially in the high-energy part of the spectrum (see figure 1). These discrepancies were attributed to geometrical effects related to the wide sensitive area (1 mm^2) of the ΔE stage.
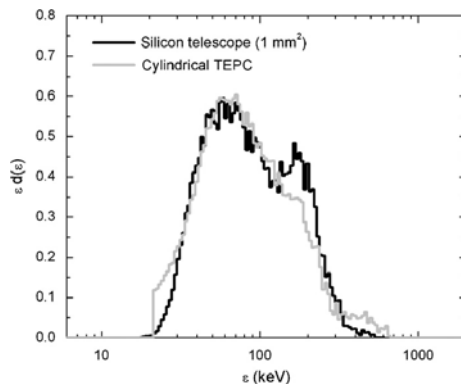

FIG. 1: *Comparison between the dose distribution of the energy imparted per event acquired with a TEPC (2.67 µm site diameter) (grey line) and with ΔE stage of the monolithic silicon telescope with sensitive area about 1 mm^2 [1] (black line). The detectors were irradiated with 2.7 MeV monoenergetic neutrons.*

In order to minimize these effects, a new telescope constituted by a matrix of cylindrical ΔE elements of a few micrometers in diameter was constructed. The detection system was irradiated with mono-energetic neutrons in the same conditions of the previous comparison with the TEPC. The distribution of the energy imparted per event was corrected for tissue-equivalence. The dose distribution of lineal energy was calculated by taking into account the geometrical dimensions of a single ΔE element.

The device is constituted by a matrix of cylindrical ΔE elements (about 2 µm thick) implanted on a single E stage (500 µm thick). The pixels are about 9 µm in nominal diameter and the pitch among them is about 41 µm. More than 7000 pixels are connected in parallel to give an effective detection area of about 0.5 mm^2.

The capacitance of the entire matrix results to be about 200 pF. The minimum detectable energy was limited to about 20 keV by the electronic noise. Therefore, the applicability of this silicon microdosimeter is addressed to high LET particles.

EXPERIMENTAL SET-UP

The pixelated ΔE-E detector was coupled to a 1 mm thick polyethylene converter and was irradiated with 2.7 MeV neutrons produced at the LNL-Van de Graaff accelerator via the $^7Li(p,n)^7Be$ reaction. Both the ΔE and the E detectors were biased and the signals generated in the two stages were amplified and shaped using two independent electronic chains. The electronic pulses generated in the two stages were acquired by a two-channel ADC in coincidence mode, in order to maintain the time correlation between the ΔE and the E signals.

The ΔE-E scatter plot is shown in figure 2. The high-LET distribution (a) corresponds to recoil-protons generated in the polyethylene converter by the impinging neutrons, while the low-LET one (b) is due to secondary electrons generated in the detector assembly by photons associated to the neutron field [2]. In addition to these two contributions, a third set of events located in an intermediate region (c) can be also observed.
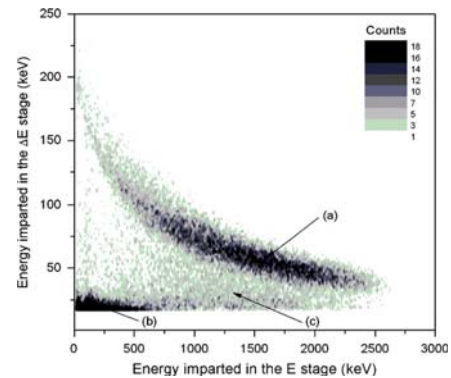

FIG. 2: *Scatter plot of the energy imparted in the ΔE stage $E_d^{ΔE}$ versus energy imparted in the E stage E_d^E acquired by irradiating the pixelated silicon telescope with 2.7 MeV mono-energetic neutrons. The high-LET distribution (a) corresponds to recoil-protons, while the low-LET one (b) is due to secondary electrons. In addition, a third set of events located in an intermediate region (c) can be also observed.*

This additive contribution was absent in the irradiation

of the detector with a wider sensitive area [1] and may be due to: i) the different track length distribution of the cylindrical ΔE stages of the pixelated detector; ii) border effects, such as charge sharing between the ΔE collecting electrode and its surrounding guard. The contribution of these effects results to be of the order of a few percent and it will be neglected.

CORRECTION CRITERIA

The distribution of the energy imparted in the ΔE elements of the silicon pixelated detector has to be corrected for tissue-equivalence in order to derive a microdosimetric spectrum comparable to that acquired with a TEPC.

The correction procedure calculates the energy imparted in a tissue-equivalent ΔE element by scaling that measured by the silicon ΔE detector with the energy-dependent ratio of the stopping powers in tissue and in silicon of the interacting particles, i.e. recoil-protons and secondary electrons. This procedure was optimized by measuring the energy of recoil-protons with the E stage of the telescope and by discriminating them from secondary electrons.

In order to optimize the comparison between the two different detectors, a shape equivalence correction was applied. This procedure was based on the parametric criteria given in the literature [3], i.e. by equating the dose-mean energy imparted per event $\overline{\varepsilon}_D$ for the TEPC and the ΔE element. The criteria for tissue-equivalence and shape-equivalence applied for the pixelated ΔE-E detector were discussed in ref. [4].

INTERCOMPARISON WITH A TEPC

A cylindrical TEPC filled with a propane-based tissue-equivalent gas was irradiated with monoenergetic neutrons at the LNL Van de Graaff accelerator, under the same conditions selected for the measurements performed with silicon detector. The pressure of the filling gas was set in order to simulate a 2.67 μm cylindrical site. The dose distributions of the lineal energy measured by the TEPC and by the pixelated silicon telescope (after the corrections) are compared in figure 3. The agreement of the two distributions demonstrates the minimization of geometrical effects observed in figure 1. The discrepancy at lineal energies higher than about 200 keV μm⁻¹ is due to alpha particles generated via the ^{14}N(n,α)^{11}B reaction (energy threshold 0.17 MeV) in the tissue-equivalent plastic of the TEPC. These particles are absent in the spectrum acquired by the ΔE-E detector since a polyethylene converter was used. At lineal energies lower than 20 keV μm⁻¹ differences due to geometrical effects
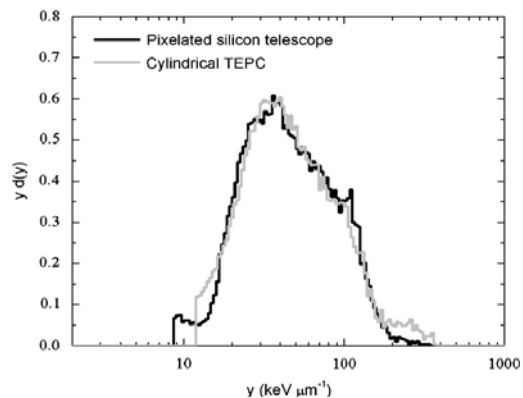

FIG. 3: *Comparison between the dose distribution of the lineal energy acquired with a TEPC (2.67 μm site diameter) (grey line) and with ΔE stage of the pixelated silicon telescope after the corrections for tissue-equivalence and geometrical shapes (black line). The detectors were irradiated with 2.7 MeV mono-energetic neutrons.*

still persist.

By excluding values of lineal energy higher than 200 keV μm⁻¹, i.e. the alpha-particles, the calculated frequency-mean lineal energy $\overline{y}_F$ results to be 36.6 ± 1.5 keV μm⁻¹ for the cylindrical TEPC and 34.5 ± 2.2 keV μm⁻¹ for the silicon microdosimeter, while the dose-mean energy imparted per event $\overline{y}_D$ is equal to 52.2 ± 2.1 keV μm⁻¹ for the TEPC and 52.1 ± 3.1 keV μm⁻¹ for the silicon microdosimeter.

CONCLUSIONS

A telescope constituted by a matrix of cylindrical ΔE elements of a few tens of micrometers in sensitive area was constructed and tested. The aim was to minimize geometrical effects that distorted the microdosimetric spectra measured by a silicon telescope with an area of the order of one mm².

The preliminary results of a comparison with a TEPC simulating a 2.67 μm tissue cylinder have been discussed. The agreement between the dose distributions of the lineal energy was satisfactory. Discrepancies due to geometrical effects still persist but their importance was reduced significantly with the new telescope matrix. A systematic comparison at different neutron energies will be performed in the future.

[1] S. Agosteo et al., Radiat. Prot. Dosim. **122** (2006) 382.
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