

CHARGE COLLECTION IMAGING OF A MONOLITHIC ΔE -E TELESCOPE FOR RADIATION PROTECTION APPLICATIONS

I. Cornelius^{1,*}, A. Rosenfeld¹, M. Reinhard², A. Fazzi^{3,4}, D. Prokopovich^{1,2},
A. Wroe¹, R. Siegel², A. Pola^{3,4} and S. Agosteo^{3,4}

¹Centre for Medical Radiation Physics, University of Wollongong, Northfields Ave, 2522, Australia

²Australian Nuclear Science and Technology Organisation, PMB 1, Menai, Australia

³Dipartimento di Ingegneria Nucleare, Politecnico di Milano, Italy

⁴Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Italy

The development of microdosimeters and particle telescopes is important for risk assessment in space and aviation applications. The charge collection properties of a monolithic particle telescope, suitable for both microdosimetry and fluence based approaches, were studied using an ion microprobe.

INTRODUCTION

Personnel taking part in space and aviation applications may be exposed to harmful levels of mixed radiation fields. To account for the variation in radiation quality, the ICRP recommends a weighting factor, w_R , be applied to the absorbed dose from each radiation type. For ions, w_R is a function of linear energy transfer (LET); however, there is compelling evidence that different biological effects can occur from different particles of the same LET. Alternative approaches are being explored (described in detail in NCRP report 137). The microdosimetry approach assumes that the quality of a radiation is related to the energy deposited, ϵ , in a microscopic sphere. Owing to the stochastic nature of energy deposition in a microscopic volume, a given mixed radiation field will be characterised by a dose weighted spectrum, $d(\epsilon)$. The equivalent dose, H , may then be calculated as the integral of $Q(\epsilon)d(\epsilon)d\epsilon$. The fluence based approach does away with the concepts of absorbed dose, weighting factors, and equivalent dose and instead considers the risk cross section, $r\sigma_i$, as the probability per unit fluence of observing some biological effect such as cancer induction. The risk, R_i , posed by the radiation is then given by the integral of $r\sigma_i(E)\Phi_i(E)dE$. Research into microdosimetry using silicon devices was pioneered by Dicello *et al.*⁽¹⁾ and Rosenfeld *et al.*⁽²⁾. Recent work has been carried out by Agosteo *et al.* using the ΔE stage of a ΔE -E telescope (Figure 1 left) as a microdosimeter in neutron fields⁽³⁾. Such devices are of particular interest as they may be used to obtain the quantities $d(\epsilon)$ and $\Phi_i(E)$ to be used with both microdosimetry and fluence based approaches. The aim of this work is to investigate

the charge collection properties of the ΔE -E telescope using an ion microprobe. In particular, we investigate the boundaries of the ΔE sensitive volume, the uniformity of the ΔE layer thickness, and the importance of channeling.

METHODS

The device was manufactured by STMicroelectronics (Catania, Italia) and consists of a ΔE and E stage of thicknesses 1 μm and 500 μm . These stages share a common p+ anode which is created by low energy boron implantation. The ultra-thin n+ cathode for the ΔE stage is formed by As implantation and contact is made by a 0.2 μm thickness Al/Si layer. Experiments were carried out at the Australian Nuclear Science and Technology Organisation using the ion microprobe and a technique known as Ion Beam Induced Charge Collection (IBICC) imaging⁽⁴⁾. The microprobe is situated on a beamline of a 10 MV Tandem Van de Graaf accelerator. A 3 MeV helium beam was focussed using a quadrupole triplet to a spot size of $\sim 5 \mu\text{m}$. Using orthogonal scanning coils, this beam was scanned over a $1.4 \times 1.4 \text{ mm}^2$ area. Using a 3 channel data acquisition system, the charge collected (proportional to energy) from the ΔE stage of the device was measured in coincidence with the beam coordinates. A data triplet (ΔE , X, Y) was then stored in list mode for each ion strike on the device. Four scans of the device were performed and images of the median charge collected at each beam location were created and combined to form an image for the entire device.

A second experiment was performed using a multi-ADC data acquisition system. This allows the measurement of a data quadruplet (ΔE , E, X, Y) for each ion strike: the charge collected from both the

*Corresponding author: iwan@uow.edu.au

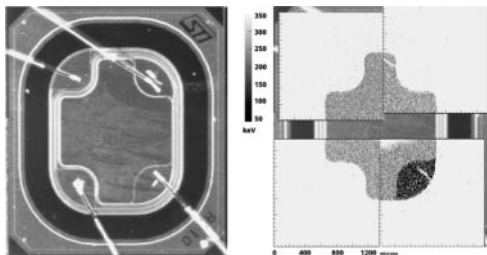


Figure 1. Optical image of the device (left) showing various bonding pads for the p+ anode and n+ cathodes. IBICC maps of charge collected from the device (right).

ΔE and E channels in coincidence with the beam coordinates. In this case, a single scan was made over the lower right corner of the device and a list mode file was created. This file was then analysed to yield a 2-D intensity plot of the number of counts: $N(\Delta E, E)$. Regions of interest were identified and used to create spatial maps which correlate these events with parts of the device.

RESULTS AND DISCUSSION

Figure 1 (right) shows a mosaic of the four IBICC scans of the device as measured by the ΔE channel. There is uniform charge collection in the ΔE stage, suggesting a uniform thickness sensitive volume. The mean energy deposition is 260 keV and ignoring energy loss in the overlayer, this gives a rough estimate of the ΔE thickness of $1.3 \pm 0.15 \mu\text{m}$. Randomly distributed low (lighter grey) energy events may result from the channeling of ions; or variation in the depth of the buried p+ layer. There is reduced charge collection for ion strikes at the bonding pad of the ΔE cathode (mean value of 50 keV). This suggests a thinner overlayer over this part of the device or a thinner sensitive volume. Regardless of its origin, this feature will effect application of the device as a microdosimeter or particle telescope as it will introduce artefacts into the measured spectra. The $N(\Delta E, E)$ plot is shown in Figure 2. Two main peaks exist in the spectrum. The first peak occurs at higher values of ΔE and E. A tail extends from this peak to lower values of ΔE and higher values of E. The slope of the tail is approximately -1 , which implies that these events are due to channeled ions or charge funneling: any energy lost from the ΔE stage is gained in the E stage, hence $d(\Delta E)/dE$ is approximately -1 . The notion of channeling was confirmed by tilting the sample $1-2^\circ$; the number of counts in the tail was drastically reduced. To correlate events in the ΔE -E spectrum with locations on the device, two regions of interest were created. Figure 3 (left) shows the spatial distribution of events from region

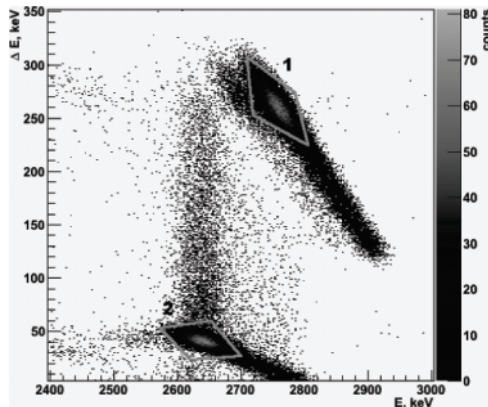


Figure 2. The ΔE -E spectrum for the scan of the lower right corner of the device. Regions of interest used in Figure 3 are indicated.



Figure 3. Spatial maps of ion strikes corresponding to region 1 (left) and region 2 (right) of the ΔE -E spectrum of Figure 2.

1: events are confined to the centre of the ΔE stage. Figure 3 (right) shows the spatial distribution of events from region 2: in this case events are confined to the bonding pad. The fact that there is charge lost from both ΔE and E stages for ion strikes at the bonding pad suggests both a thinner ΔE stage and thicker dead layer (between ΔE and E stages) under the bonding pad.

CONCLUSION

The charge collection properties of a monolithic particle telescope, suitable for both microdosimetry and fluence based approaches, was carried out using an ion microprobe. A charge collection map of the ΔE stage was created using standard IBICC data acquisition. Features were identified which could detrimentally affect the microdosimeter's performance (lower charge collection at the bonding pad and randomly distributed low energy events on the device). A novel, more sophisticated, multiple parameter IBICC technique was then employed to shed light on the origins of these features; namely, the occurrence of ion channeling and the existence of a dead layer beneath the bonding pad between ΔE

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and E stages. The fabrication of future devices can be modified in order to mitigate these effects.

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