COMPARISON OF PADC NEUTRON DETECTORS FROM DIFFERENT SUPPLIERS

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The objective of this study was to compare poly-allyl diglycol carbonate (PADC) track detectors from different suppliers for linear energy transfer (LET) spectrometry and neutron dosimetry. PADCs are commonly used for passive personal neutron dosimetry, where a common approach is to couple the PADC with a plastic radiator to generate secondary charged particles. The neutron dose can be estimated using the track density or the average LET of the secondary particles. The characterisation of PADC in terms of LET spectrometric capability and neutron sensitivity was previously performed using PADC from InterCast S.r.l., Parma, Italy, but this company stopped the production. Since it is common experience that material from different suppliers can have different properties, it became necessary to perform a comparison of PADCs from different suppliers with the InterCast material. The study permits to compare the reading procedures used at Politecnico di Milano and at the Paul Scherrer Institute.

INTRODUCTION

Poly-allyl diglycol carbonate (PADC)-based neutron dosimetry is one of the most used techniques for passive personal neutron dosimetry. One approach consists in coupling the PADC to a plastic radiator and counting the neutron-induced tracks due to secondary particles created by neutron interaction with the radiator and the PADC itself, mainly protons in case of neutron energy below ~ 10 MeV. For higher neutron energy, ^2H , ^3H and alpha particles can be produced via inelastic scattering. Alternatively, the tracks can be analysed to calculate the linear energy transfer (LET) spectrum of the secondary particles in the detector, from which a dose can be obtained by weighting the energy deposited by each particle with the LET-dependent quality factor⁽¹⁾. The LET measured by the PADC is averaged over the portion of the particle path defined by the product of the track etch rate by the etching time. In the article, this quantity is referred as LETnc to underline the difference from the definition of the LET.

A previous study^(1, 3) characterised PADCs from InterCast S.r.l. (Parma, Italy) in terms of neutron sensitivity and LETnc spectrometry capabilities, but the company stopped the production of PADC as track detectors. This raised the need to evaluate PADCs from other suppliers, which can have different sensitivities due to variations in preparation, casting and chemical additives.

The objective of this work was to perform a study of PADCs from different suppliers (Table 1) for neutron dosimetry and LETnc spectrometry application. These

PADCs were compared to the InterCast material in terms of: (1) bulk etch rate, estimated with the fission fragment technique⁽²⁾, (2) average LETnc distribution of monochromatic alpha particles⁽³⁾, (3) background track density and (4) sensitivity to neutrons from an ^{241}Am -Be source. The study also offered an opportunity to compare the reading systems and etching procedures used at Politecnico di Milano (POLIMI) and at Paul Scherrer Institute (PSI).

METHODOLOGY

The PADC detectors investigated (Table 1) were $2.5\text{ cm} \times 2.5\text{ cm} \times 1.5\text{ mm}$, except for the RTP-USA, whose thickness was 1 mm. To determine the bulk etch rate and the mean LET spectrum of alpha particles, six detectors from each supplier were irradiated with an electroplated ^{252}Cf source, and chemically etched at MIAM with an aqueous solution of NaOH 6.25 M at 98°C for 40, 60 and 90 min (two detectors each). For each supplier and etching condition, two unirradiated detectors were also used to estimate the background signal. To estimate the neutron response, 12 detectors of every supplier were coupled with a 2 mm thick polyethylene radiator and exposed on a phantom to the 3 mSv AmBe reference neutron source at PSI⁽⁴⁾. From these detectors, six were etched according to the standard etching procedures at PSI (2 h and 50 min at 85°C)⁽⁵⁾ and six according to the MIAM etching procedure (90 min at 98°C).

Table 1. PADC detector used in this study. For RTP the percentage refers to different DOP (di-octyl phthalate) concentration.

Supplier	Detector name
Track Analysis System Ltd.	TASTRAK
Intercast Europe S.r.l.	Intercast
Chiyoda Technol Corporation	Chiyoda
RTP-USA	RTP 0.1%
	RTP 0.5%
	RTP 1%
Mi-Net Technology Ltd.	Mi-Net

The bulk etch rate (V_b) estimation was obtained using the fission fragment technique⁽²⁾, where, from the minor axis measurement of the track openings generated by heavy fragments and knowing the etching time (t), the bulk etch rate can be estimated relating on the approximated equation:

$$V_b \cong d/2t \quad (1)$$

The alpha particles LETnc distribution was accomplished by acquiring the major and minor axis of the etched tracks⁽³⁾. From these values the reduced track etch rate ratio (V) can be obtained for each track and used to find the LETnc of each particle, relying on parametric correlations between the reduced track etch rate ratio V and the average particle LETnc. The same correlation was used for each detector listed in Table 1.

The track density analysis of unirradiated and neutron irradiated detectors was achieved relying on the TASLIMAGETM⁽⁵⁾ and PolitrackTM⁽³⁾ embedded algorithms, adjusting the filtering parameters when necessary. In addition, PolitrackTM allowed the dose assessment by embedding the LETnc spectrometry analysis in the evaluation software⁽⁴⁾.

RESULTS AND DISCUSSION

Bulk etch rate

The results on the V_b determination are shown in Figure 1. The graph shows the removed layer as a function of the etching time, confirming the linear trend expected for each material (excluding a non-linear region in the beginning of the etch or ~ 25 min^(6, 7)). The TASTRAK and RTP 0.1% are the 'softest' tested materials, with a V_b of 14 and 12.8 $\mu\text{m/h}$, respectively (Table 2), i.e. are more deeply etched by the chemical solution in comparison to the other materials under the same etching conditions. On the other hand, Chiyoda and Intercast are the 'hardest' ones having $V_b = 9.2 \mu\text{m/h}$. The removed layer measured for the PSI etching and the MIAM

Figure 1. Removed layer versus etch duration, showing the bulk etch rate (V_b).

etching at 60 min is the same. For this reason, they are considered equivalent.

LETnc distribution of alpha particles

Figure 2 compares the LETnc spectra of ^{252}Cf alpha particles (6.1 MeV) obtained using the 98°C/60 min etching. Each material showed a clear distribution centred on the theoretical value of 120 $\text{keV}/\mu\text{m}$ ⁽²⁾. The achieved resolution of the materials for LETnc spectrometry can be inferred from the FWHM (Table 2), which shows good values ($<21 \text{ keV}/\mu\text{m}$) for RTP 0.5%, RTP 1%, Intercast and TASTRAK.

Background track density

Figure 3 presents the results of unirradiated detectors, at different etching times, evaluated by PolitrackTM system and TASLIMAGETM. For both systems the background track density of the RTP detectors is fairly high, whereas TASTRAK, Mi-Net and Chiyoda detectors show a lower background signal. TASTRAK detectors evaluated using the TASLIMAGETM, showed low background, consistent with the fact that the track analysis algorithm is optimised for this material. The background signal of the Intercast detectors is relatively high because the detectors are from an 8-year-old batch and have accumulated tracks from cosmic ray background whose increase was observed during time. The TASLIMAGETM data referring to 90 min etching are missing, because the system was not able to read these long etched detectors within the current analysis parameters. Overall, for 40 and 60 min etching the two reading systems gave comparable results, except for RTP 0.5 and 1% where 60 min etching shows an unexpected important difference.

Figure 4 shows the average track density values of unirradiated detectors etched for 90 min at 98°C and

Table 2. Comparison of different detectors for LETnc measurement. The theoretical value of the LETnc is 120 keV/ μ m.

Supplier	Bulk etch rate (V_b) (μ m/h)	Mean LET (keV/ μ m)	FWHM (keV/ μ m)
RTP 0.1%	12.8	120.3	30.9
RTP 0.5%	10.8	120.7	15.3
RTP 1%	10.2	119.2	20.6
Intercast	9.2	120.3	18.2
TASTRAK	14	121.0	20.8
Mi-Net	11.2	119.2	48.4
Chiyoda	9.2	123.7	25.7

Figure 2. LETnc spectra of detectors from different suppliers irradiated with electroplated ^{252}Cf and etched by 6.25 M of NaOH at 98°C for 60 min.

the dose for the same detectors calculated using the LETnc spectrum. RTPs are characterised by a rather high spread of background signal, deriving from an important variability within detectors. Using the LETnc spectrum, the background signal can be decreased in certain cases. In fact, considering RTP 0.1% and Intercast, the track density of the RTP 0.1% is higher than the Intercast one, but the estimated background doses are lower. This can be explained looking at the inset graph in Figure 4, where the LETnc distribution is shown for RTP 0.1% and for Intercast. In the case of RTP 0.1% the signal is mainly due to very small tracks, originating from fabrication defects, which are similar to the

Figure 3. Track density of unirradiated detectors versus etching time for analysis using Politrack™ and TASLIMAGE™. Chiyoda PADC have been etched at 90 min only because a limited number of detector was available.

Figure 4. (a) Average track densities and calculated doses for unirradiated detectors. (b) Examples of LETnc distribution of unirradiated detectors from Intercast and RTP 0.1%. (90 min/98°C etching.)

tracks from low-LET particles, thus not contributing much to the dose. Conversely the background signal from Intercast, coming from cosmic radiation, produces wider tracks to which higher LETnc values are associated, hence, yielding a higher dose background.

Response to neutrons

Figure 5 presents the sensitivity (background subtracted) of the various PADCs after 3 mSv neutron irradiation. The graph compares data from the PSI and POLIMI readers, with different etching procedures. The PSI etching removed a layer numerically equal to the V_b reported in Table 2 and generally resulted in higher sensitivity. The sensitivities

Figure 5. Neutron sensitivity of detectors from different suppliers, readout systems, and etching procedures. The thickness of the removed layer for PSI etching is numerically equal to the V_b reported in Table 2 while the one for MI.AM etching is 1.5 times higher.

Figure 6. Sensitivity in terms of track density and average dose in PADC detectors irradiated with 3 mSv with the AmBe neutron source, normalised to the Intercastrak values. The inset graph shows the Signal/Bkg of irradiated detectors grouped by supplier, calculated based on track densities or LETnc spectrum (dose). Readout system Politrack.

measured by PolitrackTM were also typically higher: this is because the PolitrackTM operates at higher magnification, thus the filtering algorithm can better resolve the contour of each track ending up in a decreased number of rejected tracks. Despite the high background, RTP 0.1% seems to have a higher response to neutrons.

Figure 6 compares the response of neutron irradiated detectors, calculated using the track density or the LETnc spectrum, normalised to the Intercastrak response.

The inset shows the Signal/Bkg ratio for each supplier, also calculated using the track density or the

LETnc spectrum. Although the RTP detectors have higher response, the background is also high, therefore, resulting in poor signal to background ratio, except for the RTP 0.1% (dose). On the other hand, TASTRAK and Chiyoda showed better Signal/Bkg ratio, despite lower sensitivity.

CONCLUSIONS

PADCs from different suppliers were compared with the performances of INTERCAST, which is no more produced. The study allowed to compare the etching procedures and the PADC readers used by PSI and POLIMI. The results show that PSI etching offers better performances for neutron dosimetry in terms of track density. For both scanning systems the track densities were similar in the case of RTP 0.1%, Intercastrak, TASTRAK and Chiyoda. The RTP 0.1% shows a very high sensitivity, almost three times higher than the average of the other detectors. On the other hand, RTPs have a very high background, resulting in a high limit of detection. Dose estimations based on LETnc spectrum could reduce background in particular for RTP 0.1%. Signal/Bkg in terms of track density is rather poor for RTP and good for TASL, Mi-Net and Chiyoda, whereas, in terms of dose, also RTP 0.1% offers a satisfactory Signal/Bkg ratio. All the detectors are in principle fit for neutron dosimetry, with pro (high sensitivity) and cons (high background). This study helps to characterise the detectors but cannot identify the best performing one because it is limited to irradiation with an Am–Be source, without taking into account the spectral sensitivity. Effects like ageing and fading are also neglected. Moreover, the statistic is poor because of the low number of detectors available. We foresee a more in-depth characterisation, with a larger statistical sampling.

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