# NEUTRON DOSIMETRY WITH BORON-DOPED CR-39 PLASTIC PLATE

Takao TSURUTA
Atomic Energy Research Institute, Kinki University
3-4-1, Kowakae, Higashi-osaka-shi, OSAKA, 577, JAPAN

Norimichi JUTO
Film Badge Services Dept., Japan Safety Appliances Association
1-7-12, Yushima, Bunkyo-ku, TOKYO, 113, JAPAN

## 1. INTRODUCTION

Application of solid state nuclear track detectors for neutron dosimetry has attracted our attention because they have desirable characteristics such as non-fading tracks and non-sensitivity to visible-, UV-, X-, β- and γ-rays. Espesially, the thermosetting plastic of allyl diglycol carbonate, called CR-39, is remarkable as the detector material due to its high sensitivity to fast neutrons (GR81). This is because the plastic has a low threshold for track registration, which depends on energy transfer from heavy charged particles to the material.

Another advantage of the plastic is that it has an optical quality and allows the tracks to grow into very clear etch-pits on a smooth surface. This suggests that the detector, using the plastic, is applicable to an optical automatic track counting system. This induced the authors to study the application of the plastic to thermal and epithermal neutron dosimetry using $^{10}B$ as a converter. In the present study, aimed at the development of a highly sensitive, simple and safe neutron dosimeter, CR-39 plastic plates are doped with a boron compound (ortho-carborane) and their characteristics are examined.

## 2. EXPERIMENTAL METHODS AND MATERIALS

Ortho-carborane powder was mixed with allyl diglycol carbonate and diisopropyl peroxy dicarbonate, as polymerizing catalyzer, in a proportion of 0.5 : 96.5 : 3.0. The mixture, in a set of dies, was cured by heating and formed a transparent plate with a thickness of 1.6 millimeters. The plate contained natural boron at a concentration of 0.375% by weight.

The boron-doped plates were wrapped in thin polyethylene sheets to protect their surfaces and were irradiated with neutrons in the heavy water thermal neutron facility of the swimming pool type research reactor (KUR) at the Research Reactor Institute, Kyoto Unversity or in the center stringer of the Argonaut type research reactor (UTR-KINKI) at the Atomic Energy Research Institute, Kinki University. In order to check the influence of epithermal and fast neutrons, part of the plates were covered with cadmium cases during irradiation. The thermal neutron fluence rates were measured with Au-foils which were irradiated in the reactors. In order to check the epithermal neutrons, part of the foils were covered with Cd-cases during irradiation.

Irradiated plates were suspended in an aqueous solution of 30% KOH for etching. The etching solution was kept at 60±0.5°C and agitated by magmixer-driven vanes. After etching, the plates were immedately washed clean in flowing water, and subsequently dried in clean ventilation.

The etch-pits on the plates were counted using an optical microscope or an automatic track-counting system, which includes optical microscope, TV-camera and computer. The number of etch-pits on each Cd-covered plate was subtracted from the corresponding number observed on the bare plate so as to eliminate the influence of epithermal and fast neutrons.

## 3. EXPERIMENTAL RESULTS

Figure 1(a-d) reveals the transition in number and shape of etch-pits with etching time. Almost all the etch-pits originate in $^{10}B(n,\alpha)^{7}Li$ reactions. From the observation of these figures it was confirmed that the number and size of etch-pits increased with etching time during the early period of ethcing. A quantitative relation between the etching time and the number of etch-pits per unit area (density of etch-pits) is shown in Fig.2. When the etching condition and time are kept constant, the density of etch-pits $P$ (cm$^{-2}$) is proportional to the irradiated thermal neutron fluence $\Phi$ (cm$^{-2}$). Generally $P$ can be expressed as

$$P = \int_0^\infty K(E)\Phi_E dE \ , \qquad (1)$$

where $\Phi_E$ (cm$^{-2}\cdot$eV$^{-1}$) is the differential distribution of the neutron fluence with respect to neutron energy $E$ (eV), and the proportional constant $K(E)$ is termed the "complex sensitivity" or simply "sensitivity" which has no dimension. From Fig.2 the sensitivities for thermal neutron are $(2.3\pm0.2)\times10^{-4}$ and $(4.2\pm0.2)\times10^{-4}$ for 8 and 16 hrs in etching time, respectively. The range of etch-pit density at which counting can be done with reasonable accuracy is estimated to be about $10^3$-$10^6$cm$^{-2}$.

On the other hand, sensitivity $K(E)$ is derived theoretically to be expressed as

$$\begin{aligned} K(E) &= \tau\{\frac{1}{2}R\cos^2\theta_C+(1-\sin\theta_C)l\}\sigma(E) \\ &= k\sigma(E) \ , \qquad (2) \end{aligned}$$

where $\tau$ is the $^{10}$B-concentration in the plate (atoms$\cdot$cm$^{-3}$), $R$ is the mean effective range of $\alpha$- and $^{7}$Li-particles in the plate (cm), $\theta_C$ is the critical angle for etch-pit formation, $l$ is the bulk etching (cm), $\sigma(E)$ is the microscopic cross section of $^{10}B(n,\alpha)^{7}Li$ reaction (cm$^2$), and $k$ is termed the "prime sensitivity" which has a dimension of cm$^{-2}$ (TS78). Assuming that $\theta_C$ is 0°, the sensitivities are calculated to be $2.2\times10^{-4}$ and $4.0\times10^{-4}$ for 8 and 16 hrs in etching time, respectively, for the condition shown in Fig.2. The experimental values agree well with the theoretical values. As shown in equation (2), sensitivity $K(E)$ is in proportion to the microscopic cross section of $^{10}B(n,\alpha)^{7}Li$ reaction $\sigma(E)$, which is inversely proportional to the square root of the neutron energy in the neutron energy region from about 0.001eV to 0.1MeV.

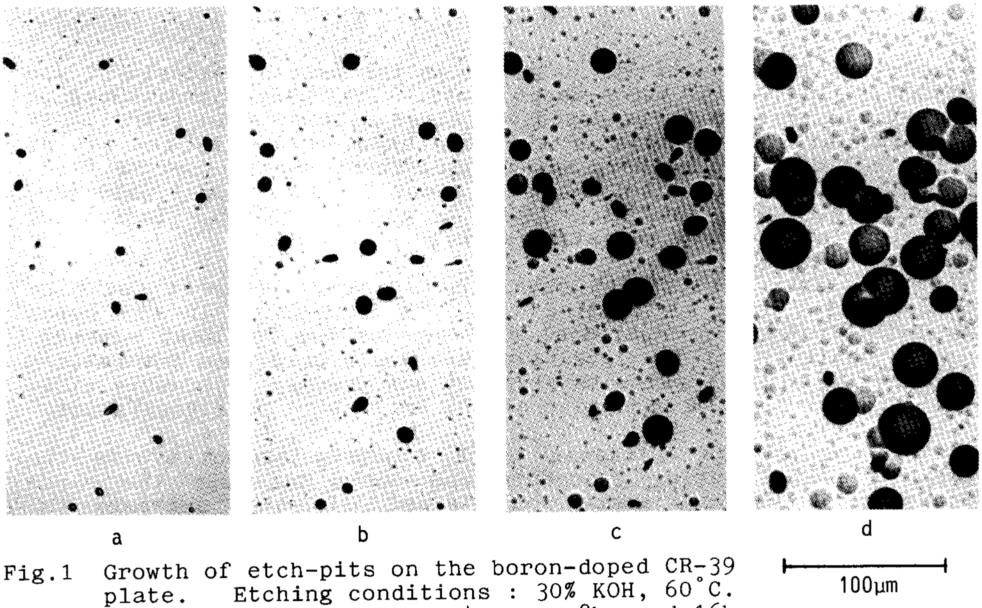

Fig.1 Growth of etch-pits on the boron-doped CR-39 plate. Etching conditions : 30% KOH, 60°C. Etching time : a 2hrs, b 4hrs, c 8hrs, d 16hrs.

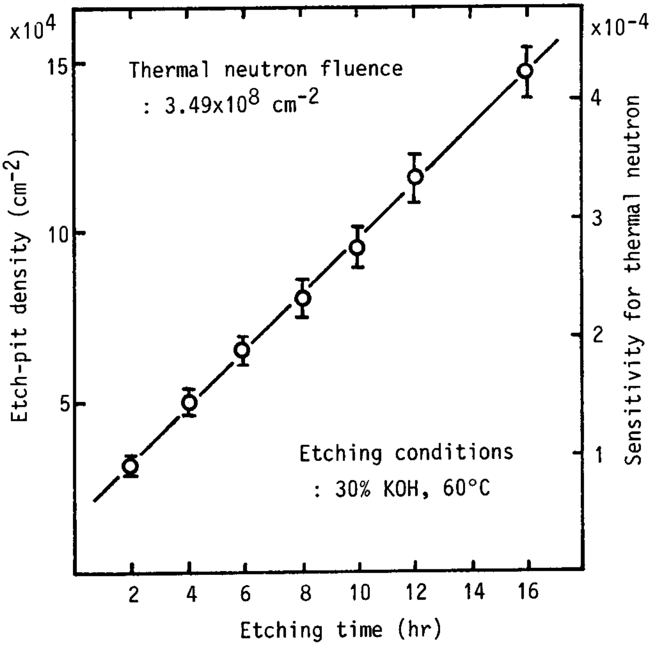

Fig.2 Increase of etch-pit density and sensitivity for thermal neutron with etching time.

## 4. DISCUSSION

The maximum sensitivity obtained in the present experiment was $4.2 \times 10^{-4}$, using 0.375% boron-doped plate. The value approximated to the sensitivity of a boron-doped cellulose nitrate film (TS82). If the lower and upper limits of the density of etch-pits are set at $10^3$ and $10^6 \mathrm{cm}^{-2}$, the corresponding significant ranges for the thermal neutron dose equivalent would be about $2.5 \times 10^{-5}$ and $2.5 \times 10^{-2}$Sv, respectively. This detection limit is good enough for individual monitoring intended for radiation workers.

The maximum sensitivity obtained in this experiment could be enhanced five times by raising the $^{10}$B enrichment in the boron compound to 100%. Occupational exposure is low for most workers. Accurate dosimetry of low level exposure would give them information for improving their working environment and process. It would ultimately do much for the reduction of the collective dose equivalent.

The use of the automatic track counting system avoids the tedious visual counting procedure and makes possible the rapid processing of a large number of plates. It also improves the objectivity of the counting.

Bare boron-doped, Cd-covered boron-doped and boron-free plates could be used in cases where thermal, epithermal and fast neutrons are significant and the energy spectrum is unknown. The coexistence of $\gamma$-rays etc., does not disturb the estimation of the neutron dose. There is no possibility of underestimating the dose equivalent due to fading. Etched and unetched plates can be preserved as material evidence for the necessary period of time. Another advantage of the plate is that it is easy to handle because the detector and converter are incorporated. Furthermore, the isotope $^{10}$B is non-radioactive and thus perfectly safe.

All the foregoing merits of the boron-doped CR-39 plate should justify its wide adoption as a suitable individual neutron dosimeter.

## ACKNOWLEDGMENT

The authors wish to express their indebtedness to Mr.O.Murata, of Sola Optical Japan Ltd., for preparration of the boron-doped CR-39 plates.

## REFERENCES

GR81 Griffith,R.V., Thorngate,J.H., Davidson,K.J., Rueppel,D.W., Fisher,J.C., Tommasino,L. and Zapparolli,G. : Rad. Prot. Dosimetry 1, 61 (1981).

TS78 Tsuruta,T. and Sakamoto,M. : J. Nuel. Sci. Technol. 15, 602 (1978).

TS82 Tsuruta,T. and Takagaki,M. : Health Physics 43, 705 (1982).