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# DIAGNOSTIC X-RAY DOSIMETERS USING STANDARD FLOAT ZONE (FZ) AND XRA-50 COMMERCIAL DIODES

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## ABSTRACT

The results obtained with a standard float zone (FZ) silicon diode, processed at the Helsinki Institute of Physics, used as on-line diagnostic X-ray dosimeter are described in this work. The device was connected in the short-circuit current mode to the input of an integrating electrometer. The response repeatability and the current sensitivity coefficient of the diode were measured with diagnostic X-ray beams in the range of 40-80 kV. The dose-response of the device, evaluated from 10 mGy up to 500 mGy, was linear with high charge sensitivity. Nevertheless, significant energy dependence was observed in the charge sensitivity of FZ device for energies below 70 kV. The dosimetric characteristics of this FZ diode were compared to those of an XRA-50 commercial Si diode, specially designed to X-ray dosimetry. The results obtained with the FZ diode evidenced that it can be an alternative choice for diagnostic X-ray dosimetry, although it needs to be calibrated for individual X-ray beam energies. The studies of long-term stability and the radiation hardness of these diodes are under way.

## 1. INTRODUCTION

Semiconductor devices have been used for photon and electron beam dosimetry mainly in the field of radiation protection, medical imaging and radiation therapy [1-3]. One of the most important reasons in using semiconductor dosimeters is their higher sensitivity per unit of volume in comparison with ionization chambers. A precise measurement of the absorbed dose below a few tenths of percent is required in the medical dosimetry. Use of Si devices demands a periodic recalibration of the dosimeter related to the sensitivity decay as a function of the accumulated dose. This drop in sensitivity due to radiation damage imposes constraint on the widespread use of ordinary silicon diodes as dosimeters [4-7].

The drawback of the sensitivity drop is being overcome by the development of radiation tolerant silicon detectors in the framework of High Energy Physics research projects [8]. Previous results obtained in our laboratory using similar radiation-hard (rad-hard) Si diodes in radiation dosimetry [9, 10] motivated us to investigate the response of an n-type float zone (FZ) diode for on-line diagnostic X-ray dosimetry. The rad-hard diode used was processed at the Helsinki Institute of Physics. The dosimetric characteristics of this FZ diode were compared to those of an XRA-50 commercial photodiode, specially designed for X-ray dosimetry [11].

## 2. EXPERIMENTAL SETUP

The radiation hard FZ diode had $p^+$-n-$n^+$ structure and thickness of 300 μm with a sensitive area of 25 $mm^2$. The XRA-50 PIN photodiode, manufactured by Detection Technology, had the same sensitive area of FZ diode (25 $mm^2$) with an ultrafine entrance window. In order to use these diodes as dosimeters, they were housed in polymethylmethacrylate (PMMA) probes with 10 mg/$cm^2$ thick paper windows.

Each device was directly connected in the photovoltaic mode to the input of a Keithley® 6517B electrometer. The irradiation was performed with diagnostic X-ray equipment, with a total filtration of 2.5 mm Al. Measurements were carried out in air, with the diodes positioned at 1 m from the focus of the X-ray tube, using radiation field of 20 cm x 20 cm. The dose rate at this position was previously estimated using a calibrated ionization chamber Radcal 2026C.

The response repeatability was evaluated for all energies by registering five consecutive current signals at the same radiation dose rate. The beam was switched on-and-off between measurements periods. At fixed voltages of 50 kV and 80 kV, the output current signals from the diodes were registered as a function of the exposure time within the dose-rate range between 1.2 mGy/min to 42.8 mGy/min.

The dose-response of the devices was investigated for doses from 10 mGy to 500 mGy. The dose-response is evaluated from the curves of charge as a function of the accumulated dose, where the charge is obtained by integrating the photocurrent signal over the measurement time. By changing the beam filtration and the bias voltage, the energy dependence of the diodes responses to 40, 50, 60, 70, and 80 kV X-ray beams was evaluated.

## 3. RESULTS AND DISCUSSIONS

The dynamic current response of the rad-hard FZ diode and the commercial XRA-50 diode was investigated with irradiation energies of the X-ray beam from 40 kV to 80 kV and the dose rate range from 9.9 mGy/min to 42.8 mGy/min. The results obtained with both devices evidenced that the current signals are very stable, as shown in Fig. 1, where five consecutive current signals of both diodes irradiated under 80 kV X-ray irradiation and average dose-rate of 42.8 mGy/min are presented.

In addition, Fig. 1 shows a good repeatability of the diodes, characterized by a coefficient of variation of 0.1% and 0.2% for FZ and XRA-50 diodes, respectively. It is important to note that within the whole energy range, the output current signals were almost four orders of magnitude higher than the dark current of the diodes (≅ 3.6 pA for FZ and ≅1.2 pA for XRA-50), recorded after each measurement period when the beam was switched off.

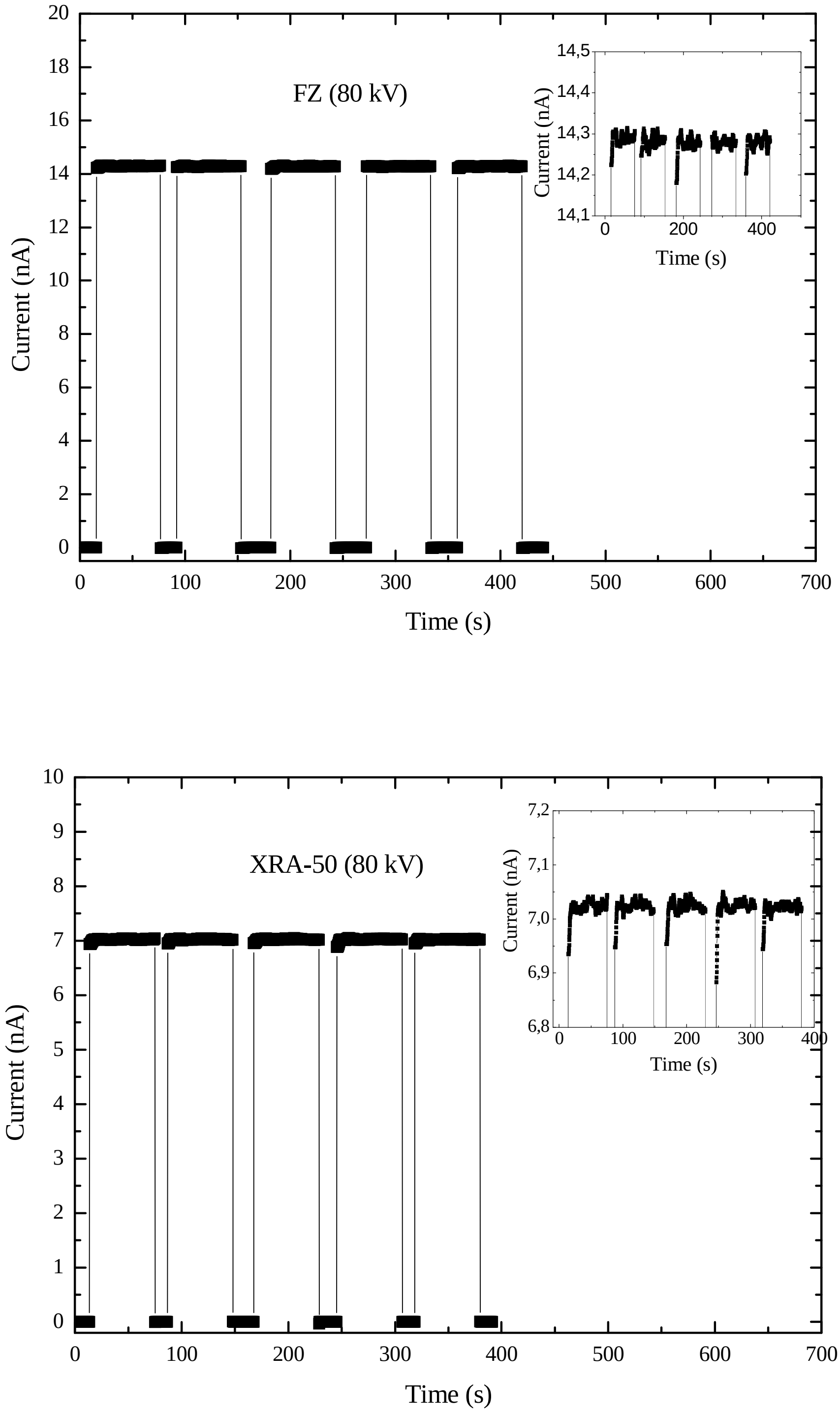


**Figure 1: Current response of FZ and XRA-50 diodes under irradiation with 80 kV X-ray beam energy (dose-rate of 42.8 mGy/min).**

For comparison, the average output current signals registered with FZ and XRA diodes irradiated with 50 and 80 kV X-rays as a function of the dose-rate are depicted in Fig. 2. Within the dose rate range of 1.2 mGy/min up to 42.8 mGy/min, the current responses of both diodes increased linearly with the dose-rate and no saturation of the current was observed. The corresponding values of the current sensitivity are presented in Table 1. The energy dependence observed for the FZ diode might be caused by the non-ideal entrance window, compared to the very thin window of the XRA-50 diode, for which no energy dependence was observed.

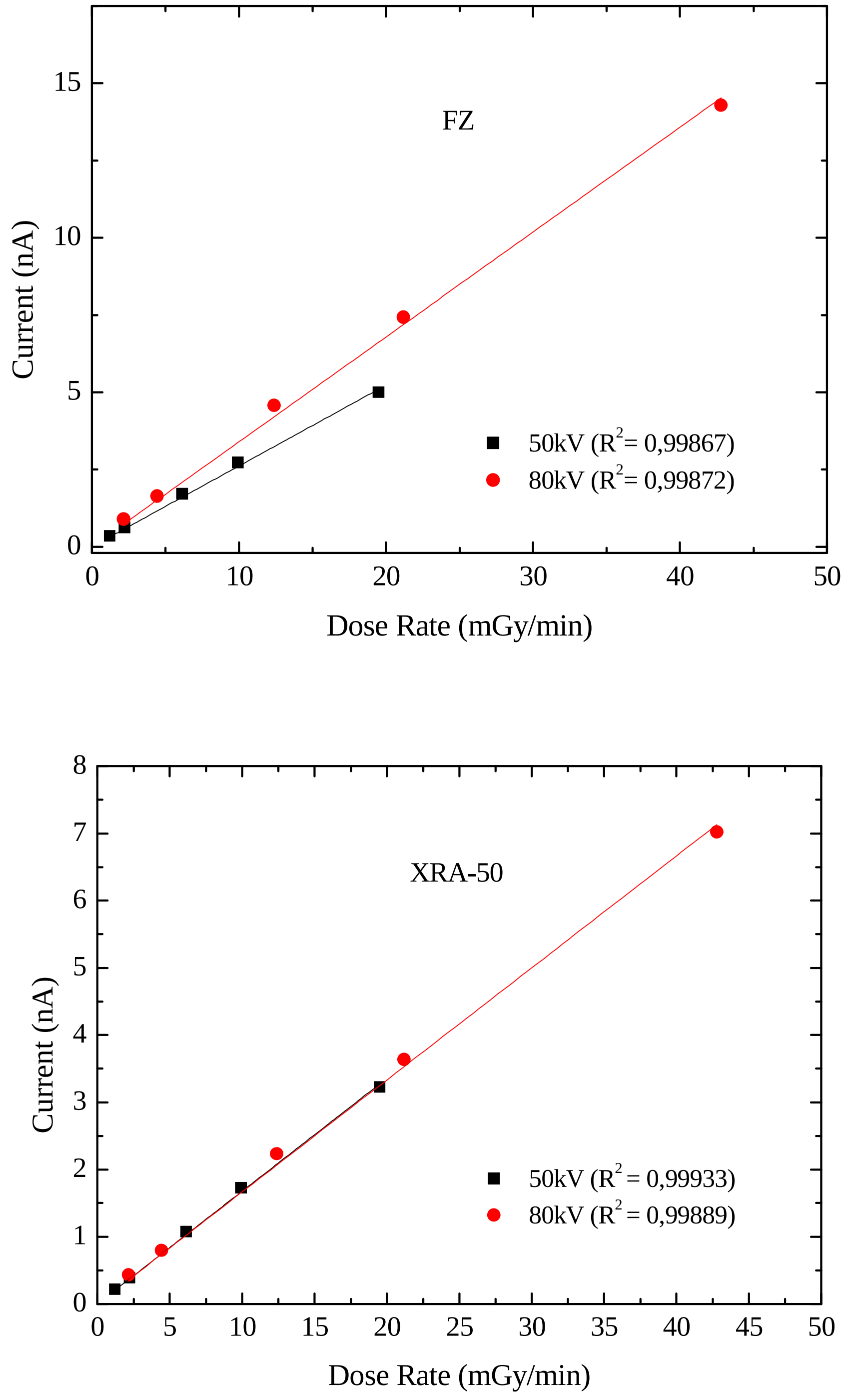


**Figure 2: Current response of FZ and XRA-50 diodes as a function of the dose-rate for 50kV and 80 kV X-ray bias supply.**

**Table 1: Current sensitivity of FZ and XRA-50 diodes for 50kV and 80 kV X-ray bias supply.**

| Energy (kV) | Current Sensitivity (nA.min/mGy) |
|---|---|
| FZ | |
| 50 | 0.262 ± 0.004 |
| 80 | 0.340 ± 0.005 |
| XRA-50 | |
| 50 | 0.167 ± 0.002 |
| 80 | 0.166 ± 0.003 |

The dose response of the diodes in the range of 10 mGy and 500 mGy is presented in Figs. 3 and 4, where the charge, obtained by integration of the current signal on a time interval of 60s, is plotted as a function of the accumulated dose. The results obtained with X-ray beam energies in the range of 40 kV to 80 kV confirm that the dose-response curves of both diodes are quite linear (coefficients of determination, $R^2$, better than 0.99999) with high charge sensitivity. From these figures, it is also clear that the FZ diode exhibits a significant X-ray energy dependence for beam energies below 70 kV, which might be attributed to the thickness of its entrance window. The correspondent charge sensitivities of the FZ and XRA-50 diodes are shown in Fig. 5 as a function of beam energies.

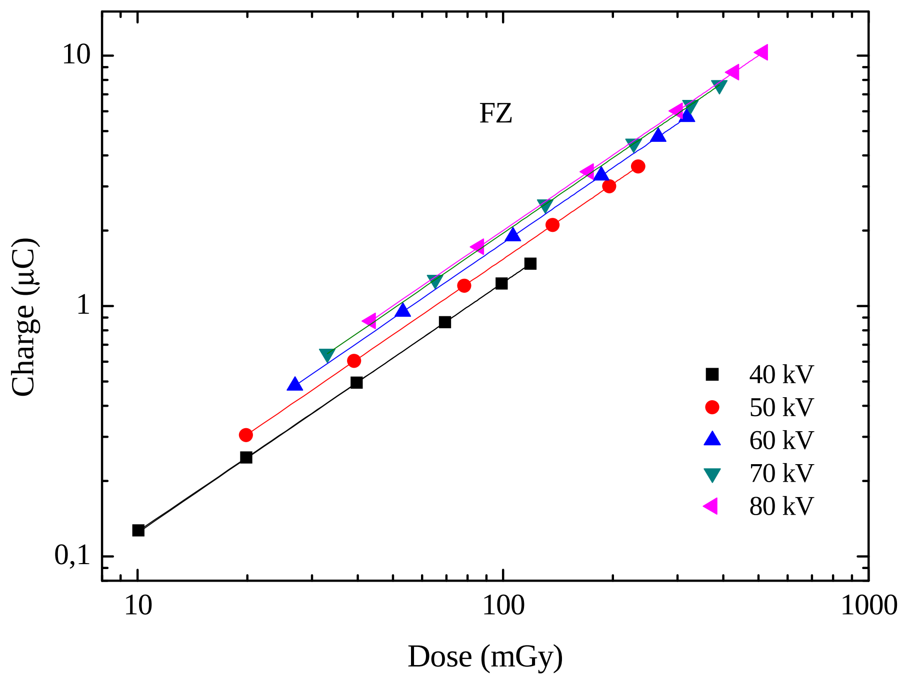


**Figure 3: Dose-Response curves of the FZ diode for 40 kV, 50 kV, 60kV, 70kV and 80 kV X-ray beam energy.**

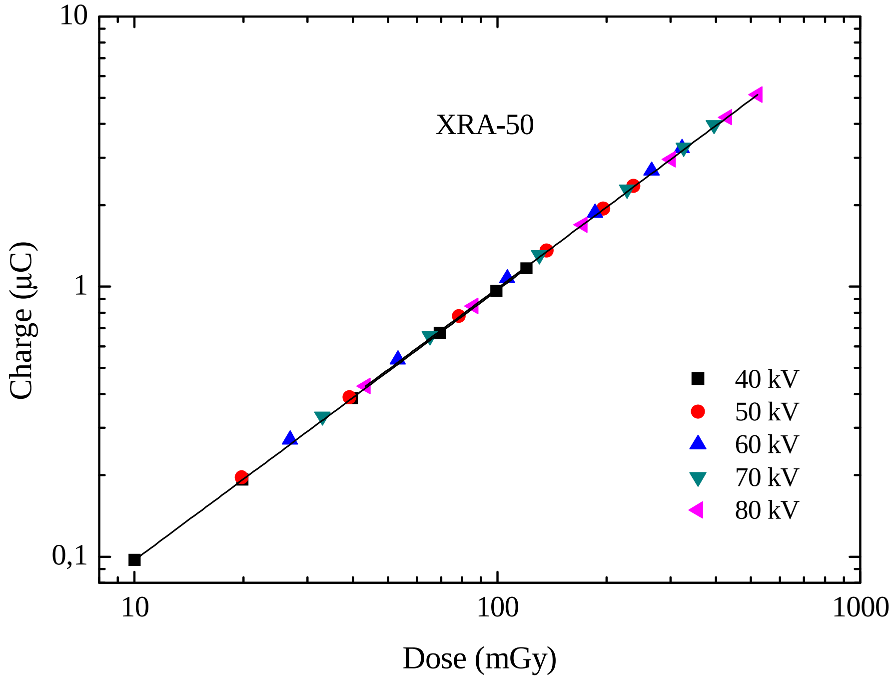


**Figure 4: Dose-Response curves of the XRA-50 diode for 40 kV, 50 kV, 60kV, 70kV and 80 kV X-ray beam energy.**

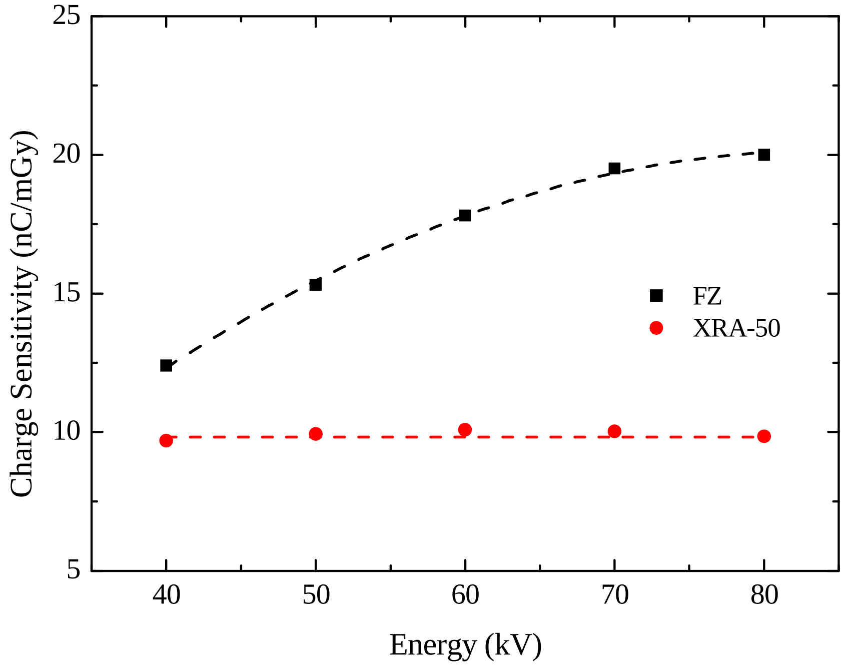


**Figure 5: Charge sensitivity as a function of beam energies for FZ and XRA-50 diodes. The spline lines are only guide to the eyes.**

## 4. CONCLUSIONS

The dosimetric characteristics of a rad-hard FZ diode were investigated envisaging its application in on-line diagnostic X-ray beam dosimetry. The results obtained within the energy range of 40-80 kV were compared to those of a XRA-50 commercial Si diode. The dose-response of both devices, evaluated from 10 mGy up to 500 mGy, was linear with high charge sensitivities (20 nC/mGy). As expected from the radiation hardness of the FZ diode, studies related with the response repeatability confirmed that this device is more stable than the XRA-50 diode. Otherwise, due to the strong energy dependence, FZ diode needs to be calibrated separately for individual X-ray beam energies. The dosimetric performance of the FZ leads us to conclude that this device is a reliable alternative choice for diagnostic X-ray dosimetry. It worth noting that it remains to be investigated the long-term stability and the radiation hardness of these diodes for absorbed doses beyond the range investigated in this work. All these studies are under way.

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