Characterization of Three Photodetector Types for Computed Tomography Dosimetry

C. M. M. Paschoal, D. do N. Souza and L. A. P. Santos

***Abstract*—**In this study three commercial semiconductor devices were characterized in the laboratory for computed tomography dosimetry: one photodiode and two phototransistors. It was evaluated four responses to the irradiation: dose linearity, energy dependence, angular dependence and loss of sensitivity after X ray exposure. The results showed that the three devices have proportional response with the air kerma; the energy dependence displayed for each device suggests that some calibration factors would be applied for each one; the angular dependence showed a similar pattern among the three electronic components. In respect to the fourth parameter analyzed, one phototransistor has the highest sensitivity however it also showed the greatest loss of sensitivity with the accumulated dose. The photodiode was the device with the smaller sensitivity to radiation, on the other hand, the loss of sensitivity after irradiation is negligible. Since high accuracy is a desired feature for a dosimeter, the photodiode can be the most suitable of the three devices for dosimetry in tomography. The phototransistors can also be used for CT dosimetry, however it would be necessary a correction factor due to loss of sensitivity with accumulated dose.

***Keywords*—**Dosimetry, computed tomography, phototransistor, photodiode

I. Introduction

THE dosimetry in computed tomography (CT), which is mainly made using a pencil ionization chamber (100 mm long), is undergoing improvement and small detectors have been suggested as an alternative for that [1]-[3]. In these cases, the procedure of single slice in the middle of the chamber is replaced by another procedure: moving the small detector across the X ray beam.

Some semiconductor based dosimeters have been used for dosimetry in tomography, *e.g.* photodiode, phototransistor, and MOSFET [4]-[6]. Although some phototransistors and bipolar transistors have already been tested for dosimetry in radiology, including CT, they were not enough evaluated for dosimetry in tomography. The great advantage of transistor type devices resides in the ability to amplify the electrical signal [6]-[8]. In this work three commercial devices, two phototransistors and one photodiode, were characterized in the laboratory in standard radiation qualities specific to computed tomography, according to the standard 61267 of the International Electro-technical Commission (IEC) [9].

Cinthia M. M. Paschoal, and Luiz A. P. Santos are with the Comissão Nacional de Energia Nuclear (CNEN)/CRCN-NE, Recife – PE, CEP 50740-540 Brazil (phone: +55 8596282000 fax: +55 8137978075 e-mail: cinthiam.paschoal@gmail.com; lasantos@cnen.gov.br), and with the Departamento de Física, Universidade Federal de Sergipe (UFS), São Cristóvão-SE, CEP 49100-000 Brazil.

Divanizia do N. Souza is with the Departamento de Física, Universidade Federal de Sergipe (UFS), São Cristóvão-SE, Brazil (e-mail:divanizi@ufs.br).

II. Materials and Methods

Three electronic components were used as the radiation detector: two phototransistors, OP520 and OP521 (OPTEK Technology [10]); and a BPW34FS photodiode (OSRAM [11]). The phototransistors have 1206 package size (3.2 mm x 2 mm) and its photosensitive area is about 1/10 that size. Both devices have a flat lens but the difference between them is the fact that OP520 has opaque lens to shield daylight. The photodiode has a photosensitive area of 7 mm^2, in a square shape, and a black plastic encapsulation of 4.5 mm x 3.7 mm size. Each device was soldered in a printed circuit board, and a cylinder cap was used to avoid the ambient light.

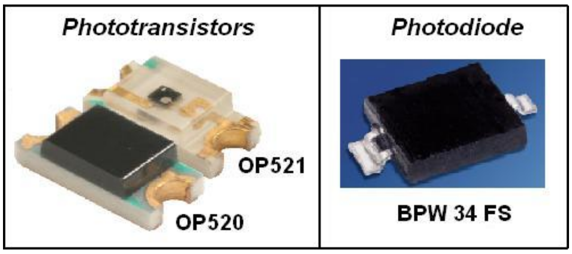


Fig. 1 The electronics devices chosen for CT dosimetry characterization: OP520 and OP521 phototransistors [10]; BPW34FS photodiode [11]

The detection system consists of: the electronic device; the Flip-flop electrometer (EFF); and the DoseX® software to acquire the data from it (Fig. 2).

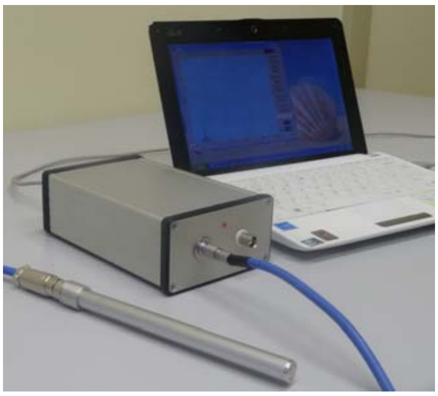


Fig. 2 The dosimetry system: the detector, the Flip-flop electrometer, a computer with the DoseX® software

The characterization was accomplished at Instruments Calibration Laboratory (LCI, *Laboratório de Calibração de Instrumentos*) of Institute of Nuclear and Energetic

Researches (IPEN, *Instituto de Pesquisas Energéticas e Nucleares*), Brasil, using an industrial X ray unit, Pantak/SEIFERT, model ISOVOLT 160HS, operating from 5 to 160kV. Based on the IEC 61267 and the TRS 457 reports [12], the RQT8, RQT9 and RQT10 standard radiation qualities were used to evaluate the devices. These radiation qualities represent simulations of the unattenuated beam normally used in computed tomography.

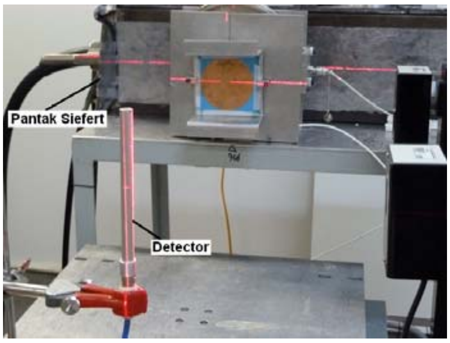


Fig. 3 Experimental arrangement with the detector positioned at 1 m distant from the X ray tube of Pantak Siefert equipment

The performed tests were: dose linearity, energy and angular dependence. The loss sensitivity in function of the radiation was also evaluated. Output linearity was evaluated for RQT9 radiation quality (tube kilovoltage of 120 kV, more commonly used in CT scans) and the air kerma measurements were obtained by varying the electrical current applied to the tube from 1 mA up to 25 mA each 5mA step. Such a methodology corresponds to an air kerma variation from 3.4 up to 83 mGy.

X ray energy dependence was analyzed for the radiation qualities RQT8, RQT9 and RQT10 which correspond to the voltages of 100, 120 and 150 kV, respectively. The electrical current was set to be 10 mA and the air kerma was maintained constant at 30 mGy. The sensitivity to the radiation was calculated as the ratio of the charge collected by the detectors and the measured air kerma.The angular dependence was performed for RQT9 radiation quality around the vertical axis of the detector, varying the angle of incidence with increments of 30° up to 360° rotation.

Loss of sensitivity to the radiation was measured with the RQT9 radiation quality. Each detector was exposed to a continuous X ray beam with air kerma rate of 0.56 mGy/s. To verify the detector response the dosimetric system was set to be current mode measurement. The devices were exposed to a set of 12 cycles of 100 seconds time interval of irradiation, totaling approximately accumulated dose of 670 mGy. The average and standard deviation of each cycle were calculated and the influence of radiation was analyzed.

III. Results

A. Dose linearity

As can be seen in the Figure 4, all devices present linear response with the air kerma. The determination coefficients were 0.99655, 0.99163 and 0.99952 for OP520, OP521 and BPW34FS, respectively. The uncertainties in the angular coefficients were less than 0.02% except for the phototransistor OP520 which was close to 0.05%.

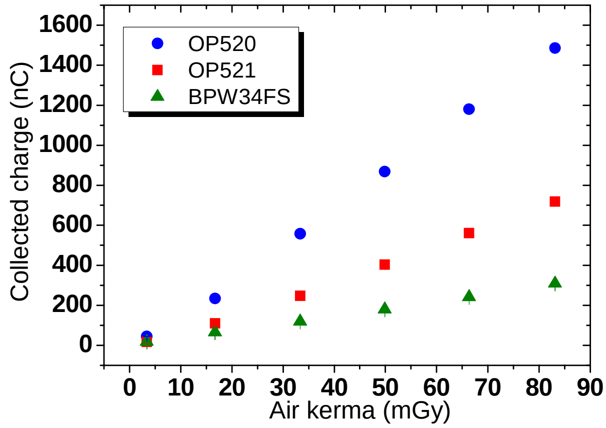


Fig. 4 Dose linearity using RQT9 radiation quality of the three devices: OP520 and OP521 phototransistors and BPW34FS photodiode

Observing the value of the collected charge in the three curves, one can notice that the OP520 phototransistor is the detector that has the highest output signal. The OP521 phototransistor yields intermediate signal and the photodiode BPW34FS presents the lowest sensitivity to the radiation.

B. Energy dependence

Figure 5 shows the energy dependence of the three devices for the RQT8, RQT9 and RQT10 radiation qualities. These responses are related to the half-value layer (HVL). The used devices have similar behavior, i.e., they have greater coefficient of sensitivity to the lowest HVL (RQT8) and lower coefficient of sensitivity to the highest HVL (RQT10). Since the sensitivities are not identical for each radiation quality used, a calibration factor is necessary to each one.

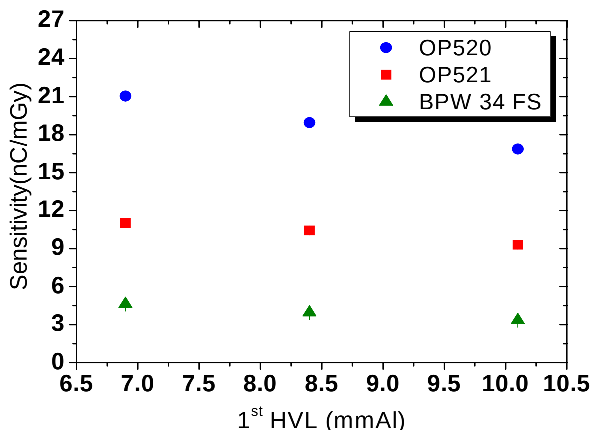


Fig. 5 Energetic dependence of the three devices: OP520 and OP521 fototransistors and BPW34FS photodiode

C. Angular dependence

Figure 6 shows the angular response for the three devices used in this work. The collected charge is normalized for the origin (0°) in this chart. The responses are very similar for different angles, especially in the case of the phototransistors.

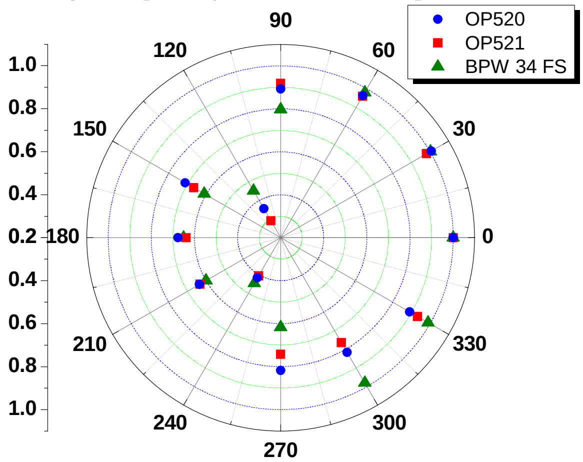


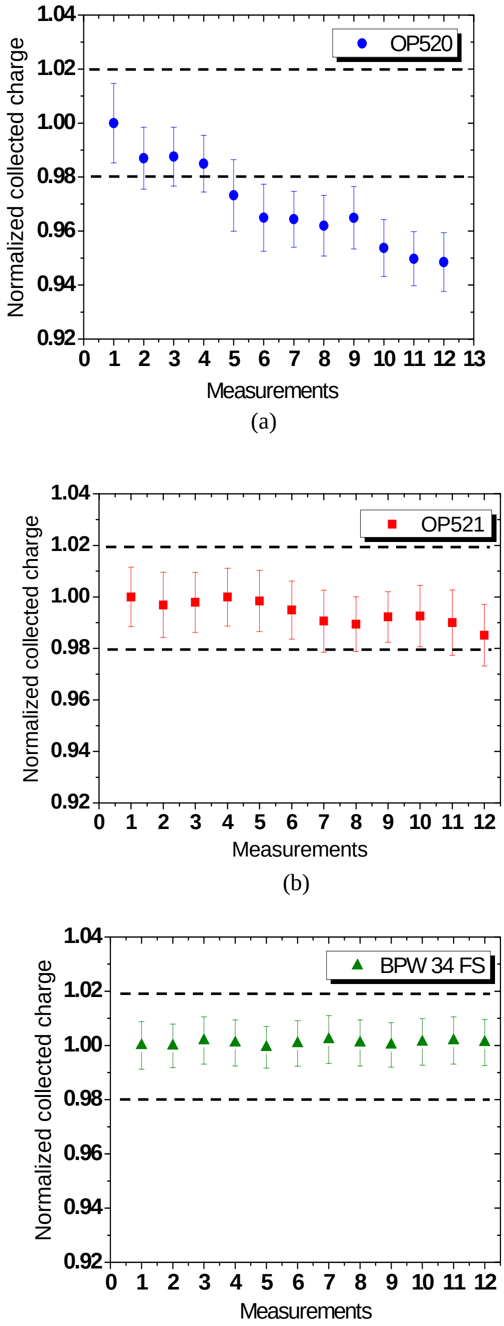
Fig. 6 Directional sensitivity of the three detector configurations analyzed for use in CT dosimetry

One can also observe that there is a marked difference in the responses between the two sides (0 and 180°) due to the asymmetric structure of these electronic components, i.e., they have a thick metal substrate where the silicon chip rests. Even considering this high angular dependence, apparently this is not a problem for computed tomography dosimetry, because the X ray tube of a tomograph performs complete rotations equally irradiating the detector.

D.Loss of sensitivity

Figure 7 shows the loss of sensitivity in function of the accumulated irradiation for the OP520 and OP521 phototransistors and the BPW34FS photodiode. Each plotted marker represents an average of one hundred sample points with its standard deviation. The mean value corresponds to a 56 mGy accumulated air kerma, and each experiment has accumulated 670 mGy for each photodetector.

The loss of sensitivity was more significant for the OP520 phototransistor and less expressive for the photodiode. Apparently, as much as larger the detector signal the loss of sensitivity is greater and vice versa. Since the stability is a very desirable feature for a radiation detector, the BPW34FS photodiode would be the most suitable for dosimetry in computed tomography. The phototransistors can also be used for CT dosimetry, however it would be necessary a correction factor at least each 500 mGy accumulated dose to maintain the high accuracy.



(c)

Fig. 7 Loss of sensitivity to 670 mGy accumulated air kerma of the three devices: (a) OP520 and (b) OP521 phototransistors; and (c) BPW34FS photodiode.

IV. Conclusions

Three photodetector types were characterized for dosimetry in computed tomography related to: dose linearity, energy dependence, angular dependence and loss of sensitivity after X ray exposure. The results showed that the devices have linear response to air kerma from standardized radiation qualities. Furthermore, the energy dependence displayed for each device suggests that some calibration factors would be applied for each one. In relation to the angular dependence, they showed a similar pattern. The OP520 phototransistor is the one with the highest sensitivity to the X rays however it also presents a greatest loss of sensitivity with the accumulated dose. In this study, the BPW34FS photodiode had the lowest sensitivity to the standardized radiation qualities, on the other hand, its loss of sensitivity after irradiation is negligible. Since a high accuracy is required for an electronic component that works as radiation detector, among the three tested devices, the photodiode would be the most suitable for dosimetry in computed tomography. The phototransistors can also be used for CT dosimetry, however it would be necessary a correction factor at least each 500 mGy of accumulated dose to maintain the high accuracy.

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