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# Calibration coefficients of epitaxial diodes used in diagnostic radiology and computed tomography

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## 1. Introduction

Silicon diodes have been widely used in photon and electron beam dosimetry, usually at null bias in the short-circuit mode. When exposed to radiation, its operating condition allows real-time acquisition of induced currents, linearly depending on the dose rate. Offline Integration of the current signals provides the corresponding absorbed dose. This easy operation, ruggedness, high sensitivity, and immediate readout are the main advantages of diodes over other available dosimeters. However, to be used as dosimeters, they must be calibrated to link the diode reading to the true absorbed dose or dose rate, chiefly measured with a standard ionization chamber under reference conditions (20ºC, 101.3 kPa). The dosimeter's calibration coefficient ($N_k$), defined as the ratio of the conventional true value of the quantity to be measured to the indication of the instrument to be tested, can be assessed through a formalism based on standards of air kerma ($K_a$) as recommended in Technical Reports Series No. 457 [1]. The value of the air kerma, $K_a$, at a reference point in the air for a reference beam of quality $Q_0$, is related to the reading $M$ of the dosimeter under the reference conditions used in the standards laboratory according to:

$$K_a = N_k \, . \, M \, . \, k_Q \, .k_T \tag{1}$$

Where $k_Q$ is a correction factor for the effects of the difference between the reference beam quality, $Q_0$, and the actual quality, $Q$, during the measurement; $k_T$ is the correction factor for the changes in air density due to changes in the ambient temperature. In this work, the calibration coefficients of a rad-hard epitaxial silicon diode, previously characterized as an online dosimeter in diagnostic radiology (RD) and computed tomography (CT), are assessed considering the RQR-5 and RQT-9 as the reference beam qualities ($k_Q$ = 1).

## 2. Methodology

The epitaxial diode used (25 mm$^2$ active area) is processed on an n-type 50 µm thick epitaxial silicon layer (resistivity of 50 Ω.cm), grown on a highly doped n-type 300 µm thick Czochralski (Cz) silicon substrate [2]. The device is housed in a light-tight probe with a thin (28 mg/cm$^2$) paper window to avoid significant X-ray beam intensity attenuation. The diode, directly connected to an electrometer Keithley 6517B in the photovoltaic mode, is exposed to X-ray beams from a Pantak/Seifert generator, model Isovolt 160 HS, previously calibrated with standardized ionization chambers. Table I presents diagnostic radiology and computed tomography X-ray qualities. Irradiations are carried out with the diode positioned at 1m from the X-ray tube (focal spot), as shown in Fig.1. Five current measurements are consecutively carried out to correlate the averaged current reading to the air kerma rate of each beam quality. With this approach, the repeatability parameter can also be evaluated through the coefficient of variation of the current signals following the IEC 61674 norm [3]. The calibration coefficients of the diode, in terms of air kerma rate, are determined for diagnostic radiology and computed tomography X-ray beam qualities presented in Table I.

Table I: X-ray Qualities used from Pantak-Seifert 160HS Isovolt generator.

| **Diagnostic Radiology** | | | | |
|---|---|---|---|---|
| **Quality** | **kV** | **mA** | **Filtration (mm)** | **Air Kerma Rate (mGy/min)** |
| RQR-3 | 50 | 10 | 2.40 Al | 22.4(2) |
| **RQR-5** | 70 | 10 | 2.80 Al | 38.6(3) |
| RQR-8 | 100 | 10 | 3.20 Al | 69.3(5) |
| RQR-10 | 150 | 10 | 4.20 Al | 120(2) |
| **Computed Tomography** | | | | |
| RQT-8 | 100 | 10 | 3.2 Al + 0.30 Cu | 22.0(7) |
| **RQT-9** | 120 | 10 | 3.5 Al + 0.35 Cu | 34.0(1) |
| RQT-10 | 150 | 10 | 4.2 Al + 0.35 Cu | 57.0(2) |


Figure 1: Probe of the EPI diode set at Pantak-Seifert 160HS Isovolt X-ray generator.

## 3. Results and Discussion

The current signals induced for all diagnostic radiology beam qualities are depicted in Fig. 2. It reveals a quite stable current response, proved by coefficients of variation (CV) less than 0.3%. Similar results are obtained with the computed tomography qualities.

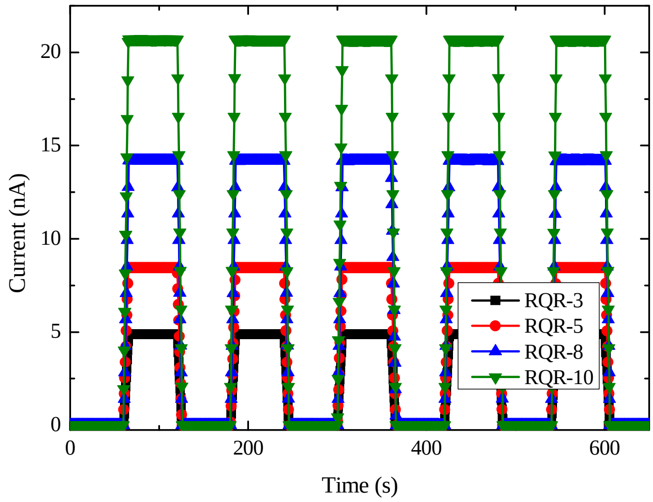


Figure 2: Current signal profiles for RQR-3/5/8/10 X-ray beam qualities. The overall experimental uncertainties (0.8 %) are smaller than the symbols' size.

The calibration coefficients ($N_k$) of the EPI diode, in terms of the air kerma rates given in Table I, are determined considering RQR-5 and RQT-9 as the reference beam qualities ($k_Q$ = 1) and room temperature of 21°C. These data are summarized in Table II, together with the correction factors for temperature variation ($k_T$) and beam qualities ($k_Q$). Changes in pressure and humidity are neglected.

Table II: EPI diode's calibration coefficients and corrections factors for the diagnostic radiology and computed tomography X-ray qualities. $N_k$ uncertainty equals 0.8% (RQR) and 1.5% (RQT).

| **Beam Quality** | **$N_k$ = 7.606·10$^4$ Gy/C** | |
|---|---|---|
| | $k_Q$ | $k_T$ |
| RQR-3 | 1.006 | 1.005 |
| **RQR-5** | 1 | 1.005 |
| RQR-8 | 1.071 | 1.005 |
| RQR-10 | 1.271 | 1.005 |
| | **$N_k$ = 1.130·10$^5$ Gy/C** | |
| | $k_Q$ | $k_T$ |
| RQT-8 | 0.871 | 1.005 |
| **RQT-9** | 1 | 1.005 |
| RQT-10 | 1.181 | 1.005 |

From the data shown in Table II, the temperature correction factor is almost negligible, unlike those correction factors due to variations in the X-ray beams for the reference ones ($k_Q$ = 1). It corroborates the previous findings concerning the energy dependence of the EPI diode, mainly for the RQR-10 and RQT-10 energy ranges.

## 4. Conclusions

The assessment of the calibration coefficients and corrected factors of an epitaxial diode, intended to be used in diagnostic radiology and computed tomography dosimetry, is reported in this work. The formalism adopted based on the air kerma rate proved suitable for precisely linking the diode's readings to the standard reference ionization chambers. Despite being close to 1, the correction factors due to variations of the RQR-10 and RQT-10 X-ray beams related to the correspondent reference qualities evidence the slight energy dependence of the EPI diode for voltages above 100 kV.

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