SILICON DIODE SIGNAL DEPENDENCE ON TEMPERATURE IN HIGH ENERGY PHOTON RADIOTHERAPY

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Abstract: *Semiconductor silicon diodes are used widely as detectors in oncology radiation centers for In Vivo Dosimetry (IVD). IVD is the ultimate method used in cancer treatment centers to detect possible errors in dose delivery. Diode dosimetry is based on the linearity of diode current with dose. Number of carriers taking part in diode current, is proportional to dose received for practical dose range. However, carrier lifetime and mobility are temperature dependent. In addition dark current increases with temperature. Correction factors are therefore needed in order to offset dark current influence, whenever dose is measured at a temperature different from calibration or reference temperature. We investigate the effect on signal for three PTW diodes in a 18 MV photon beam generated by Elekta Synergy Accelerator and find correction factors for clinical range of temperatures.*

Introduction

Quality control in Radiation Therapy is focused in avoiding errors in dose output, caused by machine and data transmission failure. Human introduced errors, patient set up errors and possible failure of quality control have been found to be the cause of costly errors and accidents during radiotherapy such as 2005 France case [1,5]. In Vivo Dosimetry (IVD) in radiotherapy, is the only method to assure accuracy in dose delivery. International Atomic Agency and world leading medical physics organizations, ESTRO, AAMP, [1,2,3] recommend that an IVD practice be implemented in cancer treatment centers. IVD is used in teletherapy as well as in brakiotherapy. It is performed by placing detectors in proximity of irradiated volume and checking dose received directly in the first few sessions of irradiation. If deviation of dose is found to be beyond a pre-determined threshold, typically of 5%[1], procedures need to be revised and errors corrected before further treatment is given.

Most commonly used detectors for IVD to date are Thermoluminescent Dosimeters (TLD) and Semiconductor Diode Dosimeters[2,7]. Ionizing radiation creates electron – hole pairs in both types of material. Number of pairs created will depend on the dose received. In Thermoluminiscent materials electrons and holes get caught in energy traps introduced by impurities in the forbidden band of host crystal. TLD-s are passive devices, dose received is measured by heating the TLD to a characteristic temperature where it will emit visible light. Heating temperature Intensity of light emitted will be proportional to dose. This process is time consuming and labor intensive. Semiconductor silicon diode detectors offer the advantage of instant reading compare to TLD. Recently developed Optically Stimulated Luminescent Detectors (OSLD), similar from the physics point of view to TLD, already popular as personal dosimeters in radiation protection, could be used as on line measurements in IVD [7]. MOSFET transistors are being used recently in IVD, but they need external bias to function as dosimeters, whereas diodes do not need any external bias. Semiconductor diode is a p-n junction device. Ionizing radiation breaks covalent bonds in Si crystal and creates electric carriers, electrons and holes. Intrinsic electric field builds up in a very small, carrier depleted volume, driven by diffusion of electrons into the p side and of holes into to the n side of p-n contact. This electric field sweeps minority carriers across the depleted volume as they diffuse into that region. Diode current that flows in external circuit will be proportional to radiation dose received. In dosimetry the very small current of diode is integrated with time by a dedicated electrometer into charge, which is used as dosimeter signal. Among silicon diodes, p-type ones are preferred to n-type, as they show a lesser dependence on accumulated dose, if other physical characteristics are the same.[4,7]. Signal or charge reading, is desired to be independent of temperature variations of detector, caused by contact of detector with patient skin. According to literature diode sensitivity depends on temperature of diode [5,6], and dependence varies from one diode to the next, even between identical diodes from the same manufacturer [1,2,8].

Therefore is recommended that temperature correction factors be used for diodes in IVD, besides correction factors related to signal dependence on dose rate, energy, gantry angle, wedges used[1,8]. The problem we are trying to solve through this work can be stated as: Do commercially available diodes exhibit a temperature dependence? How sharp is that dependence? The larger picture problem can be stated as: Are these diodes suitable for IVD? To answer these questions we investigate temperature dependence of three commercially available at hand, calculate their respective temperature correction factors for entrance dose the clinical range of temperatures.

1. Materials and Methods

One of Elekta Synergy Accelerators that are used to treat cancer patients at Hygeia Hospital Tirana was used in the 18 MV photon beam regimen for our work. PTW Frieburg silicon p type-diodes T60010HP, connected to a PTW Multidos 12 channel electrometer, were investigated as possible commissioned detectors for a proposed IVD practice. Charge from each one of three identical PTW, silicon diodes, was studied at different temperatures under radiation with 18 MV photon beam. Manufacturer has color coded red the diodes designated for higher energy range, 13 MV to 25 MV, like those investigated. Diodes come with tungsten build up of 3.0 g/cm^3, radiation hardened. Photon beam generated by Elekta Accelerator, was used to irradiate diodes placed inside water tank. Water temperature in tank was raised slowly from room temperature approximately to normal skin temperature. 18 MV photon beam was used with 10 cm x 10 cm Field Size (FS) at a Source to Surface Distance (SSD) of 100 cm. Waterproof diodes inside a water tank were irradiated with 100 MU. Diodes were placed one at a time at depth of maximum dose (d_{max}=3.2cm), along the beam axis. Signal in nC is desired not to be effected by temperature variations. Dark current, which is added to irradiation current, however, tends to increase with increased temperature, thus increasing total diode current and deforming diode linear response to dose.

Charge measured in electrometer from each one of three identical PTW, T60010HP silicon diodes, was studied at different temperatures under irradiation with 18 MV photon beam. Diodes investigated were all color coded red by manufacturer. Diodes come with tungsten build up of 3.0 g/cm^{3,} designated for energy range 13-25 MV, radiation hardened. Photon beam generated by Elekta Accelerator, was used to irradiate diodes placed inside water tank. Charge readings of electrometer were recorded for each consecutive 1^{o}C temperature increase from 19°C to 34°C. Measurements were taken in time intervals of ten minutes to allow for equilibrium in terms of heat exchange between diode and water. Correction factor CF_T for each diode, was calculated for a particular value of temperature *T*. Detector signal was studied under different diode temperatures, to replicate change of detector temperature over time when in contact with patient skin. In clinical conditions, as detectors are placed on patient’s skin, detector temperature rises from room temperature to skin temperature, typically of about 32 °C, if treatment time is considerable. Diodes were calibrated beforehand at temperature 20°C.

Correction factor CF_T for a particular diode at a temperature *T* is defined as the ratio of electrometer reading at temperature 20°C, to electrometer reading at Temperature T when other conditions of irradiation are maintained unchanged:

$$CF_T = \frac{R_T}{R_{20}} \quad (1)$$

In equation (1), R_T and R_{20} are charge readings in nC, for the particular diode when water temperature is respectively *T*°C and 20°C

3. Measurements and Discussions

Charge readings by electrometer after a irradiation of 100 MU were taken three times for each temperature for each diode. Average of three measurements is shown in tables below. Water temperature in tank was raised slowly from room temperature approximately to normal human skin temperature (around 32 ^{o}C) . High energy 18 MV photon beam was used with a 10 cm x 10 cm Field Size at a Source Surface Distance (SSD) of 100 cm. Readings were taken in time intervals of 10 minutes to allow for heat exchange equilibrium, for every consecutive °C of temperature. Correction factors CF_T for each diode in each temperature in the range were calculated.

***Table 1**: Charge readings for different temperatures for each diode*

T (°C)	R_T(37)	R_T(35)	R_T(36)
19	13.10	13.04	13.08
20	13.15	13.08	13.09
21	13.14	13.11	13.13
22	13.19	13.10	13.16
23	13.21	13.15	13.17
24	13.21	13.16	13.20
25	13.22	13.18	13.20
26	13.24	13.21	13.22
27	13.27	13.20	13.23
28	13.27	13.24	13.25
29	13.30	13.26	13.28
30	13.33	13.27	13.29
31	13.37	13.30	13.32
32	13.37	13.33	13.36
33	13.39	13.33	13.37
34	13.42	13.37	13.39

Charge values in the table represent the average of three measurements taken for each diode in every temperature. The standard deviation for all 16 means in the table for diode 00037 was between 0.018 nC and 0.039 nC; for diode 00035 was between 0.022 and 0.038; for diode 00036 standard deviation for all 16 means in the table was between 0.020 and 0.047. Values of Table 1 are plotted on Fig. 1. Dependence of diode response with temperature shows a linear trend, , for the three diodes investigated. Diode with ID number 00036 has exhibited the highest linear correlation between temperature and response with a coefficient of correlation r=0.993. Increase of signal with temperature indicates prevailing of lifetime effect, i.e. thermal energy liberating minority carriers from defects and traps, versus decreasing mobility of carriers and contribution of dark current.

Correction factors were calculated based on values on table 1 above according to equation (1). Figure 2 shows correction factors vs temperature. Numerical values of correction factors are represented on table 2. Temperature correction factor CF_T for T = 32^{o}C was found to be CF_T(37)= 0.983 for diode 00037, for diode 00035; CF_T(35) = 0.978 and for diode 00036; CF_T(36) = 0.979. Strong linearity between temperature and CF_T was found with R ≈0.98 for all three diodes. Correction factor per centigrade was found to be: Δ CF_T / ^{o}C = 0.16% for diode 00037, for diode 00035 it was found Δ CF_T / ^{o}C = 0.17% and for diode 00036: Δ CF_T / ^{o}C = 0.15%. Linearityfound is in agreement with findings of Grusell and Rickner regarding variance of signal with temperature' [6]. Low dependence of signal per ^{o}C is in agreement with conclusions of Marinello et. al [3] that dependence is below 0.2% for relatively new diodes and increases with dose accumulation. Therefore periodic verification of dependence on temperature is needed.

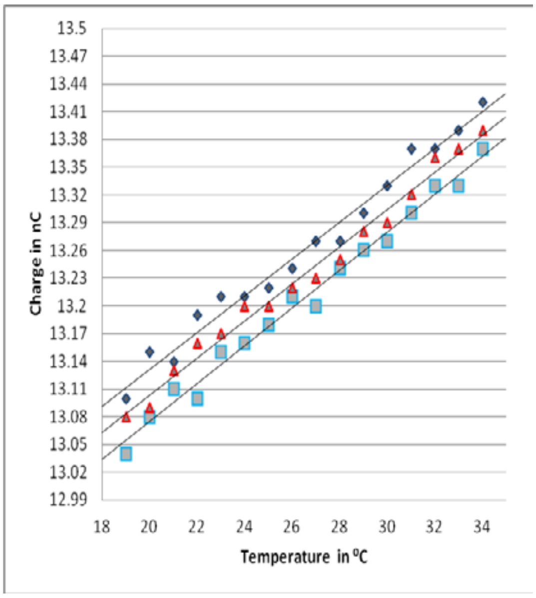

***Fig. 1** Chart of Table 1 data with linear trend line. Signal in diodes in different temperatures. Rhombus - diode 00037, triangle - diode 00036, square - diode 00035*

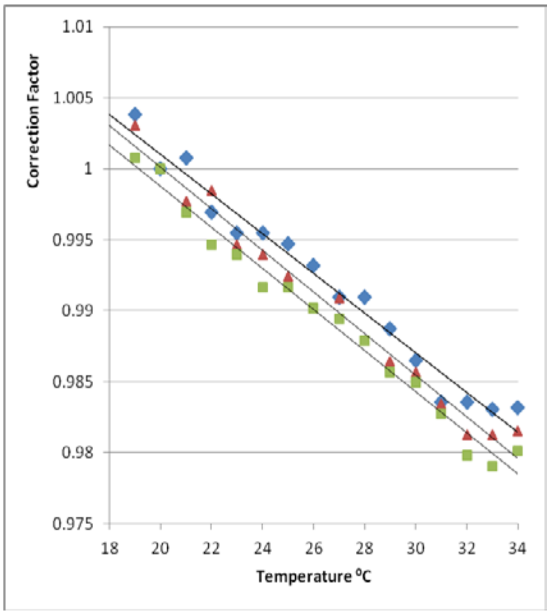

***Fig. 2** Correction factors CF_T vs temperature and trend lines. Rhombus - diode 00037, triangle - diode 00036, square - diode 00035*

Temperature ($^{\circ}$C)	CF		
	$CF_T(37)$	$CF_T(35)$	$CF_T(36)$
19	1.003816794	1.003067	1.000765
20	1	1	1
21	1.000761035	0.997712	0.996954
22	0.9969674	0.998473	0.994681
23	0.995457986	0.994677	0.993926
24	0.995457986	0.993921	0.991667
25	0.994704992	0.992413	0.991667
26	0.993202417	0.990159	0.990166
27	0.990957046	0.990909	0.989418
28	0.990957046	0.987915	0.987925
29	0.988721805	0.986425	0.985693
30	0.986496624	0.985682	0.984951
31	0.983545251	0.983459	0.982733
32	0.983545251	0.981245	0.97979
33	0.982076176	0.981245	0.979058
34	0.979880775	0.97831	0.977595

Table 2 : *Correction factors CF_T for different temperatures for each diode*

4. CONCLUSIONS

It was found that variation of detector response was linear with temperature. Correlation factor R, between temperature and CF_T for each diode is the same as correlation factor between temperature and charge reading as plotted in Figure1, because CF_T differ from charge by a factor (of R_{20}) which is constant for a given diode. Temperature dependence is not pronounced for PTW diodes designated as detectors for higher energy external beam IVD. Although for some authors temperature dependence of diode dosimeters may be neglected, it is beneficial to have all diodes used in IVD investigated regarding their temperature response. This procedure will clear diodes for any larger than usual sensitivities. Therefore temperature correction factors may be included or not for diodes in IVD depending on specific irradiation conditions.

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