Performances of homoepitaxial single crystal diamond in diagnostic x-ray dosimetry

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Pulsed x-ray dose measurements have been carried at maximum x-ray energies from 40 to 120 KeV out by using a single crystal epitaxial diamond sample grown by chemical vapor deposition (CVD). Delivered doses were between 0.1 and 10 mGy and pulse duration times between 0.01 and 0.5 s. Values of dose linearity index very close to 1 (between 1.02 and 1.07) at increasing x-ray energies and pulse decay times between 15 and 20 ms were obtained. The reproducibility was very good with no memory effects. CVD homoepitaxial diamond results to be very promising for x-ray diagnostic applications. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2195025]

It is well known that diamond[1–7] is very suitable for x-ray active dosimetry particularly because of its inherent tissue equivalence. However, until now, natural diamond must be selected and previously "primed," while chemical vapor deposited (CVD) diamond has still some problems of linearity, stability, time response, and reproducibility.[6] The recent availability of CVD diamond single crystals,[6] which are deposited by homoepitaxy on diamond substrates obtained by high pressure high temperature growth method and which can display electronic properties even superior to those of natural diamond, may open new real possibilities in the field of diagnostic x-ray dosimetry. In this work new results are reported concerning the performances of a diamond detector obtained from an epitaxial film for monitoring x-ray pulses delivered by a portable x-ray apparatus.

A homoepitaxial 150 μm thick diamond film was deposited in a properly modified microwave plasma chemical vapor deposition tubular reactor[8] on a low cost (100) synthetic IIa type single crystal diamond substrate, not intentionally boron doped, $5.0\times4.0\times0.3$ mm^3 in size. The CVD film was carefully characterized by x-ray diffraction confirming the single crystal homoepitaxial deposition and the good crystal quality of the sample. By cathodoluminescence measurements it was possible to conclude that at least in the first few micrometers below the surface the epitaxial layer was both boron- and nitrogen-free.

An x-ray dosimeter prototype was then realized by depositing interdigitated Al contacts on the CVD diamond surface by a standard photolithographic process. The interelectrode distance is 20 μm with a total sensitive surface of 0.5 mm^2. At 100 V bias voltage current intensity was below 10 pA, i.e., the resistivity of the epitaxial film was above 10^{15} Ω cm. Because of the extremely low currents it was impossible to measure the *I-V* characteristics. The applied voltage during the measurements was 20 V. Also the substrate displayed a very high resistivity, but its charge collection efficiency, as measured with 5.5 MeV alpha particles, was very low, about 3.5%, which has, compared with that measured on a material similar to that of the epilayer, which was of the order of 50%. Taking also into consideration the weak penetration of the electric field into the bulk of the device and the very low diffusion length of carriers in diamond (of the order of 1 μm), it can be concluded that the contribution of the substrate to the recorded signals is negligible.

For irradiation a standard portable x-ray apparatus with maximum x-ray energies ranging from 40 to 120 KeV was used: delivered doses in our case were between 0.1 and 10 mGy and pulse time durations between 10 ms and 0.5 s. The photocurrent pulses obtained from diamond sample polarized with 20 V bias were acquired through a precision low thermal drift of 100 MΩ resistance by means of an analog-to-digital converter (ADC) SC 2345 card (input impedance of 100 GΩ and gain of 1) connected to a PC. For each pulse, the acquisition time was 10 s and the pulse shape was digitized with a 0.1 ms sampling time. The current pulses were commonly directly collected or sometimes acquired through a Keithley model 617 electrometer. In order to calculate the collected charge, the integrals of the current pulses, which were affected by some time structure due to the ac voltage rectification at 800 KHz by some noise and by a final decay in time, were computed numerically either from raw data after the substraction of the noise level. This one was obtained by a suitable fit carried out in the first 500 channels before the start of the pulse. In the same time, x-ray pulse shapes were accurately monitored by a model 4082 RadCal accu-kV noninvasive kilovoltage meter equipped with a silicon detector array (measuring range from 40 to 160 kV and time duration range from 1 ms to 6.84 s) which was suitably connected to the second channel of ADC. In this case pulse shapes turned out to be almost perfectly rectangular. Diamond performances were also compared with those of a surface barrier silicon detector of spectroscopic grade polarized at 100 V through a 1 kΩ resistor. The doses were finally measured in the same conditions by means of a 6 cm^3 ionization chamber connected to a 9015 RadCal radiation monitor controller (energy dependence of ±5% from 20 keV to 1.3 MeV to dose range from 0.01 mGy to 600 Gy with a 0.01 mGy resolution) calibrated at National Institute for Ionizing Radiation Metrology at ENEA, Rome (Italy) with respect to a Co-60 x-ray source at a dose rate of 13.5 mGy/s within an accuracy of 2%. In some cases also a

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