OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 11, November 2010, p. 1891 - 1893

Ionization collecting of gamma radiation using two carbon nanotube electrodes

K. ARBABI[a,b], M. RAMAZANOV[b,*], M. M. LARIJANI[a]
[a]*Agricultural Medical and Industrial Research School (AMIRS), Karaj-Iran*
[b]*Department of Chemical Physics of Nanomaterials, Faculty of Physics, Baku state University, Baku, Azerbaijan*

Collecting and measurement of radiation ionization is the most important in radiation detectors. In this work, two electrodes made of carbon nanotubes (CNTs) as collecting electrodes that have a 2 mm air gap. Some characteristics of the electrodes such as leakage current and reproducibility are investigated. The polarization effects, besides voltage effect and linearity are also verified. All tests are performed using a ^{60}Co gamma radiation source.

(Received August 17, 2010; accepted November 10, 2010)

Keywords: Carbon nanotubes, Gamma radiation, Detectors

1. Introduction

Due to Carbon nanotubes (CNTs) excellent mechanical (i.e., Young's modulus 10^3 GPa), chemical and physical properties [1-3] have been considered as new materials in research work. CNTs with a length of 1 µm and a radius of about 1 nm which generate a very high electric field at relatively low voltage could be a suitable candidate for fabrication of a miniaturised gas ionization sensor and ionization chamber. Some attempts have been made to use CNTs in radiation detectors [4-6]. The results were far from the predicted requirement, maybe because of the device structure or the existence of impurities such as catalyst within the CNTs, as reported by the authors but the sensor showed little sensitivity to temperature and humidity [7].

We have developed a poly-methylmethacrylate (PMMA) parallel plate electrodes according in which the sensing elements were made of purified CNTs, in this work. Some important characteristics of constructed carbon nanotube parallel plate electrodes, i.e. polarity, saturation effect and ion collection efficiency, have been investigated for gamma rays.

2. Materials and methods

PMMA material was used as a CNT substrate to construct two electrodes. The electrodes consist of a PMMA ring of 43 mm external diameter, 28 mm internal diameter and of 8 mm thickness. The purchased multi-wall carbon nanotube (MWCNTs) powder (Ionic Liquids Technologies Co.) was characterized with purity higher than 95%, 10-30 nm diameter and 5-15 µm length. Two milligrams of MWCNTs was uniformly dispersed in chloroform solution and then spread on the disk-shaped tablets with a diameter of 26 mm. After drying, the tablet were pressed using a hydraulic press (Beckman 00-25 Glenrothes, Fife, Scotland) and a clean stainless steel mold under 8,000 kg pressure. The pressing of the CNT powder was performed on one side of each two PMMA circular plates with 28 mm diameter and 1 mm thickness already cut and machined to be readily mounted on the PMMA ring. The thickness of pressed CNTs was estimated to 200 µm by an optical microscope evaluation. The distance between the two plates used as electrodes has been fixed at two millimetres. One of the disks on which CNTs were pressed, was divided into two concentric circles by removing the CNTs (in circle shape) from the coated surface using a milling machine. The inner circle diameter is 16 mm and that of the outer circle is 26 mm. The connection of different parts of this device has been shown schematically in Fig. 1. The effective volume between the electrodes was calculated to be about 0.402 ml.

The collected charges were measured by reference level electrometer (PTW UNIDOS 10001), was connected to the electrodes via a low noise triaxial cable and a TNC connector. The triaxial cable wires were connected to the electrodes with graphite paste. A calibrated thermometer with 0.1 degree precision and a calibrated barometer with 0.5 mbar precision were used for atmospheric corrections. The electrodes were settled in a rectangular slab of PMMA with 20 mm thickness at the same level (Fig. 1).

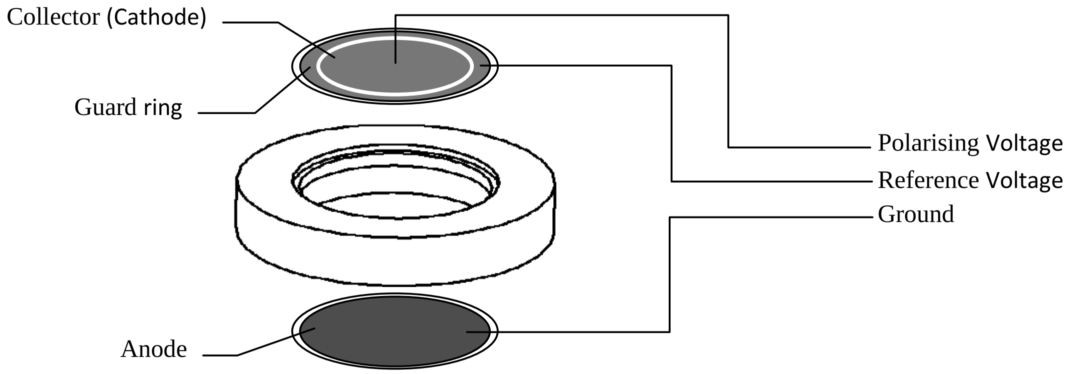

Fig. 1. Schematic of the designed charge collecting electrodes and its connections.

A Picker V9 ^{60}Co machine was used to irradiate the charge collecting electrodes (CCE) with 1.25 MeV ^{60}Co gamma rays at a maximum dose rate in water ($\dot{D}_{W_{max}}$) 0.244 Gy/min at source to electrodes distance 80 cm and field size 10 cm×10 cm. A set of measurements were performed to evaluate and characterize the CCE as follows:

- The electrodes leakage currents were tested as an indication of real currents induced by radiation.
- Stability test was carried out with a ^{60}Co field size of 10×10 cm^2, source to electrodes distance 80 cm and depth = 0.4 g/cm^2 of PMMA.
- Polarization effect was evaluated by applying ±50 V and ±200 V to the electrodes. Generally, change of polarity may yield different readings [8-9].
- Reading linearity was checked for different doses, ranging from 0.050 Gy to 5 Gy at the same dose rate at -200 V polarising voltage, and for different dose rates with integrating time of 30 s.

The irradiation conditions for all measurements were fixed at a reference field 10×10 cm^2 using ^{60}Co unit for 30 s. All readings were corrected for ambient conditions using the following formula:

$$M_C = \overline{M} \times k_{TP}, \tag{1}$$

and

$$k_{TP} = \left(\frac{273.15+T}{293.15}\right)\left(\frac{1013.25}{P}\right), \tag{2}$$

where M_C is the corrected value and $\overline{M}$ is the mean value of instrument charge measurement, and k_{TP} is the correction factor depending on temperature (°C), T, and pressure (mbar), P, of the ambient.

3. Results and discussion

The leakage current of CCE was about 2×10^{-14} A before irradiation. At the end of 10 min irradiation during which the current was 4.12×10^{-11} A, the leakage current decreased to ± 0.7% within 5 s [10].

The charge readings mean value for 10 runs with 5 consecutive readings in each run has been performed to study the stability of measurement in short term. The mean reading was 1.253 nC and standard deviation values in each run were less than ±0.3%.

The same test has been repeated during 4 months in which the mean value lies within ±1%. According to these results the limits of response variation of CNTPP chamber are well in accordance with required values [11].

Polarity effect evaluation using relation (3) has been performed at two potentials, 50 V and 200 V. According to the results summarized in Table 1, the difference of reading for ±50 V and ±200 V are 0.5% and 1.2% respectively [9].

$$k_{pol} = \frac{M^{+} + M^{-}}{2M} \tag{3}$$

where k_{pol} is polarization effect, M^{+} and M^{-} are charge reading at plus and minus voltages respectively.

Table 1. The CCE response to polarisation voltage

Voltage (V)	50	200
k_{pol}	1.0026	1.0063

The variation of the CNT electrodes response to different ^{60}Co radiation doses at applied voltage -200 V is shown in Fig. 2a presents a graph of charge over dose in C/Gy versus the dose in Gy at constant dose rate 0.244 Gy/min. It is obvious that the figure presents a constant value without any deviation from constancy. Fig. 2b depicts the collected charge versus dose rates at an integrating time of 30 s. The constancy and the linear shape of the graph in Figs. 2a and 2b respectively, indicates the linearity of the charge collecting system.

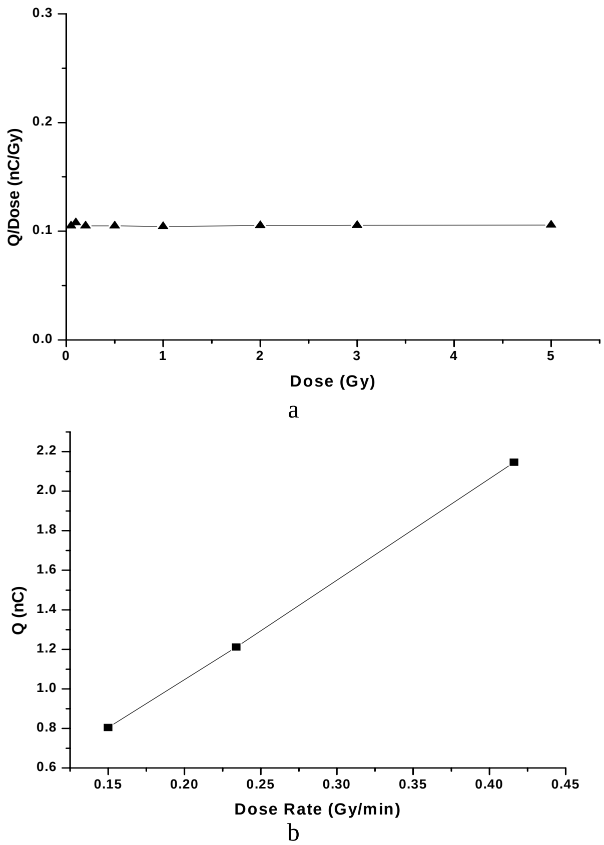

Fig. 2. Plot of a) charge over dose in C/Gy vs. the dose in Gy at -200 V with constant dose rate 0.244 Gy/min and b) charge vs. dose rate at -200 V and integrating time 30 s for ^{60}Co radiation.

4. Conclusion

The CCE were constructed using MWCNTs as sensing electrodes for radiation. Characterization of constructed electrodes was performed for polarity effects and linearity. The results show polarity effects has negligible effect on charge collecting. The deviation of empirical curves from the linearity according to Boag's theory and the Jaffe plot indicates that the ion loss in the chamber is affected by not only recombination process also the other effects probably, emission of electrons by CNT tips. The ion collection efficiency at our working conditions was 99% for the electrodes. The leakage current of CCE is very low and desirable. Also the stability of charge reading has good condition for charge measuring in time duration.

References

[1] Peter J. F. Harris, Carbon Nanotubes and Related Structures, (Cambridge University Press) (2001) ISBN 0521554462.
[2] D. Tomànek, R. J. Enbody, Science and Application of Nanotubes, (New York: Kluwer Academic / Plenum Publishers) (2000) ISBN 0306463725.
[3] Meyyappan, M. Carbon nanotubes: Science and applications, (USA: CRC Press LLC) (2005) ISBN 0849321115.
[4] Ma, J. Yeow, J. T. W. Chow, J. C. L., Barnett R. B. A. carbon nanotube-based radiation sensor, Int. J. Robot. Autom. **2**, 49 (2007).
[5] Ambrosio, A. Ambrosone, G. Campajola, L. Cantele, G. Coscia, U. Iadonisi, G. Ninno, D. Maddalena, P. Perillo, E. Raulo, A. Russo, P. Trani, F. Current results on the development of a carbon nanotube radiation detector, WSPC-Proceedings, (2007).
[6] Kotani, T. Kawai, N. Chiba, S. Kitamoto, S. Development of a new radiation detector utilizing carbon nanotube as anodes, Physica E, **29**, 505 (2005).
[7] Modi, A. Koratkar, N. Lass, E. Wei, B. Ajayan, P. M. Miniaturized gas ionization sensors using carbon nanotubes, Nature, **424**, 171 (2003).
[8] IAEA Technical Report Series No. 398. Absorbed dose determination in external beam radiotherapy: An international code of practice for dosimetry based on standards of absorbed dose to water, Vienna, (2000).
[9] IAEA Technical Reports Series No. 381. The Use of Plane-Parallel Ionization Chambers in High-Energy Electron and Photon Beams: An International Code of Practice for Dosimetry, (1997).
[10] International Electrotechnical Commission. Medical electrical equipment: Dosimeters with ionization radiation chamber as used in radiotherapy, IEC 60731, 731 (1982).
[11] International Electrotechnical Commission. Medical electrical equipment: Dosimeters with ionization chambers as used in radiotherapy, IEC 60731, 87 (1997).

*Corresponding author: mamed_r50@mail.ru, nanomaterials@bsu.az