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Development of Graphene Ion-Chamber for Radiation Dosimetry

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1. Introduction

Graphene is an exciting material due to its high electrical and thermal conductivity. After the publication by Novoselov and Geim, the Nobel prize winners in 2010, many researchers have considered graphene as a possible substitute of electrode material [1].

Recently, scientific research using graphene has been divided by two types of graphene. One is a pure graphene, and the other is graphene oxide (GO), which is chemically synthesized from graphite. A pure graphene is a single layer of graphite, and its physical characteristics are very exciting. However, making process and cost are quite complex and expensive to apply an industry. On the other hand, graphene oxide is easy to make and apply a real device. Moreover, reduced graphene oxide (rGO), made by thermal annealing of GO, has a relatively similar properties compared to graphite so that many researchers have tried to apply an industry like a graphene electrode and a graphene biomarker using rGO [2].

Until now, radiation dosimetry using an ion-chamber has been a standard protocol. For its high electrical conductivity, graphite is usually used as a wall material of ion-chamber. Graphene can be a possible alternative to graphite due to its superior electrical conductivity and mechanical integrity. In this study, Monte Carlo simulations for graphene-walled and graphite-walled ion-chambers were performed to characterize their dosimetric properties. A world-first prototype of a graphene ion-chamber was fabricated.

2. Methods and Results

2.1 Monte Carlo simulation for two x-ray irradiators

BEAMnrc was used to generate x-ray irradiators [3]. For MV photon beam, a medical linear accelerator (LINAC) in Seoul National University Hospital (Varian Clinac®) was modeled, and a biological irradiator in the radiological physics laboratory in Seoul National University (Precision X-Ray X-RAD 320) was also modeled for kV x-ray beam. The manufacturer provided a drawing of the LINAC including 6 MV flattening filter. A drawing of X-RAD 320 was used from the published geometry with minor modification [4]. The geometries of two x-ray irradiators inserted into the BEAMnrc code were presented in Fig. 1. The percent depth dose (pdd) and profile were simulated and compared to the measured data or published data until the differences of each points were within 3%. The phase space files at 50 cm from the x-ray source were generated to be used in an ion-chamber simulation.

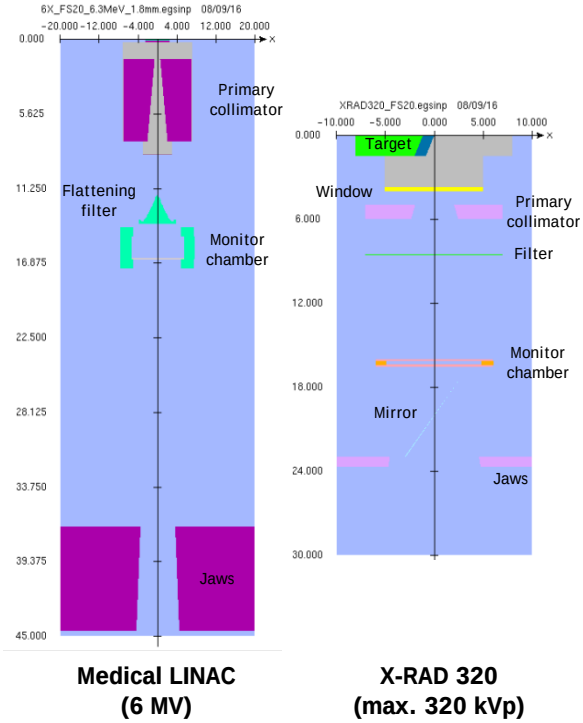

Fig. 1. The schematic diagrams of two x-ray irradiators for Monte Carlo simulations using the BEAMnrc code.

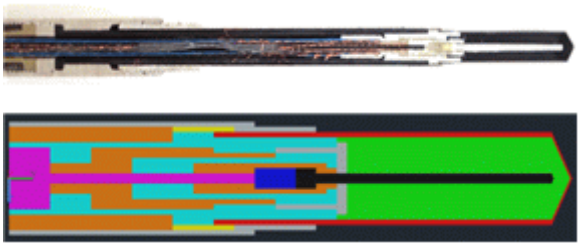

Fig. 2. A Farmer-type ion-chamber (PTW N30013) was divided into two pieces using a diamond cutter (top). Based on this information, a precise geometry of an ion-chamber was programmed into the egs_chamber code (bottom).

2.2 Monte Carlo simulation with an ion-chamber

The water phantom including an ion-chamber for radiation dosimetry was modeled using a C++ class

library for EGSnrc, egspp code. The egs_chamber code was used to improve simulation efficiency with several variance reduction techniques [5]. The surface of the water phantom was located at a 100 cm from the x-ray source. The size of the water phantom was 50×50×50 cm^3. In order to design the precise geometry of an ion-chamber, a Farmer-type ion-chamber (PTW N30013) was divided into two pieces using a diamond cutter. The cutting area and the geometry for Monte Carlo simulation were presented in Fig. 2. The wall material was changed from a graphite to graphene, actually rGO. The cross-section data of rGO for egs_chamber simulation, known as pegs4dat, were generated using the ESTAR database of National Institute of Standards and Technology. The components of rGO were 82% of carbon, 17% of oxygen, 0.5% of hydrogen, and 0.5% of nitrogen, and the density of rGO was 1.9 g/cm^3. The center of an ion-chamber was the center of the air cavity, and was located at the beam axis. For pdd simulation, the position of an ion-chamber was changed at intervals of 0.5 cm. The field size of both x-ray irradiators was 20×20 cm^2. The electron cutoff energy was 0.521 MeV and the photon cutoff energy was 0.01 MeV. The number of the incident electrons was 3.1×10^9 for X-RAD 320 and 1.3×10^{10} for LINAC. The uncertainties in Monte Carlo simulation were less than 0.4% for X-RAD and 0.2% for LINAC except the build-up regions. The dose differences between a graphite and graphene ion-chambers were within 0.4% for 6 MV LINAC and 0.7% for X-RAD 320 except the build-up regions. The simulated pdd data were presented in Fig. 3 and 4.

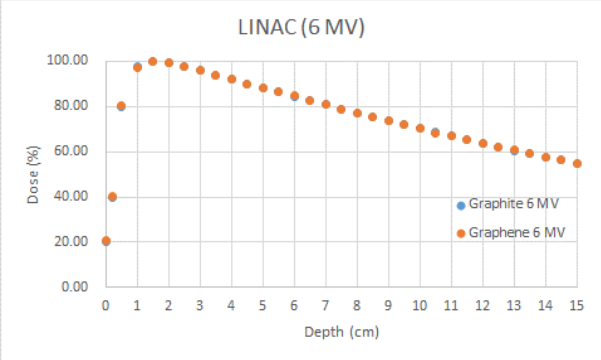

Fig. 3. The percent depth doses (pdd) of 6 MV photon beam were simulated using graphite and graphene ion-chambers.

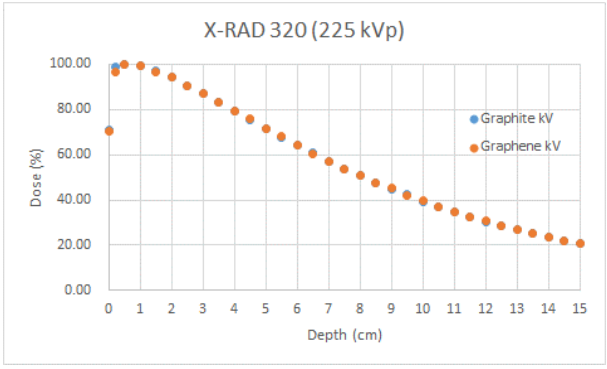

Fig. 4. The percent depth doses (pdd) of 225 kVp x-ray beam were simulated using graphite and graphene ion-chambers.

2.3 Synthesis of reduced graphene oxide

The synthesis process of GO is based on the modified Hummers' method [6]. In order to make a wall shape of an ion-chamber made of rGO, a zinc cylinder was milled. The size and shape of a zinc cylinder were same as the air cavity of an ion-chamber. GO solution has been used to fabricate a wall shape of GO. After fabrication, thermal annealing process removed oxygen component and enhanced electrical conductivity of GO. The thickness of rGO layer was approximately 100 ㎛. This thickness was similar to that of PTW N30013 Farmer-type chamber. For waterproofing, PDMA or PMMA was coated on freeze-dry state of the rGO wall. The zinc cylinder was etched by 35% of hydrochloric acid. The fabricating process of the rGO wall was presented in Fig. 5, and synthesized rGO with coated by PDMS was presented in Fig. 6.

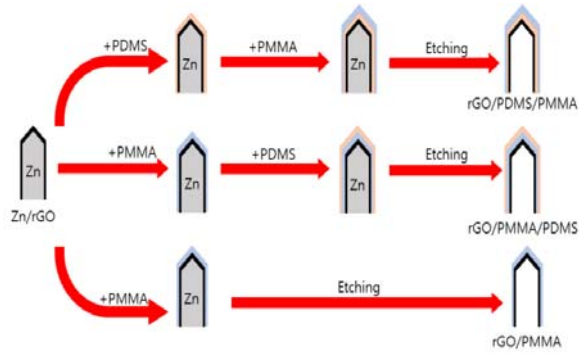

Fig. 5. Reduced graphene oxide (rGO) was synthesized and coated by PDMS or PMMA for water-proofing.

Fig. 6. An optimal synthesis for a sheet of rGO (left), ion-chamber walls made of rGO (middle), and durability test (right).

2.4 Raman spectroscopy of graphene oxide and reduced graphene oxide

Microstructure of GO and rGO was characterized by Raman spectroscopy (Horiba Scientific T64000). The reduction process of GO can be distinguished by the the change in the ratio between two intensity peaks: D band and G band. 514.5 nm wavelength of an argon laser was used. Raman spectra of GO and rGO were presented in Fig. 7. D peaks of GO and rGO were located at 1,350 cm^{-1}, and G peaks of GO and rGO were located at 1,600 cm^{-1}. The intensity ratios between D peak and G peak (I_D/I_G) of GO and rGO were 0.80 and 0.83, respectively. The increase in I_D/I_G indicated sheet-like shape of graphene oxide.

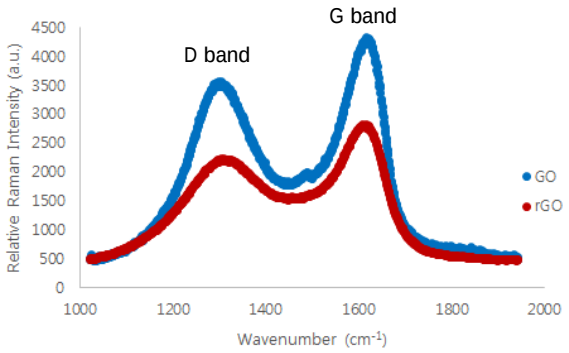

Fig. 7. Raman spectra of graphene oxide (GO) and reduced graphene oxide (rGO).

2.5 Scanning electron microscope of reduced graphene oxide

Morphological property of rGO was analyzed with scanning electron microscopy (SEM) using Hitachi S-4800 model. SEM image of rGO was presented in Fig. 8. The image was magnified by 15,000 times. The surface morphology resembled folded curtain, which indicated that rGO was overlapped instead of aggregation. However, some aggregated regions were shown in the SEM image because a thermal annealing process was not enough in order to avoid surface crack and wobbling.

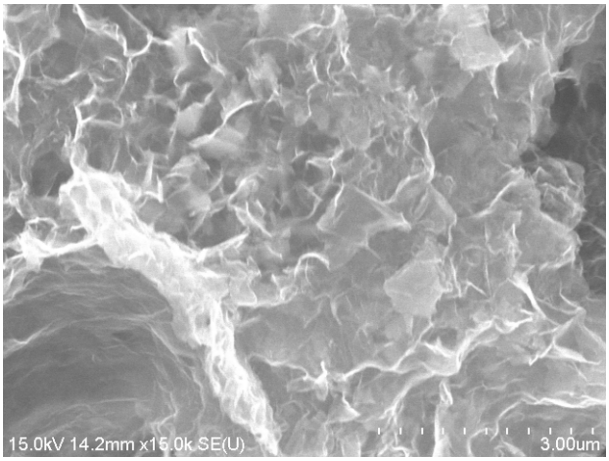

Fig. 8. A sheet structure of reduced graphene oxide was shown in the scanning electron microscope (SEM) image.

2.6 Prototype of a graphene ion-chamber

A prototype of a graphene ion-chamber was developed and presented in Fig. 9. A Farmer-type ion-chamber (PTW N30013) was disassembled, and the wall was changed from graphite with PMMA to rGO. We are planning to upgrade the quality of rGO and measure the dose using this new-type ion-chamber.

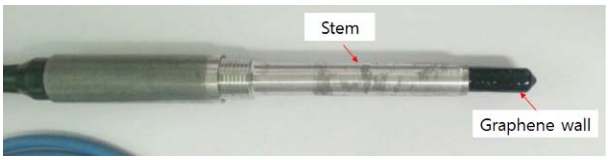

Fig. 9. A prototype of a graphene ion-chamber was fabricated.

3. Conclusions

A graphene ion-chamber was designed and its prototype was successfully fabricated. The percent depth dose curve calculated by Monte Carlo simulations for a graphene ion-chamber was compatible to the curve using a conventional graphite ion-chamber. Therefore, due to its superior electric conductivity and mechanical integrity, graphene can be a promising alternative to graphite as a wall material of ion-chamber for radiation dosimetry.

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