A Study on the use of Gafchromic™ EBT3 Film for Microdosimetry by Raman Spectroscopy

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1. Introduction

The absorbed dose is the expectation value of the energy imparted to matter per unit mass at a point [1]. However, for most radiobiological considerations this quantity may not give any information on energy actually imparted to individual cells or to subcellular structures [2]. This concept is explained in microdosimetry, which deals with the spatial, temporal and energy spectral distributions of energy imparted in cellular and subcellular biological structures and associated biological effects [1].

We at Seoul National University (SNU) are investigating on the use of unlaminated Gafchromic™ EBT3 film for microdosimetry. Our goal is to determine absorbed dose on EBT3 film with spatial distribution of as low as 10 micron using Raman spectroscopy.

2. Methods and Material

2.1. Unlamented Gafchromic™ EBT3 film

Gafchromic™ EBT3 films produced by International Specialty Products (ISP, Wayne, NJ) are near tissue equivalent, energy independent and provide high spatial resolution [3]. It consisted of active component, which include radiation-sensitive diacetylene monomers in ordered form and a polyester base as shown in Figure 1. Upon irradiation, the film undergoes a color change by polymerization of diacetylene monomers (see Figure 2).

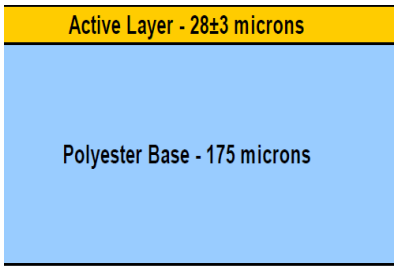

Figure 1: EBT3 film structure [3].

During the experiments the films were cut in 1cm × 1cm pieces and irradiated with 6MV photon beam at various dose levels from 0 to 50Gy.

2.2. Raman Spectroscopy

Raman Spectroscopy has been widely used to study the electronic and vibrational structure of polymers [4]. It is based on inelastic scattering of a monochromatic excitation source by molecules. The energy loss of the scattered photons relates the vibrational energy levels of the interacting molecules. When photons interact with a molecule, most of them are elastically scattered. However a small fraction (about 1 in 10^7 photons) is scattered inelastically known as Raman Effect.

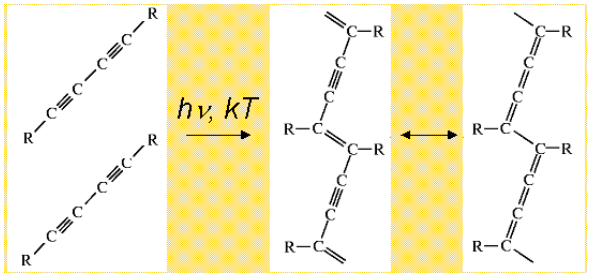

Figure 2: Polymerization of Diacetylene monomers by radiations [3].

Raman scattering can occur with a change in vibrational energy of a molecule. The difference in energy between the incident photon and the Raman scattered photon is equal to the energy of a vibration of the scattering molecule. A plot of intensity of scattered photons versus energy difference is a Raman spectrum. This spectrum can be used to identify the molecule as they provide a "molecular fingerprint" [5]. Energy range of Raman spectrum is from 200 to 4000 cm^{-1}.

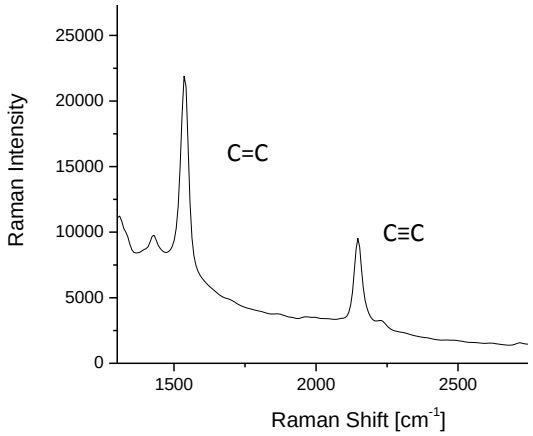

Figure 3: Raman Spectra of EBT3 film showing C=C and C≡C.

Prominent polymeric carbon-carbon bonds of EBT3 film (C≡C at 2153 cm^{-1} and C=C at 1542 cm^{-1}, Figure 3) are observed for different radiation levels and it was found out that relative peak intensities for the monomers and polymers chain can be made use of interpreting the

amount of polymerization by irradiation [4]. This increase may be used to determine absorbed dose on EBT3 film on a microscopic scale of spatial distribution.

2.3. Experimental Section

EBT3 films were cut in 1cm × 1cm pieces and irradiated with 6MV photon beam at various dose levels from 0 to 50Gy. They were marked with an arrow in the upper right corner to spot the film orientation. Pixel size of 200µm ×200µm with spatial resolution of 25µm was chosen for Raman spectroscopy using 632.8nm laser beam. Raman spectra were recorded with Micro Raman mapping system of Dongwoo Optron Co. Ltd (see Figure 4). Data was acquired using Andor SOLIS 4.16.30002.0 software whereas mapping was carried out using maple software. Laser exposure time was initially selected as 0.3 sec which was later optimized to 0.75sec. The raw data from Raman mapping was extracted using excel files and Origin Pro 9 was used for plotting and data analysis.

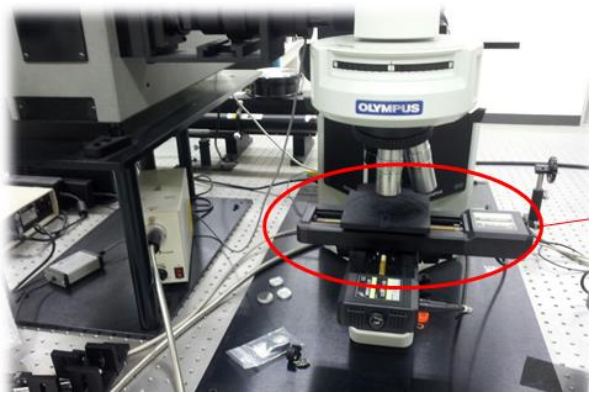

Figure 4: Raman Spectroscope at SNU.

Raman data at different points on EBT3 films were acquired by placing it on motorized stage of Raman instrument capable of moving along x and y axis. But when stage position is varied acquire different data points of same dose level; it was observed that Raman intensity was significantly changed. To investigate this effect depth profiling (along z-axis) of the film was done by manually focusing laser at different depths.

Large laser exposure time may result into the saturation of Raman peaks which means the loss of important information. Less laser exposure time means weak Raman signal. Therefore optimization of exposure time was also considered in this study.

In case of measuring optical density of film for finding dose responses, the orientation of the film remains consistent for the calibration and readout [6]. To check the same consistency with Raman spectroscopy, the data was first acquired with correct orientation and then after rotating the film around the same point at 90º.

Temporal stability was observed by acquiring Raman data from films of same batch but on different days.

Dose uniformity was checked by acquiring Raman data at different points on EBT3 film and then comparing their plots.

Dose dependency of EBT3 film was checked by observing the increase in C≡C with increasing dose.

3. Results and discussion

3.1. Depth Profile of Unlamented ™ EBT3 film

Figure 5 shows the variation in Raman intensity with depth. The maximum signal is observed at the top surface of the active layer of the film. The Raman signal weakens if spectra are taken at different depths of film in either direction.

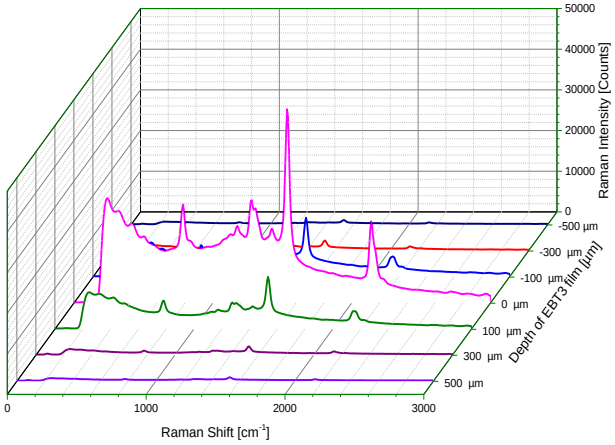

Figure 5: Depth profile of EBT3 Film.

At 0µm the Raman signal is maximum i.e. laser beam is focused at the surface. If depth is increased by 100µm then Raman intensity weakens because the laser beam is actually focused with same distance in air. Similarly, decreasing depth by 100 µm implies that laser beam is focused somewhere in the polyester base, which again weakens the signal.

During Raman mapping it was observed that at different points of same dose level, Raman intensity significantly differs. This might be due to z-axis variation of stage in micro level. The solution of this problem is to find the maximum signal on EBT3 film during data acquisition. This can be done by depth profiling. Therefore extreme care is essential when obtaining Raman spectra.

3.2. Optimization of Laser Exposure Time

Longer exposure time gives better spectra for weak Raman signal from weak Raman scattering object. Since diacetylene monomers and polymers have very strong C=C and C≡C peaks, therefore longer exposure time saturates several peaks in Raman spectra of the film. Raman spectra of EBT3 film with varying exposure time are shown in Figure 6. At 0.3 sec of exposure, four peaks were saturated. By reducing exposure time we

may extract some useful information from the spectra. After this experiment, the laser exposure time was optimized to 0.75sec so that we get the maximum signal without the loss of useful spectral information.

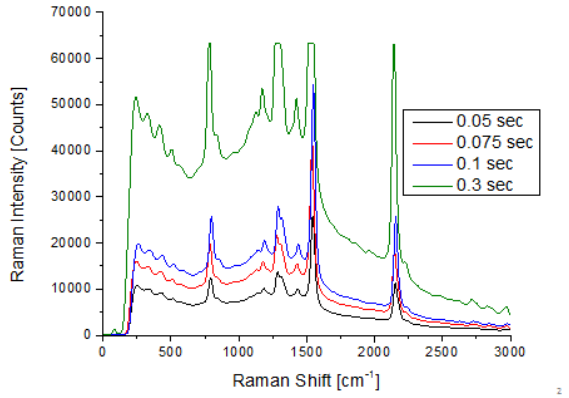

Figure 6: Optimization of laser exposure time.

3.3. Effect of Film Orientation on Raman Intensity

Effect of film orientation was investigated by acquiring data with one orientation and then by taking another set of readings after rotating the film at 90º. This effect is shown in Figure 7, where experiments were performed on EBT3 film having exposure level of 10Gy and 20Gy. Hence the orientation of film must remain constant during calibration and readout of Raman signal as reported in measuring optical density of the film.

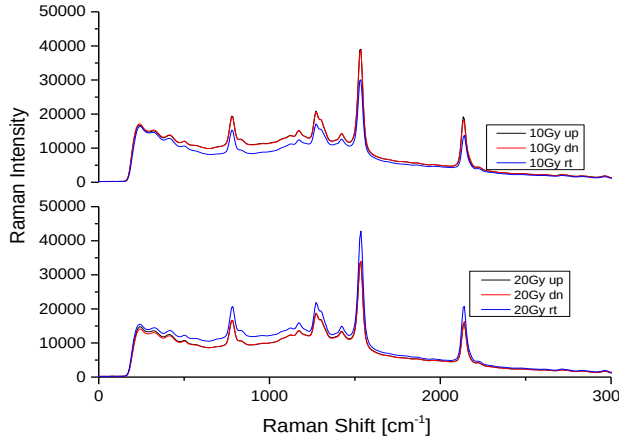

Figure 7: Effect of film orientation on Raman Spectra

3.4. Temporal stability and dose uniformity

Raman spectra of unexposed film and films exposed with 2Gy and 10Gy of X-rays were taken after 24hrs and 48hrs. It was found out that the corresponding spectra were overlapping (see Figure 8). This verifies the temporal stability of film. Moreover two different points were chosen for all exposed and unexposed films, suggesting that EBT3 films are exposed uniformly.

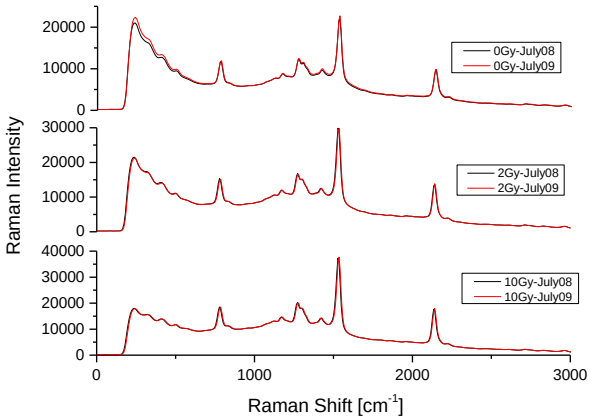

Figure 8: Temporal stability and dose uniformity of EBT3 radiochromic films.

3.5. Dose Profile of EBT3 film using Raman Spectroscopy

Figure 9 presents the Raman spectra for various levels of film exposure. For this experiment data, the pixel size of 200µm×200µm with spatial resolution of 25µm of each film was chosen.

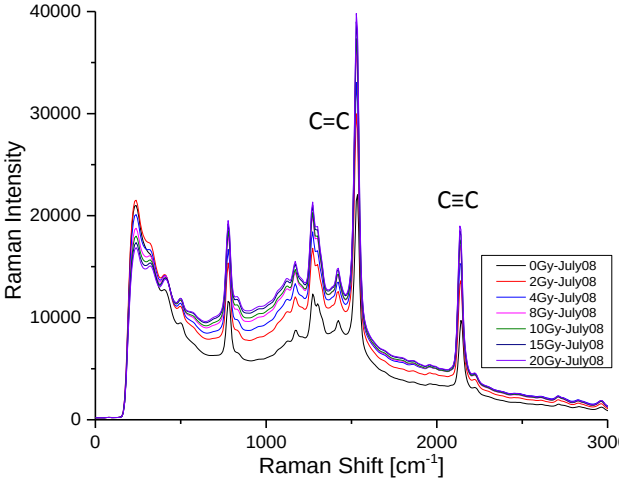

Figure 9: Dose Profile of EBT3 film

It is observed that both C ≡ C and C=C bonds increase with increasing in dose. However after 10Gy the increase rate decreases with further increase in dose. The size of cellular and subcellular structure varies between 1 to 10µm. In the future we will reduce the pixel size to 10µm×10µm to get information of energy imparted to individual cells and subcellular structures.

3.6. Calibration Curve

For calibration curve, C≡C peak heights are plotted against different dose levels. Figure 10a shows C≡C peaks of dose profiles discussed in section 3.5, whereas calibration curve is shown in Figure 10b. It can be seen, that C≡C peak height exponentially rises with the increase in dose due to polymerization effect. Initially the C≡C peak height increases with fast rate up to dose

level of 10Gy and after that the peak height increasing rate slows down.

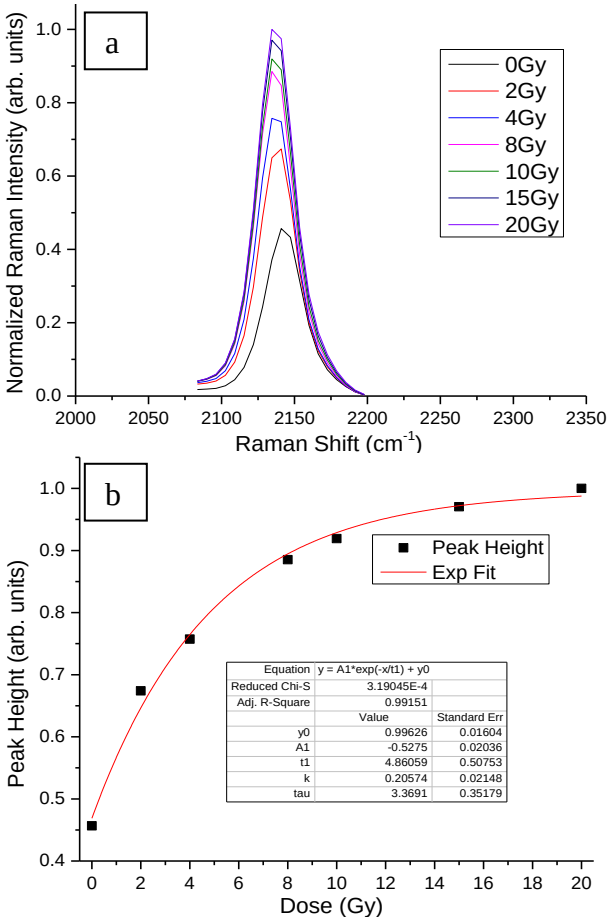

Figure 10: a) Carbon triple bond profile of Raman Spectra of Figure 9 and b) its calibration curve.

4. Conclusions

Raman spectroscopy can be used for the determination of absorbed dose by exploiting the idea that C≡C and/or C=C in EBT3 film increases with increasing dose due to polymerization of diacetylene monomer. Data acquired using Raman is reproducible and temporally stable. Proper placement of film on stage and with right orientation is very important. The peak saturation problem can be avoided by decreasing laser exposure time. Raman intensity decreases with increase or decrease of depths beyond the surface active layer. Depth profile of film for each dose level maybe used to find the maximum signal, which is useful in finding the dose profile. C≡C peak height exponentially rises with the increase in dose due to polymerization effect.

REFERENCES

[1] F. H. Attix, Introduction to Radiological Physics and Radiation Dosimetry, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, p. 501, 2004.

[2] K. R. Kase, B.E. Bjarngard, and F. H. Attix, The Dosimetry of Ionizing Radiation, Vol. 1, Academic Press, Inc., New York, p. 78, 1985.

[3] D.F. Lewis, Radiochromic Film, ppt, International Specialty Products, Wayne, NJ, 2010.

[4] M. Kamath, W. H. Kim, J. Kumar, S. Tripathy, K.N. Babu, and S. S. Talwar, Kinetics of Diacetylene Polymerization: An FT Raman Study, Macromolecules, American Chemical Society, Vol. 26, pp. 5954-5958, 1993.

[5] Kaiser Optical Systems, inc., Raman Spectroscopy A tutorial, Kaiser Optical Systems, inc, Ann Arbor, MI 48103, 2015.
http://www.kosi.com/

[6] S. Bartzsch, J. Lott, K. Welsch, E. b. Krisch, U. Oelfke, Micrometer-Resolved Film Dosimetry using a microscope in microbeam radiation therapy, Medical Physics, Vol. 42 (7), p.4071, 2015.