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Spectroscopic and sub optical band gap properties of e-beam irradiated ultra-high molecular weight polyethylene

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HIGHLIGHTS

- Urbach energy in UHMWPE is found to decrease with e-beam irradiation.
- UHMWPE direct and indirect energy band gaps are found to decrease with irradiation.
- Effect of e-beam on the number of carbon atoms in C=C unsaturation is investigated.

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ABSTRACT

Muller matrix spectro-polarimeter has been used to study the absorption behavior of pristine and e-beam irradiated (30, 65,100 kGy) ultra-high molecular weight polyethylene (UHMWPE) over the visible spectral range i.e. 400–800 nm. As a result, significant changes occur in the absorption behavior of irradiated samples due to radiation induced physical and chemical changes. To analyze these (radiation induced) changes in polymer matrix, Urbach edge method is employed for the calculation of optical activation energy. In addition to this, direct and indirect energy band gaps along the number of carbon atoms in C=C unsaturation have been determined by using modified Urbach formula and Tauc's equation, respectively. The results obtained during study reveal that Urbach energy decreases with radiation treatment and has a lower value for 100 kGy sample i.e. E_u=71.63 meV. The values of direct and indirect energy band gaps are also following the decreasing trend with e-beam irradiation. Moreover, indirect energy gaps are found to have lower values as compared to direct energy gaps. The number of carbon atoms in clusters (as estimated from modified Tauc's equation) has been found to vary from ~6 to 8 for direct energy band gaps and from ~9 to 11 for indirect energy band gaps.

1. Introduction

Importance of polymers having an enhanced surface and bulk properties is growing with each passing day due to their advantages like low weight, low cost, ease in processing and fabrication (Gul et al., 2003). Ultra-high molecular weight polyethylene (UHMWPE) is a versatile polymer which belongs to polyethylene (PE) family having an average molecular weight between 3,000,000 and 6,000,000 g/mol (Gul et al., 2003; Scholes et al., 2000). Due its chemical, mechanical, physical and biocompatible properties, it has been extensively used in the fields of electrical insulation, medicine, orthopedic, microelectronics engineering, and food industry (Buncick et al., 2000; Kumar and Pandya, 1997; Bistolfi and Bellare, 2011; Sobieraj and Rimnac, 2009).

In order to modify physical and chemical properties of UHMWPE for particular applications, irradiation of polymers is noteworthy and most reliable method at present (Mishra et al., 2001; Saad et al., 2005; Brooks et al., 2002; Kamal et al., 2015; Lee, 1999; Subba Reddy et al., 2006). All the radiation induced physical and chemical processes are mainly responsible for UHMWPE modification in order to use it for any particular

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application, e.g. to fabricate LEDs, optical sensors, antireflective coatings, polymeric optical fibers etc (Brooks et al., 2002; Lee, 1999). For abovementioned applications in the field of optics, knowledge about the optical properties and factors (e-beam radiations in this study) effecting on these properties is required. This would legitimize the requirement of studying the effect of high energy radiation on optical properties of the UHMWPE in comprehensive detail (Kamal et al., 2015).

In order to check the feasibility of using UHMWPE for aforementioned applications, research is going on to find/investigate the optical properties of pure and irradiated UHMWPE. In this regard, Abdul-Kader (2009) had studied the modification in optical properties of UHMPWE due to ion bombardment by using photoluminescence and UV spectroscopy. He had made the correlation of ion fluence with optical band gaps and activation energies of irradiated samples. He found that energy band gaps and activation energies of samples decreased with an increase in the concentration of ions. Although, this study is comprehensive as far as irradiating the samples with heavy ion like He ion but these results cannot be generalized for other type of high energy radiations like X-ray, lasers, gamma, and e-beam etc.

Recently, Raghuvanshi et al. (2012) had studied the effect of gamma rays on optical properties of UHMWPE. The major properties of PE which were focused in this study are: Urbach energy, direct and indirect band gap energies, and number of carbon atoms in a cluster of C=C unsaturation. On the basis of results obtained, it was proposed that UHMWPE can serve as material for radiation dosimeter. However, significantly higher values of gamma doses (i.e. 500–2000 kGy), thickness of PE sheets, and single data set of absorption experiment make these results questionable for potential readers.

Keeping in view the abovementioned facts related to topic of interest, this study aims at investigating optical and sub band gaps spectroscopic properties of e-beam irradiated UHMWPE. The sheets of micron size were prepared and irradiated with e-beam with absorbed dose of 30, 65 and 100 kGy. The absorbance data in the spectral range of 400–800 nm has been used to obtain the Urbach energy, direct and indirect energy band gaps, and number of carbon atoms in C=C cluster. The obtained results have been explained on the basis of well established radiation chemistry of PE.

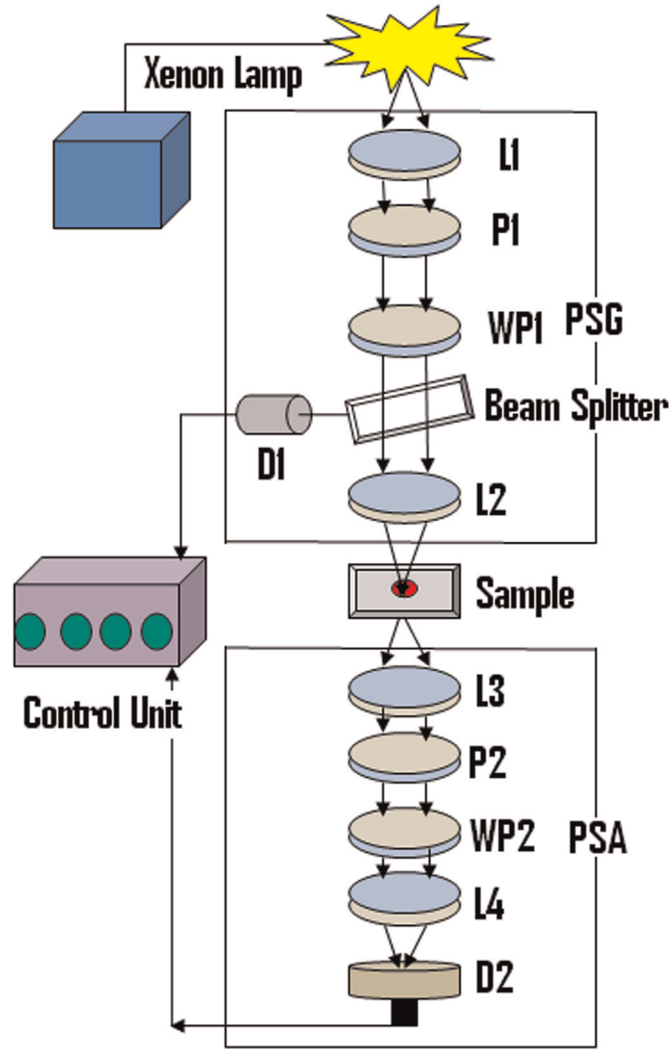

Fig. 1. Schematic diagram of Muller matrix spectro-polarimeter.

2. Materials and method

2.1. Materials, sample preparation and irradiation

Laboratory grade UHMWPE powder (average molecular weight or 3–5 million g/mol) was purchased from Sigma Aldrich. In order to prepare the sheets of micron sizes, heating press (available at Pakistan Institute of Engineering and Applied Sciences, 45650, Islamabad, Pakistan) with ramp up and cool down rate of 10 °C/min was used. The pressing of UHMWPE powder was performed under the pressure of 200 bar, and holding time of 12–15 min at 140 °C, 160 °C, and 190 °C, respectively. The compressed sheets were then cleaned with acetone to remove impurities from the surface. After measuring thickness, prepared sheets were divided into four groups; i.e. control samples (un-irradiated), samples for 30, 65 and 100 kGy irradiation. Samples prepared for irradiation were then sent to Korean Atomic Energy Agency for treating them with e-beam at a dose rate of 1 kGy/pass. Irradiations of samples were performed in open air at room temperature (~25 °C) for total dose values of 30, 65, and 100 kGy, respectively. The control sample was kept at home laboratory and was used as a reference during this study. Our choice of treating samples at or below 100 kGy was due to the reason of PE crosslinking saturation at or above 100 kGy.

2.2. Sample testing

In this experiment, an automated Muller matrix spectro-polarimeter controlled using AxoScan TM (manufactured by Axometrics, 2006) has been used for sample testing. The schematic diagram of the spectral Muller matrix polarimeter used in this particular experiment is shown in Fig. 1. For the comprehensive details of spectro-polarimeter, readers are referred to literature (Ahmad et al., 2013). Briefly, this setup comprises of a low-noise Xenon lamp of 150 W power rating as input light source. For the selection of required wavelengths in the range of 400–800 nm, spectro-polarimeter has a built-in diffraction grating monochromator with an accuracy of 6 ± 0.5 nm for any selected wavelength. Light from this source is passed to the polarization state generator via fiber optic cable in order to illuminate the sample with required polarization states. After interacting with the sample, the output light is then passed. The result file consists of transmittance data corresponding to each wavelength along with other polarization properties. The main reason of using this setup is its sensitivity and accuracy as compared to conventional UV–visible setup. The slight variations in sample placement, orientation, laboratory environment, source power, and built-in optics alignment immediately changes the results including transmittance (the data of our interest) from sample.