Laser Propagation through Poly-Methyl-METHACRYLATE (PMMA) Thin Films Prepared By Pulsed Laser Deposition

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Abstract

The paper is aimed to explore the propagation of different laser wavelengths through PMMA thin films prepared by Pulsed Laser Deposition (PLD) technique. The first step was to deposit PMMA thin films on the glass substrate, keeping it at room temperature as well as at a temperature of 300°C. The structure of the deposited films was characterized by X-Ray Diffractometer (XRD). The results reveal that the films deposited at 300°C has much ordered domain as compared to the bulk PMMA and the film deposited at room temperature. An optical microscope was used to observe the surface texture of films. The surface of the film deposited at room temperature exhibits non-uniform distribution of particulates with various particle sizes and less thickness. The uniformity, particle size and thickness of the film were found to increase when deposited at 300°C substrate temperature. The second step was to propagate the lasers of wavelength 1064 nm, 632.8 nm and 248 nm through these deposited thin films. The transmitted signals were recorded by 200 MHz digital oscilloscope in conjunction with their respective detectors. The results show that the films of PMMA deposited on substrate at temperature of 300ºC exhibit minimum propagation losses for all the wavelengths (1064 nm, 632 nm and 248 nm) in general and for UV, in particular.

Keywords: PMMA, XRD, surface morphology, thin films, IR, UV, Visible radiations

1. INTRODUCTION

Poly-Methyl-Methacrylate (PMMA) is one of the well known polymers with a reasonable mechanical strength. It has been widely studied both in bulk and thin film form [1-3]. The PMMA thin films exhibit low density and high tensile and tear strength which makes it very important from application view point [4, 5]. The PMMA thin films are widely used in data display, lithography and chemical sensing, etc [1-6]. These films are also suitable for waveguide fabrication [6] which has advantages in the development of integrated optics, optoelectronics, sensors and interface technologies [7, 8].

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Pulsed Laser Deposition (PLD) technique is the simplest and effective procedure to produce high quality thin films from organic polymers [2]. Many researchers have prepared polymeric thin films using PLD technique [9-12].

In this paper, we report the experiments aiming to fabricate waveguides from PMMA thin films prepared by PLD technique. 1064 nm (IR), 632.8 nm (Visible) and 248 nm (UV) wavelengths were made to propagate through PMMA thin films. The propagation losses of these wavelengths were calculated by processing the data obtained from their respective detectors connected with a 200 MHz digital oscilloscope.

2. Experimentation:

The experimentation has been performed in two steps. In first step thin films were deposited by PLD technique and the second step was the propagation of various wavelengths through these deposited thin films.

2.1 Set-up for thin film deposition

The pulsed laser deposition system was developed following a standard design [13]. The PMMA target material was ablated with a KrF excimer laser (248 nm, 20 ns). The ablated material was then deposited on glass substrate. The experimentation was carried out in vacuum chamber having a base pressure of 10^{-6} Torr. An optimum 0.5 cm target to substrate distance was kept during the deposition process. The incident laser beam was focused with the help of quartz lense (f = 40cm) for ablation of target material. A motorized mount having rotating at 6rpm was used to rotate PMMA target. The substrate temperature was maintained at 300^{o}C to allow the necessary adatom mobility for the near equilibrium growth of the target material as a film. The substrate was also rotated at 6 rpm with the help of a controllable motor during the deposition. The whole experimental set-up is shown in figure 1.

2.2 Set-up for laser propagation

The experimental arrangement for the propagation of lasers of wavelengths 1064 nm, 632.8 nm, and 248 nm through the deposited thin films is shown in figure 2. The films were placed parallel to the direction of the propagating laser beam. In order to make the diameter of the propagating beam comparable to the thickness of the deposited thin film, pinholes of diameter 500 µm, 300 µm and 150 µm were placed downstream to the beam reaching the film. The intensity of the each wavelength after propagating through the film was detected by the respective detector in conjunction with a 200MHz digital oscilloscope. The IR (1064 nm) , 632.8 nm (VIS) and 248 nm (UV) wavelengths were detected by BPX-65, Q60525/b and 818-BB-22 detectors, respectively.

The propagation losses through each film were evaluated by processing the data obtained from the oscilloscope signals.

3 RESULTS AND DISCUSSION

3.1 X-ray diffraction

Figure 3 shows X-ray diffraction patterns of (a) bulk PMMA (b) PMMA thin film deposited at room temperature and (c) PMMA thin film deposited at 300ºC substrate temperature. The data obtained from XRD patterns is summarized in Table 1. The XRD pattern of bulk PMMA (3-a) shows amorphous behavior with two diffraction maxima as has been reported earlier [1]. The shape of first main maxima at diffraction angle 14° (2θ) reflects the ordered packing of main polymer chains while the shape and intensity of second maxima gives information about the inside atomic ordering of the main chain [4]. The medium range ordered configuration in polymer effects the width as well as the intensity of two peaks [1]. The calculated mean size of the ordered domain of first main maxima of bulk PMMA is 2.29 nm [4].

The pattern of XRD for film deposited at room temperature (3-b) is different as compared to bulk material. The difference is the increase of intensity, narrowing of first maxima and the absence of second peak. This difference is due to modification in the ordering of the main chain [4]. The value of the ordered domain is calculated to be 9.731 nm.

It is worth noting that the film deposited at 300^{o}C (3-c) shows narrower diffraction maxima as compared to film at room temperature as well as the bulk PMMA. The value of ordered domain calculated for the maxima is 12.048 nm. The large peak intensity suggests that the film deposited at 300^{o}C is more packed and ordered [14]. The higher value of ordered domain is due to the increase in number of stacking layers and diffused atoms at higher substrate temperature because the size of ordered domain depends on substrate temperature [4].

3.2 Surface morphological analysis

Optical microscope was used to explore the texture, size particulate and thickness of the films. Figures 4-5 show the optical micrographs of PMMA films deposited at room temperature and at ST 300^{o}C, respectively. The particulate size of the film deposited at room temperature ranges from 5 µm to 60 µm whereas, the particle size for the film deposited at 300˚C varies between 5 µm-80 µm. The reason for an increase in size of particulate is the bond breaking along the main chain at higher substrate temperature generates fragments with larger masses [15]. Thin film deposited at 300̊C has a uniform and dense distribution of particles of almost circular shape.

The average measured thickness of film at 300˚C is 228 µm whereas the thickness of the deposited film at room temperature was 150 µm. The reason for the increase in the thickness is attributed to the higher substrate temperature because it allows higher mobility and causes surface diffusion resulting into good packing of the monomers or grains [16].

3.3 Propagation of lasers of different wavelengths through PMMA thin films

In order to investigate the propagation losses of various wavelengths, lasers of 1064 nm, 632.8 nm and 248 nm were made to pass through PMMA thin film. The intensity of each wavelength after passing through the film was recorded on an Oscilloscope. The signal profiles of each wavelength are discussed in the following section.

Figure 6 (a, b, c) shows the signal profiles of the 1064 nm propagating through air (a), PMMA thin film deposited at room temperature (b) and at 300º C (c), respectively. A comparison reveals that the intensity or peak voltage of the signal profile for the film deposited at 300º C is significantly higher which is indicative of a minimum loss through the film.

Figure 7 (a, b, c) shows the signal profiles of 632.8 nm wavelength propagating through air (a), PMMA thin film deposited at room temperature (b) and at 300º C (c), respectively. Figure 8 (a, b, c) shows the signal profiles of 248 nm wavelength propagating through air (a), PMMA thin film deposited at room temperature (b) and at 300º C (c), respectively.

Signal profiles of 632.8 nm and 248 nm after passing through the films exhibit almost the same trend as that for 1064 nm (Fig 6).

4 Propagation losses of PMMA thin films

The propagation losses through the films were calculated utilizing the data obtained from oscilloscope signals by using the formula [17].

$$L = [20/x \log_{10} (V_o/V_x)] \ (dB/cm) \qquad (1)$$

Where x is the length of the thin film, V_x is the input voltage and V_o is the output voltage after passing through thin film. The propagation losses for air and for deposited thin films for each wavelength were calculated. The peak voltage of the signal from air is taken as V_x and the peak voltage of signal from thin film is considered as V_o.

Although a number of pinholes were used to reduce the diameter of laser beam to bring it to the size of the thickness of deposited thin film but even then there is a probability that a portion of laser beam will pass through air. To calculate the net propagation losses through thin films, the air losses were subtracted from thin film losses. The data obtained from the calculations is listed in table 2. PMMA thin film deposited at room temperature shows maximum propagation losses as compared to PMMA thin film deposited at 300ºC substrate temperature. The film deposited at 300^0C substrate temperature has the minimum losses in the case of 248 nm (UV laser).

CONCLUSION

Thin PMMA films deposited by PLD were characterized to be used as wave guides for the propagation of IR, VIS and UV wavelengths. The X-rays Diffractometer and optical microscope were used for the characterization of the films. The PMMA film deposited at 300°C substrate temperature has the highest value of ordered domain amongst the bulk PMMA and the thin film deposited at room temperature. The film deposited at 300°C has significantly improved texture in terms of uniformity, particle size and thickness.

Thin film deposited at room temperature exhibits maximum propagation losses whereas, the PMMA thin film deposited at substrate temperature of 300°C displays minimum propagation losses for all the wavelengths (1064 nm, 632 nm and 248 nm) in general and for UV, in particular.

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Figures

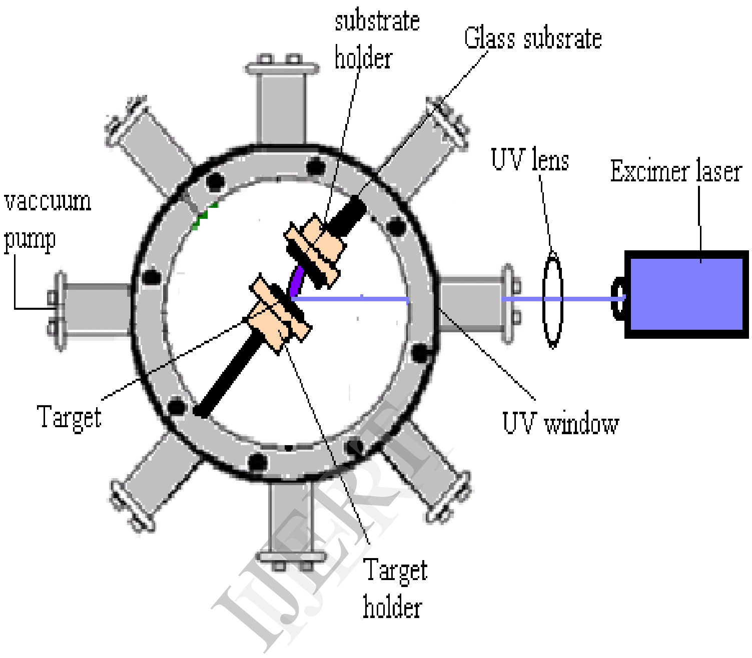


Figure 1: A Schematic diagram of PLD chamber

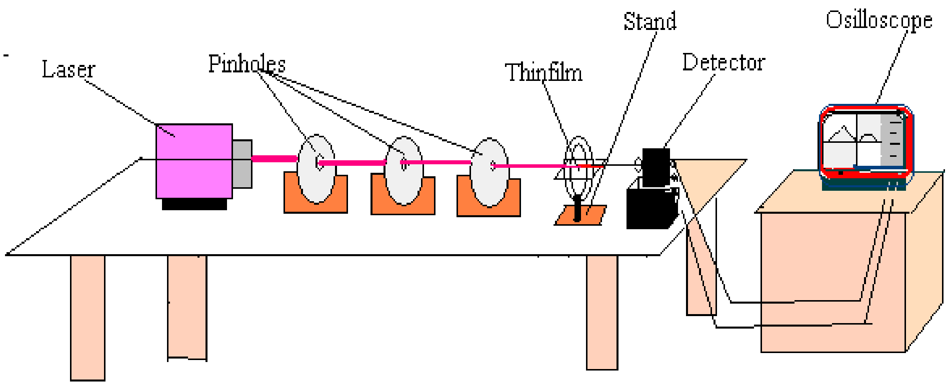


Figure 2: A schematic of the experimental setup for laser propagation

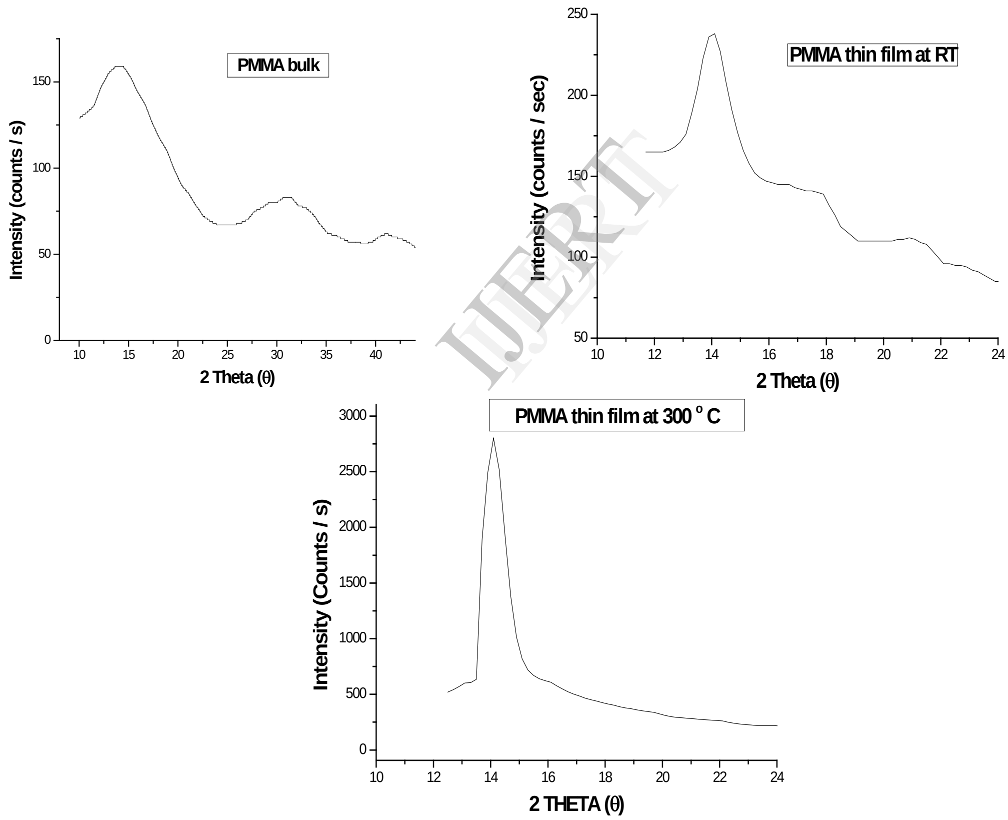


Figure 3: XRD patterns of (a) Bulk PMMA (b) PMMA thin film at room temperature (c) PMMA thin film at 300^{0}C substrate temperature

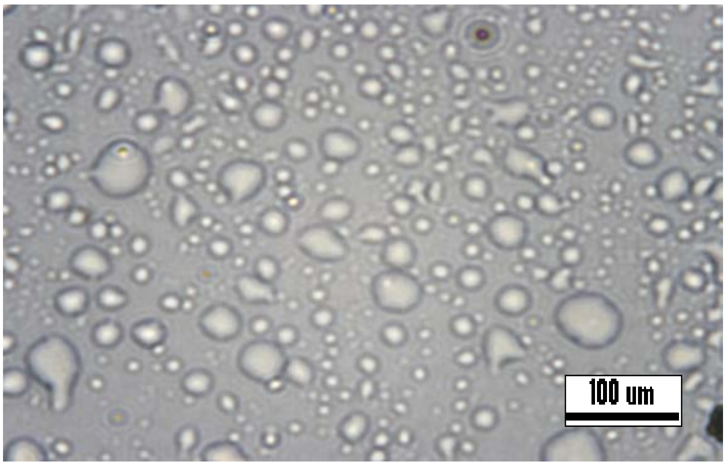


Figure 4: Optical Micrograph (×1000) Of PMMA thin film

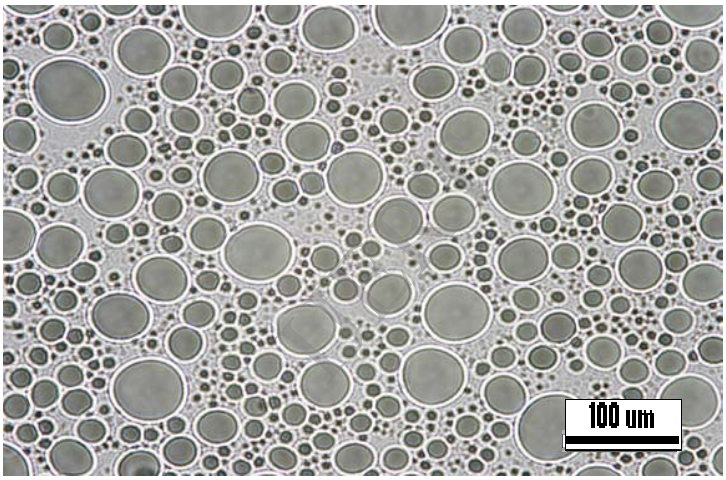
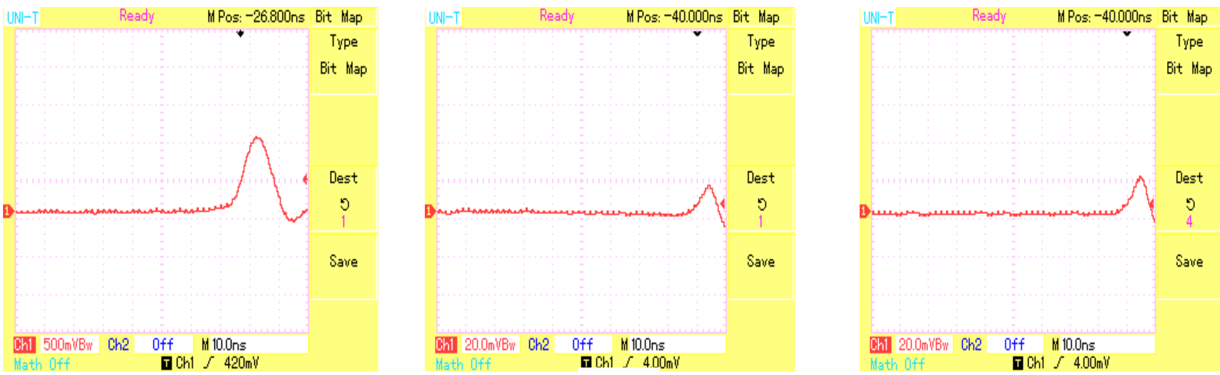
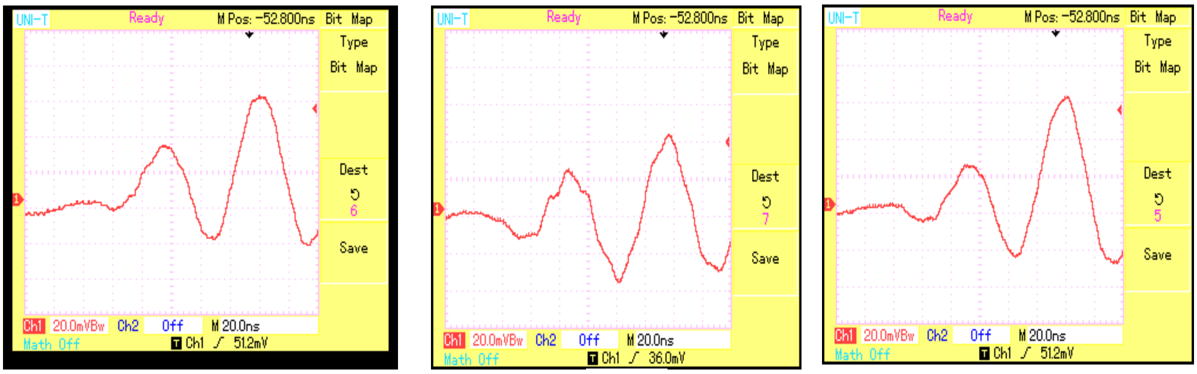


Figure 5: Optical Micrograph (×1000) Of PMMA thin film at 300˚C



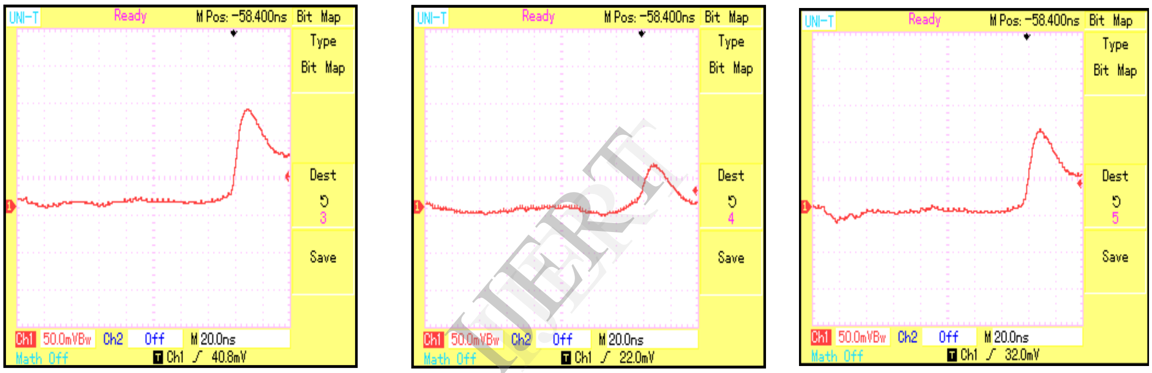
(a) **(b)** **(c)**

Figure 6: Signals profiles of 1064 nm wavelength propagating through (a) air (b) PMMA thin film deposited at room temperature (c) PMMA thin film deposited at 300º C substrate temperature



(a) **(b)** **(c)**

Figure 7 : The Signals profile of 632.4 nm wavelength propagating through (a) air (b) PMMA thin film deposited at room temperature (c) PMMA thin film deposited



(a) **(b)** **(c)**

Figure 8 : The Signals profile of 248 nm wavelength propagating through (a) air (b) PMMA thin film deposited at room temperature (c) PMMA thin film deposited at 300^{o} C substrate temperature

Tables

Table 1: XRD data of PMMA thin films

Sample name	2θ	FWHM[°] β	Grain size = $0.94\,\lambda / \beta \cos\theta$ (nm)
Bulk PMMA	14.00	3.642	2.297
PMMA thin film at RT	14.02	0.859	9.731
PMMA thin film at 300°C	14.1	0.694	12.048

Table 2: Propagation losses of polymeric thin films

Thin Films	Propagation losses (dB/cm) of various laser Wavelength (nm)		
	1064 (nm)	**632.8 (nm)**	**248 (nm)**
PMMA thin film at RT	2.52	3.26	5.629
PMMA thin film at 300C°	1.58	0.86	0.341