Electrical and Dielectric Properties of Poly (methyl methacrylate) Thin Films

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Abstract – This work investigated the behavior of poly (methyl methacrylate) (PMMA) as dielectric films. The PMMA films were deposited on the glass substrates using spin coating technique. The PMMA concentrations were varied from 0.3, 0.6, 0.9 to 1.2 g. The electrical properties results is indicated when PMMA concentration is increased, the resistivity were also increased from 3.59 Ω.cm to 1.06 x 10^7 Ω.cm and it became more insulative at the high concentration of PMMA. For dielectric properties result, the dielectric constants are in range 0.35 to 2.72 at the frequency of 1 MHz. Meanwhile the capacitance shows the value average of the PMMA concentration for capacitance in a range at ~x 10^{-10} F at the frequency of 1 MHz.

Keyword; PMMA, electrical properties, dielectric properties, morphology

I. Introduction

Most plastics are dielectrics or insulators (poor conductors of electricity) and resist the flow of a current. The polymer is made up with atoms having their electrons tightly bound through covalent bonding. This covalent bonding will bring it much more difficult for polymer to allow the movement of electrons, hence they act as insulators [1]. The value of the dielectric constant that is reported by others researchers was around 2.3 ~ 2.6 at frequency 1 MHz [2-7].

Next, the other most important factor that to determine the device performance besides electrical properties is surface morphology. The surface morphology has to be smooth and uniform because it affects the electronic transport properties which are depending on the grain boundaries and defect located in the film [8-10] .

Poly (methyl methacrylate) (PMMA) is an organic material that being used as dielectric in organic field effect transistor (OFET) and organic thin film transistor (OTFT). This is because it has good insulation for dielectric properties such as low dielectric constant and dielectric loss over a wide range of frequency [11, 12].

The PMMA thin film is being deposited by spin-coating technique which is widely used for deposition technique because it is easy, fast and controllable for the formation uniformity of the thin films.

In this paper, we have fabricated metal insulator metal (MIM) capacitor with PMMA as dielectric layer. We investigate how PMMA concentrations affect the properties of the insulating layer in MIM device.

II. Experimental Procedure

The materials used to form the PMMA film were PMMA powders (*M_w of 120,000*) and toluene purchased from Sigma Aldrich. The glass substrates were cleaned by sonicating them successively for 10 minutes in acetone, methanol and de-ionized water in the ultra sonic cleaner followed by drying using argon gas. The PMMA powders were dissolved in 10ml toluene solvent by varying the PMMA concentration from 0.3g, 0.6g, 0.9g to 1.2g. The sol-gel solution were sonicated for 30 min using the ultrasonic in order to dissolve the particle PMMA in toluene solvent before the solution were stirred for 24 hr to get the fully dissolved the PMMA particles by using heat-stir. A 60-nm thick of aluminium (Al) bottom contact was formed before we performed the spin coating technique to make the PMMA thin films. The PMMA solutions were spun on the Al-coated glass substrate with the spin speeds of 1500 rpm for 40s. The samples were then dried at temperature of 50 ^{0}C for 5 min. The summarized deposition condition is shown in Table 1.

Table 1 : The summary of deposition condition

Material	Poly (methyl methacrylate) (PMMA)
Solvent	Toluene (10ml)
Varied PMMA Concentration	0.3g, 0.6g, 0.9g, & 1.2g
Deposition Technique	Spin-coating with parameters: i. speed = 1500rpm ii. time = 40s

	iii. layer = 5 iv. drop = 10
Drying	Parameters: i. temperature = 50 °C ii. time = 5 min

After completing the PMMA deposition, the top metal contact (60 nm thick) was formed by evaporating aluminum (Al) over the PMMA film using metal mask.

The thickness of the PMMA thin film was measured using surface profiler from Veeco Dektak. Electrical and dielectric properties were measured using 2 point probe current- voltage (*I-V*) and impedance spectroscopic (Solatron 1260) measurement. The surface morphology of the PMMA thin film was investigated using field emission scanning electron microscope (FE-SEM) and atomic force microscopy (AFM) (Park System; XE-100). The overall flow of deposition process is summarized in Figure 1.

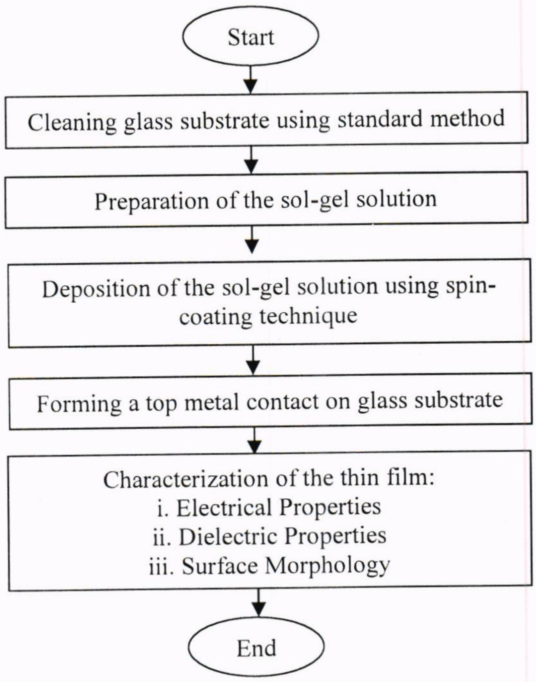


Fig. 1: The overall flow of deposition process

III. Results and Discussion

3.1 Electrical Properties

Figure 2 shows the thickness of PMMA thin films. The thickness increases as the PMMA concentration is increased. It shows that the value of the PMMA thin film thickness was 115.13nm, 351.46nm, 856.65 nm and 1161.88nm for each of different PMMA concentrations 0.3g, 0.6g, 0.9g and 1.2g. The thin films is thicker might be due to the more presence of particle atoms in the thin film. Theoretically, the value for the thickness of thin film was dependent on primary concentration, viscosity of solution and solvent vaporizability [13].

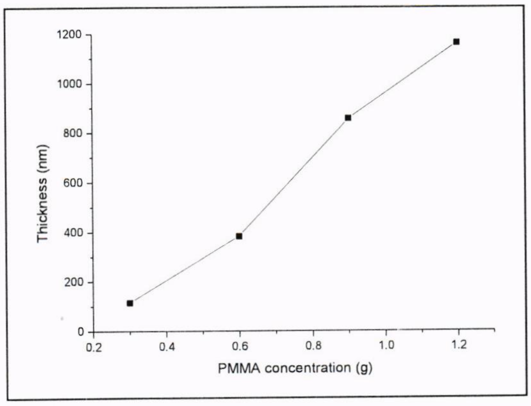


Fig. 2 : The film thickness with the different PMMA concentration

Figure 3, 4 and 5 display the I-V curve of an Al/PMMA/Al structure formed on a glass substrate. The voltage applied was swept from -10 to 10 V. The I-V curves indicated that the overall of the PMMA concentration gave the Schottky behavior. The Schottky behavior showed that the insulator can store charges in the device. This accumulation charge can be proved from capacitance-voltage measurement as being reported from Berkeley that in simulating I-V curves, it can calculates the electron/hole distribution in both inversion and accumulation [14].

The I-V curves also indicate that the current is reduced from miliampere (mA) to nanoampere (nA) when the concentration is increased. Current in mA and microampere range usually gave the device act as semiconductor [15]. It also indicates that PMMA film with 0.3g has high leakage current compared to other and it suggested that this 0.3g is not favorable to act as insulator.

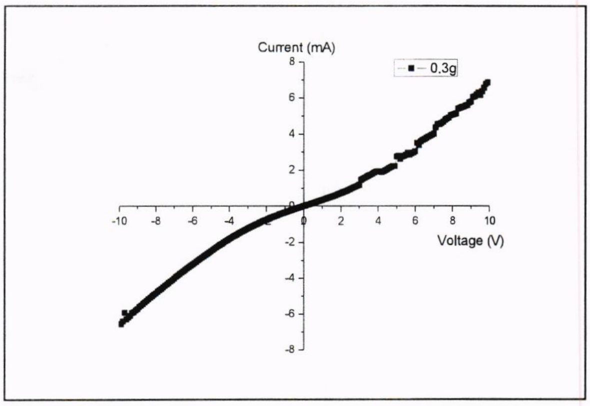


Fig. 3 : I-V curve for PMMA thin film with concentration 0.3g

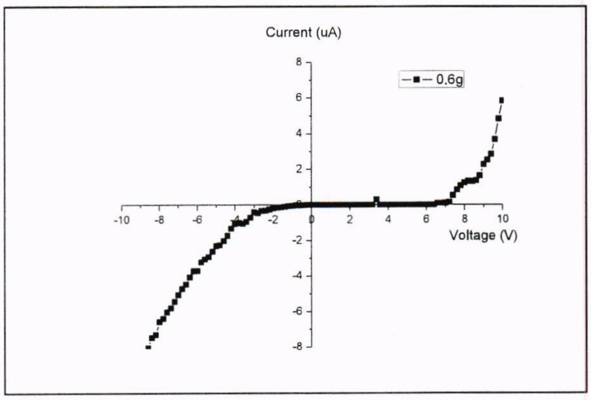


Fig. 4 : I-V curve for PMMA thin film with concentration 0.6g

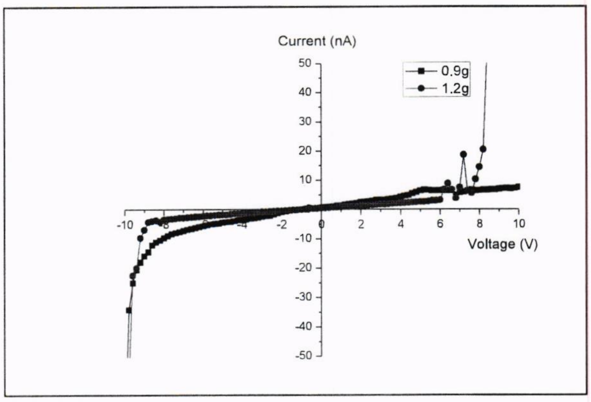


Fig. 5 : I-V curve for PMMA thin film with concentration 0.9g and 1.2g

Figure. 6 are shows the resistivity for the PMMA thin film. It shows that the resistivity is increased as the PMMA concentration increased. The result obtained in overall was approximately ~10^6 Ω.cm which is relatively low compared to other researchers in range 10^{13} Ω.cm to 10^{15} Ω.cm [4, 5]. The PMMA concentration of 0.3g showed the lowest resistivity and hence, produced of high conductivity. Furthermore, the value of the resistivity must be high if the PMMA material wants to be act as an insulator in order to limits the currents flow. The value of the resistivity of deposited thin film PMMA also can be calculated from the equation (1) below.

$$\rho = \left(\frac{V}{I}\right)\left(\frac{wt}{l}\right) \qquad (1)$$

Table 2 summarized the relation between the thin film thickness and the resistivity for different PMMA concentration.

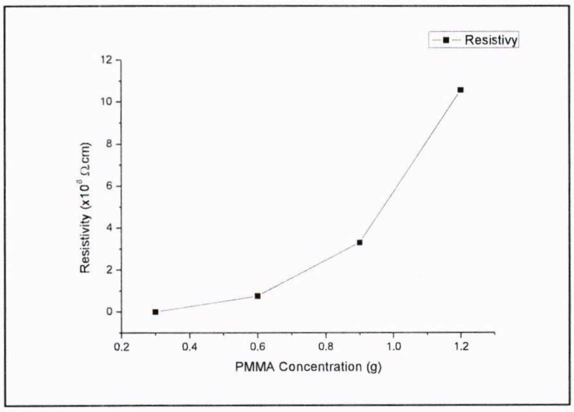


Fig 6 : Resistivity of PMMA thin film with different concentration

Table 2 : The relation between the film thickness and the resistivity by varying PMMA concentration

PMMA Concentration (g)	Film Thickness (nm)	Resistivity ($x10^6$ Ω.cm)
0.3	115.13	3.59 x 10^{-6}
0.6	351.46	0.754
0.9	856.65	3.29
1.2	1161.88	10.6

3.2 *Dielectric Properties*

Figure 7 shows the dielectric constant with respect to frequency for PMMA thin film and Figure 8 shows the dielectric constant versus PMMA concentration measuring at frequency 1 MHz. The dielectric constant was measured for frequency range of 10 Hz - 1 MHz. It shows that the dielectric constant is decreased as the frequency applied increased. The value of dielectric constant for each PMMA concentration 0.3g, 0.6g, 0.9g and 1.2g at frequency 10 Hz are 18.9, 87.1, 44.5 and 232. Basically, the dielectric constant of an organic material usually depends on the temperature and frequency [16]. As the frequency applied is increased, the dielectric constant is decreased drastically at frequency 1 kHz. It showed the dielectric constant value 3.93, 10.67, 4.48 and 25.14 for each different PMMA concentration 0.3g, 0.6g, 0.9g and 1.2g as tabulated data in Table 3. For the maximum frequency at 1 MHz, the value for dielectric constant being decreased which are 0.35, 2.72, 2.56 and 2.57 for the PMMA concentration 0.3g, 0.6g, 0.9g and 1.2g respectively. Hence, the PMMA with concentration 1.2 g gave the high dielectric constant that might be due to due to an increased of total polarization arising from dipoles and trapped charge carriers [17] and it can be suggested as the most suitable concentration to act as an insulator.

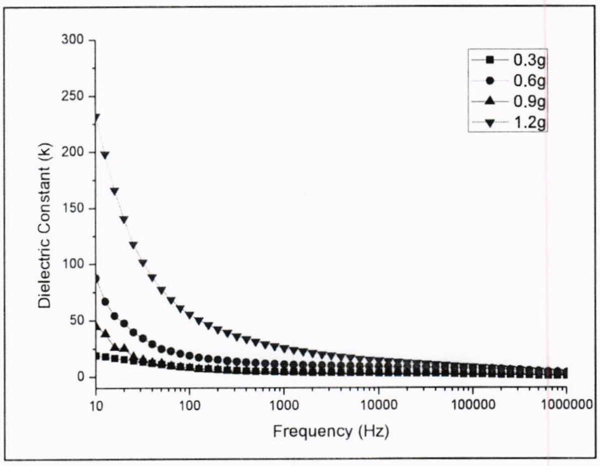


Fig 7 : Dielectric constant with respect to frequency

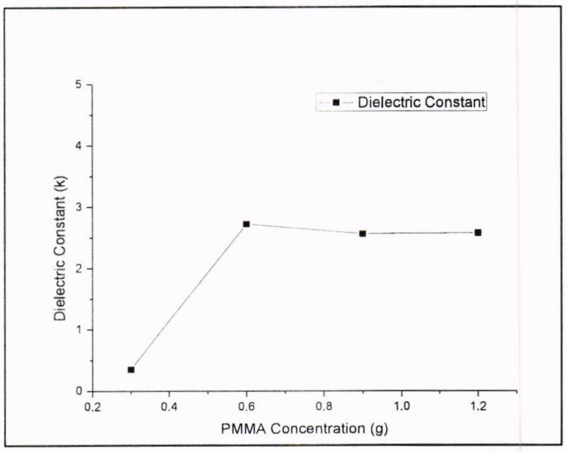


Fig 8 : Dielectric constant with respect to different PMMA concentration

Figure 9 shows the capacitance versus the frequency and Figure 10 shows the capacitance versus PMMA concentration measuring at frequency 1 MHz. The value of capacitance was measured in the range of frequency from 10 Hz ~ 1 MHz. The measured value of capacitance is also decreased as the frequency applied increased. At frequency which is 10 kHz, the values of capacitances are 1.96nF, 1.22nF, 0.324nF and 0.96nF for each concentration of PMMA 0.3g, 0.6g, 0.9g and 1.2g. For the maximum frequency at 1MHz, a drastically decreased can be seen as the value of capacitance are 0.25nF, 0.35nF, 0.24nF and 0.18nF for each of PMMA concentration 0.3g, 0.6g, 0.9g and 1.2g respectively. Since the capacitance is proportional to the dielectric constant which can be seen in equation (2), the capacitance of the capacitor need to be increased in order to increase the amount of charge stored on a capacitor.

$$C = \varepsilon_o \varepsilon_r \qquad (2)$$

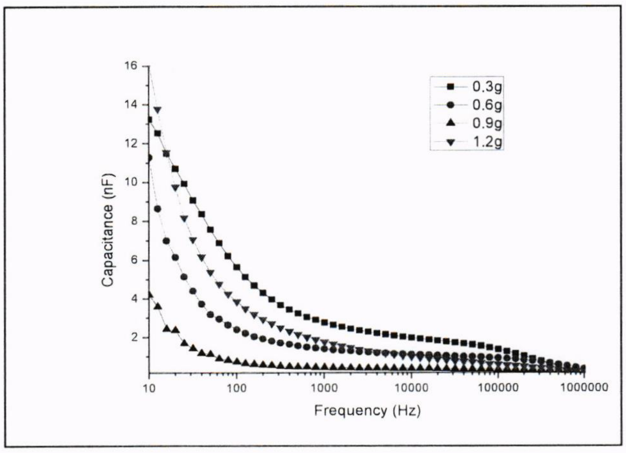


Fig 9 : Capacitance with respect to frequency

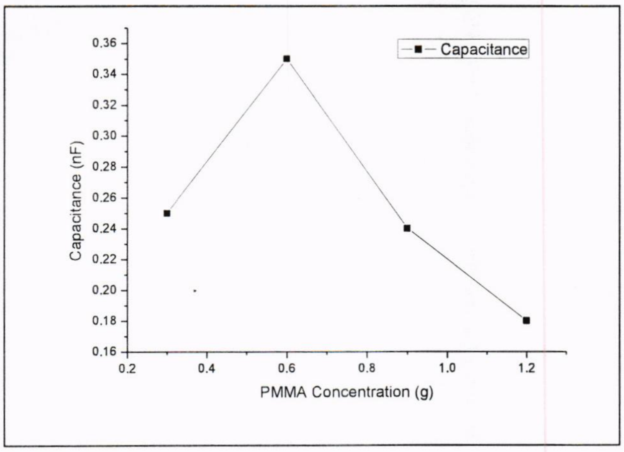
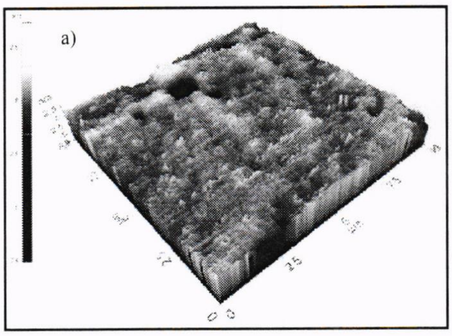
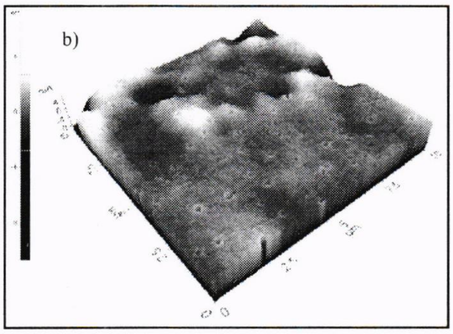


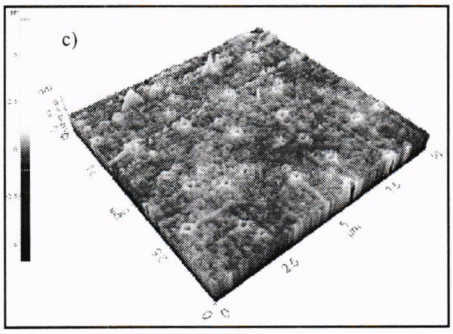
Fig 10 : Capacitance with respect to different PMMA concentration

3.3 Surface Morphology

Figure 11 show the AFM images for PMMA film with different concentration. The AFM images for PMMA concentration at 0.3g and 0.6g is not uniform. The average surface roughness is 0.246nm, 0.229nm, 0.183nm and 0.156nm for the PMMA concentration at 0.3g, 0.6g, 0.9g and 1.2g respectively. Decreasing of the average roughness might be due to the increase of solution viscosity with the increment of PMMA concentration. Table 3 summarized the characteristics of PMMA thin film with different concentration.







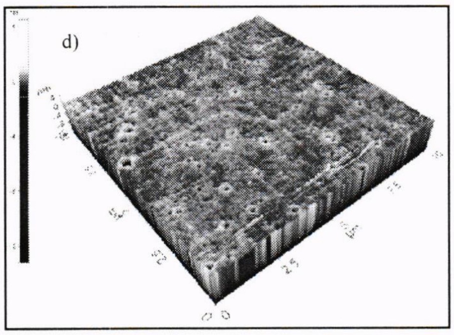


Fig. 11 : The AFM images of PMMA thin films with different concentration (a) 0.3g (b) 0.6g (c) 0.9g (d) 1.2g

Table 3 : The summary characteristics of PMMA dielectric thin film by varying PMMA concentration

PMMA Concentration (g)	Film Thickness (nm)	Resistivity ($x10^6$ Ω.cm)	Dielectric Constant, at 1MHz	Capacitance (nF) at 1MHz	Average Roughness (nm)
0.3	115.13	3.59×10^{-6}	0.35	0.25	0.246
0.6	351.46	0.754	2.72	0.35	0.229
0.9	856.65	3.29	2.56	0.24	0.183
1.2	1161.88	10.6	2.57	0.18	0.156

The FESEM images for PMMA thin film with each concentration 0.3g, 0.6g, 0.9g and 1.2g, respectively is shown in Figure 12. It shows that there is no significant difference in different PMMA concentration. Every surface shows the uniform morphology.

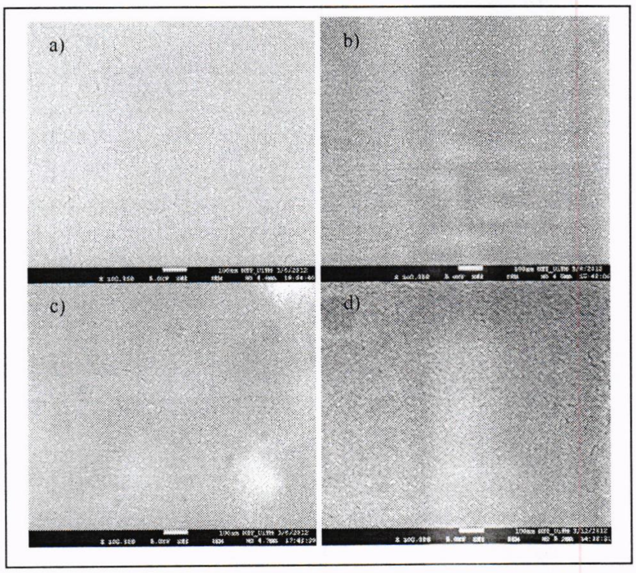


Fig. 12 : The FESEM images for PMMA film with different PMMAconcentration (a) 0.3g (b) 0.6g (c) 0.9g (d) 1.2g

IV. Conclusion and Future Recommendation

Results obtained indicate that PMMA films can use as gate dielectric and has advantages such as an easy deposition technique. For this study, we have characterized the spin coated PMMA thin films. It was shown that there is significance difference in a unit of ampere in the I-V curve for electrical properties. The PMMA concentration 0.3g shows a poor behavior in insulator since it caused the high leakage current in I-V curves compares to others concentration. Furthermore, the dielectric constant and the capacitance value are decreased as the PMMA concentration increased when the frequency is applied for dielectric properties. From the I-V curves and dielectric properties, we conclude that the PMMA concentration 0.9g and 1.2g good for insulator behavior. From the FESEM images, it can be said that there was no significance difference for the surface morphology with a different in PMMA concentration. However, for AFM images, it shows the average roughness is decreased when the PMMA concentration was varied. In summary, we have investigated the behavioral of PMMA concentration on electrical, dielectric and morphological properties of PMMA thin films. For future, we should add the capacitance-voltage measurement in the characterization of the PMMA thin film. This is because, the measurement provides the variation of the capacitance with voltage applied between the metal and insulating layer for the three main regions of operation of the capacitor (accumulation, depletion and inversion region).

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