# Effect of Dielectric Layer Thickness on the Electrical Properties of MIS Devices

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***Abstract*—This paper investigated the effect of dielectric thickness to the electrical properties metal-insulator-semiconductor (MIS) device. The MIS device were fabricated having PMMA:$TiO_2$ and ZnO as dielectric and semiconductor layer, respectively. The PMMA:$TiO_2$ nancomposite dielectric film were deposited at different deposition speed from 1000, 2000, 3000, 4000, 5000, 6000 rpm. Results showed that there is difference in the nanocomposite dielectric film thickness when varying the deposition speed. As the spin speed increased, the thickness of the nanocomposite dielectric layer was reduced from 995.52 to 383.68 nm. PMMA:$TiO_2$ nanocomposite thin film give low current compared to MIS devices with current value approximately in range of $10^{-9}$ and $10^{-5}$ ampere respectively. As the PMMA:$TiO_2$ nanocomposite thin film thickness decrease, the current increased from 2.155 x $10^{-9}$ to 2.906 x $10^{-9}$ ampere measured at 5V. The performance of MIS device is degraded when thickness of the nanocomposite dielectric layer is decreased. The AFM image was observed to have an agglomeration of particles on the nanocomposite dielectric films. Roughness increased from 11.62 to 22.00 nm when spin speed are increased.**

## I. INTRODUCTION

Metal-insulator-semiconductor (MIS) device consists of 3 layers which is metal, dielectric and semiconductor layer. The performance of MIS devices strongly depends on the interface between the dielectric and semiconductor layer [1-3]. For example, the morphology of the dielectric layer will affect the growth of the semiconductor layer and thus lead to degradation of the MIS performance [4-6]. Therefore, it is necessary to careful chosen the material and method to deposit the dielectric layer.

Generally, dielectric layer is formed between metal contact and semiconductor layer as shown in Fig. 1. Dielectric layer avoid current flow between semiconductor layer and metal contact [3]. The thickness of the dielectric layer in MIS device is very important because it prevent the excessive current flow in the MIS devices. In this work, poly (methyl metharcylate): titanium dioxide (PMMA:$TiO_2$) nanocomposite material were used to formed the dielectric layer in MIS devices. The reason of using nanocomposite PMMA:$TiO_2$ as dielectric layer is because of the limitation of PMMA is it has low dielectric constant (2.6 measured at 1MHz) which can reduce the gate capacitance which will affect the MIS device performance [2] . In order to overcome the disadvantages of PMMA, $TiO_2$ nanoparticles were used to increase the dielectric properties of PMMA due to its high dielectric constant (k=80~100 [2, 7]. There were several techniques to deposit PMMA:$TiO_2$ such as spin coating [2, 3] and deep coating [2]. Spin coating technique is selected because it is easy to handle [8], controllable [8], and low cost [1, 2].

Zinc oxide (ZnO) is chosen to be used as semiconductor layer in this MIS device because of its outstanding semiconductor properties such as wide energy band gap (3.3eV) [9-13], high chemical stability, high thermal stability [11] and high carrier mobility (0.2-31 $cm^2/V$) [10, 12]. It also proven that ZnO are compatible with organic dielectric layer for example PMMA [9, 14-16]

In this paper, thickness of the nanocomposite PMMA:$TiO_2$ as dielectric layer has been investigated. The spin speeds were varied from 1000, 2000, 3000, 4000, 5000 and 6000 rpm to obtain suitable nanocomposite dielectric thickness to be used in the MIS devices. The effect of the different nanocomposite dielectric thickness on the electrical properties of MIS is studied.

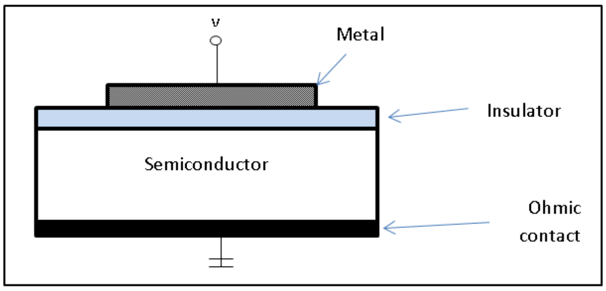


Figure 1: MIS capacitor structure

## II. METHODOLOGY

### *A. PMMA:$TiO_2$ Thin Film Deposition*

Glass substrate was used to characterize the nanocomposite PMMA:TiO2 films as shown in Fig. 2(a). Glass substrates were cleaned using three different solutions acetone ($C_3H_6OH$) followed by methanol ($CH_3OH$) and lastly de-ionized (DI) water using ultrasonic machine (Power Sonic 405) for 10 minutes. Then substrates are dried using nitrogen gas ($N_2$). The nanocomposite PMMA:$TiO_2$ solution were prepared by dissolving 0.6g PMMA powder with the molecular weight 120,000 and self-prepared $TiO_2$ nanopowder into 10ml toluene solvent. The TiO2 was fixed to 3wt%. Trimethoxymethylsilane (TMOMS) was used as a stabilizer between PMMA, $TiO_2$ and toluene solvent. The solutions were sonicated for 30 minutes under sonication temperature 50 °C. After sonication process, solutions were stirred for 24 hours. The nanocomposite PMMA:$TiO_2$ solutions were deposited on the glass using spin coating technique. Spin coater speed were varied for 1000rpm, 2000rpm, 3000rpm, 4000rpm, 5000rpm and 6000rpm for 60 seconds. The nanocomposite PMMA:$TiO_2$ film were dried for 5 minutes at temperature 50 °C to evaporate the solvent followed by annealed at 120 °C for 30 minutes to restructure the composition of nanocomposite PMMA and $TiO_2$.

### *B. Fabrication of MIS*

Indium tin oxide (ITO) glass substrate was used to fabricate the MIS device as shown in Fig. 2(b). The cleaning processes are the same in part A. The ITO was used as bottom contact in MIS device. The ZnO semiconductor layer were formed by dissolving 4.4g zinc acetate dihydrate into 50ml 2-methoxyethanol. 1.2ml ethanolamine was drop into solvent as a stabilizer. The solution was sonicated for 30 minutes under sonication temperature 50 °C. Solution was heated for 3 hours under temperature 80 °C followed by stirred for 24 hours. The ZnO solutions were deposit on ITO glass using spin coating techniques with the spin speed of 3000rpm for 60 seconds. The samples were dried for 10 minutes in 150 °C temperature. The deposition was repeated times to obtain 108.69nm thick of ZnO film. Then, the ZnO films were annealed for 1 hour at 450 °C temperature. Then, the nanocomposite PMMA:$TiO_2$ were deposit on top of ZnO film using same procedure in part A. Lastly, 80 nm thick aluminum (Al) layers were deposited to form top contact using thermal evaporation technique.

### *C. Characterization*

The nanocomposite PMMA:$TiO_2$ film and MIS device were characterized using 2 point probe current-voltage *(I-V)* measurement for their electrical properties. The films thickness of nanocomposite PMMA:$TiO_2$ dielectric layer were measured using surface profiler (VEECO DEKTAK 150). The morphology was characterized using atomic force microscopy (AFM) (Park System XE-100).

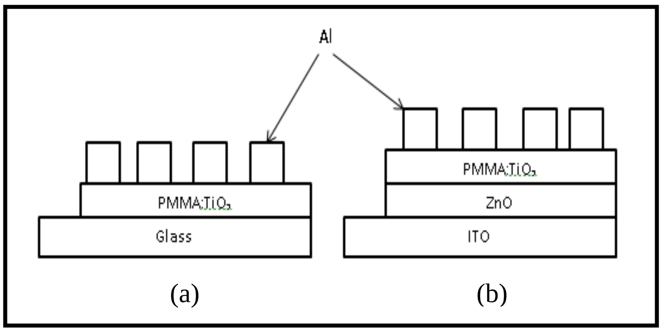


Figure 2: (a) Nanocomposite PMMA:$TiO_2$ film (b) MIS structure

## III. RESULT AND DISCUSSION

### *A. PMMA:$TiO_2$ Thin Film*

Figure 3 shown the film thickness of PMMA:$TiO_2$ depends on the spin coating speed. The thickness determine by averaging at three different measurement points for all samples. The averaging is done to showed the uniformity of the PMMA:$TiO_2$ nanocomposite layer. The thickness obtain for all samples is 995.52, 736.33, 587.68, 495.95, 443.30, 383.68 nm for 1000, 2000, 3000, 4000, 5000, 6000 rpm respectively. It can be seen that the thickness of the nanocomposite film is reduce when the deposition speed is increased which is consistent with the theory that by increased the spin speed, the film thickness will reduce. Thinner film thickness was occurred at highest speed (6000 rpm) and the thicker film at the lower speed (1000 rpm). From the result, it can be said that deposition at 3000 rpm give the suitable thickness of nanocomposite dielectric based on the electrical properties of the nanocomposite dielectric film. Thinner film may cause the leakage current flow through the device.

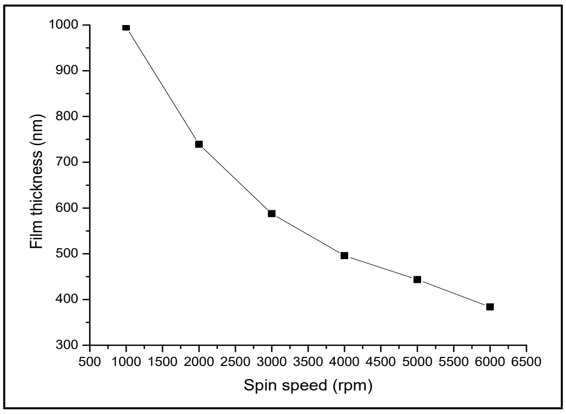


Figure 3: Film thickness of PMMA:$TiO_2$ nanocomcomposite dielectric layer with different spin speed.

Figure 4 show the *I-V* curve for PMMA:$TiO_2$ nanocomposite dielectric with the different spin speed. All samples shows an ohmic behaviour which as stated that the current increased when voltage increased. Eventhough the current incrased drastically when the voltage is increased, the amount of current is quite small in the nanoampere range (nA). As the deposition speed in increased from 1000 to 3000 rpm, there is a different in the current value as shown in Fig. 4(a). Nevertheless, there is no significant different in the *I-V* when the deposition speed is increased above 3000 rpm as shown in Fig. 4(b). Figure 4(a) indicates that 3000 rpm give the highest current meanwhile at 1000 rpm. This data is consistent with the film thickness result, at thicker film (~ 1 um) will give the lowest current because it need high voltage to accumulate the charge in the nancomposite film.

In order for a material to be good dielectric material, it need to have a high resistivity. High resistivity show that the material are insulative and can avoid the excessive current flow in the MIS devices [3]. The resistivity obtain for all sample are approximately in the range of $10^5$ Ωcm. this value is low compared to the theoretical value might be due to the $TiO_2$ content in the PMMA film.

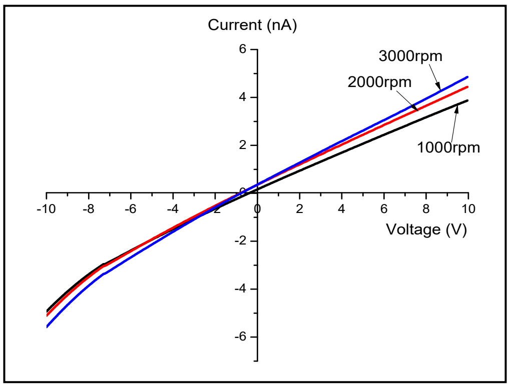


Figure 4 (a): *I-V* curve for PMMA:$TiO_2$ nanocomposite dielectric film with different speed 1000, 2000 and 3000rpm.

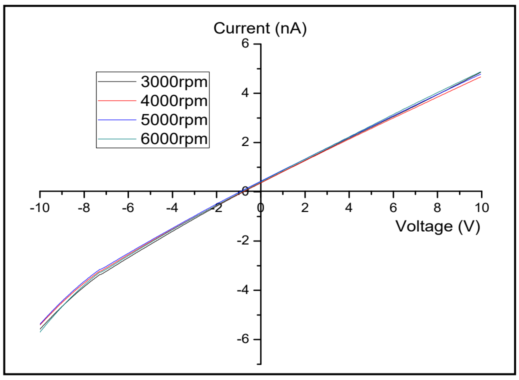


Figure 4 (b): *I-V* curve for PMMA:$TiO_2$ nanocomposite dielectric film with different speed 3000, 4000, 5000, 6000rpm.

Figure 5 show the AFM images and average roughness of nanocomposite PMMA:$TiO_2$ dielectric with different speed. At lower speed, less $TiO_2$ particles surfaced were observed. At speed 3000 rpm, big agglomeration of $TiO_2$ have seen. This is maybe at the high speed, the solution spread faster causing heavier particles which is $TiO_2$ easy to agglomerate each others. Average roughness show PMMA:$TiO_2$ dielectric film more uniform at lower speed. At speed 3000 rpm, average rougness high because of the agglomeration of $TiO_2$ particles.

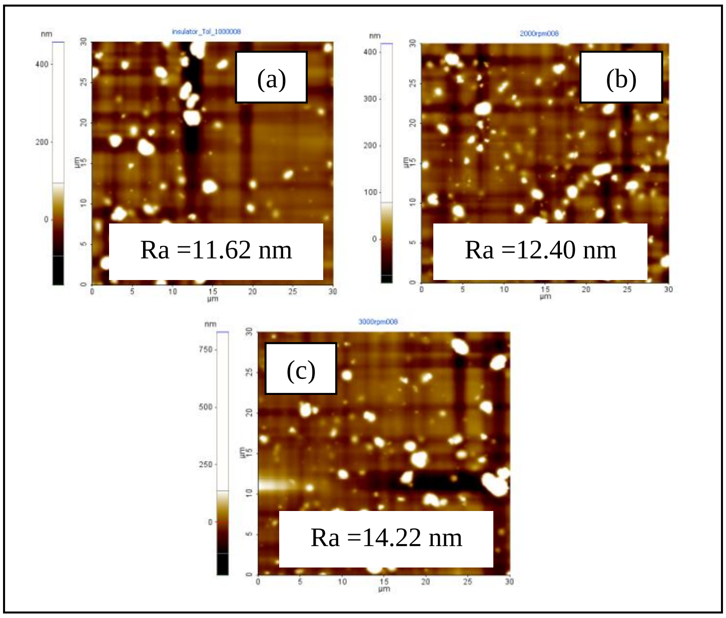


Figure 5: AFM images of nanocomposite PMMA:$TiO_2$ for (a) 1000rpm, (b) 2000rpm, (c) 3000rpm.

*B. MIS*

Figure 6 show *I-V* characteristic of MIS devices using different thickness of PMMA:$TiO_2$ nanocomposite dielectric layer. *I-V* curve of MIS shows rectifying behavior. The rectifying curve occurred depending on the applied bias voltage. When small positive voltage (V>0) is applied to the Al electrode, the valence band edge $E_v$ bends downwards near interface of dielectric-semiconductor and causes the majority carrier accumulate at the semiconductor surface. When small negative is applied the bands bend upward. The majority carriers are depleted and creating depletion region. When larger negative were applied, the bands bend even more upward so that the intrinsic level at the surface crosses over the Fermi level and creating inversion layer. At this point, numbers of holes (minority carrier) at the surface is larger than electron. Therefore the surfaces are inverted.

It can be seen also, when the PMMA:$TiO_2$ nanocomposite dielectric layer is reduced the current in MIS devices is increased as shown in Fig. 6 (a) and (b). 6000 rpm give the highest current meanwhile 2000 give the lowest current. However, 1000 rpm indicates highest current even though the thickness is approximately ~1um. This situation happen might be due to the defect occurred in the PMMA:$TiO_2$ nanocoposite dielectric film. Agglomeration of TiO2 particles in the PMMA matrix is an example of the defects. This agglomeration will create path/chain that connects Al metal contact to the semiconductor layer [17].

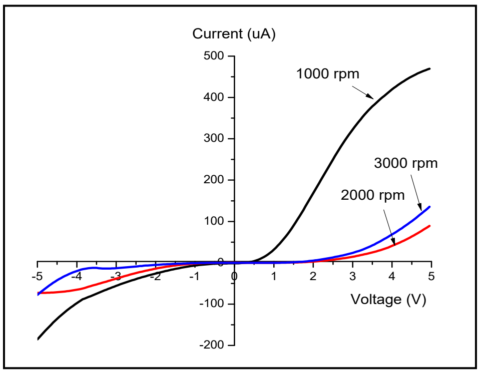


Figure 6 (a): *I-V* characteristics of MIS device using different speed 1000, 2000, 3000 rpm.

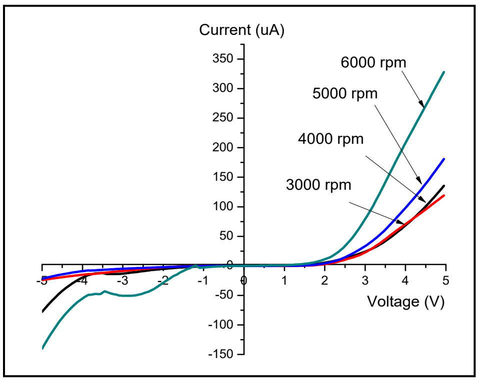


Figure 6 (b): *I-V* characteristics of MIS device using different speed 3000,4000, 5000, 6000 rpm.

## IV. Conclusion

The MIS devices has been successfully fabricated using PMMA:$TiO_2$ nanocomposite and ZnO as dielectric and semiconductor layer. The effect of varying the thickness of PMMA:$TiO_2$ nanocomposite dielectric layer was investigated. It was found that the PMMA:$TiO_2$ nanocomposite dielectric thickness decrease when the deposition speed increased. Decreasing thickness caused increasing current in the MIS devices. Higher speed (6000 rpm) give the best dielectric thickness approximately ~300nm, nevertheless, it give high current which show that is not suitable to be applied in MIS devices because it cannot withstand with high operating voltage. Lower speed (2000 rpm) are not preferable because the thickness of the dielectric layer are too thick (~800nm) which cause the MIS to operate at higher voltage. As a conclusion the best deposition speed are between 3000 to 5000 rpm because the thickness are reasonable and it can be operate at low voltage.


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