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Surface Investigations and Study Optical Properties of Si and SiO_2 Substrates- Coated with Poly (Methyl Methacrylate) PMMA for High Efficiency Solar Cells.

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ABSTRACT

In this paper, we study the optical properties, the surface roughness and the topography of Si and SiO_2 substrates-coated with PMMA film layer using UV-Vis-NIR Spectrometer and atomic force microscope, AFM. The spectral analysis on the results obtained shows high absorption and low reflection of light on PMMA/Si, but low absorption and high reflection are observed on an uncoated Si. High transmission is recorded on PMMA/SiO_2 in which more than transmission is recorded between and On the other hand, the results on the surface roughness obtained shows that the PMMA film layer reduces the root mean square roughness of both Si and SiO_2 substrates, while plasma treatment on SiO_2 increases its surface roughness.

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INTRODUCTION

High absorption of incident solar irradiance in increasing the internal quantum efficiency of crystalline silicon solar cells is very important factor in the field of solar photovoltaic (PV) concentration technology. Various transparent films such as; SiO, SiO_2, Si_3N_4 and TiO_2 e.t.c., with high refractive indices have been used as antireflection coatings (ARC). Films for ARCs are usually prepared by costly fabrication methods, such as such as plasma-enhanced chemical vapor deposition (PECVD), thermal evaporation (Maryam Alsadat Rad *et al.*, 2012) and magnetrons sputtering (Lin *et al.*, 2014) and therefore, it increase the cost of solar cells.

In recent years, non-vacuum sol-gel spin coating technique has attracted the attention of many researchers (Mokhtarimehr et al., 2013). This is due to its low-cost process and effectiveness in preparing high-quality antireflection coatings.

On its part, the surface roughness plays an important role in determining the optical, electrical and mechanical properties of semiconductor materials as well as other optical materials for both electronics and biological applications (Yuk-Hong Ting *et al.*, 2010), (Kontturi *et al.*, 2005) and (Daniela Dragoman *et al.*, 2009).

Optical polymers can be described as plastics that provide excellent transmission of light. They offer some advantages over optical glass which include lightweight and flexibility, thus they can be molded in to different shapes (Nura Liman Chiromawa & Ibrahim., 2014).

Optical polymers have wider applications in semiconductor manufacturing including; optical lenses for optical instruments, video and camera lenses, light emitting diodes, ophthalmic lenses, among other. Other applications include; optical fibers, fiber couplers and connectors as well as masks in lithography technology (Ennis & Kaiser, 2010). The most common polymers used in semiconductor industries are, poly (methyl methacrylate) PMMA, Poly Carbonate (PC), and Poly Styrene (PS) (Koleva, 2014).

In our previous paper, we studied study the feasibility and the effects of film thickness in the mid-infrared transmission through PMMA film layers of different thicknesses deposited on substrates material. Through thickness of PMMA film layer; we achieved in obtaining more than 92% transmission efficiency at the wavelength ranges from down to In the present paper, we study the effects of PMMA film layer in both the surface roughness and the variations of the optical absorption, transmission and reflection on the

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surface of crystalline silicon Si and crystalline quartz for high efficiency crystalline silicon solar cells. Low cost non-vacuum spin coating technique was used to deposit PMMA film on both and surfaces using spin coater. The surface roughness and topography of both and were studied using atomic force microscope (AFM) while the optical absorption, transmission and reflection were studied using UV-Vis-NIR-Spectrometer. The surface roughness, the optical absorption and the optical reflection were studied on the surface of silicon coated with PMMA film layer (PMMA/Si) and compared with that of an uncoated silicon while the surface roughness and the optical transmission were studied on coated with PMMA film layer (PMMA/) and compared with that of an uncoated In the present paper also, we study the effects of plasma etching in the surface roughness of SiO2 to improve the adhesion of the SiO2/PMMA interface. PMMA is chosen because of its good compatibility with Si and SiO2 as well as providing good adhesion, mechanical properties, and optical clarity (Li-Piin Sunga *et al*., 2009). It is also the most popular resist used for electron beam lithography due to its electro-optical properties and the ability to produce high resolution images. In addition to this, in plasma etching, PMMA film layer allows varieties of nano -scale geometrical structures on the surface of Si/SiO2 (Mohamed & Alkaisi, 2013). Thus, the nanostructures in Si enable more sunlight to reach solar cells (i.e for the photo-voltaic concentration), and in both Si/SiO2, it allows the formation of the optical waveguide in the semiconductor technology (Sorger *et al*., 2011). Finally, the refractive indices of PMMA (Kuchekar *et al*., 2014) and that of SiO2 is an example that shows they are optically related materials.

Experimental procedures:

P-type silicon with the orientation <100> were cleaned using the RCA cleaning techniques to remove the ionic and metallic contaminants as well as the native oxide and other associated organic contaminants. However, the most recommended technique for cleaning SiO2 is Decontaminations DECON, procedures (Zimin *et al*., 2011), hence, in this work, a wafer of SiO2 with the same dimensions as those of silicon was cleaned using Decontaminations DECON, cleaning procedures by having it immersed in a mixture of solution in the ratio of at the temperature of for about 15 to 20 minutes, then having it inserted in distilled DI, water at the temperature of and rinsed with distilled DI, water. Finally, wafers were blow-dried with nitrogen gas. Because of the poor adhesive force between the SiO2 and the PMMA; the plasma treatment was additionally done on the surface of SiO2 to increase the adhesive force between the SiO2 and PMMA interfaces. The Plasma exposure on the surface of the SiO2 substrate was realized in the Inductive couple plasma etching system ICP-RIE, (Oxford Plasmalab 80 plus) with the power RF of 100W and the process pressure of 30m Torr. Because of its effectiveness in the surface activation, Oxygen O2 (Gatzert *et al*., 2006) plasma was chosen at 10sccm flow rate for the duration of 60 seconds.

The surfaces of the substrates were then coated, with poly (methyl methacrylate) PMMA, at for to obtain a thickness. The samples were then baked in an oven to ensure a complete dryness of the resist layer. To confirm the presence of the PMMA layer on the substrates materials we used the field emission scanning electron microscope FESEM and the EDS/EBSD detector system (model: FEI Nova NanoSEM 450). Table 1: shows the EDX-analysis while Fig. 1: shows the FESEM images.

Table 1: EDX results of PMMA film layer spun coat on Si and SiO_2

S/No	Samples	Elements (Weight %)			
		Si	O	C	F
1	Si	100	0.00	0.00	0.00
2	PMMA/Si	55.98	5.54	38.48	0.00
3	SiO_2	44.07	55.93	0.00	0.00
4	SiO_2 etched	45.72	54.12	0.05	0.11
5	PMMA/SiO_2	31.62	36.64	31.65	0.09

As seen in table 1: the EDX analysis shows Si and SiO_2 in their pure form and as in Fig. 1: (A) and (C), the FESEM analysis shows the smooth surface of the substrates. This implies that the substrate materials were thoroughly cleaned. Meanwhile, the EDX analysis for the etched SiO_2 shows the increase in the percentage weight of oxygen and the presence of fluorine compositions on its surface, while for Fig. 1: (D), the FESEM analysis shows the bright dots on the surface. This shows the effects of plasma exposure and ion bombardments on the SiO_2 surface. On the other hand, in Fig. 1: (B) and (E), the FESEM analysis shows the smooth surface of the substrates with little appearance of contaminations, this may occur during the spin-coating process when the PMMA/substrate rotates at high rotational speed.

The EDX analysis for those samples has confirmed the presence of oxygen, silicon, and carbon compositions on their surfaces. This implies that, there is the existence of PMMA and its deposition products on the surface of both samples. The presence of hydrogen was analyzed on the

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EDX-spectra but it could not be reflected in the percentage weight This is because, in-terms of the weight of the hydrogen, it is the lightest element compared to other elements in the periodic table. Quantitatively, larger amount of carbon was det ected on the SiO_2-substrate (Table 1), implying that the amount of PMMA observed on the surface of SiO_2 substrate is more than that of the Si-substrate. Therefore, the thickness of the PMMA layer observed on the surface of the Si-substrate is less than that of the SiO_2-substrate.

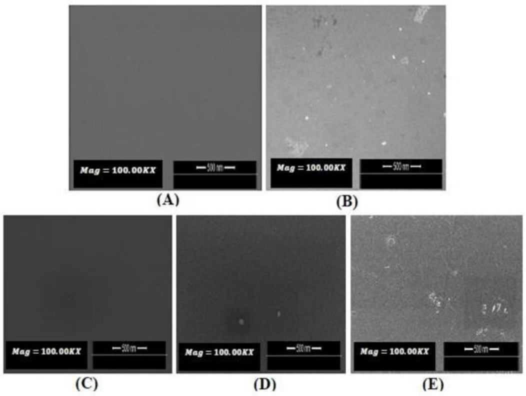

Fig.1: FESEM images Si and SiO_2 (A) Cleaned Si-substrate (B) PMMA/Si (C) Cleaned SiO_2- substrate (D) Plasma etched SiO_2-substrate (E) PMMA/SiO_2.

UV-Vis-NIR Spectrometer system (Model: Cary 5000) having the spectral range from to with the resolution of was used to analyzed the transmission of light through PMMA/SiO_2 as well the absorption and reflection of light on Si and PMMA/Si substrate materials.

In order to study the effects of light absorption and reflection through the PMMA film layer on the surface of crystalline silicon Si, the experiment was taken in two different stages. Starting with measuring the absorption and reflection on an uncoated Si wafer, this followed by measuring the absorption and reflection on Si-coated with PMMA film layer. The results obtained show that, pure or uncoated crystalline silicon Si has the high reflection with low absorption while Si-coated with PMMA film layer has the high absorption with low reflection. This shows that, the presence of PMMA film layer on Si plays a vital role in reducing the reflection and increasing the light absorption. The spectrum was recorded in the wavelength range from to with the resolution of On the other hand, to study the light transmission through PMMA film layer, the PMMA film layer was spun coat on SiO_2 and the spectrum was recorded in the wavelength range from to with the same resolution of Fig. 2: shows the UV-Vis-NIR spectral analysis of both Si, PMMA/Si and PMMA/SiO_2.

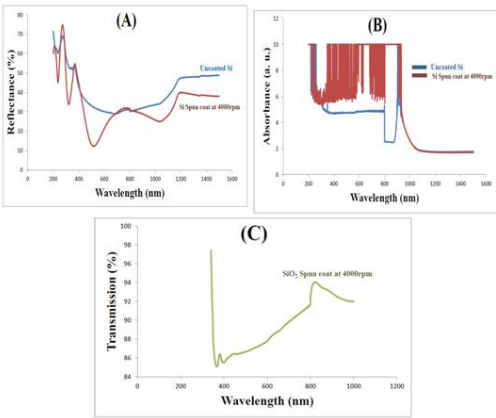

Fig. 2: The UV-Vis-NIR spectral analysis (A) Light Reflection on an uncoated Si and PMMA/Si (B) Light Absorption on an uncoated Si and PMMA/Si (C) Light transmission through PMMA/SiO_2.

The surface roughness was measured using the Atomic force Microscope, or the AFM. Fig. 3: shows the AFM images of the surface morphology of the Si-substrate after RCA-cleaning, while Fig. 4: shows the AFM images of the surface morphology of the Si substrate-coated with PMMA resist. On the other hand, Fig. 5: shows the AFM image of the surface morphology of SiO_2 substrate after cleaning, Fig. 6: shows the effects of plasma etching in the root mean square roughness in the AFM images at the surface of the SiO_2 substrate. Finally, Fig. 7: shows the same AFM images of the surface morphology of the SiO_2 substrate-coated with PMMA resist.

The entire experiments and measurements were conducted at the Nano-optoelectronic research and technology Laboratory, of the School of Physics, Universiti Sains Malaysia, in which their equipment and apparatus were used. The available Atomic force Microscope AFM, (Dimension EDGE, BRUNKER; Shimadzu) system, tapping mode was used to take some 3-dimensional images of both samples. The surface of substrates had the dimensions of a centimeter square each, but the AFM measurements were restricted to square as depicted in Figures 3, 4, 5, 6 and 7.

The surface morphology was evaluated to obtain information on the root mean square (RMS) roughness within the surface area of . All the data presented here are extracted from height images and based on ISO 1:2002 GPS, all the measurements were performed at the temperature of $20^{o}C$.

According to the AFM results obtained; the root means square roughness of the uncoated silicon substrate was found to be while was obtained as a root means square roughness of the Si-coated with PMMA film layer (as depicted in Fig. 3 and 4). In a related development, the AFM images show increases in the root mean square roughness on the surface of the SiO_2 after the plasma etching (see Fig. 5 and 6). Quantitatively, the root mean square roughness of the SiO_2 before the plasma etching was found to be but after the plasma treatment, the roughness had escalated to. On the other hand, the PMMA film layer has been shown to play a vital role in reducing the root mean square roughness of the SiO_2 down to (Fig. 7).

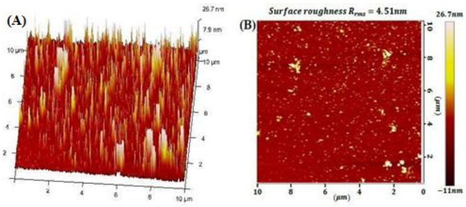

Fig. 3: The AFM images of the surface morphology of Silicon-substrate after RCA-cleaning (A) 3-dimenssional topography and (B) 2-dimenssional view.

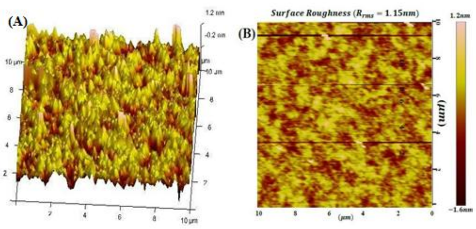

Fig. 4: The AFM images of the surface morphology of Si substrate-coated with PMMA resist; (A) 3-dimenssional topography and (B) 2-dimenssional view.

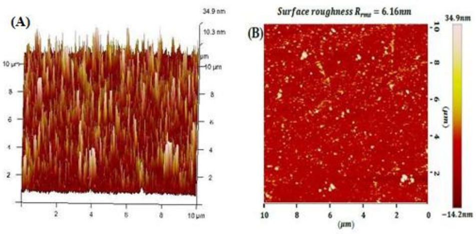

Fig. 5: The AFM images of the surface morphology of SiO_2-substrate after cleaning (A) 3-dimenssional topography and (B) 2-dimenssional view.

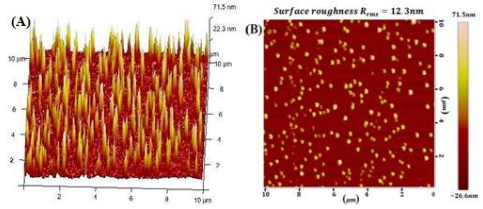

Fig. 6: Effects of plasma etching in the root mean square roughness in the AFM images at the surface of SiO_2 substrate; (A) 3-dimenssional topography and (B) 2-dimenssional view.

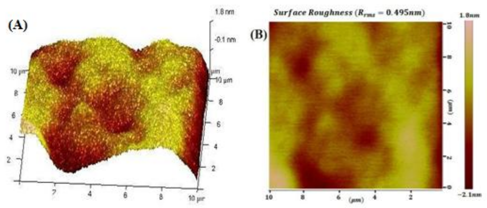

Fig. 7: The AFM images of the surface morphology of SiO_2 substrate-coated with PMMA resist; (A) 3-dimenssional topography and (B) 2-dimenssional view.

RESULTS AND DISCUSSIONS

Although all the surfaces of both Si and the SiO_2 are relatively smooth, the atomic force microscope (AFM) usually gives statistical demonstrations, showing significant differences of the surface roughness values between the two surfaces in each of the experimental steps. Quantitatively, before the PMMA resist layer was coated, the SiO_2 had more surface irregularities than Si; in other words, the root mean square roughness at the surface of the SiO_2 substrate was quite more than that of the silicon, but after the PMMA resist layer was coated on the samples, the root mean square roughness on Si became greater than that of SiO_2. Hence, the PMMA resist layer reduces the surface irregularities of SiO_2 more than Si.

The topographic analysis of the crystalline silicon substrate-coated with PMMA has shown an average depth of and the average width of, while the corresponding analysis on the SiO_2 substrate-coated with PMMA has shown the mean depth of and the mean width of On its part also, UV-Vis-NIR-Spectrometer spectral analysis shows significant differences in the optical absorption and reflection in which high light absorption and low light reflection are observed on PMMA/Si compared to that of Si as depicted in Fig. 2: (A) and (B). On the other hand, high transmission of light is observed through PMMA/SiO_2. For example, in Fig. 2: (C): over transmission is recorded between and.

Conclusion:

In this paper, we investigated the surface characteristics and optical properties of Si and SiO_2-coated with PMMA film layer as well as the effects of plasma etching at the surface of an uncoated SiO_2 using (respectively) the atomic force microscope, or AFM and UV-Vis-NIR-Spectrometer for high efficient crystalline silicon solar cells. The results obtained were then compared and it is found out that (in both cases), prior to the spin-coating of the PMMA resist layer, the surface roughness of the SiO_2 was greater than that of Si, but when the substrates were coated with the PMMA, the roughness on Si became greater than that of SiO_2. However, significant increase in the root mean square roughness on the surface of SiO_2 had been observed after the plasma etching. Thus, plasma dry etching plays a vital role in increasing the surface irregularities of SiO_2. Meanwhile, the PMMA film layer increases the optical absorption and decreases the optical reflection on the surface of crystalline silicon Si. Finally, high transmission of light is observed through PMMA/SiO_2. Therefore, the applications of PMMA thin film could be extended to antireflection coating (ARC) on crystalline silicon solar cells and as photoresist to draw some textures on the surface of silicon to allow high concentration of light for solar photovoltaic (PV) concentration applications.

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