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Effects of poly (methyl methacrylate) PMMA, film thickness in the Light Transmission through SiO_2 for Applications in Solar Cells Technology

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***Abstract:** In this study, we evaluated the attenuations in light transmissions through PMMA films of different layer thicknesses on SiO_2 substrates for solar cell applications using Fourier transform infrared (FTIR) and ultraviolet visible and near infrared (UV-Vis-NIR) spectroscopy. The results show that, film thickness decreases as rotational speed increased and light transmission decreases as film thickness increases. Highest transmissions are detected at wavelengths of 341 nm and 1282 nm. A sample coated at 4000 rpm had the highest transmission efficiency at 341 nm, while a sample coated at 500 rpmhad the lowest transmission. For a sample spun coat at 4000 rpm at 341 nm, a transmission efficiency of 96.10% was obtained, while for a sample coated at 2000 rpm 84.73% efficiency was recorded. Meanwhile, for a sample coated at 500 rpm, the transmission efficiency dropped to 82.92% at 341 nm.*

Keywords: **Si- solar cells, ARC, PV-concentrator, SiO_2, PMMA, FTIR, UV-Vis-NIR**

I. INTRODUCTION

Improving the transmittance of incident solar radiation to increase the efficiency of solar cells is a 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, with high refractive indices have been used as antireflection coatings (ARC). Films for ARCs are usually prepared by costly fabrication methods, such as plasma-enhanced chemical vapor deposition (PECVD) [1], thermal evaporation, and magnetron sputtering, all of which increase the cost of solar cells [2]. It may be feasible that low cost spin-coating techniques could be used to deposit PMMA films on SiO_2.

Optical polymers can be described as plastics that provide excellent transmission of light [3]. They offer some advantages over optical glass, including low weight and flexibility; they can also be molded in to a variety of shapes. These and other valuable optical properties cause optical polymers to dominate most of the semiconductor industries [4]. Optical polymers have wider applications in semiconductor manufacturing, including optical lenses for optical instruments, video and camera lenses, light emitting diodes, and ophthalmic lenses. Other applications include optical fibers, fiber couplers and connectors, as well as masks in lithography [5]. The most common polymers used in semiconductor industries are poly (methyl methacrylate) PMMA, poly carbonate (PC), and poly styrene (PS) [6].

Pure atactic PMMA is an amorphous plastic with a shiny surface, high brightness, high transmission efficiency of 92 % in the range of wavelengths between 380 nm and 1000 nm and a refractive index of 1.49 [7]. Other important property of PMMA is that it is compatible with crystalline silicon (Si) and crystalline quartz (SiO_2) and provides good adhesion, mechanical properties, and optical clarity [8]. Hence, PMMA is used in micro-electro-mechanical systems (MEMS) as a positive photo resist to provide high-contrast and high-resolution images [9]. In a related development, PMMA is also used for masks formation in micro/nano-fabrication of optical lenses and for lithography in semiconductor fabrication technology [10]. Furthermore, PMMA is used in the fabrication of waveguides, infrared detectors/sensors that are applicable in many electronic devices, as well as in infrared lenses [11-13].

A Fourier transform infrared spectrometer is a well-established piece of equipment used to study the optical properties of semiconductor materials and of polymer materials [14-15]. FTIR offers several advantages over dispersive spectrometers; during scanning, it can simultaneously measure all the wavelengths in the illumination source, and it offers a higher energy throughput resulting in a higher signal-to-noise ratio. Depending on the required results, three different experimental techniques can be employed: attenuated total reflectance, diffuse reflectance, and transmission mode Fourier transform infrared spectroscopy. One of the major advantages of transmission mode over the others is that it can provide quantitative information more easily because the Beer–Lambert law can be applied directly [16].

In this study, we evaluate the effects of deposition of PMMA on SiO_2 on the light transmission by FTIR and UV-Vis-NIR spectroscopy for high efficiency solar cells. PMMA was chosen because of its optical relationship with SiO_2. In addition, the refractive indices of PMMA (n and SiO_2 (are an example of properties that they are optically related materials [17]. A low cost non-vacuum spin coating technique was used to deposit PMMA film on SiO_2.

The transmission mode technique was adopted to study infrared transmissions through PMMA/SiO_2. The experiments were taken in four different stages: at the first stage, the infrared transmissions through SiO_2 were

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measured and recorded. At the second stage, 250.00 nm PMMA film layer was deposited on SiO_2 and the light transmissions through PMMA/SiO_2 were again measured and recorded. This was followed by measuring the light transmissions through 274.40 nm and 480.80 nm thick PMMA film layers on SiO_2.

II. MATERIALS AND METHODS

Four SiO_2 wafers were cleaned using the decontamination DECON, a procedure adopted from the literature [18]. The SiO_2 wafers were immersed in a mixture of (H_2SO_4 solution in the ratio of at temperature of for about 15 to 20minutes, then inserted in deionized DI, water at a temperature of and rinsed with DI, water. Finally, wafers were blown dry with nitrogen gas. The plasma exposure on the surface of SiO_2 substrates was realized in an inductively couple plasma etching system ICP, (Oxford Plasma lab 80 plus) at an RF power of 100 W and a pressure of 30 mTorr. Because of its effectiveness in surface activation, oxygen plasma was chosen at a 10 sccm flow rate for 60 s [19]. Wafers were then spin-coated with PMMA film at 4000 rpm, 2000 rpm, and 500 rpm of rotational speeds using a spin coater. The PMMA layers were analyzed using a field emission scanning electron microscope (FESEM) and an (EDX) detector system (model: FEI Nova Nano SEM 450), while the thickness of PMMA film layers on SiO_2 was determined using an optical reflector meter (Filmetrics F-20). Filmetrics F-20 analysis shows that a 250.00 nm-thick layer of PMMA was obtained at 4000 rpm, a 274.40 nm-thick layer, at 2000 rpm, and a 480.80 nm-thick layer at 500 rpm. Figure 1; shows the Filmetrics spectra and Table 1 shows the EDX data obtained from the (EDX) analysis.

Table 1: EDX data obtained from the (EDX) analysis

S/No	Rotational speed (rpm)	Elements (Weight %)			
		Si	O	C	F
1	Not Coated	45.72	54.12	0.05	0.11
2	4000	31.62	36.64	31.65	0.09
3	2000	29.25	34.37	36.35	0.03
4	500	22.62	30.19	46.98	0.01

Table 1: shows the energy-dispersive X-ray spectroscopy (EDX) results of the PMMA/SiO_2 spin-coated at three different rotational speeds. At the surface of all three substrates, the presence of silicon, oxygen, carbon and fluorine is confirmed. The presence of carbon confirmed the presence of PMMA and its decomposition products, while the presence fluorine confirmed the effects of plasma-etching on the surface of SiO_2: the higher the percentage of carbon present the thicker the PMMA layer on the SiO_2 substrate. The PMMA thickness was then measured using an optical reflector meter (Filmetrics F-20). Figure 1: shows the Filmetrics spectra of PMMA/SiO_2 spin-coated at different rotational speeds. The Filmetrics spectrum was recorded in the wavelength range from 3' to 99with a resolution of The FTIR spectrometer (Model: Perkin Elmer Spectrum GX) with a spectral range from 3 to 78and a resolution of was used to analyze the percentage of infrared transmission through each sample. The spectrum was recorded in the range from 3 to 78with a resolution of Table 2 shows the FTIR transmission results, and Fig. 2 shows the FTIR transmission spectra; Table 3 shows FTIR absorption results, and Fig. 3 shows the FTIR absorption spectra of the PMMA/SiO_2.

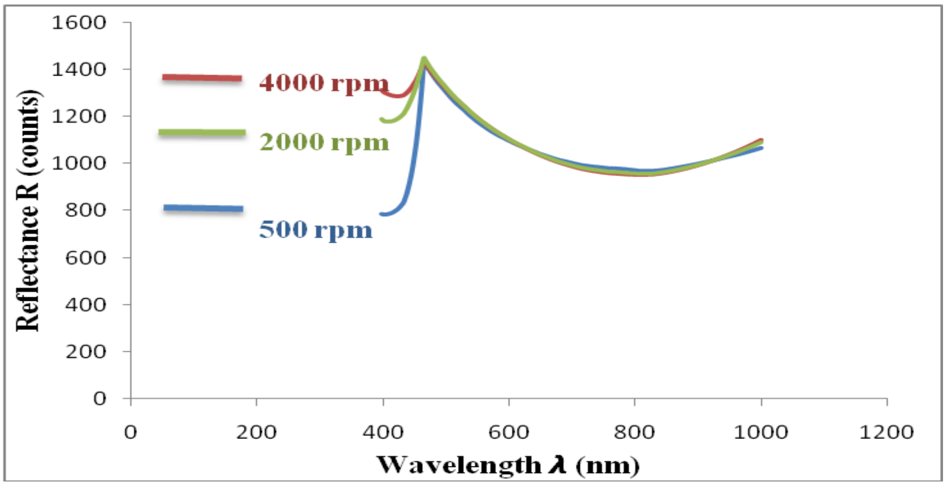

Fig 1: Filmetrics spectra of PMMA film layers deposited on SiO_2 obtained at different rotational speeds.

Table 2: FTIR transmission results for PMMA/SiO_2 at different thicknesses of PMMA

S/N	K (cm^{-1})	λ (nm)	IR Transmissions through PMMA/SiO_2 (%)			
			SiO_2	250 nm/SiO_2	274.4 nm/ SiO_2	480.80 nm/ SiO_2
1	370	27027	-0.57	5.92	6.16	4.06
2	2070	4830.9	1.56	1.41	5.31	0.85
3	2081	4805.4	4.68	4.37	7.08	2.57
4	2895	3454.2	89.97	83.10	72.62	53.84
5	2900	3448.3	90.00	82.59	71.64	53.69
6	3000	3333.3	90.86	81.92	75.96	53.25
7	4000	2500.0	91.64	90.89	86.51	57.47
8	7800	1282.1	92.14	92.84	88.40	60.69

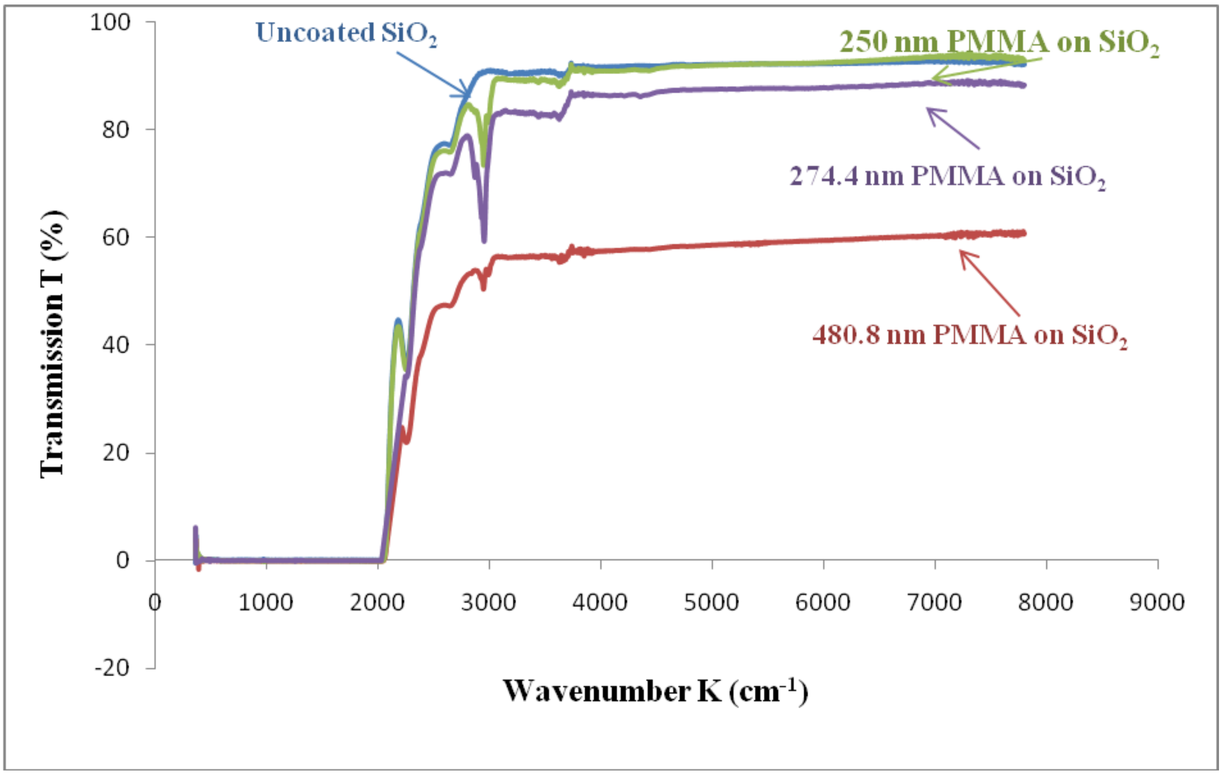

Fig. 2: FTIR spectra comparing the infrared transmissions through SiO_2 coated with PMMA film layers of different thickness.

Table 3: FTIR absorption for PMMA/SiO_2at different thicknesses of PMMA film layers

S/N	K (cm^{-1})	λ (nm)	IR Absorptions on PMMA/SiO_2 (a. u.)			
			SiO_2	250 nm/SiO_2	274.4 nm/ SiO_2	480.8 nm/ SiO_2
1	370	27027	1.729	1.564	1.899	2.370
2	2070	4830.9	1.803	1.819	1.844	2.072
3	2081	4805.4	1.349	1.449	1.354	1.576
4	2895	3454.2	0.044	0.140	0.080	0.269
5	2900	3448.3	0.044	0.146	0.083	0.270

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6	3000	3333.3	0.040	0.120	0.086	0.273
7	4000	2500.0	0.036	0.064	0.041	0.240
8	7800	1282.1	0.032	0.055	0.033	0.218

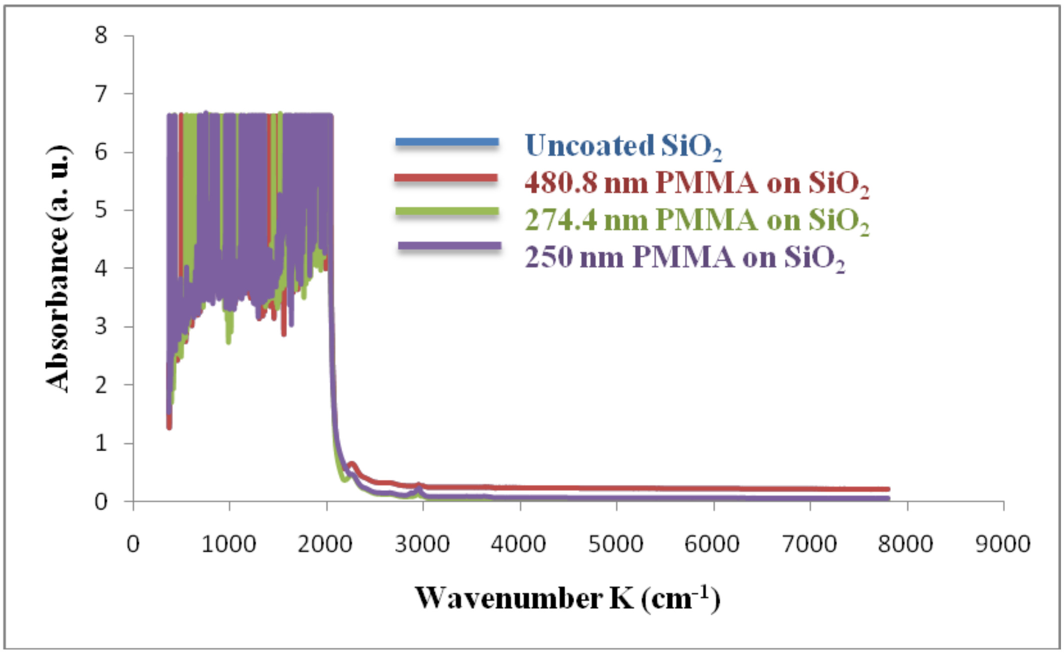

Fig. 3: FTIR spectra comparing the infrared absorptions on SiO_2 coated with PMMA film layers of different thicknesses.

Since, the spectral response of solar cells is critically dependent on the number of incident solar radiation absorbed especially from far infrared (IR) to the red-end region of visible light (VIS), we further the spectral study of light transmission with the extended range of wavelengths on PMMA/SiO_2. UV-Vis-NIR-Spectrometer (Model: Cary 5000) with the spectral range of (3300 – and the resolution of was used to study the effects of PMMA film layer thickness on the light transmission through PMMA/SiO_2. The spectrum was recorded in the wavelength range from to with the resolution of

Table 4 shows the summarized data of UV-Vis-NIR transmission analysis while Fig. 4 shows the UV-Vis-NIR transmission spectral analysis of three measured samples.

Table 4: UV-Vis-NIR transmission data analysis for PMMA/SiO_2

S/N	Wavelength (nm)	Transmissions of light through PMMA/SiO_2 at different rotational speeds (%)		
		500 rpm	2000 rpm	4000 rpm
1	1000	84.40579987	91.61369324	92.03391266
2	935	83.77999878	90.86186218	92.38264465
3	869	82.57765961	89.61537170	93.32981873
4	803	79.97712708	87.87566376	93.03218079
5	737	80.80150604	86.71165466	90.51279449
6	671	79.20931244	85.10234833	89.22286224
7	605	77.86547852	83.86666107	87.91584778
8	539	76.89575195	83.24811554	87.02878571
9	473	76.49024200	82.42963409	86.47053528
10	407	76.22681427	79.53586578	85.67855835
11	341	82.92089081	84.72609711	96.09703827

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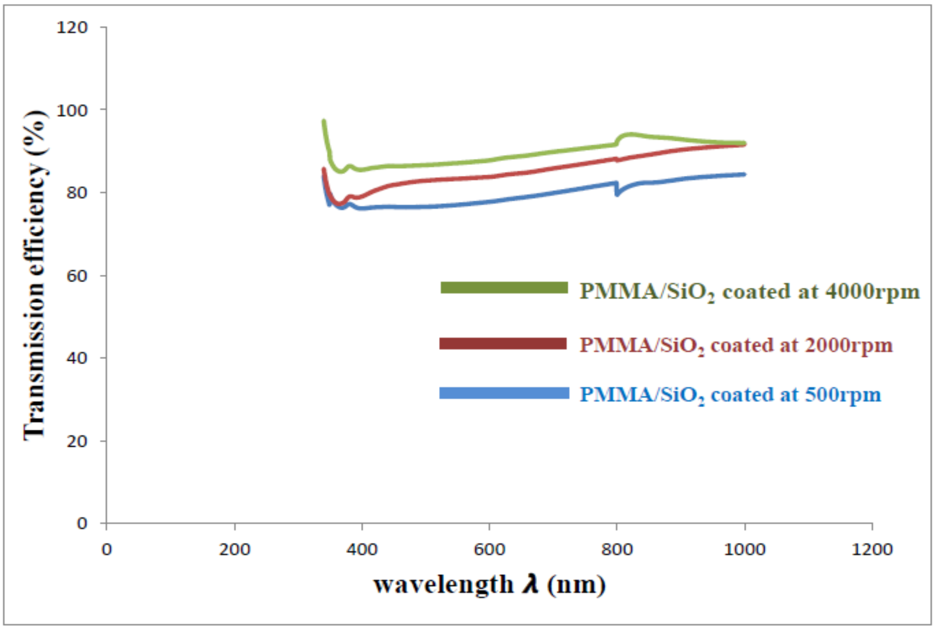

Fig. 4: UV-Vis-NIR transmission spectral analysis of three measured samples

III. RESULTS AND DISCUSSIONS

The FTIR spectra show high infrared absorptions in the range between 3 and 20, which corresponds to the wavelength range between 2 and . In addition, weak absorptions were analyzed from 20 up to 78. Figure 3 compares the FTIR absorption spectra of four samples. In both cases, almost no infrared transmissions are detected in the wave number range from 3 to 20, corresponding to the wavelength ranges between 2 and (as depicted in Fig. 2); this could be due to large wavelength having insufficient power to penetrate through the samples. Rapid increase in transmission efficiencies were observed between 20 and 28, corresponding to the wavelength range of to . However, high transmissions which are uniform with only slight differences were recorded between 29 and 78, corresponding to the wavelengths from and . In Fig 2, for uncoated SiO_2 and SiO_2 coated with 250 nm PMMA film, at 28, the transmission efficiencies of and were observed, respectively; at 30, and were recorded: at 40 the transmission efficiencies rose to and respectively. The highest transmittances were at 78, where transmission efficiencies of and were recorded respectively. This could be due to the high energy of the incident infrared radiation which may increase the excitation of the molecular vibration of PMMA so that the resultant transmitted light will be equal to the sum of the incident and the emitted radiation at 78. In addition, it clearly indicates that the effects of a thin film layer ( ) of PMMA in attenuating the infrared transmission are negligible. Meanwhile, as the thickness of PMMA film was increased to 2 (in Fig 2), the transmission efficiency recorded at 28 was ; at 30, ; and at 40 , a transmission efficiency of was obtained. However, at 78 the transmission rose to . In a related development, at a PMMA film thickness of 48 the infrared transmission was drastically reduced, and a transmission of was recorded at 28; at 30; and at 40. Finally, transmission of was obtained at 78.

In a related development, UV-Vis-NIR Transmission spectral analysis also support that of FTIR by showing the almost the same curve property. As seen in both table 4 and figure 4; the sample coated 250 nm-thick PMMA film have the highest transmission efficiency throughout the spectrum recorded while the sample coated with 480.8 nm-thick PMMA film layer has the lowest transmission efficiency. For a sample

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coated with 250 nm-thick PMMA film layer; the transmission efficiencies greater than 92% were achieved at the wavelengths of 341 nm, 803 nm, 869 nm, 935 nm and 1000 nm. Thus, the light transmission of PMMA is greatly affected by its thickness.

IV. CONCLUSIONS

In this paper, we report a study of the feasibility and the effects of film thickness on the light transmission through PMMA film layers of different thicknesses deposited on substrates. The results obtained show that the film thickness decreases as the rotational speed increases and the light transmission decreases as the film thickness is increased. High transmissions of light greater than 60% were detected through coated with PMMA film layers in the range from1282 to 3, while transmissions greater than 90% were obtained on the sample coated with a -thick layer of PMMA film layer at the same range. Thus, PMMA thin film layer (≤ can be described as transparent to both visible and mid-infrared light, but the transparency is greatly affected by increasing the film thickness (≥ .Therefore, the applications of PMMA thin films could be extended to ARCs on crystalline silicon solar cells and as photo resists to enable textures to be drawn on the surface of silicon to allow the concentration of light for solar photovoltaic (PV) applications.

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