SYNTHESIS AND CHARACTERIZATION OF HYDROPHOBIC SILICA NANO-PARTICLES AS ANTI-REFLECTIVE COATING FOR PHOTOVOLTAIC

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DEDICATION

This thesis is dedicated to my superiors, beloved parents and my dearest friends.

Thank you for the support, patience and love that all of you have shown.

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ABSTRACT

Enhancing the power conversion efficiency is an essential research subject in the manufacturing industry of photovoltaic (PV) devices which makes these devices more cost-competitive as compared to traditional energy sources. The revolutionary impact on the performance and efficiency of many optical systems and components come from the integrative design of multifunctional coatings which must be mechanically robust, efficient and a combination of required optical functions with scalable fabrication formulations. In numerous optical systems, suppression of light reflection from surfaces is a critical consideration to enhance their performance. Various designs of antireflective (AR) coatings are implemented extensively in a wide variety of optical systems to enhance the efficiency and power output . In photovoltaic devices, nano coatings are used on glass to make hydrophobic and anti-reflective coating. The rough surface and low-wetting properties of hydrophobic coating make it easier to clean the glass especially under extreme weather conditions such as pollution, rain and dust or sands. The present project proposed deposition of anti-reflection hydrophobic coating base on silica nanoparticles. The silica nanoparticles are prepared and modified using dimethyldichlorosilane (DMDCS) to enhance the surface roughness in nano-size range 60 - 90 nm. The spin-coating technique at room temperature is employed to deposit modified silica hydrophobic thin film. The deposited thin films are annealed at different temperatures (100°C, 200°C, 300°C and 400°C) for 3 hours. The deposited thin films are subjected to rain droplet and roll off simulator's performance test measurements. Field emission scanning electron microscope topographic image shows that the morphology of silica nanoparticle is rougher when it functionalized with organosilane. The water contact angle measurement shows a higher contact angle 94.45° and the lowest roll off angle 12.93° is observed for a thin film annealed at 300°C . The thin film apparently looked clean and transparent after subjected to the rain droplet simulator. Furthermore, the optical analysis revealed that all deposited thin films have no significance change of transmittance and reflectance before and after the performance test which indicate that the coatings are durable and possess hydrophobic and anti-reflective characteristics .

ABSTRAK

Peningkatan kecekapan penukaran kuasa adalah subjek penyelidikan yang penting dalam industri perkilangan peranti fotovoltaik yang sangat kompetitif berbanding dengan sumber tenaga yang tradisional. Kesan revolusi terhadap prestasi dan kecekapan kebanyakan sistem optik dan komponennya adalah dari rekabentuk bersepadu salutan pelbagai fungsi yang mekanikal bersepadu efisien dan gabungan fungsi optik dengan formulasi fabrikasi yang berskala. Dalam peranti fotovoltaik, lapisan nano telah digunakan pada kaca sebagai lapisan hidrofobik dan anti-pantulan. Permukaan kasar dan sifat pembasahan yang rendah menjadikannya lebih mudah untuk membersihkan kaca terutamanya di bawah keadaan cuaca yang melampau seperti pencemaran, hujan dan habuk atau pasir. Projek ini mencadangkan endapan asas lapisan anti-pantulan hidrofobik terhadap nanozarah silika. Nanozarah silika telah disediakan dengan mengubahsuai dimethyldichlorosilane (DMDCS) untuk meningkatkan permukaan yang kasar dan berukuran saiz nano antara 60 - 90 nm. Kajian ini menggunakan teknik putar salutan pada suhu bilik untuk menyediakan saput tipis silika hidrofobik. Saput tipis telah disepuhlindap pada suhu yang berbeza (100°C, 200°C, 300°C and 400°C) selama 3 jam dan diikuti oleh ujian prestasi menggunakan mesin titisan hujan dan simulator penggulingan. Mikroskop imbasan elektron pancaran medan telah menunjukkan morfologi nanozarah silika lebih kasar apabila dilarutkan bersama organosilane. Pengukuran sudut sentuh air menunjukkan sudut sentuh lebih tinggi pada sudut 94.45° dan sudut penggulingan yang paling rendah iaitu 12.93° untuk saput tipis silika yang disepuhlindap pada suhu 300°C. Saput tipis kelihatan bersih dan lutsinar selepas disimulasi menggunakan mesin titisan hujan. Tambahan pula, analisis optik mendedahkan bahawa tiada perubahan ketara yang ditunjukkan oleh saput tipis untuk kehantaran dan kepantulan sebelum dan selepas ujian prestasi pada saput tipis yang diendapkan di mana dapat disimpulkan yang salutan tahan lama dan mempunyai ciri-ciri yang hidrofobik dan anti-pantulan.

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LIST OF ABREVIATIONS

PV	-	Photovoltaic
AR	-	Antireflective
PID	-	Potential Induced Degradation
PDMS	-	Polydimethysiloxane
TEOS	-	Tetra Orthosilicate
DMDCS	-	Dimethyldichlorosilane
FESEM	-	Field Emission Scanning Electron Microscope
HDTMS	-	Hexadecyltrimethoxysilane
RF	-	Radio Frequency
ROH	-	Alcohol
H_2O	-	Water
PU	-	Polyutherane
CFC	-	Chloro Fluoro Carbon
HCFC	-	Hydro Chloro Fluoro Carbon
HFC	-	Hydro Fluoro Carbon
ODP	-	Octadodecylphosphonic Acid
FAS	-	Fluoroalkylsilane
HNT	-	Halloysite Nanotubes
FESEM	-	Field Emission Scanning Electron Microscopy
NaOH	-	Sodium Hydroxide
SNPs	-	Silicon Nanoparticles
MSNPs	-	Modified Silicon Nanoparticles
WCA	-	Water Contact Angle
ZnO	-	Zinc Oxide
PVA	-	Pure Poly (Vinyl Alcohol)

LIST OF SYMBOLS

°C	-	Degree Celsius
°	-	Degree
µm	-	Micrometre
cm	-	Centimetre
rot/min	-	Rotation per minute
DC	-	Direct Current
AC	-	Alternate Current
ml	-	Millilitre
Rpm	-	Revolution per minute
kW	-	Kilowatt
r	-	Roughness fact

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Solar radiations are considered one of the best prospective sources of renewable energy due to its inexhaustible nature, environmental friendliness, and the potential for high power conversion efficiency (Li et al., 2005; Tsui et al., 2014) in solar energy harvesting devices. Enhancing the power conversion efficiency is an essential research subject in the manufacturing industry of photovoltaic (PV) devices which makes these devices more cost-competitive as compared to traditional energy sources. The revolutionary impact on the performance and efficiency of many optical systems and components come from the integrative design of multifunctional coatings which must be mechanically robust, efficient and a combination of required optical functions with scalable fabrication formulations. In numerous optical systems, suppression of light reflection from surfaces is a critical consideration to enhance their performance. Various designs of antireflective (AR) coatings are implemented extensively in a wide variety of optical systems to enhance the efficiency and power output such as PV devices; light emitting diodes; architectural windows; lenses and high-power laser systems etc (Xi Zhang et al., 2008)

PV devices due to its ability to convert the solar energy directly into electrical energy (Li et al., 2005) are fast wide spreading decentralized sustainable energy production source. However, due to decentralized use on the roof of building, dust, environmental pollution (J. K. Kaldellis & Fragos, 2011; John K. Kaldellis et al., 2010;

Mani & Pillai, 2010; Pedersen et al., 2016) and climate change (Tian et al., 2007), this development is posing new challenges such as robust fouling of the PV devices, the need to decrease reflective properties to improve light adsorption, protect against debris and aggressive agents present in air. In PV solar modules, the coating enhances the durability of the module by reducing its susceptibility to potential induced degradation (PID), reduces soiling on the front surface, enhances the surface resistivity, repel moisture and seal the surface from the ingress of moisture. Therefore, the design and fabrication of multifunctional transparent (Rahmawan et al., 2013) and super-hydrophobic films/coatings with antireflection characteristics, enhanced transmittance, anti-icing, anti-fogging, anti-adhesive, corrosion-resistant, anti-bacteria and/or self-cleaning (Faustini et al., 2010; Q. F. Xu et al., 2013) is the important research subject in the manufacturing of PV devices. Geometrical structure (Faustini et al., 2010) and surface free energy are two key factors which governs the surface wettability, and can enhance by increasing surface roughness (Miwa et al., 2000). Number of reports about the successful growth of coatings with transparent hydrophobic properties (Celia et al., 2013; Ebert et al., 2012) has been published, however the balance between surface roughness and concomitant light diffuse scattering is still a big challenge to achieve further improve antireflective (AR) and hydrophobic properties.

Nano-scale porous structures and microstructures exhibit hydrophobicity. Wetting can be controlled by changing the porosity and/or roughness. The coating is used for waterproof, anti-corrosive, and possess cleaning capabilities to prevent rain droplets from clinging to glass to protect circuit and grids. Thus, the AR coating relies on a delicate micro or nano-structure for their repellence. The deposition process of hydrophobic thin film coating can be categorized in two stages. First stage is preparation of the hydrophobic solution and second stage is the efficient deposition of hydrophobic solution in form of thin film. Different types of hydrophobic coatings have been developed to fabricate nano-porous thin films such as SiO_2-TiO_2 double layer nanometric films (Guan, 2005), magnesium alloy (She et al., 2013), SiO_2 nanoparticles with polydimethysiloxane (PDMS) (Kreider et al., 2013; Lopera & Mansano, 2012; Park et al., 2015) and commercial silane (Matin et al., 2016). Two aspects are very important while depositing any hydrophobic materials coating as an appropriate hierarchical surface structure with micro-nano dual scales, and contains moderately low surface energy component such as hydrocarbon and fluorocarbon compounds. The hydrophobic surfaces have a high water contact angle (B. Chang et al., 2016) and possess unique water-repellent properties, which can potentially be used as surface structures. Procedures for roughening the surface is followed by hydrophobization or transforming of low-surface-energy materials into rough surface (Celia et al., 2013) The application of hydrophobic and super-hydrophobic films is related to their self-cleaning properties and avoidance of water stains formation on the surface. The optical requirements (J. Hong et al., 2007) for spectacle lens are fairly similar to those of PV panels. Transparency and anti-reflective are key factors for efficient coatings. In addition, super-hydrophobic coatings provide roll-over of water droplets, ensuring that dust is carried away with the droplet. Superhydrophobic materials repel water and it can bounce off the surface and have been applied in paints, coatings and textiles. These materials possess a set of unique functional properties such as water proof, corrosion resistance and ease of fluid flow.

Different techniques such as dip-coating, chemical vapour deposition, plasma etching and electrospinning are most commonly employed to deposit rough coatings for the formation of hydrophobic cellulose-based materials. The hydrophobic surfaces have a high water contact angle (B. Chang et al., 2016) and possess unique water-repellent properties, which can potentially be used as surface structures. Procedures for roughening the surface is followed by hydrophobization or transforming of low-surface-energy materials into rough surface (Celia et al., 2013). The application of hydrophobic and super-hydrophobic films is related to their self-cleaning properties and avoidance of water stains formation on the surface. The optical requirements (J. Hong et al., 2007) for spectacle lens are fairly similar to those of PV panels. Transparency and anti-reflective are key factors for efficient coatings. In addition, super-hydrophobic coatings provide roll-over of water droplets, ensuring that dust is carried away with the droplet. Superhydrophobic materials repel water and it can bounce off the surface and have been applied in paints, coatings and textiles. These materials possess a set of unique functional properties such as water proof, corrosion resistance and ease of fluid flow.

1.2 Problem Statement

Numerous investigations have anticipated with new advances related to PV solar system with the intention to increase the deployment of such environmentally friendly energy generation source. Enhancement of the power conversion efficiency of PV module is an essential research subject to make these devices more cost-competitive as compared to traditional energy sources. In PV devices, suppression of light reflection from surfaces is a critical consideration to enhance their performance. The performance and efficiency of such optical systems and components come from the integrative design of multifunctional coatings which must be mechanically tough, efficient and a combination of required optical functions with scalable fabrication formulations.

To fabricate economical transparent optical (Faustini et al., 2010) coatings for PV system to permit the maximum solar radiation to reach semiconductor intersection is a need for the widespread implementation of PV technology. Various methods to attain rough surfaces exhibit hydrophobicity have been employed such as etching (Alia Farhana, 2009; Mekhilef et al., 2012; Rahman Mohamed et al., 2006), lithography (Elminir et al., 2006; Mazumder et al., 2007), dip-coating (Al-hasan & Ghoneim, 2005; El-Shobokshy & Hussein, 1993), chemical vapour deposition (Beattie et al., 2012), electro-spinning, sol–gel processing (Beattie et al., 2012; Sayyah et al., 2014), plasma treatment (Kawamoto & Shibata, 2015; Moharram et al., 2013), one-pot reaction, and electrochemical deposition (Biris et al., 2004). However, the high-throughput and cost-effective processing methods are required to produce ARCs. Etching and lithography most widely used techniques rely on expensive tools. These expensive fabrication techniques possess several advantages, such as full wafer processing and short exposure time. However, drawbacks still exist, such as limited resolution and limited possibilities for working with pre-existing topography or curved substrates. Therefore, there is need to develop cost-effective technique for the fabrication of ARCs, which can be implemented on industrial scale. This study focuses to deposit hydrophobic coatings for PV solar cells using spin coating, a cost-effective deposition technique.

The performance deposited thin film is tested by developing water droplet and roll off simulators at laboratory scale.

1.3 Objectives

The general objective of this project is to prepare and deposit silica nanoparticles hydrophobic thin film on soda lime glass by spin-coating technique and perform simulation tests using rain droplet and roll off simulators to test the transparency and surface roughness. The specific objectives are :

1. To investigate the effect of annealing temperature on characteristics of deposited thin films i.e. transmission and morphology.
2. To design and construct the laboratory scale rain droplet and roll off simulators for performance test measurements.
3. To characterize the deposited thin films by FESEM, Water Contact Angle and UV-VIS Spectroscopy.

1.4 Scope of Study

In this project, silica nanoparticles are synthesized by using Tetra Orthosilicate (TEOS) hydrolysis dissolved in the mixture of ethanol and de-ionised (DI) water and modified by adding the Dimethyldichlorosilane (DMDCS) to make solution for hydrophobic thin film. The solution is deposited by spin-coating on soda lime glass substrates and annealed at different temperatures (100°C, 200°C, 300°C and 400°C). The deposited hydrophobic thin films are tested using rain droplet and roll off simulators which are designed and constructed at laboratory scale for performance test measurements. Modified silica nanoparticles are characterized by Field Emission Scanning Electron Microscope (FESEM) while deposited hydrophobic coating thin films are characterized by Water Contact Angle, and UV-VIS Spectrophotometer to measure the wettability, transmittance and reflection before and after subjected to rain droplet simulator.

1.5 Significance of Study

The understanding of the role of experimental parameters such as volume of solution, heat treatment and method to synthesize the silica and modified silica nanoparticles, deposition techniques, the existence of stains and the platform angles for PV application helps to develop durable, transparent and self-cleaning hydrophobic coating thin films for PV applications. This research contributes towards the development of transparent self-cleaning and anti-reflective coating on PV surface to maintain the system efficiency, in particular, compatible with Malaysian environment.

1.6 Thesis Outline

Chapter 1 presents background of project related to this project. The problem statement, objectives, scope and significance of the research interest are also presented in chapter 1. In chapter 2, literature review related to conducted research is discussed, which covers the photovoltaic panels, effect of dust accumulation on PV panels, cleaning techniques, synthesis of silica nanoparticles and modified silica nanoparticles, deposition of hydrophobic coating thin films and the performance of the hydrophobic coating thin film by scalable laboratory simulators. Chapter 3 includes the methodology of synthesis silica nanoparticles, deposition of hydrophobic coating thin films, operating procedure for rain droplet and roll off simulation and lastly followed by characterization techniques used to observe the morphology, water contact angle, transmittance and reflectance of the hydrophobic coating thin films. Chapter 4 discusses the results and discussion of deposited thin films. Towards the end of this thesis, Chapter 5 presents the conclusion and future recommendations

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LIST OF PUBLICATIONS

Journal

1. **Shahirah, F**., Chaudhary, K., & Ali, J. (2018). DEPOSITION AND EVALUATION OF HYDROPHOBIC COATING BY WIPING METHOD. *Digest Journal of Nanomaterials and Biostructures*, 13(3), 693–700.

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