Evaluation of 2.45 GHz Microwave Plasma for Conductive Glass

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Abstract. Recently, a new technology of the low cost and high stability under solar radiation was developed which is known as dye-sensitized solar cell (DSSC). The manufacturing of DSSC requires transparent conducting glass that act as an electrode. This layer is necessary since it allows sunlight penetrating into the cell. In this study, an investigation of coating process on conductive glass surface using 2.45 GHz microwave plasma was conducted for further application in DSSC. The solution was made from pure water and Titanium dioxide (TiO_2). Effect of plasma irradiation time at 1, 3, and 5 minutes in a solution was observed. Result shows that surface roughness and thickness increased as the increasing of plasma irradiation time, which optimum coating surface of 1.127 μm (roughness) can be obtained at shorter plasma irradiation time. However, the coating thickness was found to be far from the optimum range for application in DSSC. The coating surface morphology showed an increasing pore formation and agglomeration particles observed on the conductive glass surface.

INTRODUCTION

Solar energy is one of the renewable energy forms which has showed its advantages and potential for generate power. Abundant amount of solar radiation is approximately 10,000 times more than current energy demand makes this energy potential to directly convert into an electrical power using photovoltaic device. Due to the efficiency and easy manufacture, the dye-sensitized solar cell become one of the most potential option to the silicon solar cell.

Dye-sensitized solar cell (DSSC) is a next-generation photovoltaic energy conversion technology due its potential application, structural modification, ability to fabrication on various substrate and low cost. Its working devices consist of components such as conductive oxide substrates, photoanodes with wide bandgap semiconductors, dye molecules (sensitizers), counter electrodes and redox electrolytes, etc. Transparent conducting glass is an important component for the electrodes used in (DSSC) application. They are thin layer film that act as a support of semiconductor layer and a current collector and a support of the semiconductor layer in DSSCs [1]. The low electrical resistivity and high optical transparency are the two important features of this thin layer. Titanium dioxide (TiO_2) as a thin film deposited on the conducting glass film is commonly used as a semiconductor electrode. To obtain optimum electron transfer process, the thickness of the film should be in a range of 5-30 μm [2].

There have been number of methods reported for coating method such as spin coating, doctor blading, spray coating, sol-gel, and plasma coating to name a few. Each method has a significance to the thickness, roughness, morphology structure therefore to the electrical properties [3]. More recently, numerous studies have attempted on plasma coating method due to some advantages, such as single-step process in a short time and it also free dry coating. Microwave plasma is one of the well-known methods for plasma generation applied for nanoparticle synthesis due to its simple design. Despite this, very few studies have reported coating characteristic with microwave plasma applied.

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The objective of this study is to investigate coating process using microwave plasma method with variation of plasma irradiation time.

LITERATURE REVIEW

The term of “plasma” was introduced as a “fourth” state of matter, a gaseous and ionized medium with particle dynamics is dominated by electromagnetic force. The presence of free charged particles distinguishes plasma from neutral media. There is a large volume of published study describing plasma technology application in many fields. Hydrogen production [4], nanomaterial processing [5], water treatment, medicine, and agriculture processing are some of that [6].

There is a wide variety of plasma process that are well-suited for nanoparticle synthesis such as radio frequency, microwave generator, laser, and flame process to name a few. An experimental investigation on surface characterization and mechanical properties have been conducted using plasma sprayed copper coatings on copper substrate. The results showed that increasing plasma power will decrease surface roughness and affected wetting characteristic. formation of cuprous oxide was confirmed due to high temperature plasma during coating process [7].

Atmospheric-pressure plasma-enhanced chemical vapor method has reported for application in coating on transparent plastic. Titanium dioxide layer was successfully formed with 99% absorption of UV light [8]. The feasibility of manufacturing TiO_3ALC_2 examined with variation of pH value and acid property using liquid plasma spraying. The coating resulted a large roughness from less than 1 to 8 μm together with 4 μm cavities on the surface [9].

High temperature microwave coating on ceramics have been successfully prepared via atmospheric plasma spraying with thickness of 1.5 mm in the range of 8 GHz – 18 GHz. Combination with heat treatment could eliminate crack problem [10]. The atmospheric plasma spray (APS) and suspension plasma spray (SPS) techniques were reported in production of sub-micron sized patterned coating of TiO2. The optimum performance was found when using TiO2 suspension in ethanol [11].

A radio frequency (RF) plasma enhanced chemical vapour deposition (PECVD) was carried out for carbon-based coating using different combinations of methane (CH4), and titanium (IV) iso-propoxide atmospheres. The stable coatings with incorporated titanium and oxygen atoms presenting acceptable hardness, residual stress and good optical properties can be deposited [12]. Diamond like carbon coating using RF plasma had been applied associated with polydimethylsiloxane polymer at various RF power of 300, 500, and 900 Watt. The thickness analysis results showed that the growth of the plasma energetic parameters directly translates into a decrease in the thickness of the synthesized coatings from approximately 230 nm to about 50 nm for RF power 300 W and 900 W, respectively [13].

A few numbers of authors reported coating method using microwave plasma. Nickel oxide (NiOx) was coated onto a conductive substrate using microwave plasma and conventional furnace sintering. Photovoltaic performance of the DSSC coated by microwave plasma method exhibited an increasing in the conversion efficiency compared to the furnace treated coating. A 44% increase in the level of dye adsorption also obtained for the microwave plasma coating method [14]. Microwave plasma method also serve as a heat treatment method on TiO_2 and carbon-doped TiO_2 coatings onto unheated titanium and silicon wafer substrates using a DC closed-field magnetron sputtering system. Comparing carbon-doped coatings heat-treated using the furnace and microwave plasma, it was observed that the latter yielded a 19% increase in photocurrent density [15].

RESEARCH METHOD

Figures 1 and 2 show schematic diagram and the real picture of experimental apparatus. A 100 ml of pure water mixed with 20 gr of TiO2 powder. The solution was stirred using magnetic stirrer for 1 hour until it was dispersed sufficiently then pour inside the reactor. The reactor was made from acrylic and a transparent glass of 3x3 mm was hung inside the reactor at 1 cm gap from coaxial electrode. The coaxial electrode fixed to the bottom of reactor vessel is composed of a copper inner electrode in 10 mm in diameter with hemispherical tip wrapped in a Teflon coating. Plasma was generated by electromagnetic wave from microwave magnetron at 180 V of input power with irradiation time of 1, 3, and 5 minutes. Plasma was generated inside bubble then touched and coated onto a conductive glass.

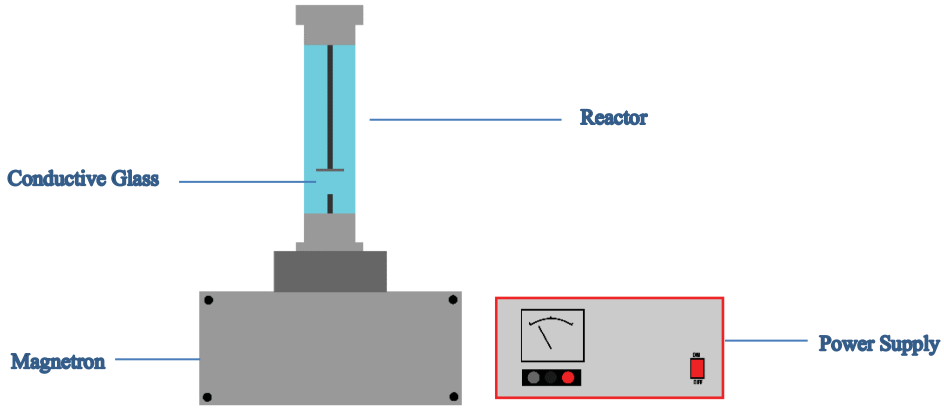

FIGURE 1. Schematic diagram of microwave plasma coating apparatus

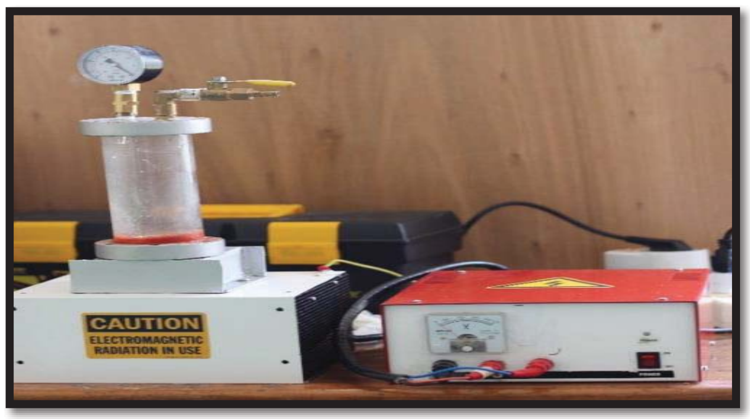

FIGURE 2. Microwave plasma coating apparatus

The thickness, roughness, and microstructure of TiO_2 coating deposited on the conductive glass then observed using 3D measuring laser OLS4100.

RESULTS AND DISCUSSION

Figure 3 shows the coating result on the conductive glass and Figure 4 shows roughness measurement of coating result with variation of plasma irradiation time. Surface roughness is defined as the shorter frequency of real surfaces relative to the troughs. Roughness average (Ra) is a coating surface roughness quantity that defined as the arithmetic mean of departures of the profile from the mean line. It was increased as the plasma irradiation time increase from 1.127 µm, 2.529 µm and 2.605 µm at irradiation time 1, 3, and 5 minutes, respectively. The coating thickness also showed a same trend, increased as the plasma irradiation time increase from 83.028 µm, 108.76 µm and 378.588 µm at irradiation time 1, 3, and 5 minutes, respectively.

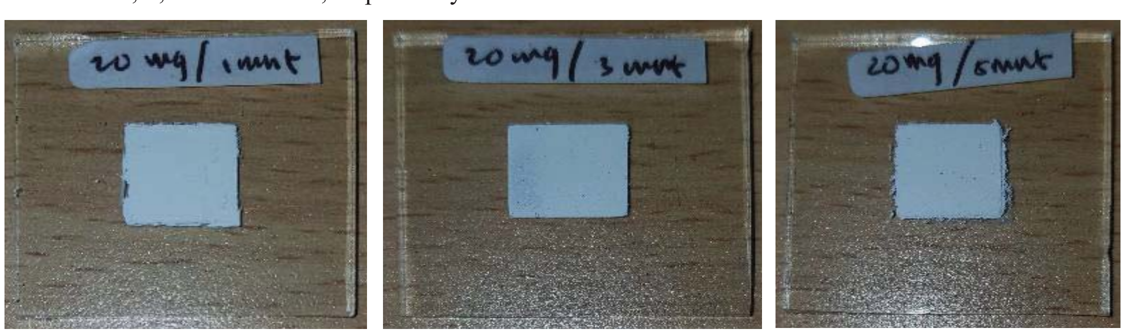

FIGURE 3. Coating result

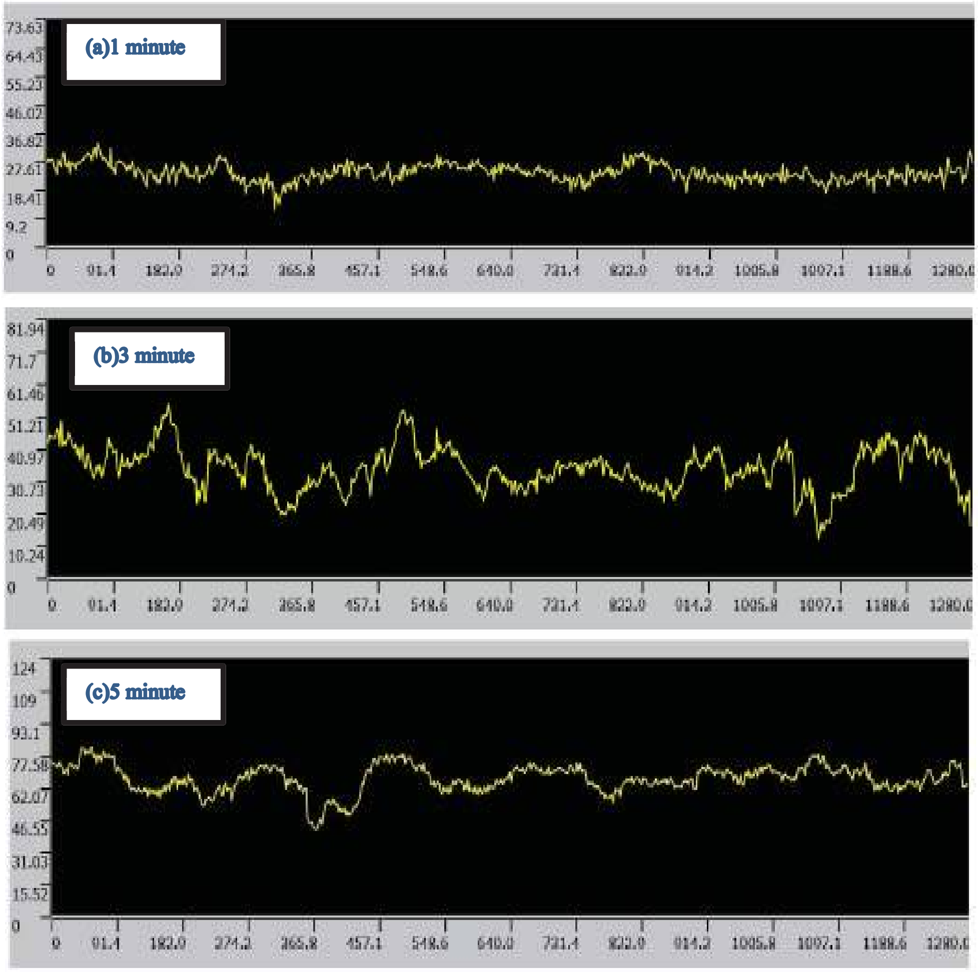

FIGURE 4. Roughness measurement of coating result with variation of plasma irradiation time (a) 1 minute, (b) 3 minute, (c) 5 minute

The Roughness average of coating layer deposited on the conductive glass is already appropriate in an optimum range. Comparing to other plasma coating method, alumina coating by the air plasma spraying process was reported the coating roughness in a range of 6.84 µm to 10.23 µm [16]. However, the thickness was found to be far from the optimum range for application in DSSC.

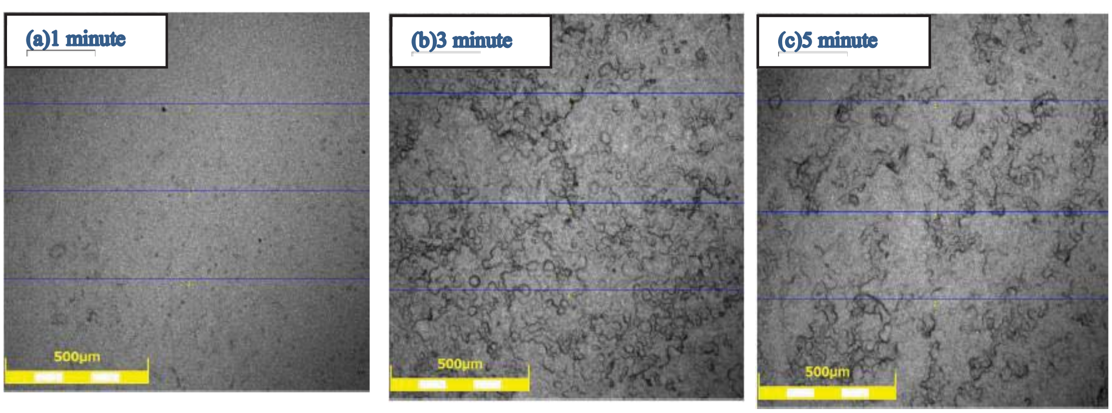

FIGURE 5. Microstructure of coating result with variation of plasma irradiation time (a) 1 minute, (b) 3 minute, (c) 5 minute

The morphology of coating surface was shown in Fig. 5. Increasing plasma irradiation time cause a larger pore formation. Agglomeration particle observed on the conductive glass surface. This result match those observed in TiO_2 coating using impulse plasma deposition process. It was assumed that this typical structure created by incomplete coalescence of the clusters created in the plasma [17]. Nevertheless, in this study, the particle is still in micron size.

CONCLUSION

The feasibility of coating process on a conductive glass using microwave plasma has been approach in a fast time of irradiation. The roughness measured of coating result is suitable for application in dye sensitized solar cell application. However, the finding on this current study for surface coating thickness and microstructure still require improvement. Further investigation in solution type and concentration will conduct to achieve an applicable result.

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