PROPERTIES OF AMORPHOUS CARBON THIN FILMS FOR SOLAR CELL APPLICATION

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ABSTRACT

This paper is presented the research on properties of amorphous carbon (a-C) thin films for solar cell application. Amorphous carbon thin films have been deposited on silicon substrate by thermal chemical vapor deposition (thermal-CVD) method at various annealing temperatures. The surface morphology and electrical properties of these films have been studied using Scanning Electron Mircoscope (SEM) and Current Voltage (I-V) Measurement (Advantest R6243 DC Voltage Current Source/Monitor Software). It was found that increasing deposition temperature had the most influence on the a-C thin films properties. In addition the carrier gas flow and catalyst concentration both showed a secondary impact on the properties of a-C thin films.

Keywords: Amorphous carbon; solar cells; thin films; thermal CVD

1.0 INTRODUCTION

Conversion of sunlight to electrical power has been dominated by solid state photovoltaic solar cells made of silicon (Si). However amorphous silicon (a-Si) has a weak bonding and is expensive to prepare. Therefore the carbon was used as an alternative material in solar cells.

Carbon (C) has many outstanding properties such as high hardness, high electrical resistivity, high thermal conductivity and high dielectric strength. Interestingly, these properties can be tailored over an unusually wide rang from that of semimetallic graphite with optical band gap ~0.0 eV to that of insulating diamond with optical band gap 5.5 eV, which promotes its application in the field of semiconductor technology [1]. For this research, camphor ($C_{10}H_{16}O$) has been used as a precursor material. Figure 1 refers to the camphor structure. Camphoric carbon (CC) is a natural source, which has hydrogen abundantly in its structure. Use of camphor as a precursor for depositing carbon thin film could be more favorable than any other precursors because a single camphor molecule contains 9 sp^3 carbon atoms. The camphor had both trihedral (sp^2) and tetrahedral (sp^3) hybridized bonds while diamond and graphite have completely 100% of sp^3 and sp^2 bonded in their lattice respectively. At the same time, the presence of oxygen atom inside the camphor molecule could help in oxidizing some non-diamond like carbons during deposition. Additionally, lower H/C ratio in case of camphoric gas has another advantage in producing lower hydrogen contents in the film compared to methane gas [2]. Furthermore, the properties of this material can be tailored by thin film deposition parameters, such as precursor material, method of deposition, types of carrier gas and carrier gas flow rate.

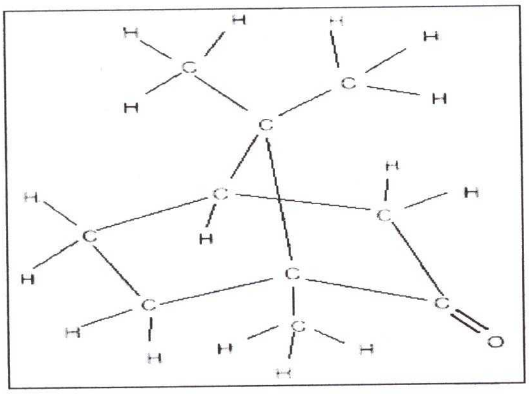

Figure 1: The starting material; chemical structure of camphor.

Thermal CVD method is used as a process to deposited a-C thin films for solar cell application. In a typical CVD process, reactant gases (often diluted in a carrier gas) at room temperature enter the reaction chamber. The gas mixture is heated as it approaches the deposition surface, heated radiatively or placed upon a heated substrate. Depending on the process and operating conditions, the reactant gases may undergo homogeneous chemical reactions in the vapor phase before striking the surface.

A key advantage of the CVD process lies in the fact that the reactants used are gases, thereby taking advantage of the many characteristics of gases. One result is that CVD is not a line-of-sight process as are most other plating/coating processes. In addition to being able to penetrate porous bodies, blind holes, large L/D tubes, CVD offers many advantages over other deposition processes. The advantage of using CVD is deposition can be prepared at any element or compound such as silicon wafer or glass. Other than that, it also produces high purity around 99.99% and also has a high density. Thermal CVD is an economical in production, since many parts can be deposited at the same time.

2.0 SCOPE OF WORK

This research has been completed after several parts of this project have been done. A literature review on a-C thin films for solar cell application is the initial stage of this research. The second stage is the process to prepare the a-C thin films by thermal CVD method at various deposition temperatures. Finally, characterize the samples of a-C thin films using SEM and I-V Measurement (Advantest R6243 DC Voltage Current Source/Monitor Software).

3.0 METHODOLOGY

The implementation of a-C thin films was developed and analyzed by using the following procedure as shown below:

i. Literature reviewed on a-C thin films for solar cell application.
ii. Prepared the a-C thin film by thermal CVD.
iii. Determined the surface morphology and electrical properties using Scanning Electron Microscopy (SEM) and Current-Voltage (I-V) Measurement respectively.
iv. Analyzed the data obtain from SEM and I-V Measurement.

4.0 EXPERIMENTAL PROCEDURE

4.1 Materials

Camphor ($C_{10}H_{16}O$) (Aldrich), ferrocene ($C_{10}H_{10}Fe$) (Aldrich), silicon substrate and argon gas were used in the experiment procedures. Moreover, acetone (CH_3COCH_3), methanol (CH_3OH) and hydrofluoric acid (HF) were used in cleaning silicon substrate.

4.2 Cleaning silicon substrate

In order to remove the native oxide layer from the surface, the substrates must be cleaned beforehand by acetone and methanol in ultrasonic bath and etched with diluted hydrofluoric acid (HF: H_2O) (1 : 10).

4.3 Preparation of a-C thin films

An amorphous carbon thin film was carried out by thermal CVD method. Thermal CVD method (Figure 2) consists of a quartz tube, an electric furnace and an argon gas cylinder. Quartz tube was inserting into double furnace. The substrate was kept in the middle portion of quartz tube in the vertical furnace. End of the quartz tube was connected to the water bubbling system and argon gas cylinder. The flow rate was maintained at 100-110 bubbles/minute. The furnace was heated to desired deposition temperature and it was allowed to remains constant for 45 minutes. After the temperature and the pressure were stabilized, a boat filled with mixture of precursor materials (camphor-3.00 g) and catalyst (ferrocene-0.01 g) was kept in the middle portion of quartz tube in the cylindrical furnace. Then, the furnace was heated to 140°C. Carbon vapor was carried over to hot zone of the furnace by carrier gas, where pyrolysis take place and the carbon were deposited on the substrate. Figure 3 shows the flow chart of the preparation of a-C thin films.

4.4 Characterization of a-C thin films

To investigate the a-C thin films properties, high resolution scanning electron microscopy (SEM) (JEOL) and Current-Voltage (I-V) measurement (Advantest R6243 DC Voltage Current Source/Monitor Software) are used. SEM is used to study the surface morphology of a-C thin films. I-V measurement is used to determine the I-V characteristic of the films. For this purpose, a-C thin films were deposited on a silicon substrate at different deposition temperature.

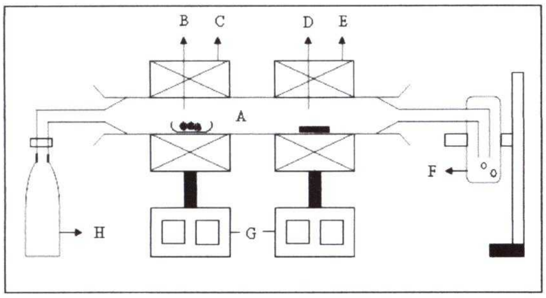

Figure 2: A schematic sketch of thermal CVD method to prepared a-C thin films. (A) quartz tube, (B) boat consist of camphor, (C) cylindrical furnace, (D) silicon substrate, (E) VT furnace, (F) water bubbling system, (G) temperature controller, (H) argon gas cylinder.

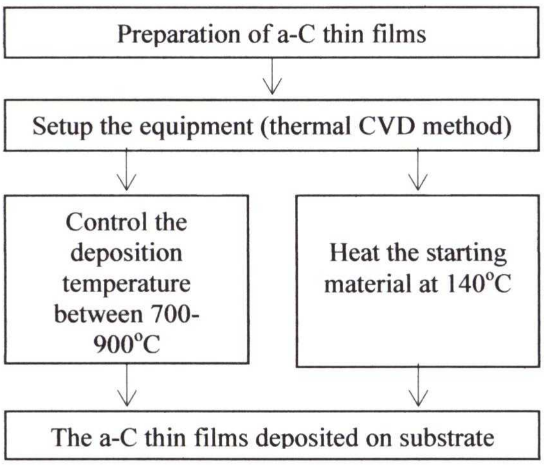

Figure 3: Flow chart of the preparation of a-C thin films.

5.0 RESULTS AND DISCUSSION

5.1 Surface Morphology

The surface morphology of amorphous carbon thin films is obtained from the pyrolosis process of camphor at different deposition temperature. Figure 4 to Figure 7 shown that as temperature of deposition increase, grain size of semiconducting carbon increase. This suggests that increase of sp^2 carbon make the films to possess smaller but interconnected grain [3]. By varying the deposition temperature it will changes the surface morphology and the structural composition of sp^2 and sp^3 carbon atoms. In addition, with increasing deposition temperature the sp^2 percentage increases and leads to narrow band gap. It is well know that, HOPG (Highly oriented pyrolytic graphite) pyrolysed at very high temperature has zero gaps. This suggests that of sp^2 plays significant role in reducing band gap of carbon films.

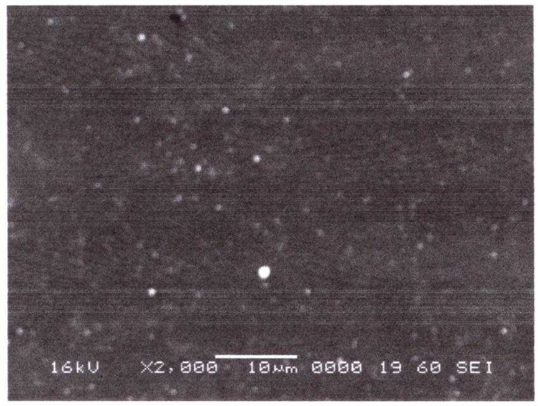

Figure 4: SEM micrograph for a-C thin films deposited on silicon substrate at 700°C.

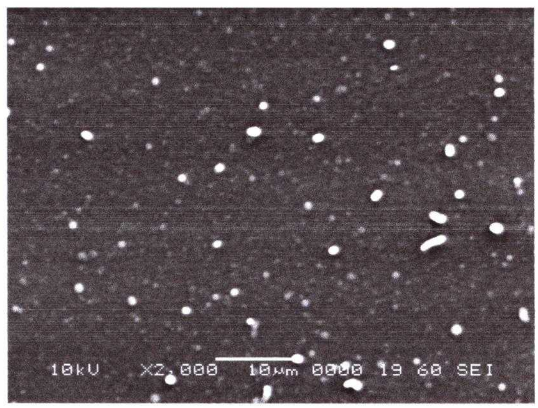

Figure 5: SEM micrograph for a-C thin films deposited on silicon substrate at 750°C.

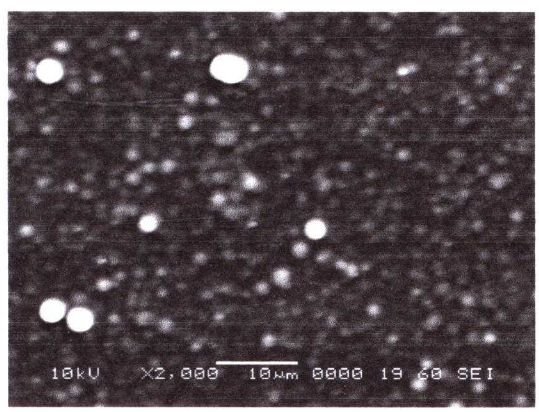

Figure 6: SEM micrograph for a-C thin films deposited on silicon substrate at 800°C.

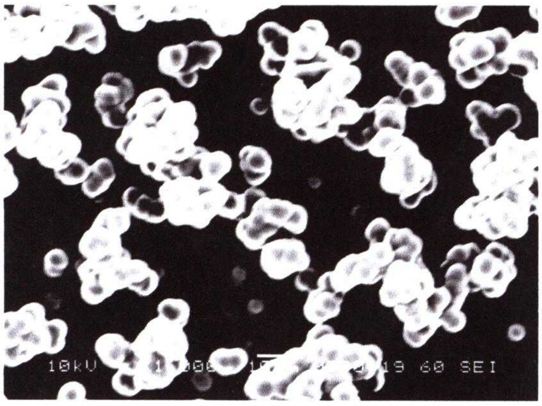

Figure 7: SEM micrograph for a-C thin films deposited on silicon substrate at 850°C.

The thickness of a-C thin films was measured by SEM at 750°C. It is difficult to measure the thickness of a-C thin films at different deposition temperature because of the high reflectivity of films. The thickness of a-C thin films deposited at 750°C is 22 μm shown in Figure 8. With increasing the deposition temperature, the thickness of a-C thin films will be increased.

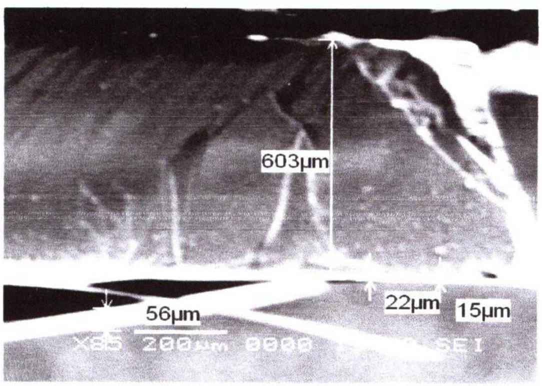

Figure 8: SEM micrograph for thickness of a-C thin films deposited at 750°C.

5.2 Electrical Properties

The electrical property of amorphous carbon thin films were analyzed by simulated the I-V Measurement (Advantest R6243 DC Voltage Current Source/Monitor Software). A schematic cross-sectional view of a-C thin films with ohmic contacts is shown in Figure 9. The front and back contacts of the films were coated with gold (Au) electrode using sputter coater. The ohmic contact will reduce the series resistance without substantially interfering with the incoming light.

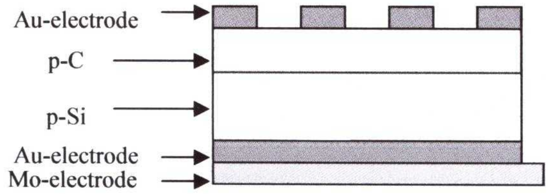

Figure 9: A schematic cross-sectional view of the a-C thin films.

The resistance (R) was measured at room temperature under illumination by a two-point probe resistance measurement method, the usual way for high resistance measurement. Figure 10 show the I-V characteristic of a-C thin films at different deposition temperature. The increasing of deposition temperature will affect the IV curve and decrease in the resistance of films (Equation 1).

$$V = IR \text{ .... } \textit{Equation 1}$$

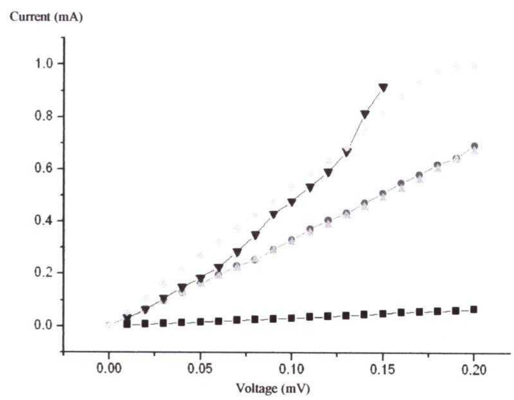

Figure 10: I-V curve at different deposition temperature 700°C (■), 750°C (●), 800°C (▲) and 850°C (▼). Silicon substrate (●).

The resistivity of a-C thin films is proportional to the value of resistance (Equation 2) and shows in Figure 11. That is suggesting that by increasing the deposition temperature, the resistivity of a-C thin films will be decrease.

$$\rho = \frac{RA}{L} \text{ .... } \textit{Equation 2}$$

Where;

ρ = Resistivity
R = Resistance
A = Thickness of thin film x Length of Au
L = Distance between Au and Mo

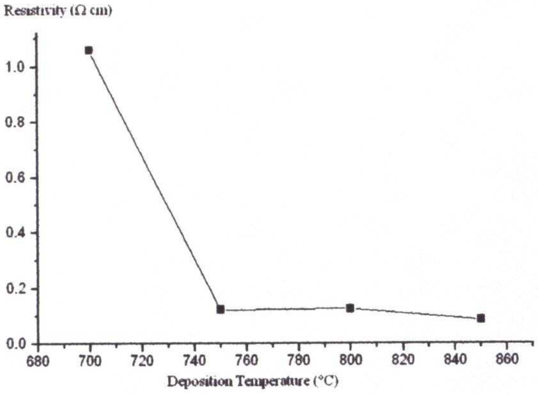

Figure 11: Electrical resistivity of a-C thin films at different deposition temperature.

Figure 12 shows the electrical conductivity (σ) of a-C thin films at different deposition temperatures. It was observed that conductivity of a-C thin films increase with deposition temperature. Furthermore, it was increase due to complete dissociation of precursor camphor and formation of more disorder sp^2 carbon site [2]. The relationship between conductivity and resistivity is written in equation below (Equation 3 and Equation 4).

$$\sigma = \frac{L}{RA} \quad \text{………} \quad \textit{Equation 3}$$

$$\sigma = \frac{1}{\rho} \quad \text{……….} \quad \textit{Equation 4}$$

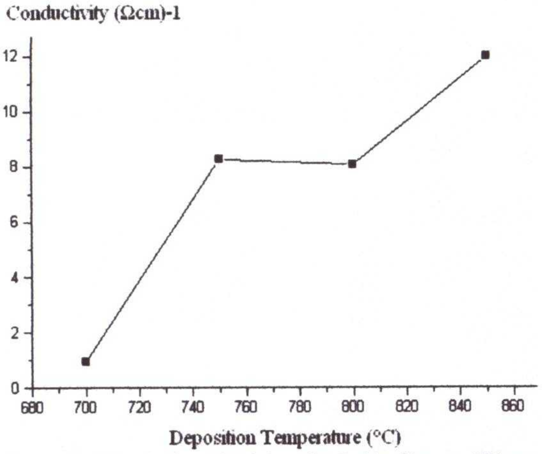

Figure 12: Electrical conductivity of a-C thin films at different deposition temperature.

6.0 CONCLUSION

Natural precursor camphor is used to synthesize a-C thin films by using thermal chemical vapor deposition. The deposition process of a-C thin films on silicon substrate is presented and the properties of films are studied in detail. Surface morphology and lattice structure of a-C thin films are changing by varying the deposition temperature. Grain size of a-C thin films is increase by increasing the deposition temperature. I-V Measurement (Advantest R6243 DC Voltage Current Source/Monitor Software) displays the I-V curve of a-C thin films. Electrical properties of a-C thin films varied significantly with deposition temperature. At the higher deposition temperature that will give the lower resistivity. However the conductivity is increase due to the formation of more disorder sp^2 carbon site. These results can be important references to optimize the properties of a-C thin films for solar cell application.

7.0 FUTURE DEVELOPMENT

Future activities will focus on the optimization of the amorphous carbon thin films properties in term of electrical conductivity, resistivity, thermo-electric power (TEP) and the efficiency for solar cell application by using thermal chemical vapor deposition method. In addition, the research will focus on a doping process of amorphous carbon thin films using phosphorus or boron.

8.0 ACKNOWLEDGEMENTS

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9.0 REFERENCES

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