Determining the Deposition Rate of Semiconducting Intrinsic Layer Prepared by Nanospray Method

Aulia Anisa Firdaus*,[1] Endhah Purwandari,[1,2] Retno Asih,[1] Ahmad Sholih,[1] and Darminto[1]

[1]*Department of Physics, Faculty of Science and Data Analytics, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia*
[2]*Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Jember, Jember 68121, Indonesia*

Abstact: Amorphous carbon (*a*-C) film provides potential ability as an i-type layer in semiconductor material for photovoltaic purposes due to its tunable properties. Here, we investigate how to get the deposition rate estimation of the thickness and homogenous surface of *a*-C film as an i-type in solar cell applications. The *a*-C was prepared from palmyra liquid sugar using nebulizer as a nanospray method. The thick palmyra liquid sugar was carbonized at 250°C for 2.5 hours then continued at 300°C for 2 hours to obtain high-carbon charcoal. The thickness was examined using a SEM cross section, and the amorphous phase was measured using XRD. The amorphous characteristic of *a*-C is confirmed by broad peaks in XRD patterns. The thickness of *a*-C films was found to be thinner than in a previous study that used a similar materials and methods but different equipment in the deposition process. The average thickness of *a*-C films is in the range of 200 to 450 nm, followed by an increase in the deposition time of 5 to 25 s. By these value, the deposition rate estimation was obtained using extrapolation linier method from the SEM result around 11.62 nm/s. This result can be used as a reference to make various thicknesses for the i-layer in order to find the maximum thickness that gives high efficiency to amorphous carbon film.

Keywords: Amorphous Carbon, Deposition Rate Estimation, Thickness

*Corresponding author: aauliaanisafirdaus@gmail.com

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I. INTRODUCTION

Photovoltaic technology is considered a great alternative energy source due to its ability to combat the negative effects produced by conventional sources, which are based on non-renewable fossil fuels [1]. The most important indicator used to evaluate the performance of photovoltaic technology is conversion efficiency, which expresses the ratio of electrical energy output to solar energy input [2]. Thin-film based solar cells have excellent properties due to their simple stage of the fabrication process, and flexibility in optical gap engineering [3]. The research about thin-film based solar cells done by Hamdani through simulation using AFORS-HET to obtain the optimum efficiency that can be reached by hydrogenated amorphous silicon (*a*-Si:H) was completed [4]. His research revealed that the optimum thickness of the i-type layer to achieve high efficiency in solar cells around 8% was estimated to be between 400 and 600 nm, but it must be remembered that this result came from simulation using hydrogenated amorphous silicon (*a*-Si:H) [4]. Other simulations that were done by Jelodarian et al. using *a*-SiGe:H by numerical modeling revealed that a thin i-layer cannot absorb enough light. The thickness of the i-layer is a key parameter that can limit the performance of amorphous thin-film solar cells. Furthermore, their research also showed that the maximum efficiency was obtained at 800 nm of thickness of the i-layer [5]. This proves that every material has its own maximum thickness in order to obtain high efficiency.

The amorphous carbon (*a*-C) thin-film-based solar cells have also already been studied by Priyanto et al., using palmyra sap as a carbon source. But in their research, the thickness of the i-layer showed around 200 nm with an efficiency that was reached for the p-i-n junction of around 0.0037%. Since there is no further experiment about the variation of thickness in i-layer in order to get higher efficiency, it is desirable to study how we can get the deposition rate of i-layer made from biomass as a continuous research from the prior study that was done by Priyanto et al. With the deposition rate that we studied in this research, we can make an i-layer of various thicknesses in order to find the maximum efficiency that can be reached by amorphous carbon thin-film using biomass as a source. The advantages of using palmyra sap as a carbon source to make amorphous carbon are that it is more environmentally friendly, low-cost, light-weight, easily processed, and flexible in tuning its optical energy gap by the doping process. There are many types of deposition processes, such as physical vapor deposition (PVD), chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), sputtering, spin coating, spraying, and pulse laser deposition (PLD) [6]. Spraying is the simple way to produce thin film because it does not require high temperatures, can produce high density film with uniform size in the thickness, easy for the deposition process, eco-friendly, and affordable in cost [7]. From the Priyanto et al. experiment, it was shown that the thickness of i-type layer varied from 0.3 to 0.9 μm, followed by an increase in the time of deposition from 5 to

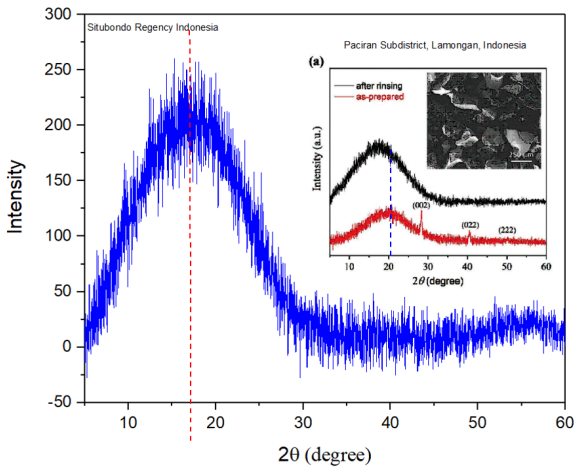

FIG. 1: XRD pattern of a-C powder derived from palmyra sugar obtained in Situbondo, inset showed the XRD pattern of palmyra sugar obtained from Paciran.

20 s using nanospray as a deposition method [8]. But there is a gap in their research, which is that the homogeneity of the thickness that was produced above the substrate was not formed well, and the thickness was still on the scale of almost micrometers in lower time deposition. The nanospray that used by Priyanto et al. is generally used for cosmetic purposes. The nozzle size of that nanospray might be almost micrometers, that is why the particle sizes that came out from the nozzle mouth are larger.

In this work, we will continue the research that was done by Priyanto et al. using the nebulizer as a nanospray method that has a smaller nozzle size inside the closed chamber during the deposition process to minimize the contamination with the outer environment and try to enhance the thickness of the i-type layer to obtain a higher conversion efficiency by determining the deposition rate of i-layer. We assume that using nebulizer as nanospray method, we will get a homogeneous thickness compared with previous study [8]. The characterizations that are used in this work are SEM cross section to investigate the average of the film thickness and XRD measurements to make sure the amorphous phase of the palmyra sugar.

II. EXPERIMENTS

Palmyra sugar is made from palmyra sap that is cooked until it becomes thick as a starting material. As already well known, palmyra sugar easily melts even at room temperature, therefore, before the carbonization process, we have to recook the palmyra sugar until it becomes thick again using a hot plate at 350°C for 15 minutes. Then, continue with the carbonization process in a furnace at a temperature around 250°C for 2.5 h until it becomes shiny black charcoal. The sample was grounded and sieved to obtain a homogeneous powder using a 400 mesh siever. Then, the charcoal was washed with distilled water and filtered three times to remove the impurities, especially the KCl content that is usually found inside the palmyra sap after heating process. The charcoal powder was dried using a hot plate at 70°C. Afterwards, to obtain high carbon charcoal, we have to do the second carbonization process at 300°C for 2 h, resulting a-C powder.

The films were fabricated using glass substrate and nebulizer equipment with a varying time deposition of 5 to 25 s. Before going into the deposition process, we have to synthesize a liquid sample of a-C. First, 1 gr a-C powder was mixed into the solvent, which is here Dimethyl Sulfoxide (DMSO) from Merck mixed with distilled water in a ratio of 1:10, respectively. Then, the solution was exfoliated using an ultrasonic cleaner in the distilled water in order to create a thinner graphitic layer for 2 h. Afterwards, to separate the large particles from the solution and produce a homogeneous solution, it was then centrifuged at 3500 rpm for 45 minutes, resulting brighter solution that will be used in deposition process. Here, we are using a nebulizer as nanospraying methods with an air-compressing Nebulizer 403C type to make films inside the closed chamber to minimize the contamination of outer area. The solution was sprayed onto 1x1 cm^2 on the clean glasses substrate with the various spraying time of 5, 10, 15, 20, and 25 s. The sprayer hole's distance from the substrate was set to be constant at 5 cm. The obtained film was then dried in an oven at 90°C for 5 minutes. The amorphous phase and thickness of a-C powder will be studied by XRD measurement using Cu-Kα radiation (λ = 0.154056 nm) and SEM cross section, respectively.

III. RESULTS AND DISCUSSION

The diffraction patterns were characterized by XRD with the range of 2θ=5-60° as shown in Fig. 1. The XRD data are obtained by using Philips X'Pert MPD diffractometer (Cu-Kα radiation with λ = 1.5406 $\AA$ at 40 kV and 30 mA), showing the broad peak at $2\theta \sim 17°$. The same peak was found in the previous study using palmyra sugar from another regency, but resulting the similar peak location as shown in the inset of Fig. 1. [8]. The KCl peak was easily removed by washing the charcoal using distilled water, therefore in Fig. 1, there is no KCl peak like shown in the inset before rinsing process. The broad peak indicated that the sample has an amorphous phase [9]. Since the target is to obtain the amorphous phase, this XRD result comfirms that even the palmyra sugar had a different treatment with the previous study, followed by a different location of palmyra trees,but it is still giving the same pattern result [8].

TABLE I: The thickness of a-C film for various deposition time.

Film	Time Deposition (s)	Average Thickness (nm)
a-C	5	219.30 ± 50.52
	10	254.36 ± 50.96
	15	327.63 ± 94.72
	20	373.10 ± 130.74
	25	450.35 ± 111.89

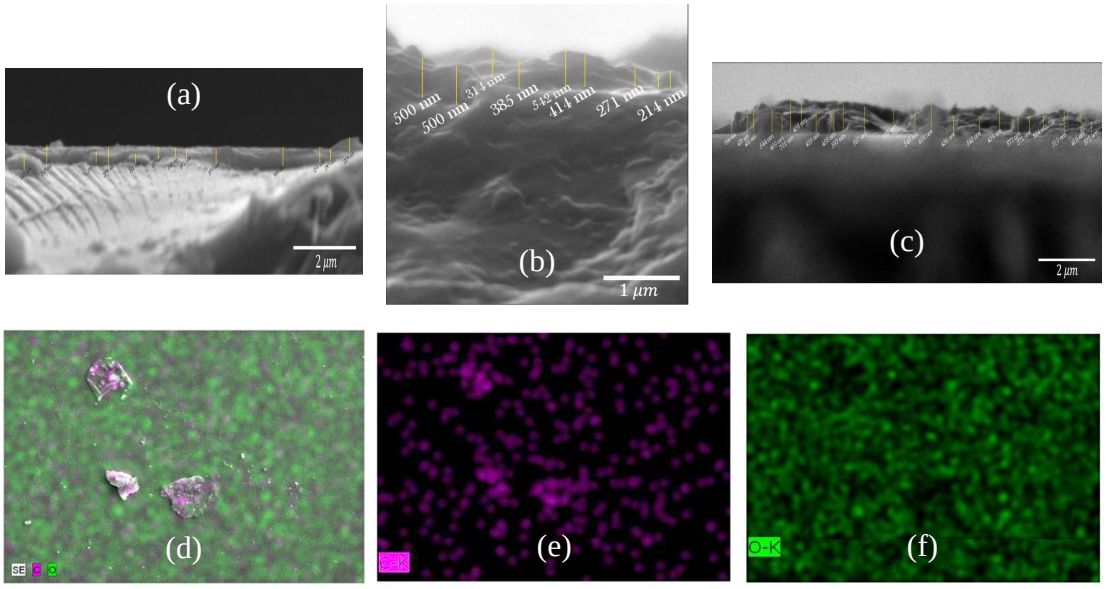

FIG. 2: SEM cross-section image of the *a*-C films prepared at the deposition time of (a)5 s, (b)20 s, (c) 25 s, (d) Elemental mapping of *a*-C films, showing the present of (e) carbon (C), (f) oxygen (O).

TABLE II: The time deposit estimation of *a*-C film made from palmyra sap using Hamdani simulation's result in the thickness as a reference.

Film	Equation	Thickness (nm)	Deposition Time (s)
a-C	y = 11.62x ± 150.69	400	21
		500	30
		600	38

From the SEM cross-section result performed by FEI, type: Inspect-S50 at 20.00 kV, showing the thickness of the *a*-C film in various deposition times of 5 to 25 s, and for the detail results, including the standar deviation value can be seen in Table I. The thickness of an *a*-C film varies from 200 to 450 nm, followed by increasing at the deposition time. The homogeneity in thickness values can be seen in the Fig. 2(a,b,c) using nebulizer as nanospray method inside the closed chamber. When compared to the results from the prior investigation, the thickness result reveals a thinner layer, proving that the technique to create a thinner layer was successful. By comparing the homogenity, it is better than the research that was done by Priyanto et al. [8]. By employing a nebulizer to spray, the amount of particle aggregation is reduced, therefore the particles should be kept separate and smaller in size. Furthermore, the elemental mapping from the EDX measurement showed that there are only C and O elements above the substrat, which indicates that there are no impurities in the liquid sample of *a*-C. The presence of O elements seems dominant compared with C elements due to the absence of binder materials, resulting in easily scratched film, therefore, the spread of C element does not go really well.

Afterwards, the deposition rate of the *a*-C film obtained from the device is estimated by extrapolation between the thickness (y-axis) and deposition time (x-axis), which is about 11.62 nm/s on average, as shown in Fig. 3. From the equation of the linier fitting line, we can get an estimation of deposition time in order to obtain various thicknesses for thin-film solar cells. For example, if we want to use the simulation's result that was done by Hamdani et al. as a reference, which is in here, the optimum thickness was obtained to be 400 to 600 nm. Therefore, by substituting the thickness value of 400 to 600 nm into the y value, we can obtain the deposition time shown as the x value, and this calculation is shown in Table II. In this equation, the x value represents deposition time, and the y value represents the thickness that we want to get. From Table II, if we want to make the fabrication of solar cell junctions, either for p-i-n or p-n junctions, we can try to choose whether to use 400, 500, 600 nm, or others various thickness in order to analyze the efficiency value that will be obtained by these thicknesses and compare the result with a prior study that was done by Priyanto et al., which used similar materials (in this case, palymra sap) and a similar deposition method (in this case, the nanopsray technique). For further research, the optimum thickness of the i-layer by using amorphous carbon from biomass can be investigated either experimentally or by simulation.

IV. SUMMARY

The study on the optimum thickness of *a*-C film has been completed. The *a*-C films were prepared using a nebulizer as nanospray method, and the raw material was derived from

palmyra liquid sugar. The XRD profiles exhibit a broad peak, indicating that this material has an amorphous phase; therefore, it is called amorphous carbon, or *a*-C. The EDX mapping confirms the presence of the C and O elements, indicating there are no impurities inside the liquid sample of *a*-C that was used for the deposition process. Then, the SEM cross-section result showed that the average thickness of the *a*-C film varied from 200 to 450 nm, followed by an increase in the deposition time from 5 to 25 s. The deposition rate of the *a*-C film was estimated to be around 11.62 nm/s from the extrapolation result, and this value of the deposition rate can be referenced in the next research while determining the optimal thickness of amorphous carbon film in order to get a higher efficiency of the solar cell compared with the prior research that used similar materials and methods.

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