

Thin Layer Deposition of a-Si: H n-Type Hydrogenated Amorphous Silicon using PECVD

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Abstracts

In this study, we report that N-type hydrogenated amorphous silicon (a-Si: H) was grown with the addition of H₂ using the Plasma Enhanced Chemical Vapor Deposition (PECVD) technique. The deposition was carried out for several process parameters including deposition time, gas pressure, and substrate temperature with the aim of obtaining a thin a-Si: H layer which has effective optical properties for solar cell materials. To indicate the nature of this semiconductor, the optical band gap is measured. From the measurement using Tauc's Plot method on the absorption data of the UV-Vis spectrum as a function of wavelength, the optical bandgap energy of the thin film was obtained. While the thickness of the thin layer was characterized by using Atomic Force Microscopy (AFM). The characterization results show that the optical band gap energy is 1.8 eV and the thickness of the thin film formed is 72 nm.

Keywords: Tauc'Plot method, optical band gap, a-Si: H, n-Type

Introduction

Amorphous silicon has a dangling bond. The appearance of a dangling bond is the result of not all amorphous silicon atoms bonding to their nearest neighbors [1]. The existence of a dangling bond causes silicon atoms to bond with other atoms, namely hydrogen, which is called hydrogenated amorphous silicon (a-Si: H) [2]. Amorphous materials differ from crystalline materials in terms of the periodicity range of the arrangement of their constituent atoms [3]. The arrangement of atoms in amorphous materials is not completely random, but there is some order in the short term [4]. In amorphous silicon, most of the silicon atoms are coordinated to form four-fold (four-fold) with a tetrahedral bond configuration like crystalline silicon [5]. The randomness of atomic positions is formed due to variations in bond angles and bond lengths, thus leading to characteristic long-term disorder.

Hydrogenated amorphous silicon (a-Si: H) thin films can be made into n-type films using a deposition technique by adding phosphor gas (PH₃) as an impurity to the silane gas mixture (SiH₄) [6]. The addition of phosphine gas functions as a dopant gas which is intended to manipulate the type of electrical conductivity [7]. In addition to the electrical properties of the thin film, the optical properties of the coating must also be considered. One of the optical properties that need to be considered is the optical band gap (bandgap) [8]. The optical band gap determines the properties of the semiconductor, including the mobility of the charge carriers in the semiconductor, the density of the charge carriers, and the absorption spectrum.

Determination of the optical band gap (bandgap) can be done by irradiating with electromagnetic waves (photons with certain energy) so that electrons can absorb energy from photons and will move or jump to a higher energy level, namely electrons move from the

valence band to the conduction band [9]. This study aims to find a good n-type material or material for solar cells [10]. The method that will be used is by mixing PH₄, SiH₄ gas, and H₂ dilution in the PECVD chamber with various gas flow rates[11]. The results of this study will obtain the optical bandgap energy value of the n-type a-Si: H thin layer.

Material and Methods

Beginning with the growth of a thin layer of a-Si: H n-type using Plasma Enhanced Chemical Vapor Deposition (PECVD) on the Indium Tin Oxide (ITO) substrate, as shown in Fig.1. Furthermore, SiH₄, H₂, and PH₄ gases flowed. During the process, the deposition chamber was given a pressure of 4800 mTorr, a temperature of 210 °C, 5 watts of rf power, and a time of 15 minutes. The SiH₄ gas rate remains at 20 sccm, the H₂ gas rate remains at 20 sccm and the PH₄ gas rate remains at 2 sccm shows in Table 1.

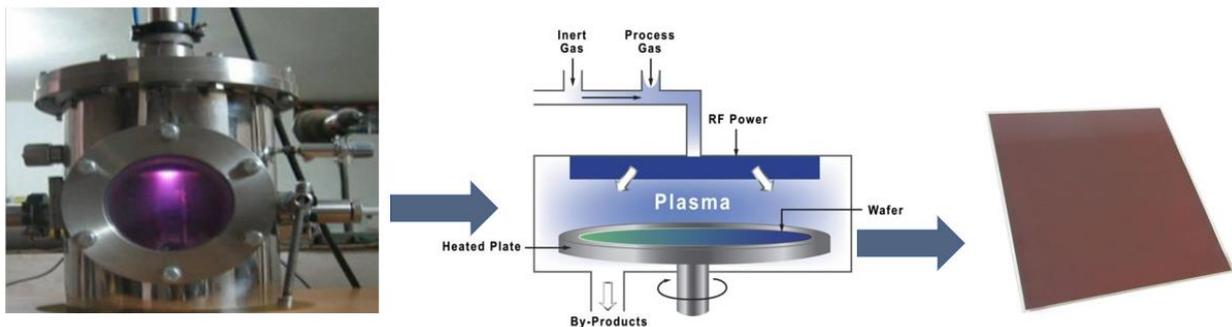


Figure 1. Schematic of RF-PECVD and a-Si: H n-Type layer

Table 1. Parameters of n-type a-Si: H layer deposition

Substrate	ITO
Temperature	210 °C
RF Frequency	13,56 MHz
RF Power	5 Watt
Pressure	4800 mTorr
Gas Source	SiH ₄ 20 sccm, PH ₄ 2 sccm dan H ₂ 20 sccm
Time	30 Minute

Following sample preparation, the n-type a-Si: H layer tests the optical properties, specifically the bandgap, using a UV-VIS spectrometer. While light is passed on the material, some of the light is reflected, scattered, absorbed, and partially transmitted. UV-VIS spectroscopy is used to determine the optical properties of the material that has been made, one of which is the band gap material. The thickness of the n-type a-Si: H film produced can be measured using an Atomic Force Microscope (AFM) assay. In addition to knowing the thickness of the thin layer produced, the

AFM test also serves to determine the surface topography formed in the deposition process.

Results and Discussion

The growth of a-Si: H material has several optimization parameters that determine the resulting physical properties which aim to increase the conversion efficiency of solar cells. The optimization parameters are hydrogen gas flow rate (H₂), chamber pressure, substrate temperature, rf frequency, rf power, deposition time, and dopant concentration. In the deposition process using silane gas (SiH₄) as the

source gas which contained 10% in hydrogen gas (H_2) and obtained an amorphous silicon material with a hydrogen content of about 10-20%. The influence of hydrogen content in the growth process causes the defect rate to move into the conduction and valence bands, so that the state

density decreases sharply [12]. Figure 2 show in schematic band diagram of a-Si: H. The continuous state distribution in the pseudo gap, tail states, and defect states, is acting as a charge reservoir which can be filled up and emptied.

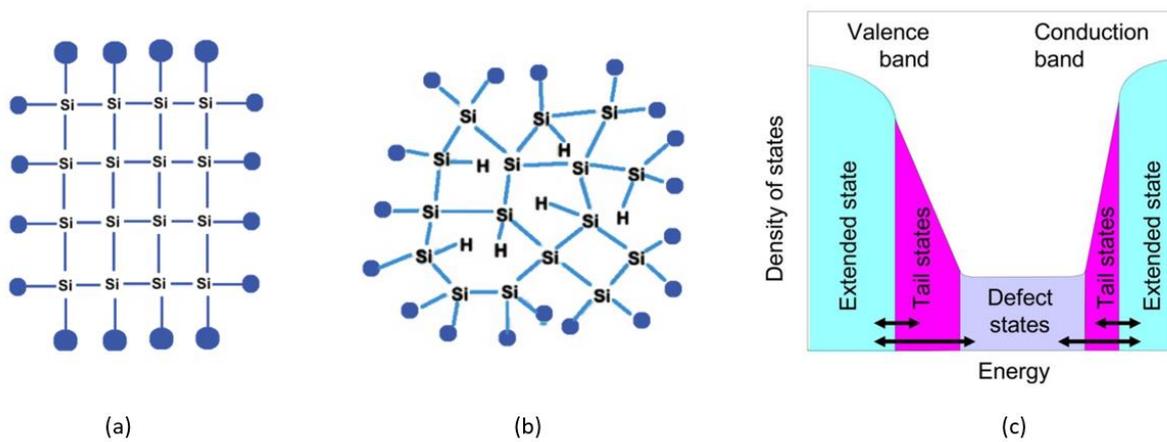


Figure 2. Schematic representation for the structures of (a) c-Si, (b) The dangling bonds in a-Si: H are saturated by hydrogen atoms, and (c) The density of states in a-Si: H.

Dangling bonds, which are unoccupied valence electrons that are not engaging in the bonding with their nearest neighboring atom, are the most significant and prevalent defect type that determines the performance of a-Si solar cells [13]. Defects in the band gap caused by dangling bonds act as possible trap sites and recombination centers and significantly lower the mobility and lifespan of charge carriers. Such amorphous semiconducting materials cannot be doped either because the extra charge carriers generated by the dopant atoms enhance the likelihood of being caught by the defect states [14]. To remedy the problem, hydrogen (H) is absorbed into a-Si throughout the manufacturing process. Si atoms lose their capacity to trap charge carriers when their unpaired electrons form a connection with hydrogen atoms.

The thickness of the n-type a-Si: H thin film is measured with an Atomic Force Microscopy (AFM) test instrument which will characterize the material by using atomic forces between the

tip and the substrate. AFM which consists of several devices such as tips, cantilever, piezoelectric sensors, and photodetectors. During the material characterization process, the tip will move along the surface of the material being tested causing the cantilever slope to change [15]. Cantilever Slope will be detected by photodetector. The laser beam given to the cantilever will be received by the detector which will be detected as the tilt of the cantilever. Measurements or scans are taken at the boundary area of the coating and substrate (no coating). This slope change will provide depth information. Scanning in this border area will obtain information on the difference in height or depth which represents the thickness of the thin layer formed [16]. The results of thickness measurements with Atomic Force Microscopy (AFM) are written in graphic form. Figure 3 shows the morphological structure and thickness of the n-type a-Si: H thin film for the rate of PH_4 2 sccm, SiH_4 20 sccm, and H_2 20 sccm.

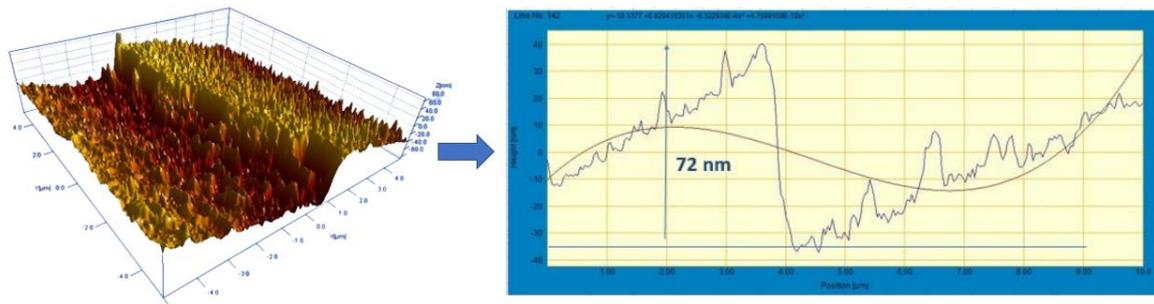


Figure 3. Morphological structure and thickness of the n-type a-Si: H film.

Bandgap measurements were carried out using a UV-Vis spectrometer with different photon energies ranging from 200 nm to 1600 nm so that the absorbance and transmittance of the thin film sample can be determined. The wavelength data on transmittance is then used in determining the bandgap using the Tauc's Plot method, namely by making a curve $h\nu$ to $(\alpha h\nu)^{1/2}$, where $h\nu$ represents the energy of the photon and α is the absorption coefficient [17]. By drawing a linear line of curvature from high energy to low energy, the intersection of the horizontal axis is obtained and is taken as the bandgap value [18]. Result of the UV-Vis absorption spectrum between transmission (T) and wavelength (λ) was applied to determine the magnitude of the optical band gap. Figure 4 shows UV-Vis measurements of deposited samples from PECVD with variations in the growth parameters of gas flow rate and substrate temperature.

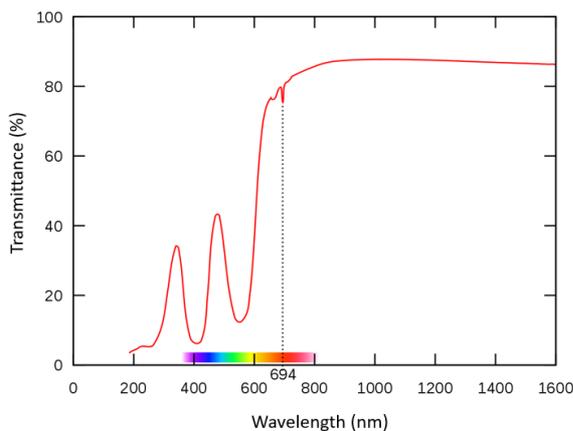


Figure 4. UV-Vis Transmittance Spectrum on an n-type a-Si: H thin film.

The light that hits the surface of the thin film will be reflected, absorbed, or transmitted,

but in this observation, the light reflected/reflected by the surface is very small, close to zero, so light that is not transmitted is considered absorbed by the sample. Figure 3 shows a graphic depiction of the optical absorption coefficient on photon energy at a wavelength of 694 nm for an n-type a-Si: H thin film. From the curve in Figure 4, the optical bandgap energy width of the n-type a-Si: H thin film with a thickness of 72 nm evaluated from the linear data section is empirically defined in the formulation of the Touch-plot method and obtained an energy gap width of 1.8 eV and this is obtained at time $h\nu = E_{Opt}$ from extrapolated linear data.

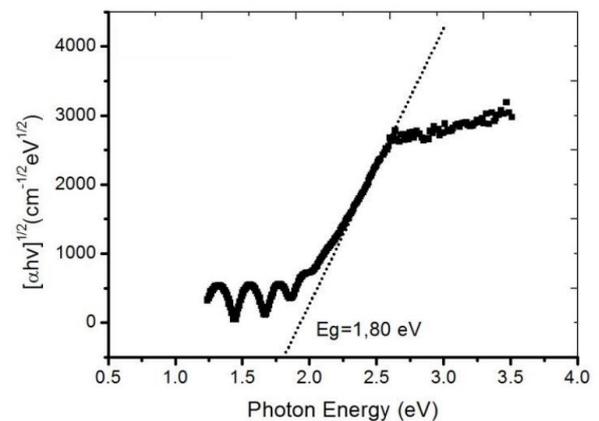


Figure 5. Graph of optical absorption coefficient on photon energy of n-type a-Si: H thin film.

The characterization stage is the last stage that shows the physical properties produced by optimizing the growth parameters. The physical properties obtained to become the benchmark for the next optimization stage to get a better quality of a-Si: H thin film [19]. The increase in the hydrogen rate causes the more regularity of the n-type a-Si: H layer that is formed but the increase in the PH_4 rate causes the irregularity of

the formed layers. The optimization parameter becomes the main indicator of the physical properties that will be produced [20]. However, the development to obtain a-Si: H material is still based on technology that is easy, cheap, efficient, and has good quality.

Conclusion

In Summary, the n-type silicon amorphous hydrogenated (a-Si: H) thin film was deposited, and the related UV-Vis spectroscopic data Tauc's Plot revealed an energy bandgap. based on the research conducted, it can be concluded that the nature of the n-type a-Si: H layer is affected by the rate of a source gas (SiH₄, PH₄, and H₂). The rate of source gas affects the number of radicals formed in the plasma, so it also affects the effectiveness of interactions (bonds) between atoms. In the n-type a-Si: H layer with H₂ dilution, the thickness is 72 nm, and the optical bandgap energy is 1.8 eV. We believe that the performance of n-type a-Si: H photovoltaic devices can affect the performance of solar cells, and we conclude that the findings of this work can contribute to improving the power conversion efficiency of solar cells.

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