Orissa Journal of Physics
ISSN 0974-8202

© Orissa Physical Society

Vol. 32, No.1
February 2025
pp. 63-77

Performance and Stability of Thin Film Silicon Solar Cells with P- Type Layers

BISHAL KUMAR MISHRA[1] and BIKASH RANJAN MOHAPATRA[2]

[1]*Department of Chemistry, mishrabishal1717@gmail.com 9439432572*
[2]*Department of Physics brmohapatra2@rediffmail.com 9861345648*
KiiT International School, (KiiT group of institution) Bhubaneswar

Abstract: The simplest semiconductor junction that is used in solar cells for separating photogenerated charge carriers is the p-n junction, an interface between the p-type region and type region of one semiconductor. The major issues of thin-film silicon solar cells have been the light-induced metastability of hydrogenated amorphous silicon (a-Si:H) and the weak infrared light absorption of hydrogenated microcrystalline silicon (μc-Si:H). Doping concentration, p-layer thickness and deposition temperature all show flat optimization maxima which gives a user friendly, robust deposition process.

Keywords: solar cell, physical vapor deposition, drop casting, interfacial impact, efficiency

INTRODUCTION

The p-n junction is an interface between the p-type and n-type regions of a single semiconductor, and it is the simplest semiconductor junction used in solar cells to separate photogenerated charge carriers. In order to be considered for use in solar cells, a material must first demonstrate its fundamental semiconductor property, namely, the ability to vary its conductivity by doping. This was the case for amorphous silicon. Films of "silicon from silane" deposited in a radio frequency glow discharge were reported as the first amorphous silicon layers in 1965. However, it was not until scientists Spear and Lacombe from Dundee University showed that amorphous silicon could be doped type and p-type by adding phosphine or diborane to the glow discharge gas mixture that it was widely accepted that amorphous silicon possessed semiconducting properties. The widespread belief that amorphous silicon could not be doped prior to this finding made this breakthrough all the more significant. At that time, it was not recognized immediately that hydrogen played an important role in the newly made amorphous silicon doped films. In reality, amorphous silicon is an alloy of silicon and hydrogen, making it ideal for electronic applications that call for doping. Hydrogenated amorphous silicon is the name given to the amorphous silicon used in electronics (a-Si:H).

After the material was successfully doped, research activity in this sector exploded across the globe. This curiosity was fueled by two primary factors. To begin, it possessed a number of promising features that may be used in a wide variety of semiconductor device contexts. Second, a-Si:H films may be manufactured at low temperatures over wide areas thanks to the glow discharge deposition method. This material is currently utilized in a variety of applications, including but not limited to photoconductive layers in electrophotography, thin film transistors, and solar cells. A single micrometer (m) thick layer of a-Si:H is sufficient to absorb 90% of useful solar light energy because of its high absorption coefficient in the visible region of the solar spectrum. Because of the low processing temperatures, a variety of inexpensive substrates can be used, including glass sheet, metal foil, and polymer foil. Due to its favorable characteristics, a-Si:H has emerged as a potential material for inexpensive thin-film solar cells. Thin-film solar cells, which can be made at a low cost, are generally considered to be the second- generation solar cells for use on Earth.

(2019) The thin film deposition process is an area where thin film technology excels, and it also provides the door for new methods to be used in industrial settings. Thin film technology as it exists now is a highly refined method of improving both the functionality and aesthetics of new functional devices. Finding novel materials for thin film solar cells is one such application since it addresses the current energy issue. There are many different kinds of solar cells, each optimized for a certain manufacturing method. It's clear that thin film solar cells and silicon wafer solar cells have the greatest potential. Thanks to advancements in thin-film technology, the development and implementation of solar-cell-powered devices is now a more realistic prospect. These solar cells still have room for development in terms of efficiency. Numerous studies have been conducted to enhance solar cells, from the well-known CIGS (copper indium gallium selenide) variety to more recent technologies like dye-sensitized solar cells and perovskite solar cells. Tin or other elements that match the attained efficiency of lead are used instead of lead in perovskite solar cells because of its poisonous nature and environmental effect. Therefore, advances in thin film solar cells to advance the photovoltaic sector by increasing its efficiency continue along the same route as the quest for novel materials.

The advantages of thin-film silicon solar cells over crystalline silicon solar cells have been widely recognized over the past four decades. These advantages include lower raw material consumption, scalability for mass-production, and the ability to apply the technology to lightweight flexible modules. Initial reports of the deposition of hydrogenated amorphous silicon (a-Si:H) were published in 1975, and subsequent demonstrations of a functional p-i-n solar cell by Carlson and Wronskian sparked a period of intensive investigation and development (1976). Hydrogenated microcrystalline silicon (c-Si:H), also known as hydrogenated nanocrystalline silicon (nc-Si:H), has gained popularity as a substitute for a-Si:H as a light-absorbing material in the 1990s. These materials have been included into double; and triple- and quadruple-junction; Schutte While they have improved solar cell efficiency, it is still lower than that of technologies based on inorganic absorber materials such as crystalline silicon, III-V, Cu (In, Ga) Se2, and CdTe (Green et al., 2017). The light-induced metastability in a-Si:H, also known as the Staebler- Wronski effect (Stabler and Wronskian, 1977), and the weak infrared absorption of c-Si:H as a result of its indirect bandgap nature is primarily responsible for the poor device performance of thin-film silicon. In order to overcome these obstacles, we have presented a new method of a- Si:H deposition and a light-trapping approach for c-Si:H absorbers. This has allowed us to set new world records for device efficiency in both single- and multi-junction configurations (Green et al., 2017).

In order to deposit a-Si:H and c-Si:H suitable for use in devices, plasma-enhanced chemical vapor deposition (PECVD) is often utilized, using a standard parallel-plate electrode shape (diode configuration, see Fig. 1(a)). SiH4 is used as the source gas, and the material phase may be changed from a-Si:H to c-Si:H by varying the H2 dilution ratio. It is well known that the degradation of a-Si:H caused by exposure to light may be mitigated by reducing the rate of deposition. While increasing the deposition rate causes a-Si:H to show a greater density of nano- sized voids and dihydride bonds (or hydrides at the surface of pores), infrared spectroscopy (Bhattacharya and Mahan, 1988, Nishimoto et al., 2002, Smet's et al., 2003) and positron annihilation spectroscopy (PaS) show otherwise (Elsken's et al., 2014). New EPR evidence suggests that metastable dangling bonds on the inner surface of nano-voids are responsible for the photo-induced breakdown of a-Si:H. (Fehr et al., 2014). Higher-order silane radicals and/or polyhedroid nano-clusters, both leftovers from the SiH4 glow-discharge process, play a crucial role in the creation of a porous microstructure in a-Si:H. Comparing the abundance of these species to that of the primary deposition precursor, SiH3, has been discovered to have an effect on the metastability of a-Si:H. (Takagi et al., 1999, Koga et al., 2004).

To prevent the formation of thick a-Si:H films with an excessive amount of dihydride bonds, it has been proposed to use a radical separation approach, such as a remote plasma technique with a triode electrode configuration (see Fig. 1(b)) (Matsuda et al., 1983). Strong initial performance in single-junction a-Si:H solar cells and reduced light-induced degradation are both possible with triode PECVD despite its slower deposition rate (101 nm/s) compared to that of conventional diode PECVD (>105 nm/s) (Shimizu et al., 2005, Snooze et al., 2006, Matsui et al., 2013). Nonetheless, our previous studies have demonstrated that further reducing the deposition rate does not improve light-soaking metastability (Matsui et al., 2015a). Based on the results, it seems that producing entirely stable a-Si:H is not possible and that some degradation due to light exposure is unavoidable**.**

LITERATURE REVIEW

H Kang (2017) First, the article gives a quick overview of the three types of silicon and their respective structures, highlighting the key distinctions between crystalline silicon, amorphous silicon, and hydrogenated amorphous silicon. The report then provides a side-by-side analysis of c-Si solar cells and a-Si solar cells, highlighting the key differences and similarities between the two. Later, we'll look at how various silicon architectures affect each PV property. Finally, this study analyses the pros and cons of using c-Si vs. a-Si solar cells, and examines when each kind of cell is better suitable for a certain application. In conclusion, crystalline silicon solar cells are successful due to their excellent conversion efficiency and user-friendly cost, while amorphous silicon solar cells are disruptive due to their demonstration of several optical and electrical properties, such as a high absorption coefficient and the Staebler-Wronski Effect.

Thierry de Vrijer (2018) Recently, thin-film silicon solar cells have used doped hydrogenated silicon oxide layers (SiOX:H) as front window layers, rear reflector layers, intermediate reflector layers, passivation layers, and junction layers with great success. A device's performance may degrade over time if the SiOX:H layers were deposited under unfavorable circumstances. In this study, we provide evidence for the mechanism at fault. It is shown that this deterioration is due to the oxidation of p-type doped (p-)SiOX:H with high crystallinity and, hence, poor passivation of crystalline grains. p-SiOX:H oxidizes when air moisture diffuses into it. High-pressure processing yields stable p-SiOX:H. Further, utilizing dense n-type (n-)SiOX:H in the cell's back reflector is one way to protect it against deterioration.

Senthil T.S et.al (2019) The thin film deposition process is an area where thin film technology excels, and it also provides the door for new methods to be used in industrial settings. Thin film technology as it exists now is a highly refined method of improving both the functionality and aesthetics of new functional devices. Finding novel materials for thin film solar cells is one such application since it addresses the current energy issue. There are many different kinds of solar cells, each optimized for a certain manufacturing method. It's clear that thin film solar cells and silicon wafer solar cells have the greatest potential. Thanks to advancements in thin-film technology, the development and implementation of solar-cell-powered devices is now a more realistic prospect. These solar cells still have room for development in terms of efficiency. Numerous studies have been conducted to enhance solar cells, from the well-known CIGS (copper indium gallium selenide) variety to more recent technologies like dye-sensitized solar cells and perovskite solar cells. Tin or other elements that match the attained efficiency of lead are used instead of lead in perovskite solar cells because of its poisonous nature and environmental effect. Therefore, advances in thin film solar cells to advance the photovoltaic sector by increasing its efficiency continue along the same route as the quest for novel materials.

Abu Kowsaret.al (2019) Thin-film solar cells are attractive because they need few inputs, can be synthesized cheaply, and are on the verge of achieving higher efficiencies. From their inception to their current state-of-the-art development, five major types of thin film solar cells (TFSC) are presented in this review paper: the amorphous silicon (a-Si) solar cell, the copper indium gallium selenide (CIGS) solar cell, the copper zinc tin sulphone (CZTS) solar cell, the cadmium telluride (CdTe) solar cell, and the dye-sensitized solar cell There has also been research into the many cell topologies, the various layers of these cells, their development techniques, their function, and their modification to create functional solar cells. Both the existing situation and the critical challenges that restrict the functioning of these cells have been addressed. Finally, the work has been summed up in the form of a comparative study between the five major types of TFSCs, highlighting state-of-the-art data for structural, optical, and electrical properties, material availability, toxicity, stability, and highest efficiency to aid readers in understanding the major challenges for popularization and commercialization of this technology.

Erteza Tawsif Efaz et.al (2021) Because of their low production costs, little material requirements, and promising efficiency growth, thin-film solar cells are quickly becoming the preferred technology. This study provides a comprehensive overview of three different kinds of thin-film solar cells, from their genesis to the finest laboratory-developed module: cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (-Si). Each technology's extraordinary development, cell design, restrictions, performance, and worldwide market share are dissected. Similar attention is paid to examining the respective methods' dependability, availability of cell materials, and property comparisons. New solar cell technologies, which offer important clues and potential answers for the future of the industry, are also discussed. The purpose of this abridged analysis is to aid readers in identifying viable research directions with respect to optimal solar cell uses and manufacturing.

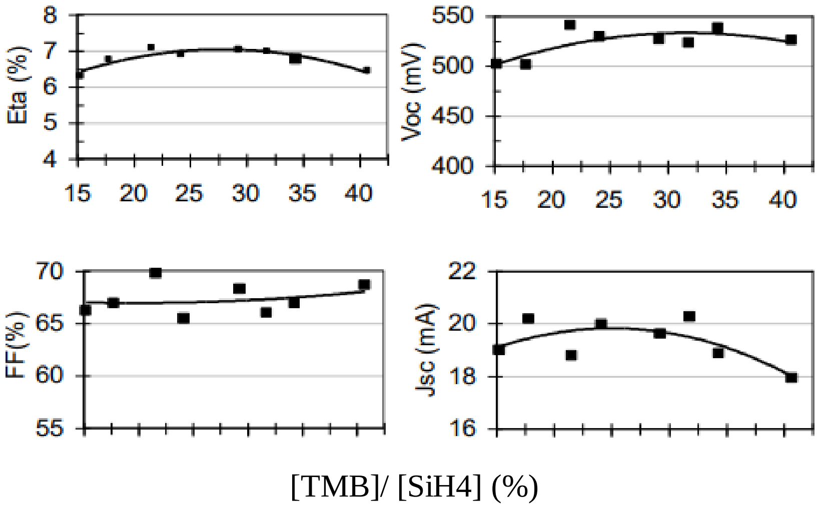
RESEARCH AND METHODOLOGY

Solar cells made from microcrystalline silicon thin films on Al doped ZnO coated (TCO) glass substrates were developed [4]. When studying cells, it is common practice to change just the p- layer while keeping the intrinsic layer conditions unchanged. Both layers are microcrystalline, with the first being deposited in a multi-chambered UHV system using VHF-PECVD (95 MHz). The p layers are made using a dilution ratio of 1.5% silane to hydrogen. The dopant gas for is trimethyl boron (TMB) diluted to 1% in helium. The thickness and substrate temperature have been manipulated, and the gas phase doping ratio (=[TMB]/[SiH4]) has also been changed. With a silane to hydrogen dilution ratio of 5%, the c-Si:H layer is formed on the cusp of the amorphous growth phase. The best performance of solar cells was measured under these circumstances. This layer's thickness is consistently 1 m. The n-layer (phosphorous doped from phosphine source gas) is deposited at 13.56 MHz while remaining amorphous to prevent current collection from the sides by a highly conducting microcrystalline n-layer. Thin ZnO/ Ag rear reflector is applied to the n-layer for improved back reflection. The cells' I-V curves were analyzed at 25 degrees Celsius using an AM1.5 solar simulator. Taken in relation to a calibrated diode, the spectra of the cells' intrinsic quantum efficiencies are shown.

DATA ANALYSIS

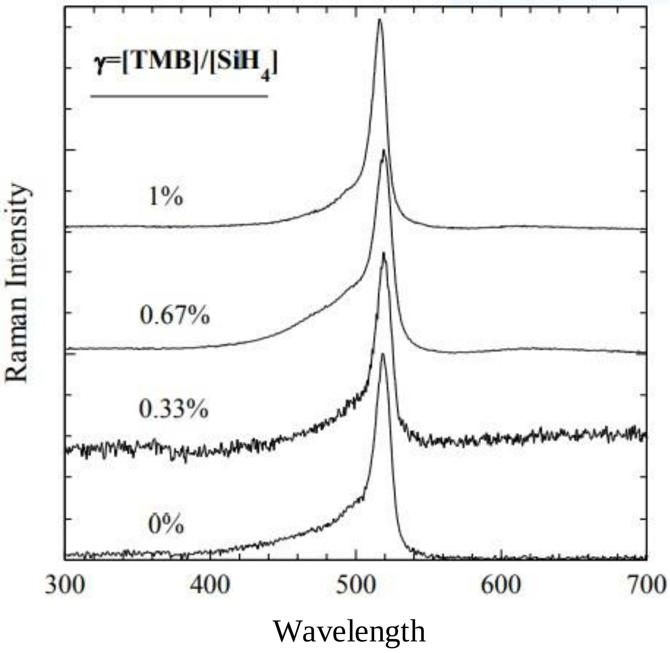
Doping Variation

The p-layer(22nm) doping series for 1 thick i-layers in c-Si PIN solar cells



Pictorial Representation No. 1 (a). Parameters of AM1.5-illuminated c-Si:H solar cells for a range of gas-phase doping ratios

Figure 1(a) displays the efficiency (Eta), open-circuit voltage (Voc), fill factor (FF), and short- circuit current density (Jsc) of single-junction pin microcrystalline solar cells constructed with varying densities of microcrystalline p-layers. Preparation of these p-layers takes place over the same amount of time, despite using varying gas phase doping ratios (). (5min45sec). It is well knowledge that higher concentrations of TMB in the gas phase result in faster deposition rates. Thus, it is anticipated that the p-layer thicknesses will vary for the various gas phase doping ratios. We will go into detail about how the p-layer thickness impacts the cell's characteristics as a consequence. However, it is worth noting that the p-layer thickness is around 30nm at the sweet spot of TMB (= 1%). Beyond =0.5%, which seems to be the minimal doping concentration needed for completely building up a maximum Voc, all other solar cell characteristics show only a mild relationship (Fig. 1(a)). 2 causes a little drop in FF and Jsc, and low doping

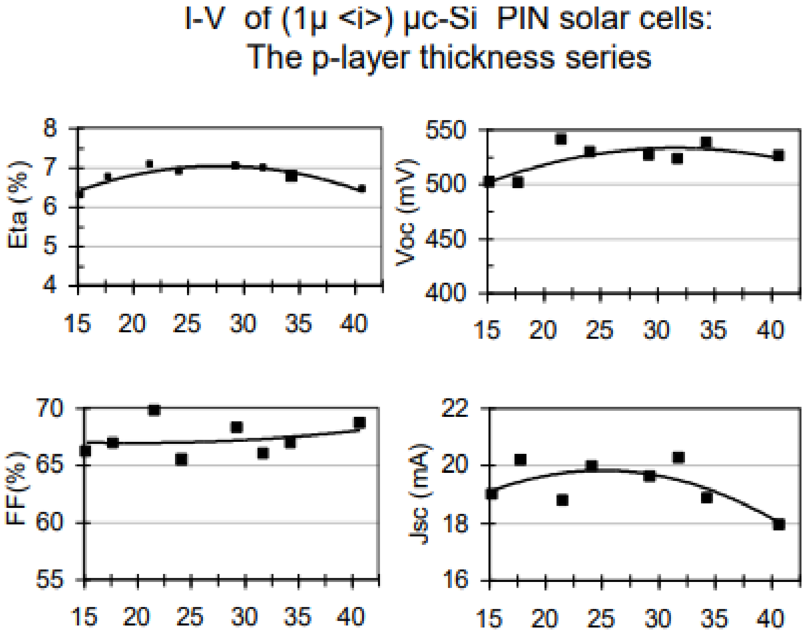


Pictorial Representation No. 1 (b). Raman spectra of p-layers of c-Si:H (thickness 500nm) generated at various values. Rates of deposition are shown in the inset.

As a result, efficiencies are achieved between =0.5 and 1.5%, with =1% serving as an optimal target for future study. Raman spectra of thick (500nm) p-layers grown on glass are shown in Fig. 1(b). The crystallinity of the films is not significantly affected by the TMB doping gas up to a doping level of 1.0%, indicating that the doping gas has no negative influence on the crystallinity of the films when starting with undoped material. Results from various solar cells are shown in fig. 1(c), which displays the corresponding quantum efficiency spectrum (a). The data agrees with the Jsc findings shown in Fig. 1. (a). The current losses at low doping (0.2%) are concentrated in the long wavelength band, suggesting insufficient carrier collecting. Poor blue response is seen at high doping (2%), which may be due to enhanced absorption in the p- layer.

Thickness Dependence

Series of p-layer thicknesses and their effects on the I-V curve of (1 c) c-Si PIN solar cells



the thickness of the p layer is estimated to be (nm) (does not take into account incubation time)

Similar pin solar cells (1m layer) were produced, but with varied p-layer deposition periods at the optimal doping ratio =1.0 in order to examine the impact of the p-layer thickness in more detail. Using the deposition rates found for thick p-layers (40/min), the thickness of the p-layers may be derived from the deposition timings. Since the layer development requires some incubation time during the nucleation step, the true layer thickness is likely to be on the thinner side. The properties of the solar cells are shown in a plot in Fig. 2. (a). The solar cell characteristics show a relatively flat dependency on the p-layer deposition timings, similar to what was shown for the doping variation. Over a wide variety of thicknesses, the FF is very stable (i.e., from 15 – 40nm). A predicted thickness of just 15 nm yields a Voc of 500 mV. Absorption losses in the Jac only diminish somewhat for the thickest player.

Across a broad range of thicknesses, the effects of the layer seem to be minimal. Simply said, after the thickness of the cell is reduced to less than 35 nm, no more improvements can be made to the parameters, and the cell is inside a safe processing zone. Raman spectra are shown in Figure 2(b) for a thin a-c-Si:H layer formed over TCO with the same deposition period as employed in the solar cell under optimum circumstances (1% TMB doping and 1.5% silane dilution in hydrogen).

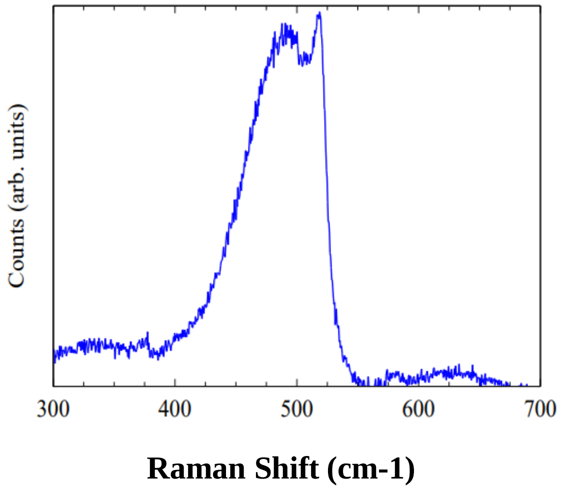
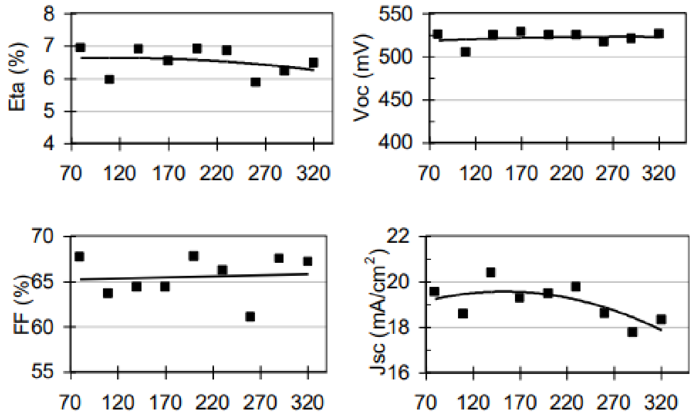


Figure 2(b) Raman spectra of a thin (~22nm) □c-Si:H<p>, optimised for cell.

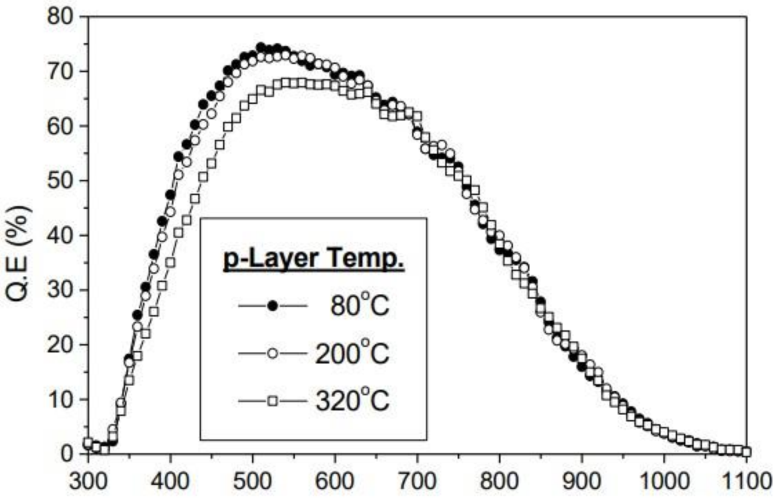
The predicted thickness of thick sheets is 22nm based on the rate of deposition. Raman spectra of the 1% gas-phase doped sample are given in Fig. 1 for comparison (b). This sample is 500 nm thick and was made under the same circumstances as the thinner one under discussion. In contrast to the almost completely crystalline nature of the bulk sample, the thin layer retains a sizable amorphous component. This makes sense, since the structural evolution of c-Si:H films with thickness has been extensively studied. However, the fact that high solar cell performance is achieved with this layer may come as a surprise. Therefore, it is reasonable to suppose that a negligible quantity of p-layer crystallinity is all that's needed to generate the highest possible VOC and foster the healthiest possible layer development. This, however, is by no means indicative of the use of an amorphous p-layer in the same manner. Because the tiny crystallinity of the is required for the to develop microcrystalline under the preparation circumstances employed here, a 1m thick microcrystalline pin cell deposited over a totally amorphous gives properties identical to an all-amorphous cell (not shown).

The amounts of boron and carriers in the 500 nm thick p-layer have been determined using secondary ion mass spectrometry (SIMS) [7] and Hall measurement, respectively. The boron density is 1 x 1020 /cm3, while the carrier density is 2 x 1019 /cm3. This translates to a doping efficiency of 10–20%, which is much lower than the near-unity doping efficiencies found by utilizing diborane (or phosphine for n-type c-Si:H) [8]. When utilising TMB as a doping gas, the high carbon content of 3 x 1020/cm3 observed simultaneously may suggest the buildup of B-C- Hx groups. Additional evidence for the high electrical Substrate Temperature Dependence quality of this material is provided by its mobility of 2 cm2 /Vs and conductivity of 7.4 S/cm.

c-Si PIN solar cell p-layer temperature dependence on substrate temperature.



Surface Temperature (in degrees Celsius) Diagram No. 3 (a). Parameters of a c-Si:H solar cell constructed in AM1.5 light at varying substrate temperatures.



Microcrystalline pin solar cells with p-layers constructed at various substrate temperatures, and their corresponding quantum efficiency spectra.

We have also investigated the effect of changing the substrate temperature on the performance of the p-layer in thin film p-i-structures. The deposition duration is 270s (22 nm), and the doping ratio is =1%. A wide temperature range, from 80 to 320 degrees Celsius, is used for the deposition process. The specifications of a solar cell are shown in Figure 3(a). Surprisingly, the VOC does not change from 520 to 530 me throughout a deposition temperature range of 80 to 320°C. Similarly, the deposition temperature has no impact on the FF, and only the JSC drops at 250°C. The spectra of quantum efficiencies of a few of these cells are shown in Figure 3, and they provide a fitting complement to the Jac curve's behavior (b). As the layer thickness increases with increasing temperature, the blue response of the constructed cell decreases, which is responsible for the decrease in Jsc. The p-layer may be deposited at temperatures as low as 80oC, which might in the future allow for a wider variety of substrates to be used.

CONCLUSIONS

It had previously been believed that amorphous silicon could not be doped, hence this breakthrough was monumental. To create p-i-n single-junction solar cells, a high-quality a-Si:H absorber layer is deposited using the PECVD method, with a triode electrode arrangement. Number of Raman Chirps (cm-1) (arb. units) Raman spectra (Figure 2(b)) of a thin (22nm) c- Si:H that has been optimized for use in cells. It seems that a low crystalline volume fraction in the p-layer is sufficient to foster the formation of a high-quality i-layer. There are no negative effects on crystal growth up to an optimal doping concentration of 1% of B(CH3)3.

REFERENCES

1. H Kang (2017) Crystalline Silicon vs. Amorphous Silicon: The Significance of Structural Differences in Photovoltaic Applications doi:10.1088/1755-1315/726/1/012001
2. Thierry de Vrijer (2018) Chemical Stability and Performance of Doped Silicon Oxide Layers for Use in Thin-Film Silicon Solar Cells Print ISSN: 2156-3381Electronic ISSN: 2156-3403
3. Senthil T.S et.al(2019) New Materials for Thin Film Solar Cells DOI: 10.5772/intechopen.81393
4. Abu Kowsar et.al (2019) Progress in Major Thin-film Solar Cells: Growth Technologies, Layer Materials and Efficiencies
5. ErtezaTawsifEfaz et.al (2021) THIN FILM SILICON SOLAR CELLS WITH P- TYPE LAYERS. Eng. Res. Express 3 032001
6. Benmira, A., & Aida, M. S. (2013). Analytical modeling and simulation of CIGS solar cells. *Energy Procedia*, *36*, 618-627. [Links]

7. Bernal-Correa, R., Morales-Acevedo, A., Montes-Monsalve, J., &Pulzara-Mora, A. (2016). Design of the TCO (ZnO:Al) thickness for glass/TCO/CdS/CIGS/Mo solar cells. *Journal of Physics D: Applied Physics*, *49*(12), 125601. [Links]

8. Busacca, A. C., Rocca, V., Curcio, L., Parisi, A., Cino, A. C., Pernice, R., . . .& Miceli, R. (2014). Parametrical study of multilayer structures for CIGS solar cells. In *3rd international conference on renewable energy research and applications* (pp. 964- 968). Milwaukee: IEEE. [Links]

9. Daza, L., Castro-Rodríguez, R., Cirerol-Carrillo, M., Martín-Tovar, E., Méndez-Gamboa, J., & Medina-Esquivel, R. (2017). Nanocolumnar CdS thin films grown by glancing angle deposition from a sublimate vapor effusion source. *Journal of Applied Research and Technology*, *15*(3), 271-277. [Links]

10. Fardi, H., &Buny, F. (2013). Characterization and modeling of CdS/CdTe heterojunction thin-film solar cell for high efficiency performance. *International Journal of Photoenergy*, *2013*, 1-6. [Links]

11. Filmetrics. (2016). *Filmetrics*. Retrieved from Filmetrics: http://www.filmetrics.com/refractive-index-database [Links]

12. Green, M. A., Emery, K., Hishikawa, Y., Warta, W., & Dunlop, E. D. (2015). Solar cell efficiency tables (version 46). *Progress in Photovoltaics*, *23*(7), 805-812. [Links]

13. Heavens, O. (1954). *Optical properties of thin solid films*. New York: Dover. [Links]

14. Ibdah, A. R., Aryal, P., Pradhan, P., Rajan, G., Li, J., Rockett, A., . . . & Collin, R. (2014). Solar cells with thin Cu(In $_{1-x}$ Ga$_x$)Se$_2$ absorbers: Optical analysis and quantum efficiency simulations. In *40th photovoltaic specialist conference* (pp. 373-378). Denver: IEEE. [Links]

15. W. Palz, Photovoltaic Solar Energy Conference: Proceedings of the International Conference, Held at Cannes, France, 27–31 October 1980: Springer Science & Business Media, 2012.