Fabrication Of A-C:B/N-Si Solar Cells With Low Positive Bias By Custom-Made-CVD

A. Ishak, Ahmad Nurrizal Muhamad, M. Rusop

Abstract: Boron doped amorphous carbon (a-C:B) film fabricated on n-type silicon using waste palm oil precursor by low positive bias voltage is presented. The rectifying curve were found for all samples under dark measurement revealed that those samples were p-type semiconductor. The +30 V was found the optimized of the electronic properties with the open circuit voltage (VOC), current density (JSC), fill factor (FF) and efficiency (%) were approximately 0.259034 V, 1.299456 mA/cm^2, 0.240011, and 0.080788 %, respectively. The conversion efficiency of a-C:B has been improved under the influenced of low positive bias.

Keywords: Carbon; Palm-oil; Positive bias; Boron; Custom-made

I. INTRODUCTION

Renewable precursors such as camphor powder, turpentine oil, coconut oil have been used for synthesize many diversity of carbon instead of non-renewable precursor [1-3]. Beside of those precursors, palm oil the other abundantly promising 'green' source was successfully synthesized the carbon nanotube (CNT)[1-3]. Palm oil is scientifically known as hexaeconoic acid which was derived from fibrous exocorp and mesacarp of the fruits of palm tree [2-4]. The palm oil is contained carbon (67), hydrogen (127) and oxygen (8) to form the chemical binding of C67H127O8 (3). If optimize energy were used for break down the binding, high number of carbon (67) will be released. Dc bias either positive or negative were reported by others groups in helping to accelerate particles through bombarding process [5,6]. The DC bias tried to attract the opposite charge atom and repel the equalize charge being reach on the substrate [7,8]. As a result, the chamber under deposition will be dominated by negative charge of carbon and boron atoms rather than unwanted particles thereby could minimize the other particles from being deposited on the surface of substrate. The present of amorphous carbon (a-C) in CNT has brought the negative effect of CNT production, it has benefited to the other area in semiconductor industry especially for fabricated carbon-based photovoltaic solar cell by the ability to be a semi-conductive material [9,10]. However, undoped a-C was reported as a weakly p-type [10,11] in nature despite of complex structure, high density of defect which restricted to dope efficiently and those factors were the main barrier for its application in various electronic devices.

- *Ishak, Ahmad Nurrizal Muhamad, M. Rusop*
- *NANO-ElecTronic Centre, Faculty of Electrical Engineering, UniversitiTeknologiMARA, 40450 Shah Alam, Selangor, Malaysia*
- *NANO-SciTech Centre, Institute of Science, UniversitiTeknologi MARA, 40450 Shah Alam, Selangor, Malaysia*
- *Facuty of Electrical Engineering, UiTM SarawakKampus Kota SamarahanJalanMeranek, Sarawak*

As such, it was hypothesis that by properly control the doping the existing of defect could be reduced and at the same time could be modified the electronic properties. In this paper, the carbon-based solar cell of boron doped amorphous carbon (Au/a-C:B/n-Si/Au) were fabricated on the n-type silicon using low positive bias from 0 V to +50 V. There are less study on low positive bias for fabricated Au/a-C:B/n-Si/Au solar cell using palm oil precursor. To the best of our knowledge, none of the report on the use of 'green' source from palm oil fabricated by low positive bias for Au/a-C:B/n-Si/Au carbon-based photovoltaic solar cell.

II. EXPERIMENTAL

The influenced of low positive bias on boron doped (a-C:B) a-C solar cells were deposited by using bias-assisted pyrolysis-CVD onto the corning glass substrates (thickness: 1mm) and n-Si (100) (thickness 325 ± 25 µm, resistivity 1-10 Ω cm). Substrates (glass and n-silicon) were together cleaned with acetone (C_5H_6O) followed by methanol (CH_3OH) for 15 min in Ultrasonic Cleaner (power Sonic 405), respectively and the glass substrates were then rinse with DI water for 15 min. However, excess oxide layers of n-type silicon substrates were continued by the etching process with diluted hydrofluoric acid (10%) solution for about 2 min before rinsing in DI water. Substrates were then blown with nitrogen gas. The cleaned of glass and silicon substrate was finally attached inside the chamber as shown Fig. 1. The deposition temperature was set at 325^{o}C for 1h deposition. A liquid palm oil precursor was heated outside the chamber at 150^{o}C by using hot platter (Stuart CB162). The vaporized of palm oil was then pressured into the chamber by using aquarium air pumps (GA8000). The amount of vaporized palm oil, carrier gas argon used into were set to be constant at 114 mL/min, 200 mL/min, respectively. For doping process, 160mg of boron was placed on the heater metal plate by using aluminium foil. The positive bias is varied in the range of +10 V to +50 V. The zero bias is also fabricated and used as a reference. In the measurement of solar cell device, both sided of silicon (buttom and top) is deposited with approximately 60 nm and 12 nm of gold, respectively. The gold contact of 60 nm were sputtered at the top of 12 nm gold for conform the point of probe is properly contacted on the gold metal contact. The light closure is attached at the top of the device as shown in Fig. 2 to ensure light strike only the area of 2 cm^2. The other probe is connected to the conductive metal holder as shown in Fig. 2.

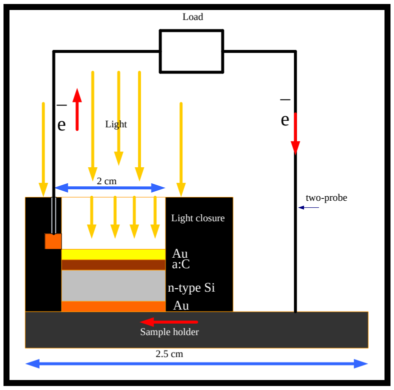

Fig. 2. *The measurement technique of heterojunction Au/a-C:B/n-Si/Au solar cell*

Solar simulator (Bukuh Keiki EP200), surface profiler (VeecoDektak 150), JASCO UV-VIS/NIR Spectrophotometer (V-670 EX) and Park system XE-100 atomic force microscope (AFM) to characterize the electronic and optical properties.

III. RESULT AND DISCUSSIONS

Fig. 3 shows the current density voltage (J-V) characteristics of the solar cell under dark at 100 mW/cm^2 using AM 1.5 solar simulator fabricated by low positie bias voltage. The rectifying curve are found for J-V characteristics for all samples of heterojunction carbon-based solar cell. We predicted, the diode formation is came from the different layer of n-type Si and p-type a-C:B. The a-C:B layer acted as a p-type while silicon substrate acted as as an n- type which formed the rectifying behaviour. The same trend behaviour of heterojunction carbon solar cell were obtained by others but fabricated using different method and precursor [12-14]. Beside forming of diode behaviour, precursor of palm oil has a good potential in fabricated photovoltaic carbon solar cell in the near future as proved in Fig. 4 where various level of working curve are present.

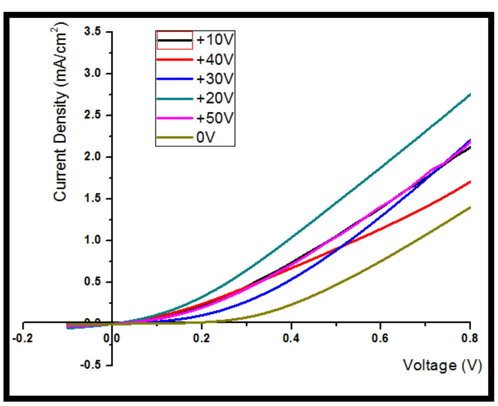

Fig. 3. *The current-voltage characteristics under dark of Au/a-C:B/n-Si/Au fabricated with low positive bias voltage*

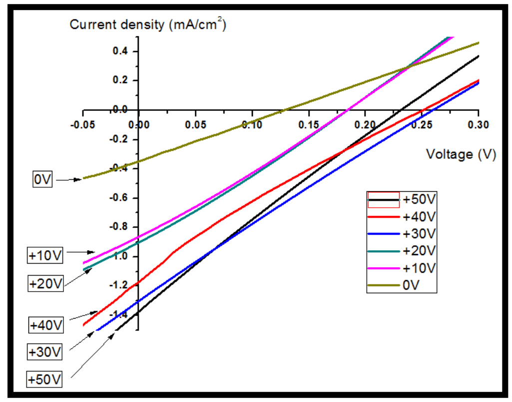

Fig. 4. *The current density-voltage characteristics of the working curve of the Au/a-C:B/n-Si/Au solar cell fabricated with positive bias voltage*

The light illuminated J-V characteristics of heterojunction carbon solar cell fabricated by low positive bias voltage using palm oil precursor is shown in Fig. 4. The photo current and open circuit voltage are found varied under the influenced of low positive bias voltage as depicted in Fig. 4. The curves of all solar cell devices by our configuration is less broaden and more to a straight line curve compared with ideal solar cell. This phenomena is attributed from the series and shunt resistance from the material and metal contact configuration which significantly affect the solar cell devices. The high series resistance gives rise to the voltage drop and therefore minimize the full photovoltaic voltage across the load. The shunt resistance on the otherhand, deviate some part of the current from generated carriers and therefore deteriorate the photo curent density J_{sc}. The electronic properties are summarized in Table I. The efficiency of boron doped fabricated without the used of low positive bias has found lower as compared with low positive bias where its open-circuit voltage (V_{OC}), current density (J_{SC}), fill factor (FF) and efficiency (%) are 0.127516 V, 0.346546 mA/cm^2,0.254029, and 0.011225 %, respectively. The electronic properties of boron doped fabricated by low positive bias in the range of +10 V to +50 V are shown in Table I. The optimize efficiency is found at +30V where its V_{OC}, J_{SC}, FF, % is 0.259034 V, 1.299456 mA/cm^2,0.240011, and 0.080788 %. We found, convension efficiency has been improved under the influenced of low negative bias. Low values of V_{OC}, and J_{SC} are believed from low buit-in voltage which caused by defects in a-C:B thin film and thus influenced the shorter lifetime and diffusion length and movement of drift carriers. The drift of carriers by buit-in electric field plays an important role in cells [12-14]. Less of drift carriers might be due to the smaller built in voltage and therefore electron-hole pairs generated are recombined near surface. The shorter lifetime of excess carriers and diffusion length are responsible for the low photocurrent [13-15]. The existing of weakly pi (π) [15-17] bond are easy to be broken and therfore, form high density of intrinsic defect. Furthermore, boron will induce high concentration boron defect [15,16]. All these defect will introduce deep state in the gap, and as a result, the lifetime of minority carriers and diffusion length will be reduced, which in turn reduce the photocurrent density.

Table I. The Electronic properties of boron-doped a-C solar cell fabricated with low positive bias voltage

Positive bias (V)	Open circuit voltage (V_{OC})	Current density (mA/cm^2)	Fill-factor (FF)	Conversion efficiency (%)
0	0.127516	0.346546	0.254029	0.011225
+10	0.183422	0.861707	0.270101	0.042691
+20	0.184036	0.946730	0.273165	0.047594
+30	0.259034	1.299456	0.240011	0.080788
+40	0.250352	1.169343	0.217392	0.063641
+50	0.231440	1.321446	0.238328	0.078289

Fig. 5 shows spectral response of boron doped a-C solar cell fabricated from 0 V to +50 V using palm oil precursor. The highest spectral response is at sample of +30 V while the lowest is at sample of 0 V. The highest spectral response is supported by the highest convension efficiency as shown in Table I and Fig. 4. We found all samples fabricated with low negative bias has higher spectral response compared without low negative bias. Although solar cell properties are low, our objective is to clarify the function of boron and successfully vaporized of palm oil used as a precursor. The spectral response indicates two broad bands at the peak wavelength approximately 550 nm and 720 nm. It was reported that the wavelength above 700 nm is negligible since the photocurrent is mostly generated in the silicon substrate [15,16,18]. In the region below 700 nm, we predicted the boron doped layers act as carbon photon absorber, and quantum efficiency has a peak in short wavelength region. The photo current peak at approximately 550 nm is good agreement with the optical band gap measurement of boron doped thin film. We conclude the observed responses in the wavelength range from 300 to 700 nm are characteristics of the a-C:B cells.

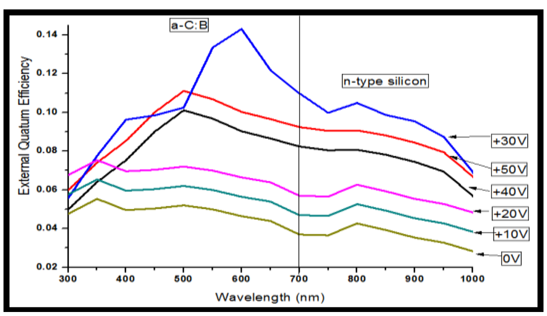

Fig. 5. *Spectral response of a-C:B solar cell fabricated with low positive bias voltage*

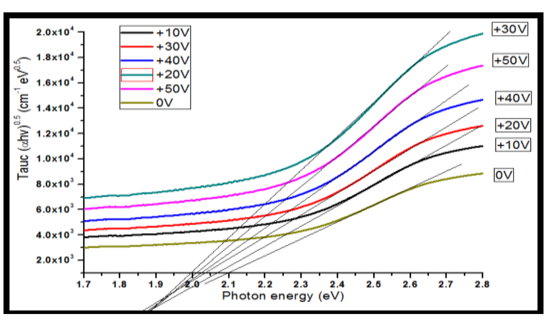

Fig. 6. *The optical band gap of a-C:B thin film deposited with low positive bias voltage*

The optical properties of thin films are investigated by UV-visible spectroscopy measuremets using the films deposited on glass substrates in the wavelength in the range of 200-1200 nm, to derive the Tauc optical band gap (E_g) for amorphous semiconductors [18,19]. The E_g of the thin films is obtained from the extrapolation of the linear part of the curve at the α=0, using the Tauc relation, $(\alpha h\nu)^{1/2}=B_2(E_g-h\nu)$, where B_2 is the Tauc parameter. The estimated E_g of a-C:B is approximately in the range of 1.8 to 2.1 eV as shown in Fig. 6. The boron doped a-C thin film deposited by low positive bias decreased gradually the E_g from 2.1 to 1.8 eV. The interstitial doping of boron (B) in a-C films through modification of C-B bonding configurations might caused the changing of E_g. The declined in E_g by low positive bias voltage may be indicated an increase of trihedral (sp^2) fraction due to graphitization of the a-C:B film which is probably induced by B content in the film similar to the high nitrogen content in the film induce graphitization in nitrogen doped thin films [6,20].The values of these E_g were a good agreement why the spectral response and efficiency of boron doped with low positive bias have higher than without the use of low negative bias. The E_g of carbon solar cell by low positive bias are in the range of optimum E_g of solar cell (1 eV to 2 eV). None of the report of E_g by using this method and precursor have been found in the literature. However, the decreasing of E_g due to other parameters such as the percentage of dopants, (nitrogen and phosphorous), and deposition temperatures have been reported by others [19,20].

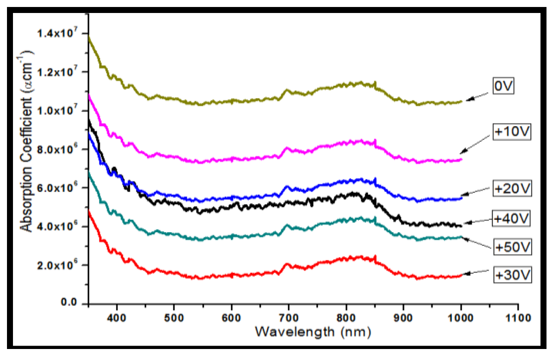

Fig. 7. *The absorption coefficient of a-C:B thin film deposited with low positive bias voltage*

The absorption coefficient of a-C:B thin film deposited with low positive bias voltage in the range of 0 to +50V is shown in Fig. 7. The results show all a-C:B films are responded with the photon energy at difference absorption distance for generating of minority carriers when reach the depletion region. The Aurum (Au) electrode films was high absorption coefficient (α) of about $2.4x10^5$-$5.3x10^5$ cm^{-1} in the lower wavelength region [12,13]. All a-C:B thin films have high α from $2.0x10^6$ to 1.2 10^7 compared with Au and therefore, photon incident on the front surface of a-C:B thin films might be strongly absorbed by the Au electrode rather than a-C:B. As a result, most part of the generated electron-hole pairs are recombined in the surface and only a few of them can arrive at depletion region. The low external quantum efficiency and high α in lower wavelength region of the Au electrode, a-C:B are taught to be responsible for low external quantum efficiency and conversion efficiency of a-C:b/n-Si solar cells.

IV. CONCLUSIONS

The a-C:B heterojunction carbon solar cell has been successfully fabricated using palm oil as precursor under the influenced of low positive bias. Although the conversion efficiency is still low, it has shown that there is the possibilty of the improvement of the effiiency of the a-C:B/n-Si heterojunction photovoltaic solar cells by optimizing the depostion conditions.The electronic properties of a-C:B heterojunction carbon solar cell were improved when deposited with low positive bias. The optimum a-C:B/n-Si was found at +30 V where the V_{OC}, J_{SC}, FF, and η were 0.259034 V, 1.299456 mA/cm^2, 0.240011, and 0.080788 %, respectively. The optical band gap of a-C:B at 0 V is approximately 2.1 eV and slightly drop to be 1.85 eV under negative bias deposition. Deposition with low negative bias were improved the electronic properties of a-C:B as well as optical band gap of a-C:B thin film. The results would encourage the future prospects of clean, low-cost and reasonably high efficiency carbon solar cells. Further studies on the junction properties of a-C:B/n-Si structure is still under progress.

ACKNOWLEDGEMENT

Theauthors thankto Ministry of Higher Education (MOHE) Malaysia for the scholarship, UniversitiTeknologi MARA, Kota Samarahan Sarawak and Research ManagementInstitute(RMI) UniversitiTeknologi MARA (UiTM)for thefacilities.

REFERENCES

[1] K. Ghosh, M. Kumar, T. Maruyama, and Y. Ando,Micro-structural electron-spectroscopic and field-emission studies of carbon nitride nanotubes grown from cage-like and linear carbon sources, Carbon , 47 (2009) 1565-1575.

[2] A. Ishak, M. Rusop, P-type properties of micro and nano-structured carbon films from hydrocarbon palm oil in photovoltaic heterojunction solar cell applications, IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 9 (2014) 110-115.

[3] P. Ghosh, T. Soga, R.A. Afre, and T. Jimbo, Simplified synthesis of single-walled carbon nanotubes from a botanical hydrcarbon: Turpentine oil, Journal of Alloys and Compounds, 462 (2008) 289-293.

[4] S. Paul, and S.K. Samdarshi, A green precursor for carbon nanotube syhthesis, New Carbon Materials, 26 (2011) 85-88.

[5] A. Ishak, K. Dayana, and M. Rusop, Surface Morphology and Compositional Analysis of Undoped Amorphous Carbon Thin Films Via Bias Assisted Pyrolysis-CVD, Advanced Material Research, 667 (2013) 468-476.

[6] M. Rusop, S.M. Mominuzzaman, T. Soga, T. Jimbu, M. Umeno, Nitrogen doping in champoric carbon films and its application to photovoltaic cell, Surface Review and Letters, 12 (2005) 35-39.

[7] Hongwei Zhu, Jinquan Wei, Kunlin Wang, and Dehai Wu, Applications of Carbon Materials In Photovoltaic Solar Cells, Solar Energy Materials & Solar Cells, 93 (2009) 1461-1470.

[8] A. Ishak, K. Dayana, M. H. Mamat, M. F, Malek, and M. Rusop, Deposition of Amorphous Carbon Film Using Natural Palm Oil by Bias Assisted Pyrolysis-CVD for Solar Cell Applications, International Journal of Power and Renewable Energy Systems 1 (2014) 12-23.

[9] A. Ishak, M. Rusop, Structural Properties of P-Type Boron Doped Carbon Film from Hydrocarbon Palm Oil for Photovoltaic Heterojunction Solar Cell Device, International Journal of Engineering Invention 3 (2014) 35-41.

[10] X. M. Tian, M. Rusop, Y. Hayashi, T. Soga, T. Jimbo, and M. Umeno, “A photovoltaic cell from p-type boron-doped amorphous carbon film,” Solar Energy Materials and Solar Cells, vol. 77, pp. 105-112, 2003.

[11] Y. Hayashi, S. Ishikawa, T. Soga, M. Umeno, and T. Jimbo , “Photovoltaic characteristics of boron-doped hydrogenated amorphous carbon on n-Si substrate prepared by r.f. plasma-enhanced CVD using trimethlboron,” Diamond and Related Materials, vol. 12, pp. 687-690, 2003.

[12] M. Rusop, X. M. Tian, S. M. Mominuzzaman, T. Soga, T. Jimbo, and M. Umeno,“Photoelectrical properties of pulsedlaser deposited boron doped p-carbon/n-silicon and phosphorous doped n-carbon/p-silicon heterojunction solar cells,” Solar Energy, vol. 78, pp. 406-415, 2005.

[13] H. A. Yu, T. Kaneko, T. Yoshimura, S. Suhng, and S. Sasaki, “ The spectro-photovoltaic characteristics of a carbonaceous film/n-type silicon (C/n-Si) photovoltaic cell,” Applied Physics Letters, vol. 69, pp. 4078-4080, 1996b.

[14] A. Ishak, M. Rusop, Structural Properties of Micro and Nanostructured Amorphous Carbon Films from Liquid Hydrocarbon Precursor in Photovoltaic Heterojunction Solar Cell Applications, International Journal of Latest Research in Science and Technology 3 (2014) 90-94.

[15] M. Rusop, X. M. Tian, S. M. Mominuzzaman, T. Soga, T. Jimbo, and M. Umeno,“Photoelectrical properties of pulsedlaser deposited boron doped p-carbon/n-silicon and phosphorous doped n-carbon/p-silicon heterojunction solar cells,” Solar Energy, vol. 78, pp. 406-415, 2005.

[16] Kalaga M. Krishna, Y. Nukaya, T Soga, T. Jimbo, M. Umeno, “ Solar cells based on carbon thin films,” Solar Energy Materials and Solar Cells, vol. 65, pp. 163-170, 2001.

[17] K. L. Narayanan, O. Geotzberger, A. Khan, N. Kojima, and M. Yamaguchi, "Boron ion implantation effect in C60 films," Solar Energy Materials & Solar Cells, vol. 65, pp. 329-35, 2001.

[18] S. Bhattacharyya, C. Vallee, C. Cardinaud, O. Chauvet, and G. Turban, " Studies on structural properties of amorphous nitrogenated carbon films from electron energy loss, ellipsometry, auger electron spectroscopy, and electron-spin resonance," J. appli. Phys.. vol. 85, pp. 2162-2169, 1999.

[19] Hiroki Akasaka, Takatoshi Yamada, and Naoto Ohtake, "Effect of Film Structure on Field Emission Properties of Nitrogen Doped Hydrogenated Amorphous Carbon Films," Journal In Diamond & Related Materials, vol. 18, pp. 423-425, 2009.

[20] M. Rusop, S. M. Mominuzzaman, T. Soga, T. Jimbo, M. Umeno, " Effect of substrate temperature on growth of nitrogen incorporated camphoric carbon films by pused laser ablation," International Journal Modern Physics B, vol. 16, pp. 866-870, 2002.