Electronic Conduction Processes in Amorphous Silicon-Carbon Alloy (a-Si:C:H) Thin Films Prepared by RF Magnetron Sputtering

Lau Chen Chen, B. Ismail, ***R. Muhammad*** *and M. N. Yusuf*
Department of Physics, Faculty of Science
Universiti Teknologi Malaysia, 81310 Skudai, Johor

Abstract

Thin films of amorphous silicon-carbon alloy (a-Si:C:H) were prepared by RF magnetron sputtering onto glass substrates maintained at room temperature. Aluminium (Al) electrodes were provided by thermal evaporation to form sandwich structures. The amorphous state of the films was confirmed by XRD analysis and their constituent was checked using FT-IR System-Spectrum machine. Capacitance measurements indicate that the films have a relative permittivity value of 6.93. A detailed study of dark current-voltage (*I-V*) characteristics clearly reveals the conduction mechanism as ohmic at low voltages and that of trap limited space charge limited conduction (SCLC) at higher voltages. Further evidence for space-charge-limited conduction process is provided by a linear dependence of log I on log d, log V_x on log d and log V_{TFL} on log d. The trap density is found in the order of 10^{21} m^{-3}.

Keywords: a-Si:C:H thin film; *I-V* characteristics; SCLC mechanism; localized traps.

I. Introduction

Amorphous silicon-carbon alloy film was first successfully deposited using the glow discharge technique by Anderson and Spear [1]. Since then, intense research on a-Si:C:H films have been carried out due to their potential applications in electronics and optical devices. This includes using the material as transmitting window layer in photovoltaic solar cells [12], in light emitting diodes [8] and as the top blocking layer in amorphous-silicon-based xerography coating [9] due to their wide and variable optical band gap properties. It also provides an interesting system for the fundamental study of amorphous material with different degrees of disorder [1].

The disorder materials, particularly amorphous semiconductors, covering a wide range of compositions and with interesting electrical properties, have been studied in greater detail [4,10,11]. Study on I-V characteristics is a matter of importance in analysis of conduction mechanism in films. A non-linear curve often may reveal the existence of different kinds of conduction mechanisms. Mechanisms, which might explain one or more of the observed characteristics, are ionic, schottky, Poole-Frenkel and space-charge-limited conduction depending on the film growth and experimental ambient conditions.

In this paper, the results of a detailed study on the electrical properties of a-Si:C:H will be presented. We will present and analyze the *I-V* results and suggest the prevalent conduction mechanism in rf sputtered a-Si:C:H films.

II. Experimental

Polished microscope glass slides which were used as substrates, were cleaned by ultrasonically in chromic acid and then in distilled water. The masks, which were used to obtain the desired patterns, were cleaned thoroughly with soap, rinsed in distilled water and then ultrasonic agitation for 10 minutes in distilled water. After the cleaning, the slides and masks were transferred to the chamber of an Edwards, 306 coater, where the 100 nm thick aluminium films were evaporated from tungsten filament in the chamber as base and top electrode. Samples of amorphous hydrogenated silicon-carbon alloy films (a-Si:C:H) were deposited at room temperature using a Neva RF magnetron sputtering system. The target used was 99.999% polysilicon in ambient of 20% CH_4: 80% Argon with the latter's pressure was maintained at about 0.1 torr. The thickness of the films measured using a $Dektak^3$ surface profiler varied from 397 nm to 1107 nm. The effective area of each sandwiched structure was 4 x $10^{-6} m^2$.

The dark current–voltage (*I-V*) measurements of the Al/a-Si:C:H/Al sandwich structures were carried out at room temperature in a vacuum chamber using Keithley 6517a electrometer. Capacitance was measured at a standard frequency of 1KHz using an Agilent 4192A LF Impedance Analyzer.

III. Results and Discussion

Figure 1 shows the dependence of film capacitance *C* on a-Si:C:H thickness d at 1 KHz. The relationship between the two quantities is clearly linear and may be expressed in terms of a parallel-plate capacitance,

$$C = \frac{\varepsilon_r \varepsilon_o A}{d} \qquad (1)$$

where ε_r is the dielectric constant of the film relative to the permittivity of free space, ε_o and *A* is the contact area. The slope of the graph is $\varepsilon_r\varepsilon_o A$ from which a permittivity value of 6.14 x 10^{-11} Fm^{-1} may be derived (relative permittivity ε_r = 6.93). Recently, several workers have reported that a-Si:C:H films showing Poole-Frenkel effect at high-frequency (1 MHz). For this frequency, Chew, K. *et al.* [2] has reported a value of ε_r of 4.02 for films grown with ECR-CVD while ε_r in the range of 2.71 – 3.84 at 1 MHz with variation of CH_4 ratio obtained by Li, X.M. *et al.* [7] for films grown using PECVD.

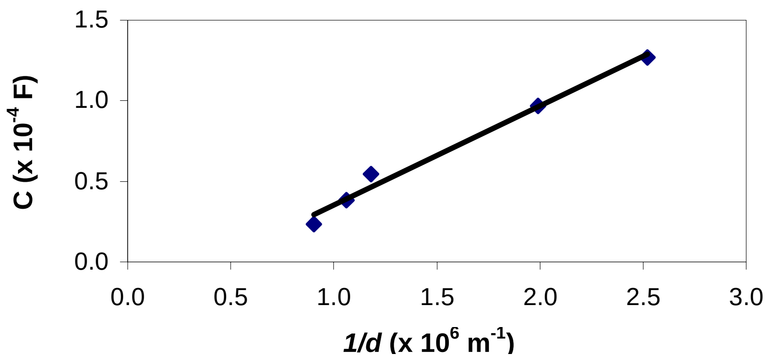

Figure 1: Dependence of film capacitance on a-Si:C:H thickness at 1KHz. A value of ε_r = 6.93 is consistent with the data.

A typical result of the *I-V* characteristics of Al/a-Si:C:H/Al samples with different thicknesses (plotted on a log-log scale) is shown in Figure 2. It is observed that, the current flowing through the samples decreases with increase in film thickness. However, the nature of the curves remains the same. There are three distinct regions for each characteristic having different slopes, which implies that the I-V relation is of the type $I \propto V^n$ where *n* is the slope of the curve. At very low voltages (curve AB), the slope is equal to unity ($n \approx 1$) indicating that the conduction mechanism is ohmic in the first region. In region 2 (curve BC), the slope is found to be nearly equal to 2, i.e. a square-law region. It clearly suggests that the conduction in this region is essentially dominated by space charge limited conduction (SCLC) mechanism. In the third region (curve CD), the slope increases to0 much larger than 2, indicating that the current-voltage relation follows a much higher power law.

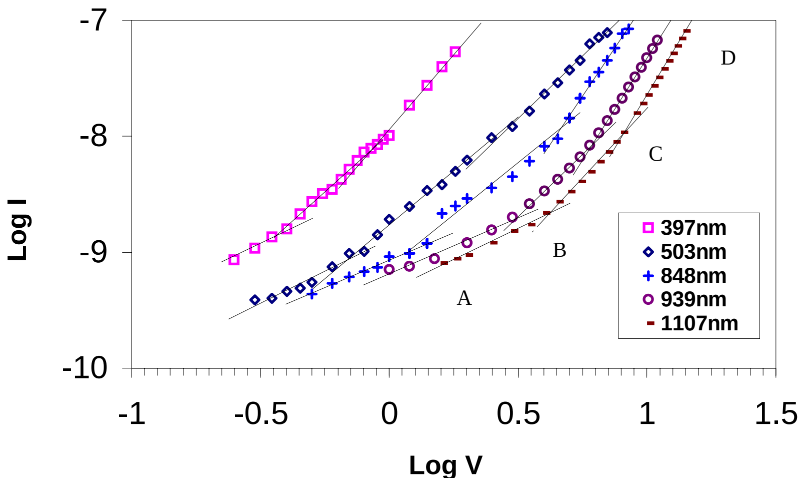

Figure 2: Log I-log V characteristic of the a-Si:C:H with different film thicknesses at room temperature (298K)

In the ohmic region the current density may be described by

$$J = n_o e \mu \frac{V}{d} \qquad (2)$$

where n_o is the concentration of electrons in the conduction band due to thermal excitation from centers in the band gap, *e* is the electronic charge, μ is the electron mobility and *d* is the film thickness. Hole transport is assumed to be negligible.

According to Lampert, M.A. and Mark, P. [6], the current density in the second region is given by,

$$J = \frac{9}{8}\theta \varepsilon_r \varepsilon_o \frac{V^2}{d^3} \qquad (3)$$

where θ is the ratio of free charge carriers to the trapped carriers, ε_r is the dielectric constant of the material, ε_o is the permittivity of free space, *V* is applied voltage and *d* is the thickness of the film. Equation (3) suggests that to establish the existence of SCLC a plot of log *I* versus log *d* should exhibit a straight line with slope equal to –3. Figure 3 shows log *I*-log *d* curve generated using data Figure 2 corresponding to a constant voltage bias of 2.5 V. It is seen that this plot is a straight line with slope equal to –3.12.

Figure 2 shows two distinct cross-over voltages, V_x representing transition clearly from ohmic conduction to the SCLC with traps and the V_{TFL}, which is transition from SCLC with traps to the trap filling level. This implies that the traps, in the present case are situated at energy level higher than that of the fermi level of the material. V_x and V_{TFL} are expected to be dependence on the film growth conditions. It is also noted from Figure 2 that V_x and V_{TFL} increases with film thickness. The transition voltages, V_x and V_{TFL} are given by Lampert, M.A. [5],

$$V_x = \frac{8en_o d^2}{9\theta} \qquad (4)$$

$$V_{TFL} = \frac{eN_t d^2}{2\varepsilon_r \varepsilon_o} \qquad (5)$$

where N_t is the density of the traps. Equation (4) and (5) suggests that the plots of log V_x versus log *d* and log V_{TFL} versus log *d* should yield straight lines with slope 2. In Figure 4, curve A represents log V_x – log *d* while curve B represents log V_{TFL} versus log *d*. The slopes of the curves A and B are 2.22 and 1.88 respectively, which provide additional support for the existence of SCLC. Equation (5) enables us to evaluate the density of the traps, N_t for various film thicknesses. These values are shown in Table 1. It is seen that the trap density of the order of 10^{21} m^{-3} exists for the present films. These values are in close agreement with results obtained by Kalita, P.K. *et al* [4] and Ismail, B.B. and Gould, R.D. [3] for their CdSe thin films.

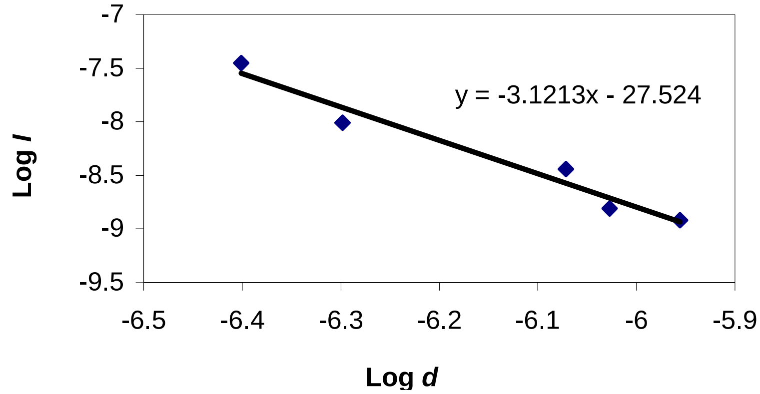

Figure 3: Log *I*-log *d* characteristics of a-Si:C:H films in the square law region at room temperature (298 K).

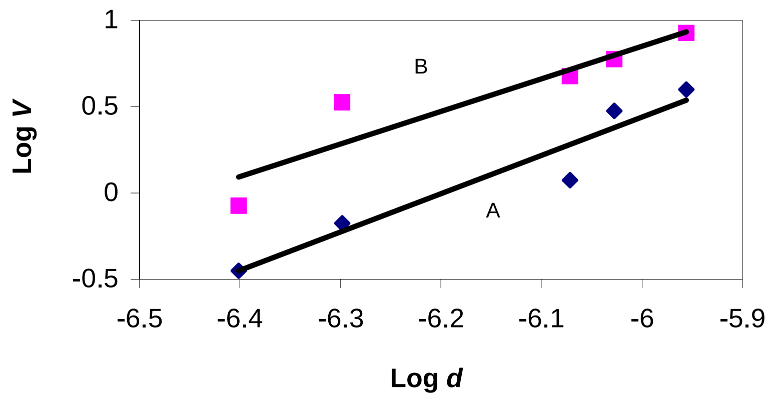

Figure 4: Curve A is log V_x – log *d* characteristics while curve B is log V_{TFL} – log *d* characteristics of a-Si:C:H films at room temperature (298K).

Table 1: Variation of trap density with thickness at room temperature (298K)

Thickness (nm)	N_t (m^{-3}) X 10^{21}
397	4.10
503	11.02
848	5.05
939	5.19
1107	5.27

IV. Summary and Conclusion

An analysis of film capacitance as a function of thickness yields a relative permittivity value of 6.93. The dark *I-V* characteristics of a-Si:C:H thin films showed ohmic conduction at low voltages and space-charge-limited conduction at high voltages which progressively become high power law conduction as the voltage increases further. Calculations show that the trap density is found in the order of 10^{21} m^{-3}.

Acknowledgements

L.C.C wishes to thanks the National Science Foundation Malaysia for its support during this work.

References

[1] Anderson, D. A. and Spear, W. E. (1976). Electrical and Optical Properties of Amorphous Silicon Carbide, Silicon Nitride and Germanium Carbide Prepared by the Glow Discharge Technique. *Philosophical Magazine.* 35: 1-16.

[2] Chew, K., Rusli, Yu, M.B., Yoon, S.F., Ligatchev, V. and Ahn, J. Density of Gap States in Amorphous Hydrogenated Silicon Carbide Determined Using High-Frequency Capcitance-voltage Measurement Technique. *Diamond and Related Materials.* 10: 1273-1277.

[3] Ismail, B.B and Gould, R.D. (1989). Structural and Electronic Properties of Evaporated Thin Films of Cadmium Telluride. Physica Status Solidi. 115: 237-245.

[4] Kalita, P.K., Sarma, B.K. and Das, H.L. (2003). Space Charge Limited Conduction in CdSe Thin Films. *Bulletin Materials Science.* 26(6): 613-617.

[5] Lampert, M.A. (1964). Volume-Controlled Current Injection in Insulators. *Reports on Progress in Physics.* 27: 329-367.

[6] Lampert, M.A. and Mark, P. (1970). Current Injection in Solids. New York and London: Academic Press.

[7] Li, X.M., Wong, T.K.S., Rusli and Yang, D.J. (2003). Structural and Electronic Properties of Low Dielectric Constant Carbon Rich Amorphous Silicon Carbide. *Diamond and Related Materials.* 12: 963-967.

[8] Morimoto, A., Miura, T., Kumeda, M. and Shimizu, T. (1982). Defects in Hydrogenated Amorphous Silicon-Carbon Alloy Films Prepared by Glow Discharge Decomposition and Sputtering. *Journal of Applied Physics.* 53(11): 7299-7305.

[9] Morimoto, A., Miura, T., Kumeda, M. and Shimizu, T. (1982). Glow Discharge a-$Si_{1-x}C_x$:H Films Studied by ESR and IR Measurements. *Japanese Journal of Applied Physics.* 21(2): L119-L121.

[10] Mukolu, A.I. (2001). Space Charge Limited Current at High Fields in Al-Ge-Al Surface Barrier Devices. *Turk Journal of Physics.* 25: 385-392.

[11] Wagle, S. and Shirodkar, V. (2000). Space-Charge-Limited Conduction in Thin Film Al/$Sb_2Pb_1Se_7$/Al Devices. *Brazillioun Journal of Physics.* 30(2): 1-13.

[12] Tawada, Y., Tsuge, K., Kondo, M., Okamoto, H. and Hamakawa, Y. (1982). Properties and Structure of a-SiC:H for High-Effiency a-Si Solar cell. *Journal of Applied Physics.* 53(7): 5273-5281.