

CARBON IN LIGHT ENERGY CONVERSION DEVICE: OPTO-ELECTRICAL PROPERTIES

K. M. Krishna^{a)}, K. Hagimoto^{b)}, S. M. Mominuzzaman^{c)}, T. Soga^{b)}, T. Jimbo^{b)} and M. Umeno^{a, c)}

^{a)}Research Center for Micro-Structure Devices, ^{b)}Department of Environmental Technology and Urban Planning, ^{c)}Department of Electrical and Computer Engineering, Nagoya Institute of Technology, Gokiso-cho, Showa-ku, Nagoya 466 8555, JAPAN

Introduction

Efforts toward carbon, as an electronic material, for optoelectrical devices are limited till date [1, 2]. Doping of carbon has been attempted by a few authors and successful n-type doping has been achieved through dopants such as nitrogen and phosphorus. Here, we present the semiconducting properties of ion beam sputtered phosphorus (P) doped amorphous carbon thin films and photoelectrical characteristics of n-carbon/p-silicon heterojunction solar cells.

Experimental

Camphor, a natural precursor, has been used as a source of carbon soot. The details of soot generation and thin film deposition by ion beam sputtering have been reported elsewhere [3]. Thin films of P-doped carbon have been deposited on quartz and p-Si, with different substrate temperatures (RT-300°C) and sputtering powers (20-30 W). Structural, optical and electrical properties of the films have been studied through standard experimental characterization techniques. Solar cells of configuration Au/n-C/p-Si/Au have been fabricated and their photoresponse characteristics have been studied under AM0 and 1 SUN conditions. The contacts of the gold electrode to the p-Si and to the n-C, both showed ohmic characteristic. The surface area of the gold electrode was about 0.25 cm² and served as an active area for the cell of above configuration.

Results and Discussion

Raman analyses indicate the amorphous nature of the carbon thin films. The optical absorption derived from the uv-visible reflectance/transmittance measurements, indicate that the carbon film is a semiconductor with the absorption coefficient of the order of 10⁴ - 10⁵ cm⁻¹ for the measured photon energy range (1-4 eV). The optical gap has been increased with increasing sputtering power and decreasing substrate temperature, as seen from Figs. 1 and 2, owing to the structural changes as also envisaged by Raman scattering through the evolution of D and G bands.

Optical gap of 1 eV has been obtained for the films deposited at room temperature (RT) and with 30 W sputtering power.

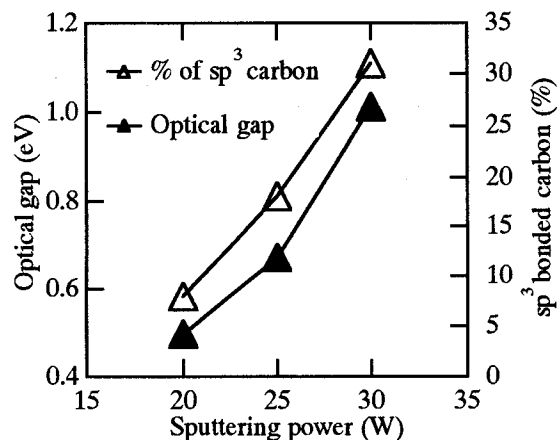


Figure 1. Optical gap and % of sp³ bonded carbon as a function of sputtering power. The films are deposited at room temperature.

The C (1s) x-ray photoelectron spectroscopy (XPS) analyses of the films indicate the presence of sp³ bonded carbons as high as 30% (Figs. 1 and 2), responsible for the optical gap (1 eV) and the semiconducting nature of the

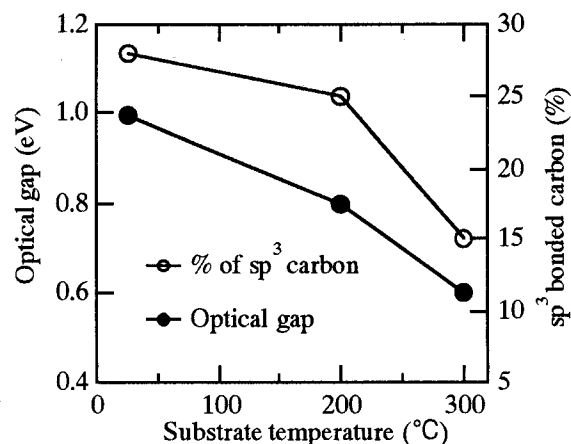


Figure 2. Optical gap and % of sp³ bonded carbon as a function of substrate temperature. The films are deposited with 30 W sputtering power.

carbon films. It is clear from these figures that the percentage of sp^3 bonded carbon increases upon increasing the sputtering power and decreasing the substrate temperature which is further in agreement with the behaviour of the optical gap.

The electrical conductivity of the films has found to increase with the measurement temperature, suggesting the semiconducting nature of the carbon thin films [3]. The conductivity has been increased upon doping by two orders and found to be in the range of 10^{-1} to $10 \Omega^{-1} \text{cm}^{-1}$ depending upon the amount of doping. These results are in agreement with Raman, uv-visible, XPS analyses. The hot probe technique indicates the n-type (10^{18}cm^{-3}) nature of the P-doped carbon thin films.

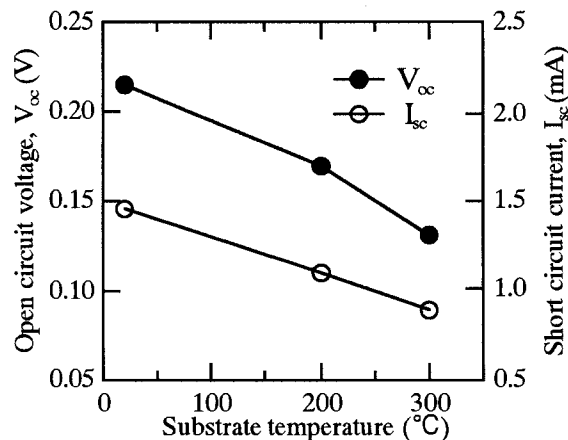


Figure 3. Substrate temperature dependence of the V_{oc} and I_{sc} of the n-C/p-Si solar cell.

The current-voltage characteristics of the n-C/p-Si photovoltaic solar cells, without light irradiation, displayed a rectifying characteristic. Figures 3 and 4 show the substrate temperature dependence of open circuit voltage (V_{oc}), short circuit current (I_{sc}) and photoconversion efficiency (η) for the cell of above

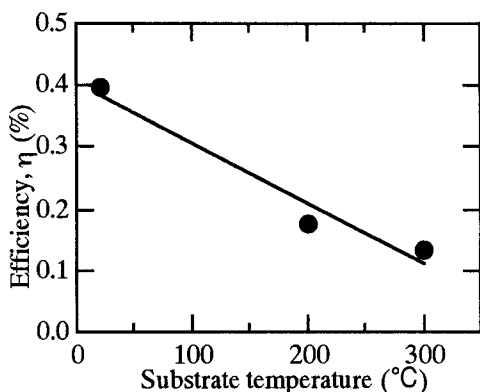


Figure 4. Substrate temperature dependence of the photoconversion efficiency of n-C/p-Si solar cell.

configuration and for the samples sputtered with 20 W power, under AM0 and 1 SUN illumination conditions. Both the V_{oc} and I_{sc} are decreased along with the η with increasing substrate temperature, due to the decrease in the band gap thus making the cell photoresponsive to far IR. The behaviour may also be attributed to the enhancement of defect structure due to the presence of dangling states, owing to the amorphous nature of carbon.

It is found that the photovoltaic characteristics are improved with increasing sputtering power and decreasing substrate temperature. Furthermore, as the thickness of the carbon film increases, the V_{oc} and I_{sc} are improved with increasing η . The photovoltaic solar cell of film thickness 100 nm, deposited with 30 W sputtering power and at RT, reveals I_{sc} of 2.19 mA, V_{oc} of 0.15 V and an efficiency of 0.44 %. These values are improved further for the film annealed at 800 °C for 10 min in N_2 ambient, and reveals I_{sc} of 4.60 mA, V_{oc} of 0.48 V and photoconversion efficiency of 2.07% under the same illumination conditions [4].

Conclusions

A systematic study of the deposition of carbon thin films by ion beam sputtering through changing the substrate temperature, sputtering power and film thickness has been investigated to tailor the band gap of carbon. High sputtering power and low substrate temperature yield better photoresponsive films of amorphous carbon. Study on p-type doping of carbon is in progress in order to realize a complete carbon based photovoltaic solar cell.

References

1. Veerasamy VS, Amaratunga GAJ, Park JS, MacKenzie HS, Milne WI. IEEE Trans Electr Dev 1995;42(4):577-585.
2. Yu HA, Kaneko T, Otani S, Sasaki Y, Yoshimura Y. Carbon 1998;36(1-2):137-143.
3. Mominuzzaman SM, Krishna KM, Soga T, Jimbo T, Umeno M. Jpn J Appl Phys 1999;38(2A):658-663.
4. Krishna KM, Soga T, Jimbo T, Umeno M. Carbon 1999;37(3):531-533.

Acknowledgments

This work was partly supported by the Japan Society for Promotion of Science under the program "Research for Future". KMK is grateful to the Marubun Research Promotion Foundation for the young scientist research grant. We are also grateful to the Ministry of Education, Science, Sports and Culture.