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Diamond like carbon (DLC) thin films: Preparation and Characterization

Sekhar C. Ray^{1,a}, W. Mbiombi^{2,b} and P. Papakonstantinou^{3,c}

¹Department of Physics, College of Science, Engineering and Technology, University of South Africa, Private Bag X6, Florida, 1710, Science Campus, Christiaan de Wet and Pioneer Avenue, Florida Park, Johannesburg, South Africa.

²School of Physics, University of the Witwatersrand, Private Bag 3, WITS 2050, Johannesburg, South Africa

³Nanotechnology and Integrated Bio-Engineering Centre, University of Ulster, Shore road, Newtownabbey, BT37 0QB, United Kingdom

^ae-mail: Raysc@unisa.ac.za, ^be-mail: Wilfred.Mbiombi@students.wits.ac.za,
^ce-mail: p.papakonstantinou@ulster.ac.uk

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Abstract. Diamond-like carbon (DLC) thin films are prepared using plasma enhanced chemical vapour deposition (PECVD) process at different bias voltage. We have studied their microstructural and electrical properties using Raman spectroscopy and current (I) – voltage (V) relationships. Electrical conductivity is gradually decreases with bias voltage as the films are becoming more and more diamond like carbon as observed from Raman spectroscopy results. Raman spectroscopy result shows that the I_D/I_G ratio gradually decreases indicating formation of more diamond like carbon films that responsible for the decrease of conductivity of the films. The full width half maximum of G peak increase with increase the bias voltage indicating the ring-like sp^2 transforms to sp^2 chains and raises the amount of sp^3 -chains. The structural disorder arises from the bond angle and bond length distortions in amorphous carbon films. Thus the structural disorder and mechanical properties such as hardness and elastic modulus increase with bias voltage.

Introduction

Since last few decades, much attention has focused on diamond-like carbon (DLC) thin films which are very promising materials for electronic, optical, and wear protection applications due to their versatile mechanical, electrical, optical and biocompatible properties [1]-[9]. The DLC films contain significant fractions of sp^3 type carbon bonds, giving them attractive physical and mechanical properties, some similar to a certain extent to diamond. The DLCs are chemical inertness, high hardness, low friction and high thermal conductivity. Hence, by varying the proportion of sp^3/sp^2 ratio, one can modify the mechanical, electrical and optical properties of DLC films. A large number of deposition processes are already established such as ion beam [10]; laser ablation [11], sputtering [12] and chemical vapor deposition (CVD) [13] employ energetic species to deposit DLC films. But the plasma enhanced chemical vapour deposition (PECVD) process is more superior to any other process.

In this work, we report the DLC films prepared by the RF-PECVD technique at different bias voltage and studied their microstructural properties, which are correlated with electrical properties.

Experimental Details

The DLC films were prepared using acetylene (20 sccm) as a carbon precursor by the plasma enhanced CVD (PECVD) method at different bias voltage in presence of Ar^+ atmosphere (10 sccm) [14]. The microstructures of DLC are studied Raman spectroscopy excited by 488 nm laser light. The voltage (V) and current (I) data were measured using 4140Bp instruments.

Results and Discussion

The Raman spectra of DLC thin films obtained at 488 nm of LASER excitation energy within the range of 1000 - 1800 cm^{-1} . A wide peak around $\sim 950 \text{ cm}^{-1}$ is the second-order Raman peak of the silicon substrate (not shown in figure). The appearance of this peak is a measure of the transparency of the films near the wavelength of 488 nm. The Raman spectra of disordered graphite show two modes, the G-peak around 1580–1600 cm^{-1} and the D-peak around 1350 cm^{-1} , usually assigned to zone centre phonons of E_{2g} symmetry and K -point phonons of A_{1g} symmetry, respectively [15].

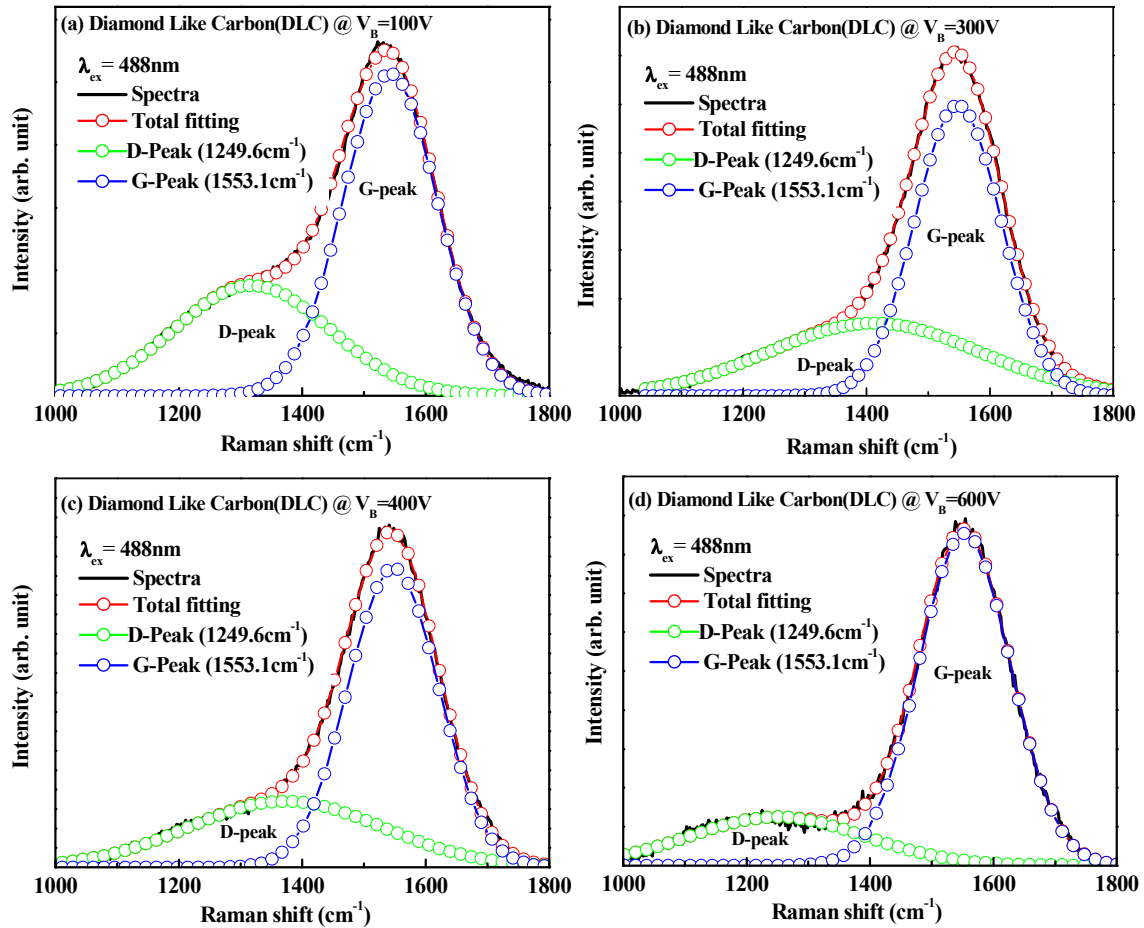


Fig. 1 Deconvoluted Raman spectra of diamond like carbon (DLC) thin films. (a) $V_b = 100 \text{ V}$, (b) $V_b = 300 \text{ V}$, (c) $V_b = 400$ and (d) $V_b = 600$

It is noted that the DLC films are similar thickness and is $\sim 150 \pm 15 \text{ nm}$. However, to obtain the clear evidence for the presence of D-peak and G-peak in all spectrums, we have deconvoluted all Raman spectrums into distinct D-peak and G-peak with two Gaussian's peak shown in Fig.1. We obtained the peak width W_D (353-279 cm^{-1}) and W_G (136-149) and corresponding I_D/I_G ratios (0.67 – 0.27). The results show that the W_G increases (W_D decrease) and I_D/I_G ratio decreases with increase of bias voltage during deposition process that indicates the increase of sp^3 -fraction in the DLC film structure forming more diamond like carbon films. The precursor gas C_2H_2 is used in this PECVD process and it has a significant effect for the formation of DLC thin films as well as their properties. It is well known that the acetylene (C_2H_2) has a small H/C ratio that affects the resulting film. The result also shows that the G peak positions of DLC films are gradually shifted at higher energy level (from 1544 cm^{-1} to 1553 cm^{-1}), when bias voltage (V_b) is increases gradually that reveals the formation of higher sp^3 -content. This parameter is proportional to the mechanical properties and Csp^3 - Csp^3 bonding content of the film. It means that when the bias voltage increases during deposition process then some sp^2 -C is converted to sp^3 -C that becoming stronger / harder films. The I_D/I_G ratios are related with the sp^2 sites configuration i.e. topological disorder. The decrease of

ratios indicate that the sp^2 decrease in rings and rise in chains. The increase sp^3 -content correlates with the hardness of the films. We are in agreement with the work done by Tamor and Vassel [16] by using Raman spectroscopy with visible excitation wavelength 514 nm of a-C:H.

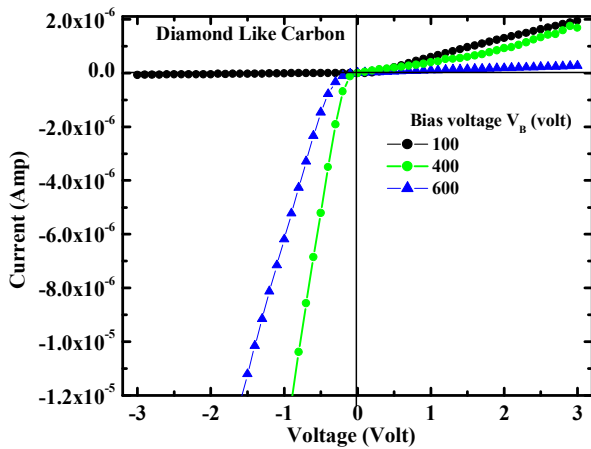


Fig. 2 Current-Voltage characteristics of Au/DLC/Au structure for various bias voltage deposited DLC thin films (V vs I)

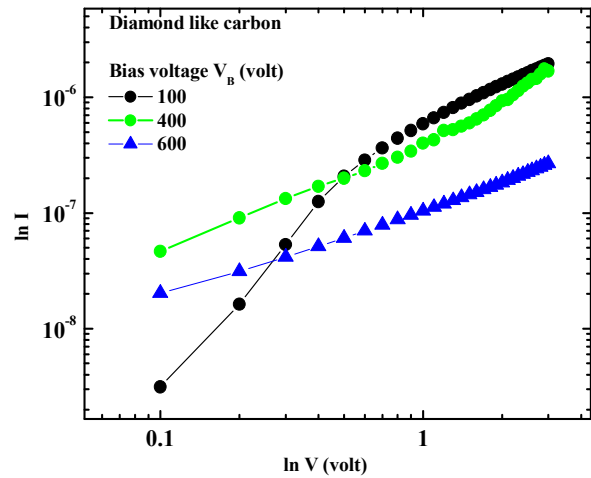


Fig. 3 Current-Voltage characteristics of Au/DLC/Au structure for various bias voltage deposited DLC thin films [$\ln(V)$ vs $\ln(I)$]

The voltage (V) – current (I) relationship of DLC films is presented in different ways as shown in Fig.2-3. The electrical properties of diamond-like carbon films can vary from that of a semimetal. The electrical properties of diamond-like carbon have been modelled assuming a band structure consisting of only a mobility gap, where carriers residing in gap states are localized [17]. All the above figures clearly indicates that the DLC films becoming more and more sp^3 -rich films when biasing voltage is increases gradually during deposition process and hence the conductivity is decreases gradually. We observed in Raman spectroscopy results that I_D/I_G ratio decreases with increases of bias voltage i.e. increasing sp^3 -content and hence decrease the conductivity is well agreed with this V-I results.

Conclusion

The diamond-like carbon films enables the adjustment of their properties over large value ranges; however, their disordered structure leads to poor semiconducting properties. The films are being used as wear and corrosion protective coatings of magnetic mechanical, electrical and optical devices, and for fabrication of optical components. They have a strong potential for application in passive electrical devices. A large effort is being invested in investigating the suitability of DLC for use as active elements in electrical devices, such as field emission displays.

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