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Preparation of diamond like carbon thin films above room temperature and their properties

Hare Ram Aryal [a,*], Sudip Adhikari [b], Dilip Chandra Ghimire [a], Golap Kalita [a], Masayoshi Umeno [b]

[a] Department of Electrical and Electronic Engineering, Chubu University, 1200 Matsumoto-cho, Kasugai 487-8501, Japan
[b] Department of Electronics and Information Engineering, Chubu University, 1200 Matsumoto-cho, Kasugai 487-8501, Japan

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Abstract

Diamond like carbon (DLC) thin films were deposited on p-type silicon (*p*-Si), quartz and ITO substrates by microwave (MW) surface-wave plasma (SWP) chemical vapor deposition (CVD) at different substrate temperatures (RT ~300 °C). Argon (Ar: 200 sccm) was used as carrier gas while acetylene (C_2H_2: 20 sccm) and nitrogen (N: 5 sccm) were used as plasma source. Analytical methods such as X-ray photoelectron spectroscopy (XPS), FT-IR and UV–visible spectroscopy were employed to investigate the structural and optical properties of the DLC thin films respectively. FT-IR spectra show the structural modification of the DLC thin films with substrate temperatures showing the distinct peak around 3350 cm^{-1} wave number; which may corresponds to the sp^2 C–H bond. Tauc optical gap and film thickness both decreased with increasing substrate temperature. The peaks of XPS core level C 1 s spectra of the DLC thin films shifted towards lower binding energy with substrate temperature. We also got the small photoconductivity action of the film deposited at 300 °C on ITO substrate.

Keywords: DLC; Surface-wave plasma; Substrate temperature; FT-IR

1. Introduction

Diamond like carbon (DLC) thin film is an interesting material and has been widely investigated in the past three decades. DLC materials are becoming increasingly attentive material in many forms of industrial applications such as coating and as well as semi-conductor devices [1–3]. The term DLC covers a range of materials that can vary from those similar to graphite to those approaching to diamond. It could be deposited conveniently on room temperature. This material has been shown to behave as semi-conducting material [4–10], which is able to accept dopants, shows photoconductivity and suitable for optoelectronic devices. However, some problems such as low photo-conversion efficiency due to sp^2/sp^3 bonding structure and difficulties in controlling the conduction type, carrier concentration, etc. still exist. It is known that deposition parameters affect the formation of crystalline phase and structure of DLC thin films. Since the microstructure characteristics of DLC thin films is strongly dependent on the deposition conditions; in this study, we discuss the optical, structural and I–V characteristic of DLC thin films deposited by microwave (MW) surface-wave plasma (SWP) CVD at different substrate temperatures. The objective of this study is to analyze the influence of substrate temperature on the properties of DLC thin films in order to optimize the properties of the films for its possible application on photovoltaic energy conversion.

2. Film deposition and characterizations

We used the MW SWP CVD system for the deposition of DLC thin films. The detail of the system is described elsewhere [11–16]. DLC thin films were deposited at various substrate temperatures ranging from room temperature (60 °C) to 300 °C on p-type silicon (*p*-Si), quartz (Qz) and ITO substrates. The CVD chamber was evacuated to a base pressure at approximately 9.0×10^{-4} Pa using turbo molecular pumps. Before deposition, the substrates were cleaned beforehand by acetone and methanol for each at 5 min in an ultrasonic bath and only Si substrates were

* Corresponding author. Tel.: +81 568 51 9244; fax: +81 568 51 1478.
E-mail address: aryal_hareram@yahoo.com (H.R. Aryal).

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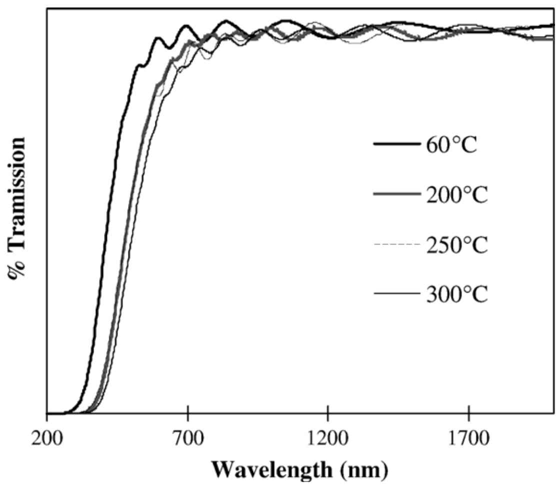

Fig. 1. UV/VIS/NIR transmission spectra of DLC thin films deposited at different substrate temperatures.

etched with diluted hydrofluoric acid (10%) in order to remove the resistive native oxide layer over the substrates surface. After cleaning, the substrates were dried by nitrogen (N) gas and placed quickly on the stage inside the chamber. For film deposition, we used Ar as carrier gas and acetylene (C_2H_2) and N as plasma sources. The flow rate of Ar, C_2H_2 and N were maintained fixed as 200 sccm, 20 sccm and 5 sccm respectively for the series of experiments. The launched microwave power was typically maintained at 550 W throughout the deposition (30 min) of DLC thin films for all experiments.

JASCO V-570 UV/VIS/NIR spectrophotometer was used to investigate the optical properties of the films. While Nanopics 2100/NPX200 was used to measure the film thickness. The X-ray photoelectron spectroscopy (XPS) was measured by ESCA-3300 KM Electron Spectrometer utilizing an AlKα ($h\nu$= 1486.6 eV) radiation as an X-ray source, under high vacuum conditions of about 10^{-7} Pa. While FT-IR spectroscopy measurements were performed in order to study the structural properties of the DLC thin films. Solar simulator (JASCO SS-200 W) was employed to characterize photovoltaic properties. Xenon lamp is used as the light source under AM 1.5 illumination condition (100 mW/cm^2) at room temperature.

3. Results and discussion

To study the optical characteristics of DLC thin films, reflectance and transmittance of Qz substrates were measured by UV/VIS/NIR spectroscopy in the range of 100–2000 nm. Fig. 1 shows the UV/VIS/NIR transmission spectra of DLC thin films

Table 1
Film thickness and band gap of DLC thin films deposited on Qz substrate at various substrate temperatures

Deposition temperature	Thickness (nm)	Band gap (eV)
60 °C	1434	2.4
200 °C	1229	2.1
250 °C	902	2.1
300 °C	570	1.9

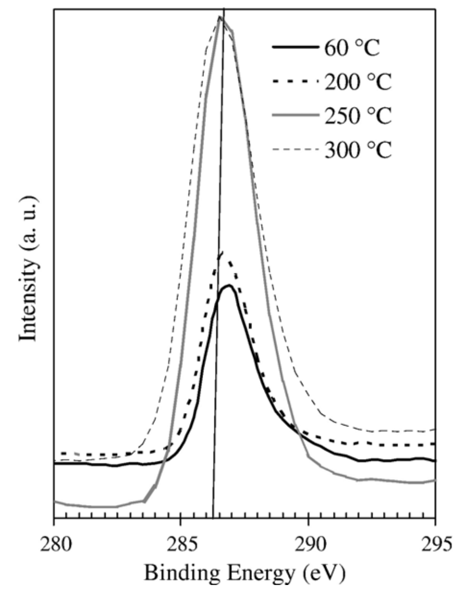

Fig. 2. Core level XPS spectra of C 1 S of DLC thin films deposited at various substrate temperatures.

deposited at various substrate temperatures. The transmission spectrum of the films deposited at 300 °C shows the lowest % transmission in the visible wavelength region. While the % transmission obtained from the films deposited at 200 and 250 °C almost overlap in the visible region and the film deposited at room temperature shows the highest % transmission. These results may lead to conclude that the DLC thin film prepared at 300 °C substrate temperature has the maximum photon absorbance in the visible region. This behavior is clearly reflected in the optical band gap.

In order to calculate the optical band gap of the films, optical transmission and reflectance were measured by UV/VIS/NIR spectroscopy in the range of 100–2000 nm using Qz substrates. The absorption coefficient (α) was calculated by the spectral reflectance and transmittance, and the film thickness data. Optical band gap was obtained from the extrapolation of the linear part of the curve at $\alpha=0$ by using the Tauc equation: $(\alpha h\nu)^{1/2}=B\,(E_g-h\nu)$; conventionally defined for amorphous

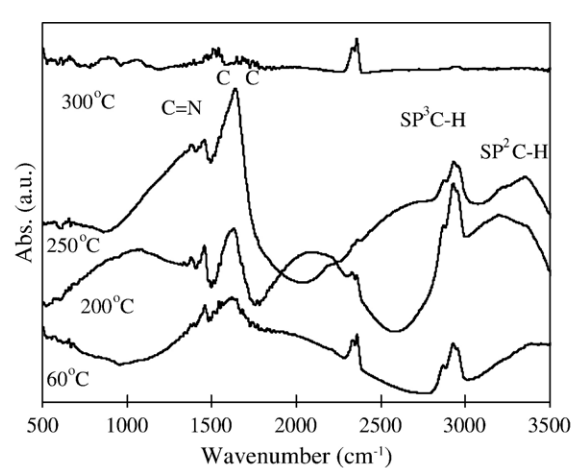

Fig. 3. FT-IR spectra of DLC thin films deposited on various substrate temperatures.