L-11

Aluminum-Doped Diamond Like Carbon as Photovoltaic Cell by Infrared Ray Assist Pulsed Laser Deposition

○Sakae Yonekawa[1] , Kota Takahashi[1], Ken Takayama[2],
Satoshi Kurumi[3] and Kaoru Suzuki[3]

Abstract: To obtain variable band gap, we investigate diamond like carbon (DLC), which has characteristic intermediate between diamond structure and graphite, by controlling sp^2:sp^3 ratio and impurity doping. In this study, Al-doped *p*-type DLC (*p*-DLC : Al) films were deposited on quartz and n-type silicon (*n*-Si) substrates by YAG laser deposition method to research characteristic of *p*-DLC:Al. The quartz and silicon substrates were heated from 373 K to 673 K by infrared lamp. We find out that *p*-DLC / *n*-Si have properties of diode with V-I characteristic. Energy gap of *p*-DLC / *n*-Si decreases with increasing substrate temperature.

1. Introduction

The application of carbon has been attempted in the form of a diamond,[1] or diamond like carbon (DLC) or C_{60}. There are used semiconductors in optoelectronic devices such as photovoltaic cells. We investigate DLC which have intermediate properties between diamonds structure (sp^3) and graphite (sp^2). In general, silicones are used as a material for photovoltaic cell, whose band gap is about 1.2 eV. On the other hand, diamond, which has a wide energy (5.47 eV) band gap, is insulator and graphite is conductor. Thus, band gap of DLC can be controlled according to the sp^2:sp^3 ratio and impurity doping. Consequently, DLC can control a particular absorption wavelength.[2] Many experiments show that B-doped *p*-type DLC (*p*-DLC:B) films have characteristic as a photovoltaic cell. In this paper, we investigate on Al-doped *p*-type DLC (*p*-DLC:Al) films by inferred ray (IR) assist pulse laser deposition (PLD) method. We report optical and electrical characteristic of Al-doped DLC by IR heating.

2. Method

Figure 1 presents deposition of Al-doped DLC by IR assist PLD method. Al-doped DLC (*p*-DLC:Al) films were prepared on silicon (*n*-Si) and quartz substrate by YAG laser (λ : 1064 nm, τ : 20 ns, energy : 200 mJ/pulse, repetition rate : 10 Hz), which was focused on the target balk at incidence angle of 45 degrees.[3] The target bulk was prepared by mixing the graphite (C_n) powder with containing of 1.0 wt% Al. The substrates were cleaned by ultrasonic cleaning using ethanol and wet etching with ammonium fluoride at 343 K. The experiment condition was kept under argon atmosphere of 3×10^{-2} Torr. The laser was irradiated the target bulk for 15 minutes. The silicon (*n*-Si) and quartz substrates were heated from 373 K to 673 K by infrared lamp. Characteristic of *p*-DLC:Al films were studied by Focused Ion Beam (FIB), Raman spectroscopy and X-ray photon electron spectroscopy (XPS). The voltage-current (V-I) characteristics of DLC films were measured by two probe method.

3. Results and Discussion

Figure 2 shows DLC film, which is measured to be apploximately 500 nm for the silicon substrate by FIB. The Raman spectra of the films doposited on quartz substrates are shown in Fig. 3. Raman spectra is containing two peaks which are known for disorder (D) and graphite (G) peaks. D peak derive from disoder of sp^2 hybridized and G peak derive from graphite of sp^2 hybridized. They are typical in DLC films.When the substrates are heated from 373 K to 673 K by infrared lamp, D peak increase as substrate temperatur increade. From this, we conclude that the

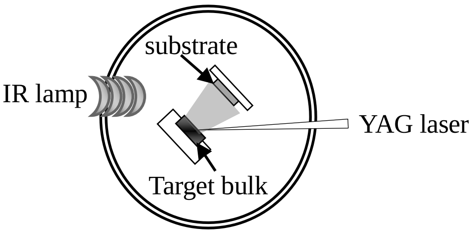

Figure1. Experimental Setup

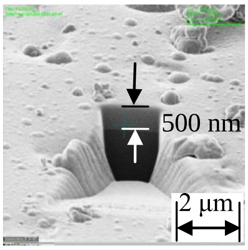

Figure2. surface of DLC film (300 K)

---

[1]Course of Electrical Engineering, [2]Graduate Course of Electrical Engineering,[3]Department of Electrical Engineering,

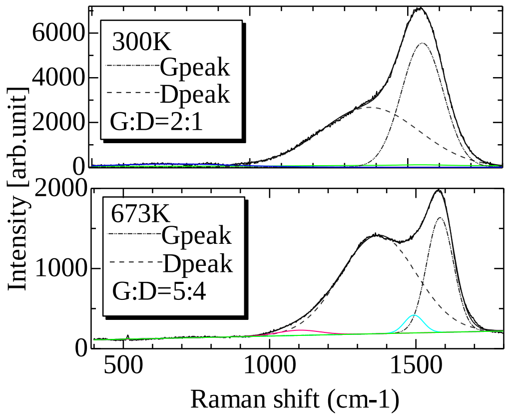

Figure3. Raman spectroscopy

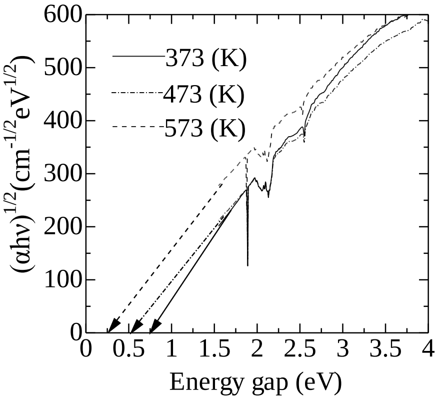

Figure4. Energy band gap

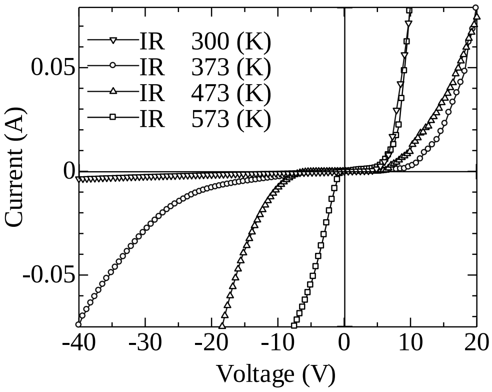

Figure5. V-I characteristic without illumination

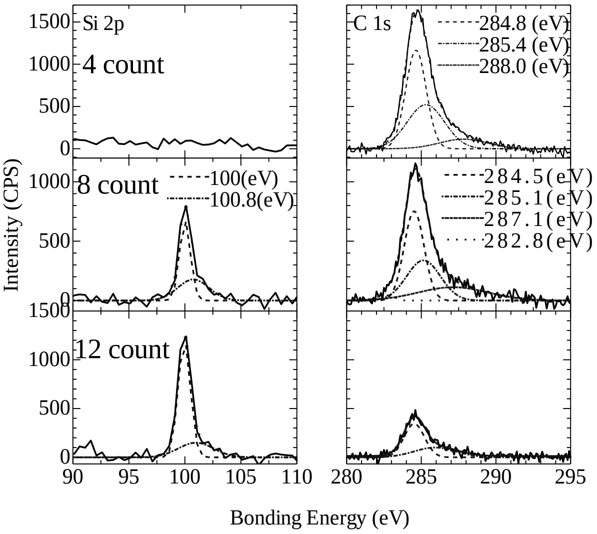

Figure6. X-ray photon electron spectroscopy (473 K)

results are from the carbon's structure that is disordered by heat. It is known that proportion of sp^3 hybrids increases as D/G ratio decreases.[4] Therefore, energy gap decrease with increasing temperature (Fig. 4) because proportion of sp^3 hybrids decrease with increasing substrate temperature. Figure 5 presents the V-I characteristics of *p*-DLC:Al in the dark. Zener breakdown voltage of *p*-DLC / *n*-Si decrease because energy gap decrease with increasing D/G ratio and tunneling probability increased.[5] When substrate temperature is 473 K, the intensity of silicon and carbon are obtained in 8 counts by XPS (Fig.6). And then, result from carbon measurement suggests that carbon combine with silicon, because the peak of C 1s intensity was shifting to the right.

4. Conclusions

We investigate into the optical and electrical characteristics of *p*-DLC:Al of Photovoltaic Cell by Infrared ray Assist PLD method. The *p*-DLC : Al/ *n*-Si is observed for characteristic of semiconductor as photovoltaic cell. D peak increased, energy gap decreased and zener breakdown voltage decrease with increasing substrate temperature. There for, energy gap can decrease by IR heating.

5. Reference

[1] S. Koizumi “*Electrical Properties of P-Doped Diamond films*” J. NEW DIAMOND 13 (1998) L26-L27

[2] K. M. Krishna *et al.* “*Photovoltaic and spectral photoresponse characteristics of n-C/p-C solar cell on a p-silicon substrate*” J. Appl. Phys 77 (2000) L1472

[3] K. Takayama *et al.* “*Ascent of Open Circuit Voltaige on Diamond Like Carbon Photovoltaic Cell by Infrared Heating Assist Pulsed Laser Deposition*” J. COLA 10 (2009) L245

[4] S. Taniguchi *et al.* “Tribological Behavior of High Energy Ion–irradiated Ultra High Molecular Weight Polyethylene” J. Bulletin of TIRI 1(2006) L58-L61

[5] T.Ishida *et al.* “Semiconductor Devices” J. Corona Publishing (1980) L77