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Photoconduction of B-doped ultrananocrystalline diamond/hydrogenated amorphous carbon composite films in metal semiconductor metal geometry

Takanori Hanada, Shinya Ohmagari, and Tsuyoshi Yoshitake

Department of Applied Science for Electronics and Materials, Interdisciplinary Graduate School of Engineering Sciences, Kyushu Univ., Japan

6-1 Kasuga Kouen, Kasuga, Fukuoka, 816-8580, Japan

Abstract

Photoconduction properties of B-doped ultrananocrystalline diamond/hydrogenated amorphous carbon composite (UNCD/a-C:H) films were investigated in metal-semiconductor-metal (MSM) geometry. Cu contacts exhibited the highest contact resistance among examined metals and are suitable for photodetection in MSM geometry because of dark current being suppressed. Photocurrent spectra showed clear responses in the UV and visible wavelength ranges, which might be attributable to photogenerated carriers at UNCD grains and grain boundaries, respectively. We firstly demonstrated the photoconduction of MSM structural B-doped UNCD/a-C:H.

1. Introduction

Semiconducting ultrananocrystalline diamond (UNCD)/hydrogenated amorphous carbon (a-C:H) composite (UNCD/a-C:H) films have a specific film structure, wherein a large number of diamond nanograins are embedded in an a-C:H matrix.[1] They have been extensively studied for their application to nano/micro-electro mechanical systems (NEMS/MEMS),[2,3] optoelectronics devices, and field emission sources,[4] since they possess the following unique features: (a) they possess higher temperature stability than that of diamond-like carbon (DLC); (b) easy growth on foreign solid-state substrates, which is in contrast to the growth of single-or poly-crystalline diamond films;[5] (c) they have unique optical and electrical properties owing to a large number of grain boundaries (GBs).[6,7] Here, the GBs exactly represents interfaces between UNCD grains and those between UNCD grains and an a-C:H matrix. For instance, it has been experimentally reported that the UNCD/a-C:H films prepared by pulsed laser deposition (PLD) possess large optical absorption coefficients of more than 10^5 cm^{-1} in the photon energy range between 3 and 6 eV, which might be due to GBs.[8,9] UNCD/a-C:H provides three band gaps of 1.0, 2.2, and 5.5, which presumably attributable to a-C:H, grain boundaries, and diamond crystallites, respectively.[10] These optical features are profitable for the application of thin-film based photodetectors.

The semiconducting electrical properties of UNCD/a-C:H have received considerable attentions. It has been theoretically predicted that additional energy states are introduced between the bandgap of diamond owing to a large amount of GBs.[11] Doped impurity atoms are preferentially incorporated into GBs.[12] As a result, the production of p-type and n-type conduction with enhanced electrical conductivities is realized by B[13] and N[14] doping, respectively. Thus far, p-type UNCD/a-C:H films were deposited on n-type Si substrates, and it was confirmed that they exhibit typical rectifying behaviors.[15] The UNCD/a-C:H films certainly act as drift layers in heterojunction diodes. Moreover, our recent studies have experimentally proved that UNCD/a-C:H can detect deep-ultraviolet (DUV) light with high external quantum efficiencies.[16]

Although the peculiar photodetection properties might be attributable to GBs, the details were unknown.

In this study, single-layered B-doped p-type semiconducting UNCD/a-C:H devices were fabricated, and their photoconduction properties were investigated in MSM.

2. Methods

0.6 at.% B-doped UNCD/a-C:H films with a thickness of approximately 600 nm were deposited on insulating Si substrates at a substrate temperature of 550 °C and an ambient hydrogen pressure of 53.3 Pa by pulsed laser deposition (PLD). The carrier concentration of the films, estimated from the capacitance-voltage characteristics, was approximately 10^{17} cm^3. The thickness and resistivity of the substrates are 260 μm and 2-5 kΩ•cm, respectively.

Figure 1 shows schematic image of the MSM geometry. As electrodes, Al, WC, Pt, Ti, Ag, Pd and Cu were deposited on the films by RF sputtering, and their contacts with the films were studied. Current-voltage (I-V) characteristics were measured with source meter unit (Keithley 2400).

The diameter of the dot shaped electrodes was fixed to be 500 μm, and the distance between the electrodes on the films was 500 μm. The finger-shaped electrodes for photoconduction spectra were fabricated by standard photolithographic technique with 20 μm wide and 380 μm long with a spacing of 20 μm, and the active area was 5.1×10^{-4} cm^2 shown in Fig. 2. The spectral response was investigated by incident photon to current conversion efficiency (IPCE) measurement apparatus (Peccell PEC-S20) with a 150W Xenon lamp in the wavelength range of 200 to 1180 nm. The incident light power was calibrated with a UV-enhanced Si photodiode.

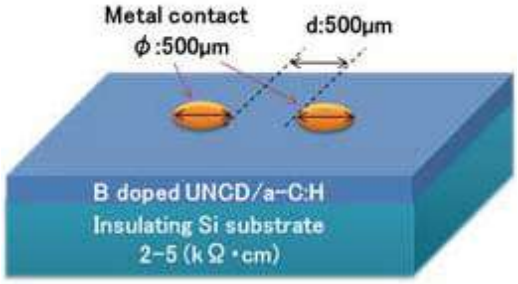

Figure 1. Schematic of MSM structure comprising B-doped UNCD/a-C:H film and metal electrodes.

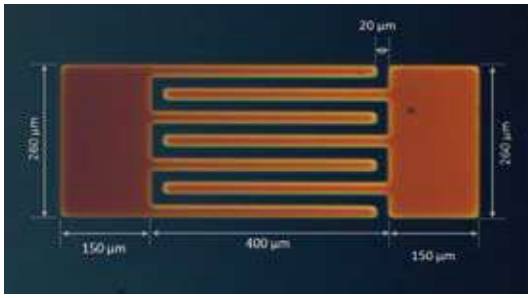

Figure 2. Optical microscopic imagery of finger-shaped electrodes deposited on B-doped UNCD/a-C:H films.

3. Results and Discussion

Figure 3 shows the I-V characteristics of a MSM strtuctural B-doped p-type UNCD/a-C:H films and different metal electrodes. Except for the MSM structure with Cu electrodes, the I-V curves of the other MSM structures show ohmic behaviors. The I-V curve of the MSM structure with Cu electrodes is not complete ohmic behavior, which might implies that the formation of a weak Schottky

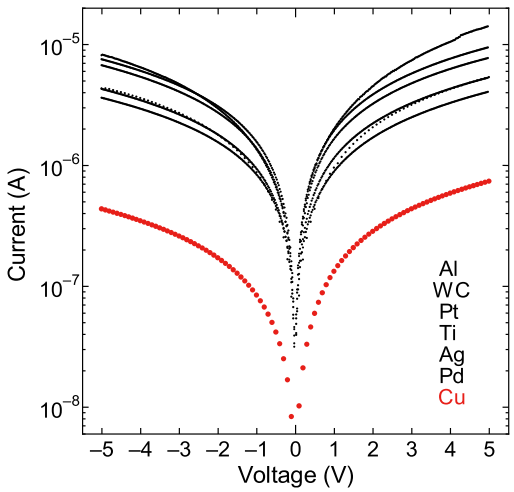

Figure 3. Dependence of each measuring contact metal as I-V characteristics of B-doped UNCD/a-C:H composite films.

barrier between the UNCD/a-C:H films and Cu electrodes. The contact resistance was calculated by simple Ohm's law (R = V/I), and plotted as a function of work function of metal as shown in Fig. 4. It was found that the contact resistance has no dependence on the work function of metals and Cu possesses high metal-semiconductor resistivity that can effectively suppress dark current. Cu was selected for the contact electrodes for photoconduction measurements. Figure 5 shows the photoconduction spectra of the MSM structures with with finger-shaped Cu electrodes, measured at bias voltages of 1 and 5 V. The spectra clearly

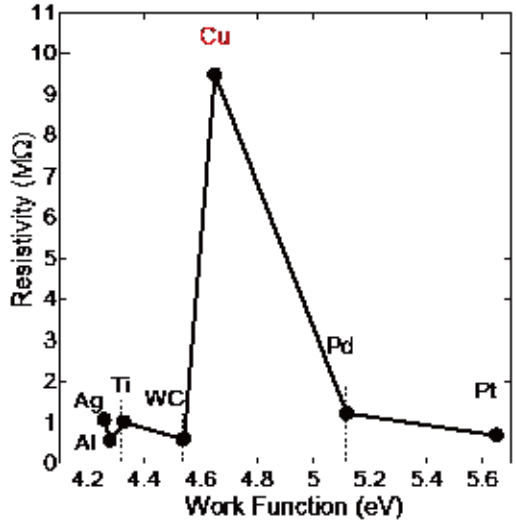

Figure 4. Contact resistance between B-doped UNCD/a-C:H film and metal as a work function of the metal.

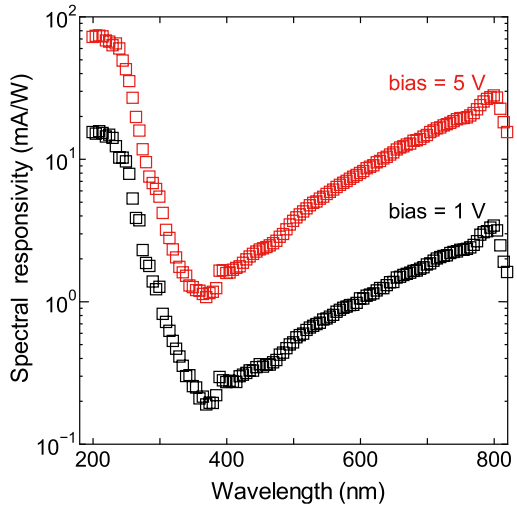

Figure 5. Photoconduction spectra of B-doped UNCD/a-C:H film evaluated in MSM geometry.

exhibit photoresponse in the UV wavelength range. This response would originated from the bandgap transition of diamond. A large number of diamond nanograins embedded into a-C:H matrix certainly act as photodetection centers. At a wavelength of 200 nm, the responsivity and EQE were estimated to be 70 mA/W and 43 %, respectively. The spectra exhibit an additional response in the visible wavelength range. The origin might be related to the mid-gap states introduced into the band gap of diamond. The grain boundaries and a-C matrix might provide additional defect states, which are photo-electrically active. We experimentally proved that UNCD/a-C:H possesses a high potential as a photodetection device.

4. Conclusion

Photocunduction properties of p-type B-doped UNCD/a-C:H films were investigated in MSM geometry. The Cu electrodes were selected as suitable metal for the MSM photodetection since the high contact resistance can suppress the dark leakage current effectively. The photoconduction spectra of the B-doped p-type semiconducting UNCD/a-C:H films with finger-shaped Cu electrodes, clearly exhibited photocurrent in the UV and visible wavelength ranges, which might originate from UNCD grains and grain boundaries, respectively. We firstly demonstrated the photoconduction properties of single-layered UNCD/a-C:H films, and it was experimentally proved that UNCD/a-C:H is a new candidate applicable to photodetectors.

Acknowledgment

This work was partially supported by Advanced Low Carbon Technology Research and Development Program (ALCA), Japan Science and Technology Agency (JST) and "Open Advanced Re-search Facilities Initiative" (Kyushu Synchrotron Light Research Center, Proposal No. 1104035AS) of the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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Email: takanori_hanada@kyudai.jp