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Heterojunction Diodes Comprising Nitrogen-doped Ultrananocrystalline Diamond Films Prepared by Coaxial Arc Plasma Deposition and p-Type Silicon Substrates

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Abstract

Semiconducting nitrogen-doped ultrananocrystalline diamond/hydrogenated amorphous carbon composite (UNCD/a-C:H) films were deposited on p-type Si substrates in nitrogen and hydrogen mixed gas atmospheres by coaxial arc plasma deposition with graphite targets. Resultant heterojunctions exhibited typical rectifying actions as diodes. It was demonstrated that the heterojunctions clearly exhibit photocurrent under deep UV light illumination at reverse voltages and experimentally proves that nitrogen-doped UNCD/a-C:H works as photovoltaic materials.

1. Introduction

Ultrananocrystalline diamond/hydrogenated amorphous carbon composite (UNCD/a-C:H) is a new candidate carbon semiconductor, and the application to electrical devices has received much attention. It has been known that nitrogen-doping for diamond is ineffective for realizing n-type conduction at room temperature because nitrogen form a deep donor level of 1.7 eV below the bottom of the conduction band in diamond. For a-C:H, n-type conduction is realized by nitrogen doping, however it is difficult for the carrier density to be controlled widely. On the other hand, it has been reported that nitrogen doping makes possible n-type conduction accompanied by an enhancement in the carrier density for UNCD/a-C:H films prepared by chemical vapor deposition (CVD) and pulsed laser deposition (PLD) [1-3]. It has been experimentally demonstrated that p-type UNCD/a-C:H films deposited by PLD with boron-blended graphite targets exhibit an excellent photodetection performance for UV light [4]. On the other hands, there have few reports on the application of nitrogen-doped UNCD/a-C:H films to optoelectric devices. In this work, heterojunction photodiodes comprising nitrogen-doped UNCD/a-C:H films deposited by coaxial arc plasma deposition (CAPD) and silicon substrates were prepared and their photodetection performance was studied.

2. Experimental methods

Nitrogen-doped UNCD/a-C:H films were deposited by CAPD on p-type silicon (100) substrate at a substrate temperature of 550 ºC in a nitrogen and hydrogen mixed gas atmosphere 53.3 Pa. Inflow ratio of nitrogen and hydrogen was set to be 0.3. The nitrogen content in the film was estimated to be 3 at. % by X-ray photoemission spectroscopy. The current-voltage (*I-V*) and capacitance–voltage (*C-V*) characteristics of heterojunction diodes comprising nitrogen-doped UNCD/a-C:H films and p-type silicon were measured using source meter (KEITHLEY 2400) and LCR meter (Agilent E4980A), respectively.

3. Results and discussions

The current-voltage (*I-V*) curves of the heterojunction diodes exhibit typical rectification actions with rectification ratios of approximately 4 orders of magnitudes at bias voltages between ±5 V, as

shown in Figure 1. The nitrogen-doped UNCD/a-C:H evidently acts as a n-type semiconductor. A capacitance-voltage (*C-V*) curve is shown in Figure 2. The capacitance is decreased with increasing reverse voltage. The depletion region in the diode certainly spreads under the reverse bias. The inset shows the plot of $1/C^2$ against the reverse bias. The built in potential was estimated to be 0.3 eV. The UV detection characteristics of the heterojunction diode is shown in Figure 3. The *I-V* curves were measured in the dark and under illumination with a 254 nm monochromatic lamp. Under illumination, current due to photogenerated carriers is clearly detected at reverse voltages.

4. Conclusion

Nitrogen-doped UNCD/a-C:H film were prepared in nitrogen and hydrogen mixed gas atmospheres by CAPD, and photocurrent predominantly attributable to photocarriers generated in UNCD grains was clearly detected in the heterojunction diodes comprising the nitrogen-doped UNCD/a-C:H films and p-type silicon substrates. It was experimentally demonstrated that nitrogen-doped UNCD-a-C:H is a potential n-type semiconductor.

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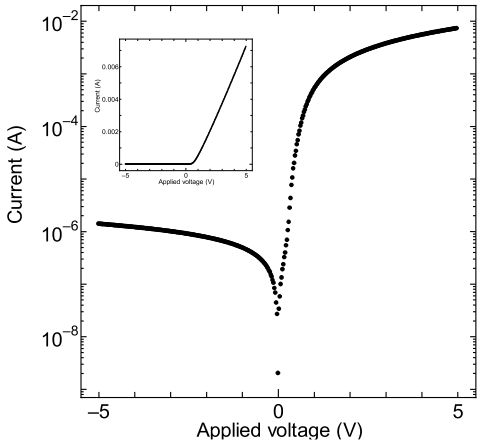

Figure 1. Current-voltage characteristics of diodes comprising nitrogen-doped UNCD/a-C:H film and p-type silicon substrate.

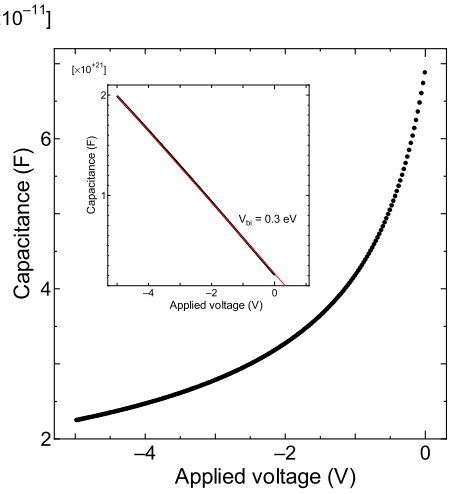

Figure 2. Capacitance-voltage characteristics of diode comprising nitrogen-doped UNCD/a-C:H film and p-type silicon subatrate.

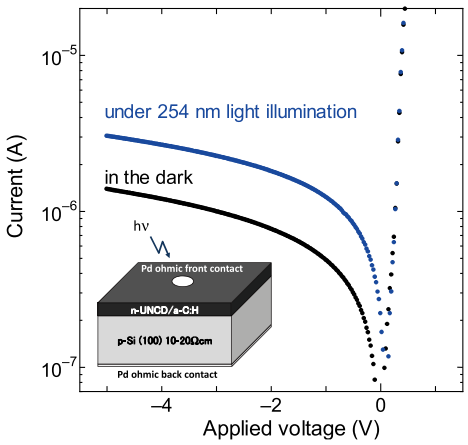

Figure 3. Deep ultraviolet light detection characteristics of diode comprising nitrogen-doped UNCD/a-C:H film and p-type silicon substrate.