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Heterojunction diodes made from B-doped diamond grown heteroepitaxially on Si-doped c-BN

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Abstract

Boron-doped p-type diamond thin film was grown heteroepitaxially on silicon-doped n-type cubic boron nitride (c-BN) bulk crystal by the conventional hot-filament chemical vapour deposition method. A diamond thin-film/c-BN heterojunction p–n diode was fabricated by the covering technique for the first time. The rectification ratio of the diode reached five orders. The threshold value is 1 V; the reverse bias voltage is 6 V. The results indicate that the device is of great importance.

1. Introduction

It is common knowledge that diamond has a lot of excellent qualities, such as a wide band gap, high breakdown voltage [1, 2], high electron and hole mobilities [3], high saturation electron velocity [4], and high thermal conductivity [5]. So diamond is suited to electronic applications requiring operation under extreme environmental conditions. A number of works have reported on diamond devices such as point contact diodes, transistors [6], and MISFETs [7–10]. However, the difficulty of producing adequate n-type diamond has limited such applications to just a few special cases.

Cubic boron nitride (c-BN) is similar to diamond in structure and properties—such as high hardness and high thermal conductivity. As c-BN is an artificial material and its size is limited, the electrical properties of c-BN such as mobility and band gap have not been studied in detail. Since p-type c-BN was produced by Be doping and n-type c-BN was produced by S or Si doping [11], it has been reported that a p–n homojunction diode has been made by a conventional high-pressure high-temperature (HPHT) method [12], but an ohmic c-BN contact has not been made.

In 1994, it was reported that a p–n heterojunction diode was made from diamond film/c-BN for the first time [13], and an ohmic electrode had been made; also its I–V characteristics has

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been measured. Owing to the low doping efficiency of Si into c-BN by using HPHT method, the threshold value of the diode was very high and its rectification function was very poor.

In the past few years, we have carefully studied n-type doping of c-BN, ohmic contacts of n-type c-BN, and preparation of p-type diamond film/n-type c-BN single-crystal heterojunctions. As the size of c-BN is very limited, we have utilized a covering technique and fabricated a heterojunction diode; also we measured its I–V characteristics using a specially made device.

In the present work, we describe the preparation of a heterojunction p–n diode, utilizing a covering technique, for the first time. High rectification ratios (up to 10^5), small threshold values (up to 1 V), and high reverse bias voltages (up to 6 V) were measured for this diode.

2. Experimental details

The c-BN substrates were prepared by the conventional HTHP method. The starting material was hexagonal boron nitride (h-BN) with a solvent. Applying pressures of 4.0–6.0 GPa at temperatures of 1400–1900 °C for 10–20 min, c-BN single crystals were obtained. The size of the crystals used was about 0.3 mm. Si-doped n-type c-BN was obtained by the conventional high-temperature diffusion method. The c-BN crystals were covered by fine Si powder. The diffusion conditions were: pressure: 10^{-3} Torr; specimen temperature: 850 °C; diffusion time: 5 h. The resistivities of the specimens were lower than 10 Ω cm.

Heteroepitaxial growth of the B-doped diamond thin film was carried out utilizing the hot-filament CVD (HFCVD) method. Prior to deposition, the c-BN substrates were cleaned with an organic solvent mixture of toluene, alcohol, and acetone; this was followed by a deionized water rinse, then drying with an infrared lamp. The source gas was 0.8% methane diluted with hydrogen, and the growth conditions were: pressure: 40 Torr; total flow rate: 100 sccm; substrate temperature: 900 °C. The deposition time was 2 h. The thicknesses of the diamond films were approximately 1 μm. B doping was carried out by placing B powder near the specimen. Diamond films on the c-BN substrate were observed by SEM and Raman spectroscopy. The resistivity of the film was lower than 10^{-3} Ω cm.

The process of fabrication of the diamond/c-BN heterojunction diode is illustrated in figure 1. First, Si-doped c-BN was laid on a Si flat which has a small hole of diameter 0.1 mm (figure 1(a)). A p-type diamond layer was grown on the c-BN crystal and the Si flat substrate (figure 1(b)). The ohmic electrodes of Ti (10 nm)/Mo (20 nm)/Pt–Au (20 nm) for the p-type diamond and n-type c-BN were deposited by electron beam evaporation (figure 1(c)). The specimens were then annealed at 350 °C in air for 15 min to achieve ohmic metal alloying. The specimen was dug out from the Si flat (figure 1(d)). Thus, a diamond/c-BN heterojunction was obtained.

The electrical characteristic of the diamond/c-BN heterojunction diode was measured using a specially made device which is shown in figure 2.

3. Results and discussion

The diamond thin film deposited on the Si-doped c-BN was examined by Raman spectroscopy and its spectrum is shown in figure 3.

The diamond peak of this specimen was broadened compared with the bulk diamond peak; the quality of the present diamond film was poor. This is presumably due to the instability of the crystalline quality of c-BN as well as the deposition conditions.

The ohmic characteristics of the Ti/Mo/Pt–Au electrodes on Si-doped c-BN are shown in figure 4. As linear current–voltage characteristics were obtained, it is considered that the contact between the Ti- and Si-doped c-BN was ohmic.

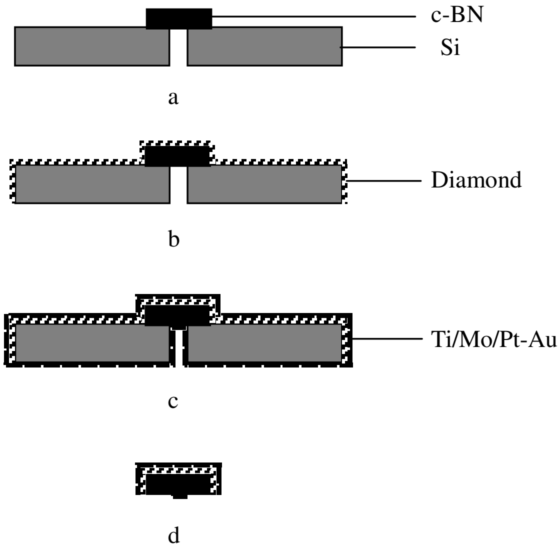

Figure 1. The procedure of fabrication of the diamond/c-BN heterojunction diode: (a) positioning of the c-BN; (b) growth of diamond on c-BN and a Si flat by HFCVD; (c) deposition of Ti/Mo/Pt–Au ohmic metal on diamond and c-BN; (d) obtaining the diamond/c-BN heterojunction.

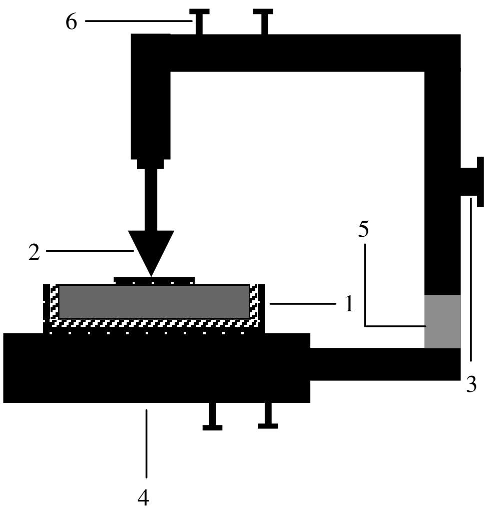

Figure 2. The device used to measure the electrical characteristics of the diamond/c-BN heterojunctions: 1, sample; 2, probe; 3, fluctuation rotational shear; 4, metal plate; 5, insulator materials; 6, terminal.

Figure 5 shows current–voltage characteristics for a diamond/c-BN heterojunction p–n diode. As can be seen from figure 5, the reverse current is not large until 5.5 V is reached.

As long as a revere bias was applied, up to 5 V, we did not observe any indication of breakdown. The diode characteristics can be enhanced by improving the diamond deposition process as well as by increasing the level of Si doping of the c-BN bulk crystal.

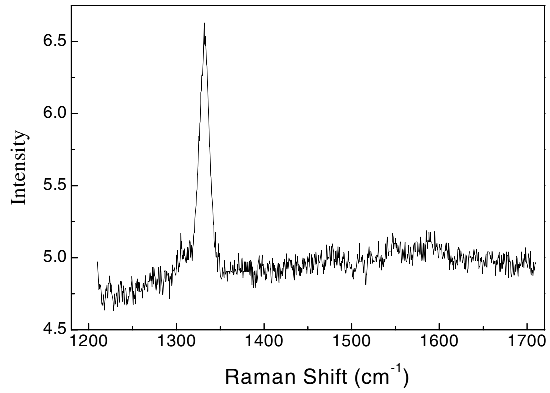

Figure 3. Raman spectroscopy of the diamond film on the n-type c-BN substrate.

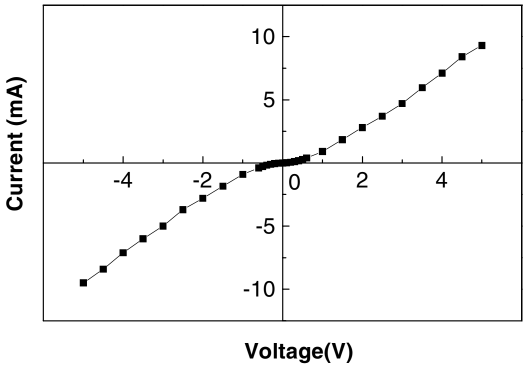

Figure 4. Current–voltage characteristics of the Ti/Mo/Pt–Au electrodes on the Si-doped n-type c-BN.

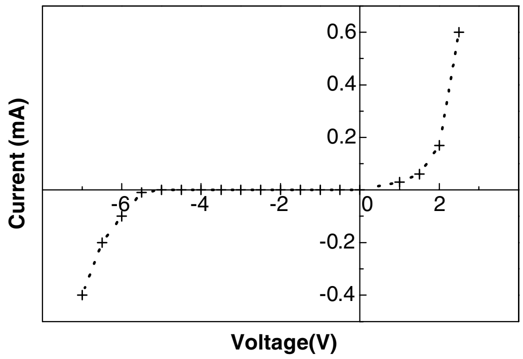

Figure 5. Current–voltage characteristics of the diamond/c-BN heterojunction diode.

4. Conclusions

By means of heteroepitaxial growth of a B-doped diamond thin film on Si-doped c-BN, a diamond/c-BN heterojunction diode has been fabricated. The fabrication processes involved a covering technique which was applied for the first time. The reverse bias leakage current was more than five orders higher than the rectification ratio. The threshold value is 1 V. The reverse bias voltage is 6 V. The results indicate that the device is of great importance.

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