# Two Steps B Ion-Implantation of Diamond Film Grown on an n-Type Si Substrate and Its p-n Junction Effects *

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**Abstract:** Polycrystalline diamond thin films are deposited on an n-type Si substrates by hot filament chemical vapor deposition, and then are implanted with boron ions in a 200keV ion implanter. In order to achieve a better distribution of the implanted element, boron ions are implanted by two steps: implanting boron ions with the energy of 70keV first, and then with the energy of 100keV. The homogeneous distribution of the B ion is gained. The current-voltage characteristics of the samples are studied. It is found that the p-n heterojunction effect is achieved in these samples.

**Key words:** ion implantation; diamond film; p-n junction
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## 1 Introduction

Since the success of synthesizing diamond films under low-pressure conditions from gas matters, the diamond films have been applied in many fields. In recent years, the application of diamond film in semiconductor devices is one of the most important attempts[1~3]. Diamond electronic devices are believed to have many attractive properties such as a wide band gap (5.5eV), high mobility of both electrons and holes ($2100cm^2/(V \cdot s)$ and $2000cm^2/(V \cdot s)$), and a small dielectric constant ($\varepsilon_r = 5.5$).

In the past years, many works have been reported on the semiconductor devices made by doped diamond. Three methods have been used for the doping of diamond: diffusion technology, doping growth, and ion implantation techniques. Many researchers have studied the electrical properties and photoconductive properties of B doped diamond films[4~6]. In 1996, Phetchakul *et al.* reported the p-n heterojunction between a B doped diamond film and silicon substrate. He used the method of doping growth, but the p-n junction effect was not obvious[7].

In this work, we use the method of two steps ion-implantation of diamond film grown on an n-type Si substrate. The p-n heterojunction structures are formed between boron ion implanted diamond films and an n-type Si substrate. The *I-V* characteristics of the heterojunctions are studied. The ratio of forward resistance to backward resistance is about 2 orders, and the p-n junction effect is obvious.

## 2 p-n junction fabrication

Diamond films were deposited in a hot-filament CVD system. The substrate was an n-type (100) silicon wafer; the temperature of the filament and the substrate was 2100 ℃ and 850 ℃, respec-

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tively. The distance between the filament and the substrate was 5mm. A mixture of $CH_4$ and $H_2$ was used as a reaction gas. The concentration of the $H_2$ was 1 %. The gas pressure was 1. 8kPa.

The doping of the boron element was carried out in the 200keV ion implanter. In order to achieve a better distribution of boron element, the boron ions were implanted by two steps with different energy. First, the boron ions were implanted with an energy of 70keV, then the boron ions were implanted with an energy of 100keV, and the implantation doses were $10^{15} \sim 10^{17} cm^{-2}$. After that, the samples were annealed rapidly in a vacuum chamber at 700 ℃for 5min in order to make the B element occupy the crystal lattice. The surface of the samples was cleaned with $CrO_3 + H_2SO_4$ in order to eliminate the graphite and impurity on the diamond surface. The surface of the silicon substrates was cleaned with HF to dissolve the oxidation layer. After that, the samples were rinsed with deionised water in order to get ohmic contact between the electrodes and the sample surface, a 150nm thick Ti layer was deposited on the sample surface by means of electron-beam evaporation. Subsequently, a 70nm thick Au layer was evaporated on the Ti layer to prevent it from being oxidized (Fig. 1), then, the samples were annealed at 350 ℃ for 10min protected by $N_2$ to stabilize the ohmic contact. Secondary ion mass spectrum (SIMS) was used to investigate the distribution of the implanted boron element in the diamond film. *I-V* characteristics of the sample were analyzed to study their p-n heterojunction properties.

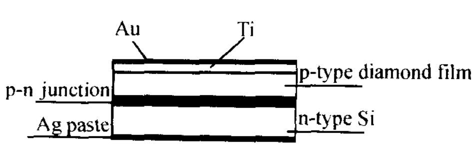


Fig. 1 Schematic diagram of the heterojunction between B doped diamond film and Si substrate

## 3 Experiment and discussion

Figure 2 is the SIMS of the diamond film implanted with boron ions. During the measurement, the sample surface was sputtered by $Ar^+$ (2kV), with a sputtered speed of 32nm/ min. In Fig. 2 the horizontal coordinate is the sputtering time which corresponds to the depth of the film where the boron element is, and the vertical coordinate of the figure is the counting number of boron, that corresponds to the boron element. The curves in this diagram illustrate the B element concentration distribution changing with different depths in the diamond film. Curve *a* is the result of implantation with boron by two steps with the energies of 70keV and 100keV, respectively; curve *b* is the result of implantation with boron by one step with the energy of 120keV. It is obvious that the distribution of boron implanted by one step is in Gauss distribution, while that implanted with two steps is the sum of the two Gauss distribution. Curve *a* is flat near the peak, and the B element distribution is homogeneous in a broader rage, which is advantageous for the fabrication of p-n junction.

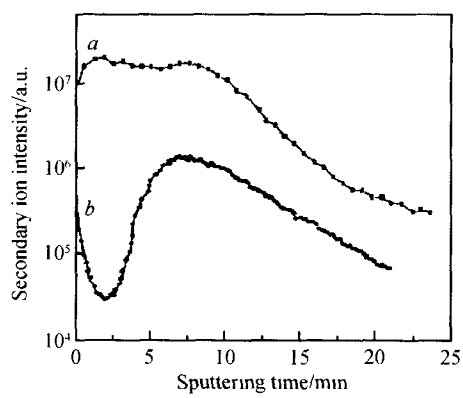


Fig. 2 SIMS spectra of the diamond films implanted with boron by two steps (curve *a*) and by one step (curve *b*)

Figure 3 is the *I-V* characteristics of the samples implanted with different B doses. As positive voltages are applied to the samples, all the currents in the samples increase sharply, while negative voltages are applied to the samples, only a small current flows through the sample. In addition, the currents change little over a wide range of voltage. It suggests that the heterojunction between a boron implanted diamond and n-type silicon substrate has the p-n junction effect. This p-n junction is formed through diffusion. When a p-type diamond film is contacted with an n-type Si, the distribution of electrons and holes is not homogenous. The concentration of electrons in an n-type Si is much higher than that in a p-type diamond, while the concentration of holes in a p-type diamond is much higher than that in an n-type Si. So electrons in an n-type Si will diffuse into a p-type diamond, and holes in a p-type diamond will diffuse into an n-type Si. A p-n junction is formed at the interface between the p-type diamond film and n-type Si when the diffuse reaches a balance.

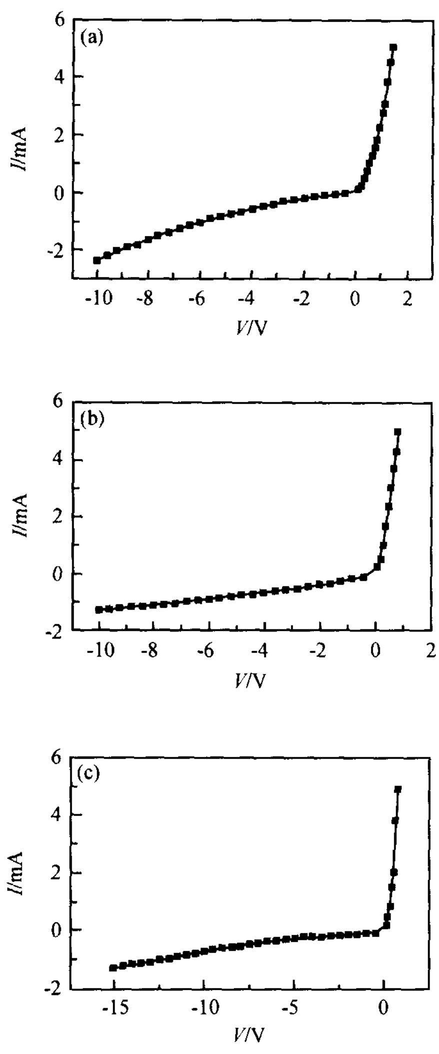


Fig. 3 I-V curves of the samples implanted with different B doses (a) $5\times10^{15}cm^{-2}$; (b) $1\times10^{16}cm^{-2}$; (c) $3\times10^{16}cm^{-2}$

It is evident from Fig. 3 that with the increase of boron implantation dosage, the forward resistance become smaller. When the implantation dose is $5\times10^{15}cm^{-2}$, the forward resistance is around 180Ω; when the implantation dose is $1\times10^{16}cm^{-2}$, the forward resistance drops to 150Ω; when the dose increases to $3\times10^{16}cm^{-2}$, the resistance reaches 75Ω. As for the backward resistance, it increases with the increase of the implantation dosage. This phenomenon indicates that increasing implantation dosage in a certain range is advantageous to the property of this p-n heterojunction. The volume of resistance of the samples, which may be gained through the curves of Fig. 3, is given in Table 1.

Table 1 Resistance of the samples under the different B doses

| B dose / $cm^2$ | Minimum forward resistance/Ω | Maximum back resistance/Ω |
|---|---|---|
| $5\times10^{15}$ | 180 | 20000 |
| $1\times10^{16}$ | 150 | 22800 |
| $3\times10^{16}$ | 75 | 25000 |

Table 1 indicates that the ratio of back and forward resistance is raised with the increasing of B doses, then the p-n junction effect becomes evident.

## 4 Conclusion

Using the two steps B ion implantation method, the homogeneous distribution of B element in diamond film can be gained. The p-n heterojunction between the B doped diamond film and the Si substrate has smaller forward resistance and bigger positive resistance. The p-n junction effective is evident.

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# 在 n 型硅基底上二次注入硼离子金刚石膜的 p-n 结效应 *

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**摘要**: 在 n 型 Si 衬底上用热丝化学气相沉积方法制备了多晶金刚石膜 ,用 200keV 的离子注入机在金刚石膜中进行了二次硼离子注入 ,第一次注入能量为 70keV ,第二次注入能量为 120keV ,获得了硼离子的均匀分布 ,测试了样品的 *I-V* 特性 ,发现其具有明显的 p-n 异质结效应.

**关键词**: 离子注入; 金刚石膜; 异质结

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