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SIMPLIFICATION OF OHMIC ELECTRODE STRUCTURE ON *n*－TYPE DIAMOND SEMICONDUCTOR SUBSTRATE BY Ar ION IMPLANTATION

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Abstract

We studied the ohmic electrode structure necessary for the evaluation of electric properties of the diamond semiconductor. In the previous studies, ohmic property were confirmed in the Au/Pt/GLC(Ti) (graphite-like carbon) electrode at the temperatures from 300 to 800°C, where the GLC layer was formed by Ti ion irradiation with a total fluence of 1×10^{16} cm^{-2} at room temperature. In this study, we aim to simplify the electrode structure by forming a low-resistance GLC layer using Ar ion irradiation (GLC(Ar) electrode), instead of Ti irradiation. The electric properties were evaluated by *I*-*V* measurements using the Van der Pauw method at the temperatures from 300 to 800°C. As a result, good ohmic property for the *n*-type Ib substrate with the Au/Pt/GLC(Ar) electrode was obtained at the temperature range from 300 to 800°C, though the ohmic property was not observed at higher temperatures than 600°C for that with the conventional Au/Pt/Ti and Au single layer electrodes without the GLC layer. The GLC layer is therefore found to be necessary to obtain the ohmic property for the *n*-type Ib diamond.

I. Introduction

The final goal of this study is the electrical activation of dopants introduced by ion implantation in pure diamond substrates (IIa diamond substrates) synthesized by high-temperature and high-pressure condition or in chemical-vapor-deposited high-quality diamond layers on the Ib diamond substrates. It is quite necessary that a good ohmic contact can be obtained for reliable electrical measurements, however, it has not yet been particularly found in the *n*-type diamond semiconductor. We have so far studied the optimum ohmic electrode structures for *n*-type diamond semiconductors by utilizing a graphite layers formed by ion beam irradiation. In our previous studies, we investigated the tri-layer electrode structure of Au/Pt/GLC(Ti) (300/50/100 nm) in which the GLC(Ti) layer was formed by Ti ion irradiation in a *n*-type Ib diamond substrate (Fig. 1). As a result, the ohmic property was obtained at 300 to 800°C temperatures. In this study, we aim at simplifying the electrode structure and formation process of the GLC layer using Ar irradiation.

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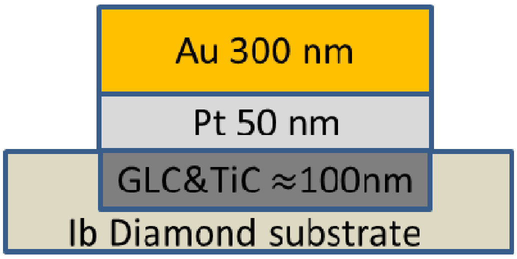
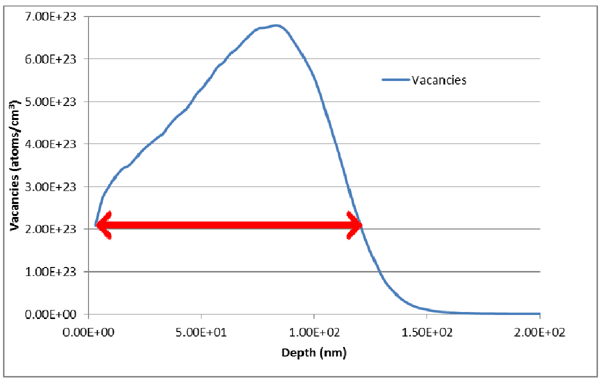


Fig. 1. Tri-layer electrode structure of Au / Pt / GLC & TiC (300/50/100 nm)

II. Experiment

Firstly, we estimated in advance using TRIM simulation code, the implantation conditions so that the created vacancy density becomes more than 2.0×10^{23} atoms/cm^3 (this value equals to that of the atomic C density of diamond) from the surface to the depth of around 100 nm. As a result, we found that the 190-keV Ar^+ ion with a fluence of 1.03×10^{16} ions/cm^2 can effectively break the crystalline sp^3 structure to the depth of ~100 nm. The sp^3 bonding orbit is the peculiar orbit structure of diamond, consisting of combination for one 2*s* electron orbit with three 2*p* electron orbits. The poly-crystalline graphite structures that have the sp^2 bonding orbit will be effectively formed after post-annealing, resulting in the formation of a GLC layer (Fig. 2). The sp^2 bonding orbit consists of combination for one 2*s* electron orbit with two 2*p* electron orbits and the free electron (π electron) inducing the conductive property of graphite layer.



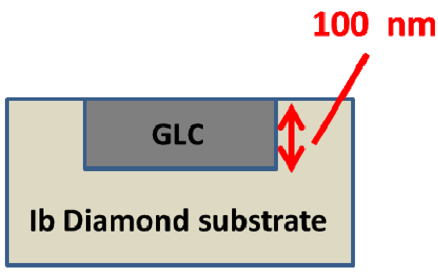


Fig. 2. Vacancy profile simulated by TRIM

Next, Ar^+ ions were irradiated into the type Ib diamond substrate at room temperature under the above condition, estimated by the TRIM simulation. Ar^+ ions were irradiated through the metal mask put near the four corners of the substrate with a diameter of 0.5 mm, as shown in Fig. 3. After irradiation, the sample was annealed at 800°C for 1 h in Ar atmosphere. Di-layer metal electrodes of Au/Pt (300/50 nm) were then deposited on the GLC(Ar) layer by magnetron sputtering system at the substrate temperature of 550°C. The electrical properties (I-V characteristic) were evaluated by using the Van der Pauw method at temperatures ranging from 300 to 800°C.

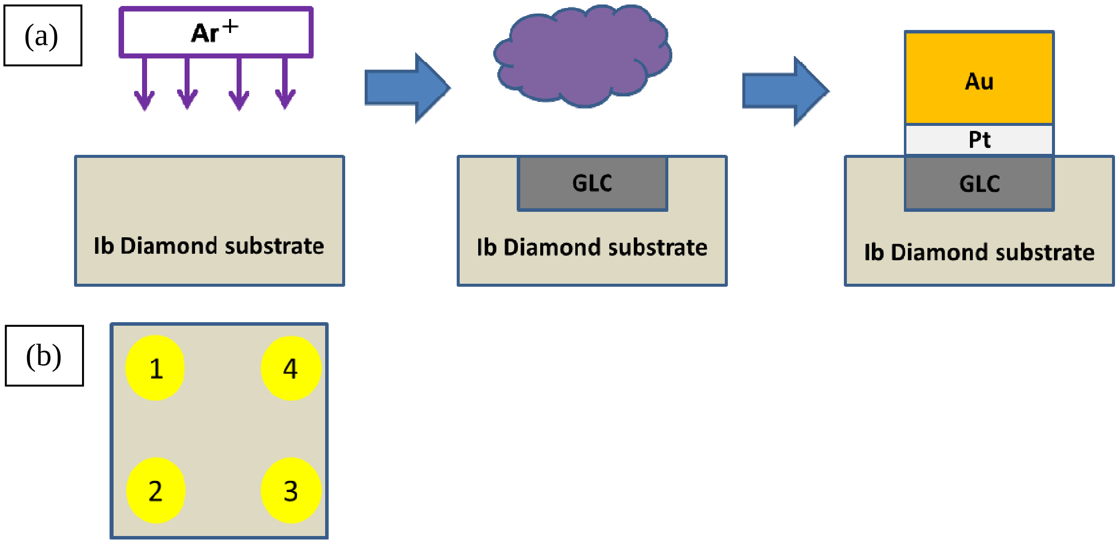


Fig. 3. Formation process of simplified electrode structure(a) and plan view image of the electrodes(b).

III. Results and discussion

The *I-V* properties observed for the samples having a single Au layer electrode and the Au/Pt/GLC(Ar) electrode at 400, 600, and 800°C are shown in Figs. 4 (a)(d), (b)(e), and (c)(f), respectively. The Figs. 4(a) – (c) and (d) – (f) show the results of the Au single layer electrode and those of the Au/Pt/GLC(Ar), respectively. The Au single-layer electrode structure shown in Figs. 4(a) – (c) was made for reference. The gradient of *I-V* curve for the Au/Pt/GLC(Ar) was steeper than that of the Au single layer electrode structure, indicating that the resistivity of the Au/Pt/GLC(Ar) structure is lower. In addition, the electrode clearly shows good ohmic property, which can be confirmed by the linearity of the *I-V* curve even at 800°C. On the other hand, the single Au layer electrode shows the ohmic property only at 400 and 600°C as shown in Figs. 4 (a) and (b). It is indicated that the GLC layer is necessary for obtaining the ohmic property at wide temperature range. As a result, the Au/Pt/GLC(Ar) electrode was found to be better ohmic contact than the Au single layer electrode. In other words, the electrical contact is significantly improved by forming the GLC layer. In the present study, the ohmic property was confirmed without a Ti layer; therefore, Ti is not necessary to obtain excellent ohmic property in *n*-type diamond semiconductor substantially. Consequently, we succeeded in simplifying the electrode structure without Ti layer.

In the GLC layer, the sp^2 - like structure and vacancy-interstitial complexes are definitely formed by ion irradiation followed by high-temperature annealing. However, it is not clear what factors play an important role in the appearance of the ohmic property, actually: GLC layer or ion-irradiation itself.

In the future, we will try to investigate the limit of ion fluence to obtain the ohmic property. We adjust the ion fluence so that the vacancy density in the diamond crystal becomes a few orders smaller than the atomic density of diamond; it will clarify the crucial factor that the ohmic property is observed.

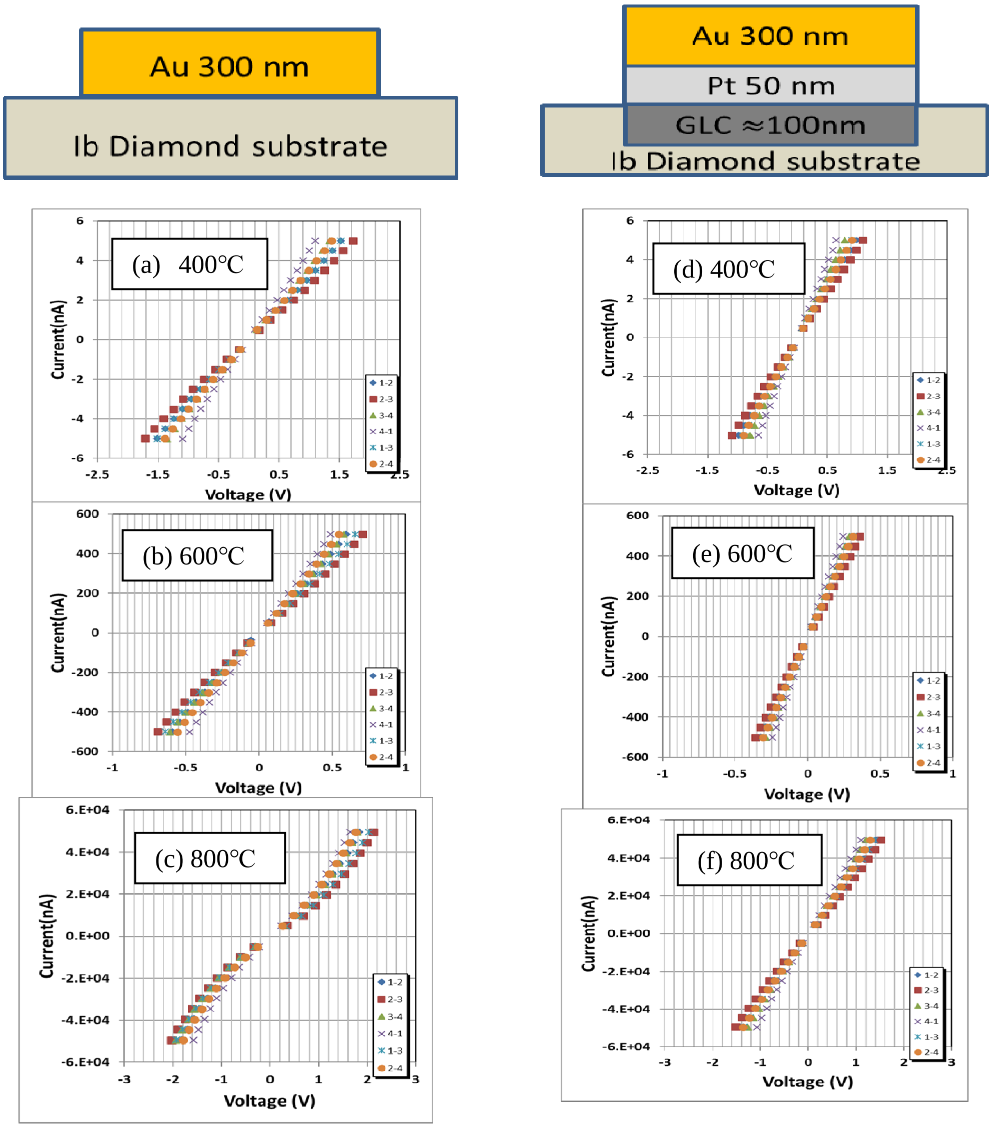


Fig. 4. I-V curves observed for the ohmic measurements using Au single- layer electrode structure and Au / Pt / GLC electrode structure at 400°C,600°C and 800°C.

IV. Conclusions

We investigated the formation of simple electrode structure for ohmic electrode on a type Ib diamond semiconductor by forming the low-resistance GLC layer below the metallic Au/Pt layers using the Ar ion irradiation. As a result, excellent ohmic property was observed for the sample with the Au/Pt/GLC(Ar) electrode structure at the wide temperature range from 300 to 800°C compared to that with the conventional Au/Pt/Ti and a single Au layer electrode without the GLC layer. It is clearly found that the GLC layer is necessary to improve the electrical contact between the *n*-type substrate and the electrode, and Ti was not substantially necessary for ohmic contact. Finally, we succeeded in simplifying the electrode structure for the *n*-type diamond semiconductor.