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Process Damage Influence for Electrical Property of Diamond Schottky Barrier Diodes

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Abstract

We investigated recovery treatment to remove damaged layer induced by inductively coupled plasma (ICP) etching process on diamond Schottky barrier diodes (SBDs). We attempted "soft-etching" treatment which can effectively remove surface damaged layer. From current density–voltage measurement, degradation of device properties of SBDs could not be confirmed. We found that soft-etching treatment did not produce additional damage for the surface from X-ray photoelectron spectroscopy analysis. Thus, soft-etching is promising treatment for remove of surface-damaged layer induced by ICP-etching process.

1. Introduction

Diamond has attracted attention as one of the next generation high-power device materials due to the excellent physical properties of bulk diamond, such as high-breakdown field, high-carrier mobilities, and so on. However, it is difficult to realize diamond devices with expected properties because of the degradation of crystallinities due to process damages [1]. In order to show the potential of diamond devices, optimized device processes are required. On device fabrication, since wet etching process is difficult for diamond due to its chemically inert, dry-etching process such as inductively coupled plasma (ICP) etching have to be used to form device structure such as mesas and trenches. However, ICP-etching process degrades surface flatness and crystallinity, therefore, the surface roughness and the damage-recovery techniques have to be established [2-4].

In this study, we focused on the ICP-etching process and investigated the damage-recovery treatments of the etched surface, which affects device properties. As damage-recovery treatments, we attempted "soft-etching" treatment. The ion energy of the soft-etching is lower than that of general ICP-etching used to fabricated device structure, with 40% lower antenna power and zero bias power. The etching rate of soft-etching treatment is 0.6 nm/min which is 1/200 times lower than that of ICP-etching, that is, the surface damaged layer can be removed selectively [4]. We fabricated Schottky barrier diodes (SBDs) to investigate effect of device properties because SBDs were very sensitive for the surface condition. Moreover, we analized the surface damaged layer by X-ray photoelectron spectroscopy (XPS).

2. Experimental

Boron doped p-type diamond was grown onto IIb-type (100) oriented high-pressure and high-temperature substrates. Acceptor concentration was estimated to be 1.25×10^{17} cm^{-3} from capacitance–voltage measurement. We performed soft-etching treatment under condition indicated in Table I. Treatment was done to remove graphite layer. Fig. 1 shows the sample preparation procedure. Samples were treated a mixed-acid to remove surface contamination such as graphite, and to terminate surface with oxygen. After the mixed-acid treatment, SBDs were fabricated. Ti (30 nm)/Pt (30 nm)/Au (100 nm) as ohmic electrodes were deposited onto back surface of samples and were annealed at 420 °C for 30 min in Ar atmosphere to form ohmic contacts. Mo electrodes were formed on p-type layer as Schottky metal. Current density–voltage (*J*–*V*) characteristics of fabricated SBDs were measured.

Table I Condition of soft-etching treatment

O_2 (sccm)	95
CF_4 (sccm)	2
Antenna Power (W)	300
Bias Power (W)	0
Pressure (Pa)	2
Etching rate (nm/min)	0.6
Etching time (sec)	400

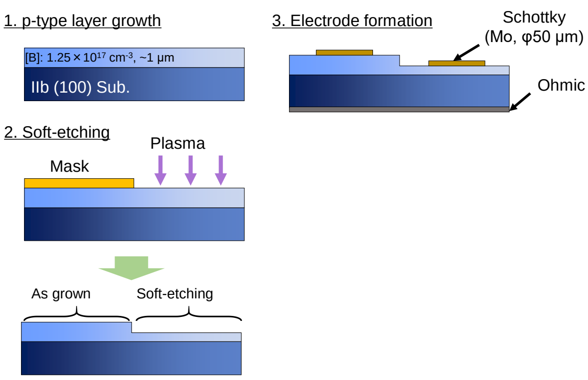

Fig. 1 Sample preparation flow

3. Results and Discussion

Fig. 2a shows the *J–V* characteristics of SBDs. On samples treated soft-etching, the leakage current was ~10^{-8} A/cm^2 which is comparable for SBDs fabricated onto as-grown surface. Therefore, damage which causes leakage current would not be produced by soft-etching treatment. Slope of linear region in forward bias regime and forward current density are hardly changed by soft-etching treatment. Fig. 2b depicts the comparison of the Schottky barrier height and ideality factor which were estimated with the thermionic emission (TE) model in the linear region of forward biased regime. These parameters were hardly changed. Therefore, soft-etching treatment can keep device properties which are equivalent to as-grown SBDs.

XPS analysis were performed to investigate surface condition of as-grown and soft-etched surface. Fig. 3 shows C 1*s* peaks measured at 20° in take-off-angle which corresponds to the photoelectron escape depth in 0.8 nm. All spectra were normalized by the peak intensity at 284.7 eV. We confirmed three components: carbon-oxygen double (C=O) bonds at 287.4 eV, carbon-oxygen single (C-O) bonds at 286 eV, and sp^2 carbon at 283.3 eV at vicinity of binding energy of the C 1*s* peak. According to ref. [4], these components are considered as damage although oxygen rerated components which were detected in this study are considered to be surface-terminated oxygen and/or adsorbed oxygen from air. On soft-etching treatment, the intensities of three components were comparable for that of as-grown sample and this is indicated that soft-etching treatment does not produce the additional damage to the surface.

4. Conclusions

We investigated recovery treatment to remove damaged layer induced by ICP-etching process. Soft-etching treatment were applied as damage-recovery treatment. We found that soft-etching treatment does not degraded electrical properties of SBDs. From XPS analysis, surface condition of treated samples was comparable to as-grown surface. This is indicated that soft-etching treatment does not produce additional damage. Thus, soft-etching treatment can keep surface condition and device properties. Soft-etching treatment is a promising process to remove surface-damaged layer induced by the ICP-etching process.

Acknowledgements

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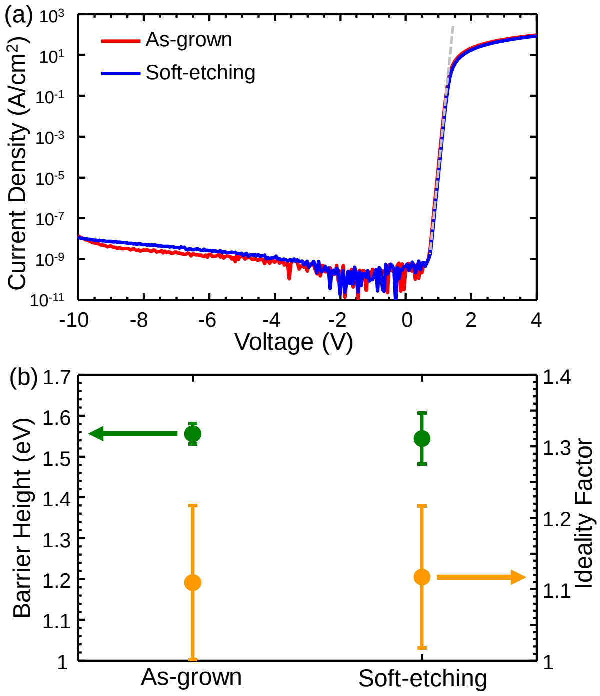

Fig. 2 (a) Typical *J–V* characteristics of SBDs fabricated onto as-grown (red curve) and soft-etched surface (blue curve). The dotted line represents fitting line using the TE model. (b) Comparison of the Schottky barrier height and ideality factor estimated with TE model. Error bars represent standard deviation.

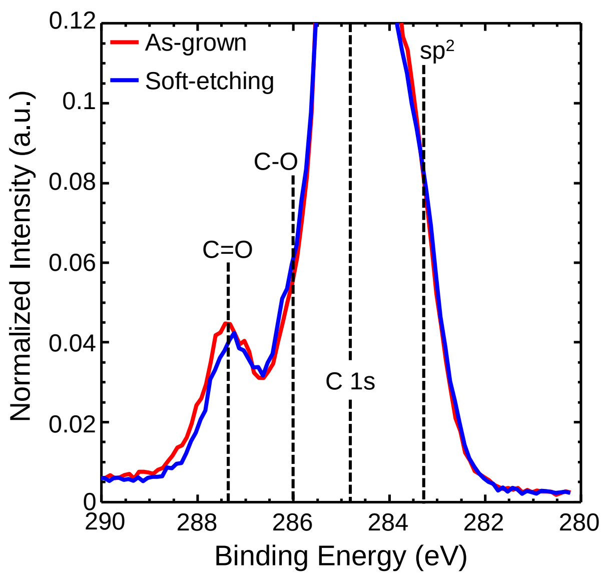

Fig. 3 XPS spectra measured at 20° in take-off-angle.