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Electrical properties of diamond platinum vertical Schottky barrier diodes

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Abstract

Electrical and photoelectrical properties of Pt vertical Schottky barrier diodes prepared on thick lightly-doped CVD diamond grown on heavily-doped IIb HPHT substrates were studied. The films were p-type, with the concentration of residual boron acceptors in the mid-10^{14} cm^{-3}. The Schottky barrier heights determination from photocurrent spectra measurements revealed the presence of two barrier values of 1.45 eV and 2 eV. The former dominated the temperature dependence of the forward current, the latter determined the voltage cut-off in C-V measurements. The results are explained by difference in oxygen termination conditions. The higher barrier is attributed to oxygen-related states at the terminated surface, the lower barrier is associated with native defects.

Keywords: Diamond film; Schottky barrier diode; Deep trap; Fermi level pinning; Photoconductivity

1. Introduction

Diamond is considered as an ultimate semiconductor for high-frequency/high-power applications due to its high charge carrier mobility and saturation velocity, very high electrical breakdown field and excellent thermal conductivity (see e.g. Ref. [1,2]). Nowadays, single crystalline diamond can be grown with high structural quality and low impurity contamination by high pressure high temperature (HPHT) temperature gradient method (see e.g.

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Ref. [3,4]) or by various chemical vapor deposition (CVD) techniques (see e.g. Ref. [5,6]). Both HPHT and CVD diamond crystals and films can be doped to p-type by introducing B acceptors (see e.g. Ref. [3,4,7,8] and, to some extent, to n-type by introducing N or P donors (see e.g. Ref. [9,10]).

Preliminary work on diamond-based devices has demonstrated good promise for devise performance of high-voltage/high-power Schottky barrier diodes (SD) [1,8,9], UV light emitting diodes (LEDs) built on p-n junctions [10], high-power field effect transistors (FETs) on doped and hydrogen terminated diamond films [11,12], and of radiation detectors built on diamond (see e.g. Ref. [13] and references therein). However, not very much is known about the properties of Schottky barrier diodes prepared on CVD diamond films. In particular, the nature of the band bending in Schottky barrier diodes is not well understood. Strong discrepancies have been observed in the Schottky barrier heights determined from capacitance-voltage (C-V) measurements and from current-voltage (I-V) characteristics [14]. In what follows we tried to clarify the issue and show that such factors as the spatial non-uniformity of the Schottky barrier height across the diode area possibly caused by the Fermi level pinning by localized states could be at play.

2. Experimental

The samples studied in this paper were grown by microwave plasma enhanced CVD (MPE-CVD) [5] on boron doped synthetic diamond (IIb) substrates cut from diamond crystals prepared by temperature gradient pulling in the HPHT process. These crystals were doped by B to the concentration of ~10^{19} cm^{-3} by adding about 1 atomic percent of amorphous boron into the growth ambience [4, 15]. The crystals were sliced into 4×4×0.3 mm^3 slabs with the (001) orientation of the surface. Those were used as substrates in epitaxial growth. Before CVD deposition of diamond the substrates were mechanically polished, etched in a mixture of HCl and HNO_3, cleaned in organic solvents, and annealed in dry oxygen at 680 °C in order to remove the remnants of the graphitic phase. The thickness of the diamond layers was close to 30 µm. They were not intentionally doped, but some light B doping occurred from the B doped substrates via gas phase transport. The back ohmic contact to the HPHT substrate was prepared by magnetron sputtering of Ti(20 nm)/Pt(10 nm)/Au(100 nm) with subsequent annealing at 800 °C to form the transition layer of TiC. The Schottky barrier (SB) contact was prepared by magnetron sputtering of Pt through a shadow mask. The thickness of the contact was about 50 nm, and the diodes area was varied from 5×10^{-3} - 0.1 cm^2. Prior to the Schottky barrier diode deposition the surface was mechanically polished, chemically cleaned in $HCl+HNO_3$ and organic solvents and annealed in oxygen at 680 °C. The surface of the samples not covered by the Schottky barrier was passivated by Al_2O_3.

The grown films were characterized by current-voltage (I-V) and capacitance-voltage (C-V) measurements in the temperature range 85-400K, and by photocurrent and photocurrent spectra measurements. In spectral measurements, a set of high-power light-emitting diodes (LEDs) with optical power output near 100 mW and peak wavelength ranging from 660 nm to 365 nm was used. This provided spectral probing in the extrinsic wavelength range. For intrinsic excitation a deuterium UV lamp source with the peak wavelength of 200 nm was employed. The growth and characterizations for the HPHT diamond substrates were described in detail in earlier papers [4, 15].

3. Results and discussion

The major properties of the four studied diamond samples with Schottky barrier diodes are summarized in Table I. Three samples with numbers 1, 2, 3 in the table were basically grown in the same fashion and underwent the same surface preparation prior to the Pt Schottky barrier diodes deposition. They, however, differed by the area of the Schottky barrier diodes. Namely, samples 1 and 2 had relatively large area (0.04 cm^2) Schottky barrier diodes, while the area of the Schottky barrier diode on sample 3 was the lowest among all studied samples (0.005 cm^2).

Table 1. Properties of the studied samples.

Sample #	Thickness (µm)	Diode area (cm^2)	C-V concentration (cm^{-3})	C-V voltage intercept (V)	Ideality factor
1	25	0.04	4.6×10^{14}	2.1	1.1
2	25	0.04	5.0×10^{14}	2.2	1.1
3	36	0.005	5.6×10^{14}	2.1	1.1