Control of Schottky Barrier Heights to Diamond for Reducing Leakage Current

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Introduction

Schottky barrier diodes (SBD) are essential in power electronics, for example as free-wheeling diodes or in power rectifier applications. As a majority carrier device, the SBD has little to no reverse recovery and a low forward voltage drop in comparison to PN diodes, which enables more efficient circuits with lower losses; however, the reverse leakage current is relatively large. To address this issue in SiC, increasing the Schottky barrier height (ϕ_{SB}) has led to commercialized Schottky diodes with reduced leakage. Thus, in this study, the barrier height and reverse leakage in diamond is analyzed as a function of different contact metals (Ti and Mo), surface treatment (UV/ozone), and edge termination (field plate) in efforts to develop increasingly efficient high-voltage Schottky barrier diodes due to diamond's ideal material properties.

Device Structure Fabrication

To fabricate a p-type Schottky barrier diode, a 1.3 μm thick p- epilayer (boron concentration of ~5×10^{16} cm^{-3}) /2.84 μm p+ epilayer was grown on a (100)-oriented, 3° offcut, single-crystalline diamond substrate by MPCVD. Then, the diamond structure was cleaned, and oxygen terminated in a boiling mixture of 1:3 HNO_3:H_2SO_4. Ohmic contacts were formed by oxygen RIE plasma etching through the p- layer and e-beam evaporating Ti/Pt/Au contacts to the p+ epilayer, and the circular Schottky contacts were deposited directly on the p- layer (Fig. 1a). A subset of the diodes was exposed to 30 min of UV irradiation treatment with 0.5 L/min O_2 flow prior to Schottky contact deposition (Mo/O_3), and some were fabricated with a 40 μm field plate using 340 nm SiO_2 dielectric (Mo/O_3/FP).

Data/Results and Discussion

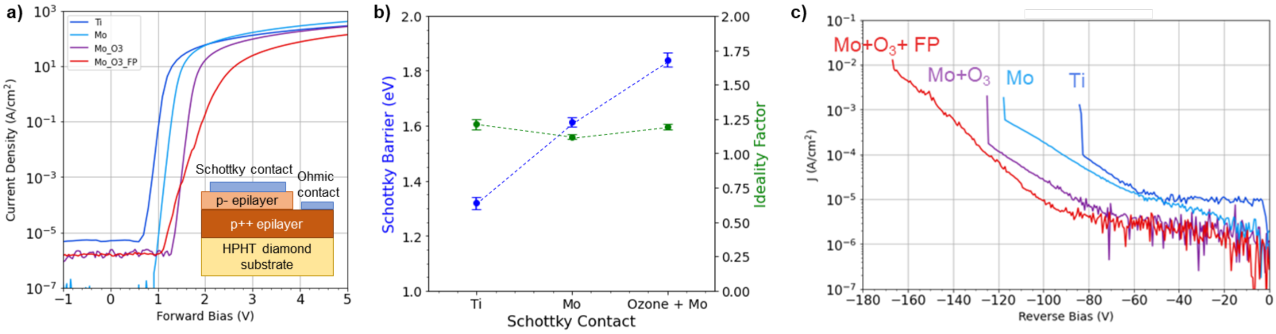

Figure 1a) Forward bias IV characteristics and schematic of pseudo-Schottky diamond diodes, b) Schottky barrier height and ideality factor, and c) reverse bias IV characteristics.

Fig. 1a depicts the DC forward bias current-voltage characteristics of the diodes. It can be observed that between Ti and Mo, the turn-on voltage shifts from <1 V to >1 V, and with O_3 treatment, the turn-on voltage further increases. This corresponds with the increasing trend of the Schottky barrier height (Fig. 1b), which was determined by fitting the exponential segment of the forward bias curve to the conventional thermionic emission model. The model also indicates a relatively low ideality factor in the non-field plated diodes.

Fig. 1c summarizes the reverse IV characteristics of all samples. On average, the leakage current was ~10 μA/cm^2 at low bias voltages, and eventually increased at higher reverse biases until reaching a sharp breakdown point. It can be observed that the leakage current was higher in diodes with lower ϕ_{SB} at the same reverse biases. Furthermore, for Ti, the breakdown voltage occurred at ~75 V, Mo at ~125 V, Mo/O_3 at ~150 V, and Mo/O_3/FP diode at ~170 V. Thus, we conclude that as ϕ_{SB} is increased, the leakage current is decreased, and breakdown voltage improved. The increased ϕ_{SB} from UV/ozone treatment is hypothesized to be due to increased oxygen termination of the diamond surface, which influences the diamond surface electron affinity and surface inhomogeneity. Furthermore, CV measurements indicated a 0.7 μm drift region thickness. Thus, the average estimated breakdown field of the Mo/O_3/FP diode was ~2.45 MV/cm as opposed to 1.78 MV/cm from the Mo Schottky diode, and a 37% increase in breakdown field was achieved.

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