Fabrication and characterization of n-SiC / p-diamond heterojunctions

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Abstract

This work reports the fabrication of diamond-SiC heterojunctions through deposition of p-type polycrystalline diamond films on n-type SiC by HFCVD. The quality of the films was analyzed by SEM and Raman spectroscopy. The rectifying behaviour of these heterojunctions was demonstrated with room temperature I-V measurements.

Introduction

SiC is a wide bandgap (WBG) material that provides a highly efficient energy conversion at high powers, outside the current realm of technology [1-4]. In particular, unique properties of the 4H-SiC poly-type include high critical electric field (3 MV/cm), large bandgap (3.2 eV), high saturation velocity (2×10^7 cm/s), high thermal conductivity (4.9 W/(cm K)) as well as good electron mobility (~1000 cm^2/Vs for //*c*-axis) [5], making it a material particularly suited to high power and high switching frequency applications. The unique electrical and thermal properties of diamond also make it a natural choice for high power and high temperature applications.

Semiconductor heterojunctions, such as those formed between p-type diamond / n-type SiC and vice versa, exhibit some useful electronic properties, associated with discontinuities present in the local band structure at the interface. The most important single property of a semiconductor heterojunction is the band line-up, i.e., the relative position in energy of the band-gaps in the two semiconductors. The line-up determines the conduction and valence band discontinuities and hence the effective barrier for electron or hole transport across the interface. Hence a deeper understanding of the SiC-diamond interface and the heterojunction is a fundamental requirement for the development of SiC-diamond devices.

Though the cost of commercially available epitaxial n/p type SiC wafers remains high, diamond films can be deposited using an economical and versatile process, namely, chemical vapour deposition (CVD), a technique thoroughly investigated in the last decades since first successful experiments by Eversole (1962) [6] and Derjaguin (1968) [7]. This process enables a precise and reproducible control of specific material properties important for particular applications. With more recent advances, both p and n-type diamond films can be grown, meaning that the desirable electronic properties exhibited by a few, very rare natural diamonds can now be achieved in an engineered diamond material [8-10].

From obtaining the first, optically transparent SiC contact on naturally occurring semiconducting diamond back in 1993 [11] to recent studies on the SiC-diamond Schottky heterojunctions [12], work on the SiC-diamond heterojunction has been sparse. Some highly-rectifying NCD/SiC heterojunctions with high forward current densities and on/off current ratios have been demonstrated. The reported curvature coefficient of 105 V^{-1} was among the highest known for a diode [13].

The quality of the diamond films is a key issue for power electronics applications as the device performance itself depends on the quality of grown diamond films and surface termination, metal/diamond junction characteristics and geometrical factors [14]. Hence a study of the variations in the heterojunction electrical behaviour heterojunction with the variation in diamond film properties (such as crystalline size and sp3-sp2 content) which in turn depend on the particular deposition parameters used during the CVD process is important and necessary.

This work explores the effect of novel nucleation procedure (NNP), a standard step in CVD process introduced by Rotter in 1991 [15], on the rectifying behaviour of p-type boron doped diamond (BDD) films and n-type 4H-SiC heterojunctions. NNP treatment enhances this behaviour: it leads to greater film uniformity, therefore, less defects at the interface and better electrical behaviour.

Experimental

In the present work, p-type BDD films were deposited on n-type 4H-SiC wafers, (purchased from Cree Inc. and laser diced to 25 mm^2 pieces) using hot filament CVD (HFCVD). Post cleaning, the samples were introduced into the HFCVD chamber and underwent pre-treatment (PT) under diamond growth conditions. Half of the samples were given the PT, and the other half underwent the next step without PT.

After PT, both categories of samples were "seeded" using an aqueous nano-diamond slurry, in an ultrasonic bath, for 30 minutes. The "PT+ seeding" steps constitute the NNP. Finally they were introduced into the HFCVD chamber under doped diamond growth conditions, details of which may be found elsewhere [16], for a duration of 4 hours, followed by an hour long cooling step. The boron doping source, boron oxide (B_2O_3) diluted in ethanol, was dragged by a constant Ar flow at different CH_4/H_2 gas ratios and system pressures. For all runs (PT and growth), the SiC samples were placed in the sample holder during filament carburization. Samples were then assessed under SEM (Hitachi SU70) and Raman spectroscopy (spectra were excited with an Ar+ laser, 514.5 nm, focused to a spot of 1 μm in diameter with an incident beam power of about 5 mW). Room temperature I-V characteristics of the devices were then measured.

Results and discussion

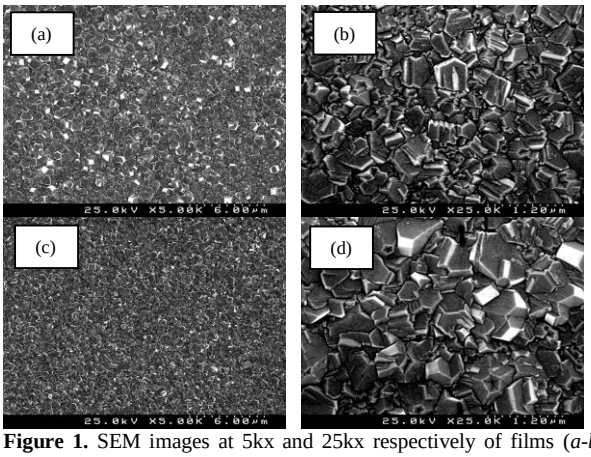

Figure 1. SEM images at 5kx and 25kx respectively of films (*a-b*) with no PT and (*c-d*) with PT

All samples analyzed by Raman spectroscopy showed characteristic diamond peak at 1332-1334 cm^{-1} (results not shown). The D and G bands were observed around 1350 and 1550 cm^{-1}, respectively.

SEM images showed that both categories of samples, with and without PT, had closed, highly adherent, polycrystalline diamond films, with crystals ranging from 100 nm to 1 µm in size, after a 4 hour deposition (Figure 1).

Rectifying behaviour of the p-n heterojunctions was observed in I-V measurements (Figure 2), proving that B atoms were successfully incorporated in the diamond lattice. In all cases, PT samples showed superior rectifying behaviour and lower reverse currents than no PT samples. This means that, as expected, the pre-treatment improves the homogeneity of the diamond / SiC interface. However, in both cases leakage currents remain high. This may have two causes: not efficient cleaning of the SiC surface prior to diamond deposition or the deposition of non-sp3 carbon during filament carburization.

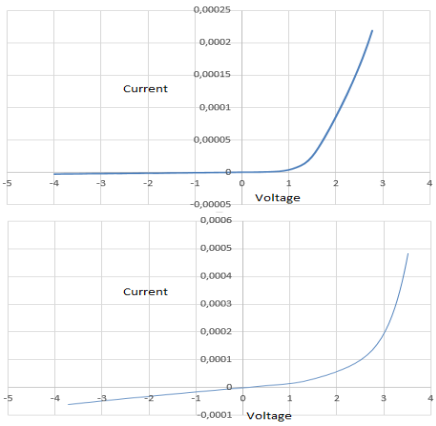

Figure 2. IV measurements of sample (*top*) with PT and (*bottom*) without PT

Future work involves the use of a different and more efficient cleaning procedure, to remove any unwanted molecules from the SiC surface prior to diamond deposition, and the use of a different HFCVD system for the PT step.

Conclusions

SiC-diamond have been fabricated and analyzed. The results have highlighted a number of issues that need to be solved, with regards to improving the quality of the heterojunction interface as well as its theoretical modelling. In order to begin improving the interface quality, the HFCVD process, must be fine-tuned to obtain not only good quality films but a fine nucleation interface for the diamond as well.

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