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Comparison of the electrical behavior of Schottky diodes built on the nucleation and growth surfaces of polycrystalline diamond

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Abstract

In this work free-standing polycrystalline diamond was used to build Schottky diodes both on nucleation and growth surface of different films, in surface contact geometry, using gold and aluminum electrodes. The surface films were characterized by micro-Raman spectroscopy and Atomic Force Microscopy. The current–voltage characteristics of the devices were measured in a temperature range from 50 K to room temperature. The diodes showed a barrier height, attributed to the interface grain–metal, ranging from 1.26 to 1.74 V and an ideality factor from 1.4 to 1.8. All the diodes revealed the presence of deep states of energy, and its density close to the Fermi level ranges from 2×10^{12} to 8×10^{16} eV^{-1} cm^{-3}. These different characteristics were then related with both the films quality and the surface. The hypothesis of using the nucleation surface for building electronic devices is discussed.

Keywords: Diamond film; Electrical properties characterization; Electrical properties; Schottky diodes

1. Introduction

Diamond films have unique properties that make them attractive for mechanical and electronic applications. The thermal conductivity, in particular, turns them a promising material for high power electronics. Both homoepitaxial and polycrystalline films have already been used to fabricate promising power devices [1,2]. Polycrystalline films have also been used to build superficial MESFET devices [3] and other devices [4] with some excellent characteristics, as high rectification ratios (>200) and a breakdown voltage of 500 V.

While homoepitaxial diamond is a very expensive material, and is available in a very limited area, polycrystalline diamond can be easily grown in large silicon wafers by the standard chemical vapor deposition (CVD) methods. Nevertheless, it has some additional problems. Its intrinsic polycrystalline nature, with some defects arising from the grain boundaries, is responsible for the creation of energy states that may degrade the electrical behavior of the devices [5,6]. In addition, the surface roughness may become a problem for thicker films, promoting the oxide disruption in metal-oxide based devices. Therefore, a study of the roughness and surface defects influence on metal–polycrystalline diamond carrier injection is necessary in order to plan and develop more efficient devices.

In order to get an insight of what happens with the carriers when an external applied field is applied, both surface and bulk conduction mechanisms were studied in this work. Appropriate metallic contacts were evaporated on both sides of a free-standing MPCVD diamond film. Both transverse and longitudinal fields were then applied and the current measured. The relationship of electrical behavior found and surface structural defects are also studied. An attempt to establish a model is made.

2. Experimental

The diamond film was grown on n-type silicon substrate in an AsTex PDS-18 MPCVD system. The growth parameters were 3700 W, 110 Torr, 450 sccm H_2, 10 sccm CH_4 and 1 sccm O_2. After deposition, the Si substrate was removed in an HF solution. The film's thickness ranges from 12 to 15 μm.

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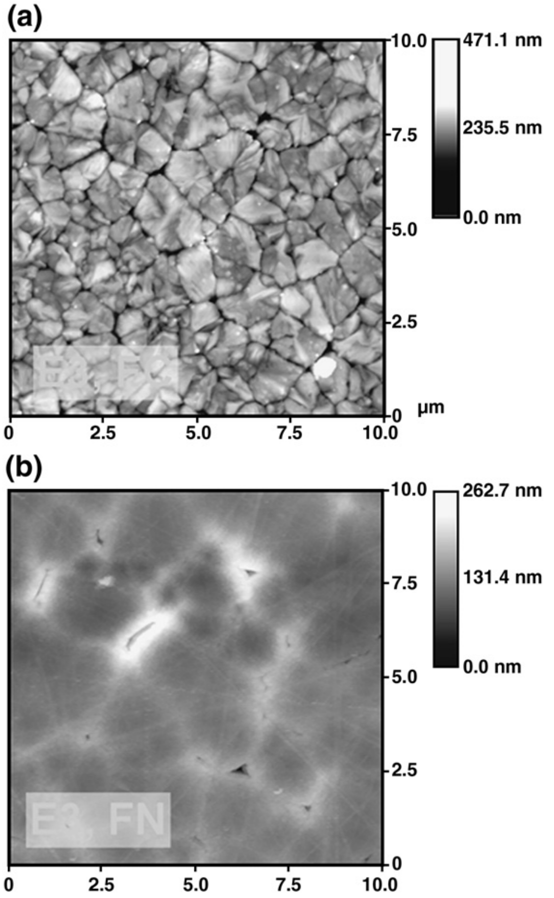

Fig. 1. Atomic Force Microscopy images from the (a) growth and (b) nucleation surfaces of a free-standing polycrystalline diamond used for building the Schottky diodes.

Gold and aluminum 1.5 mm^2-rectangular contacts were evaporated in a clean room both on the nucleation and growth surfaces of the film.

Micro-Raman spectroscopy was obtained in a Renishaw 2000 spectrometer with a He–Ne laser line for excitation. The DC current vs. applied voltage measurements (*I*–*V*) were obtained using a Keithley 2410 SourceMeter with a resolution of 1 pA. The measurements were made in high vacuum and the temperature was held constant within 0.2 K from 35 to 300 K by means of a closed cycle helium cryostat.

3. Results and discussion

Fig. 1 shows the AFM (for a typical sample) for both growth and nucleation surfaces. The main difference is the usual typical low roughness in the nucleation surface. The Raman spectra for both surfaces are shown in Fig. 2. Both spectra are very similar showing common Raman bands associated with hydrogen related defects (1188 cm^{-1}, 1247 cm^{-1} and 1451 cm^{-1}) and graphite (D and G — 1380 cm^{-1} and 1570 cm^{-1}). Amorphous carbon (1510 cm^{-1}) is also observed. Using the Raman data it's possible to obtain an estimate of the pure diamond percentage in each surface [7]. In a nucleation surface the diamond phase ranges from 95.7% to 98.3% while in a growth surface it is from 97.0% to 98.8%. Although very similar, all samples have a higher diamond phase percentage in the growth surface. In this surface we can observe perfect diamond microcrystals and the effects of a more pronounced hydrogen gas etching can explain these results.

In Fig. 3 the *I*–*V* curve with temperature for each type of diode is shown. In this case two extreme situations are exhibited. All devices present a more high rectification rate when the nucleation surface is used to build the electrodes. While in the growth surface the rectification ratio (@ ±4 V) ranges from near 8 to near 60, in the nucleation surface the interval is from near 70 to 200. As a first explanation, the roughness can play an important role in all the electrical carrier injection throughout the aluminum electrode. The temperature dependence reveals a small difference in the activation energy. The diodes built in the nucleation surface have a systematically higher activation energy (near 120–130 meV) in opposite to the values near 100–110 meV for the diodes built in the growth surface. Curiously the diodes built in the surface with a relatively high non-diamond defects density present a higher activation energy, suggesting that the defects distribution inside the band gap and near the Fermi level is different.

Using a methodology described elsewhere [8] the heterogeneous Schottky barrier model was used in order to estimate the apparent Schottky Barrier Height (SBH) and ideality factor of our devices. We found that the highest SBH (~ 1.8 V) and the lowest ideality factor (~ 1.4) occur when the nucleation surface is used to built the diodes. In opposite, the lowest SBH (~ 1.4 V) and the highest ideality (~ 1.8) are found on devices built on the growth surface. These results, although not much different, suggest that the nucleation surface provides better Schottky diodes performance.

Concerning the bulk conduction, the electrical behavior can be treated in SCLC [9] or Poole–Frenkel [10] frameworks. In our samples the behavior seems to be comparable to that expected for a SCLC trap-dependent. Following the Child Law [11] a trap filled limit around an electrical field near 100 V/cm can be observed and an increase of current with a quadratic power in applied voltage is also observed (when the trap levels

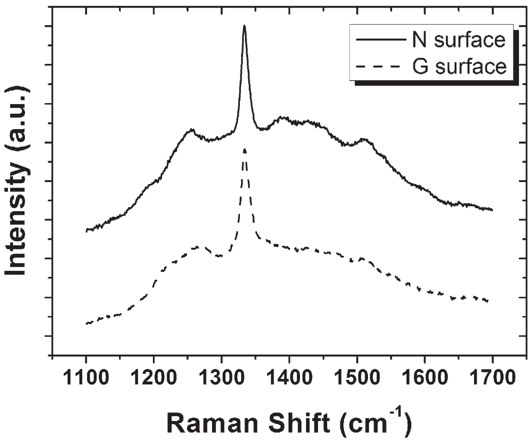

Fig. 2. Micro-Raman spectra of the growth (a) and nucleation (b) surfaces of the sample. Room temperature.