Growth and Characterization of Synthetic Diamond

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Abstract:
Diamond exhibits superior material properties such as high breakdown field, high saturation velocity, high carrier mobilities, optical transparency over a wide transmission range, and the highest thermal conductivity of all materials [1]. These properties make it desirable to deliver future high quality electronic devices and detectors. Hot filament chemical vapor deposition (HFCVD) was used to grow polycrystalline diamond on various substrates. Atomic force microscopy (AFM) and scanning electron microscopy (SEM) confirmed diamond growth due to the resulting diamond facets on the substrate surfaces. Diamond grown on diamond yielded the highest grain size. A Raman shift value of 1332 cm$^{-1}$ confirmed the presence of high quality polycrystalline diamond. Titanium-gold (Ti-Au) ohmic contacts were fabricated and annealed at 950°C for ten minutes in an H$_2$/Ar ambient environment. Linear-IV curves confirmed ohmic behavior. Nickel (Ni) was used as a Schottky contact and its IV curve was nonlinear as expected. Electrical properties of selected diamond films were also analyzed using the Hall effect. Diamond grown on 3C-SiC yielded a mobility of 221 cm$^2$/V·s and carrier concentration of 7.2E16 cm$^3$.

Introduction:
The first “manmade diamond” was created by General Electric in 1956, using a process called high pressure high temperature (HPHT). This method imitates natural diamond formation, but with carefully selected input materials to catalyze crystal growth [2]. In recent years, chemical vapor deposition (CVD) has been used to produce diamond from a heated mixture of hydrocarbon gas and hydrogen in a vacuum chamber at very low pressures. The method is less expensive and more suitable for diamond growth in the semiconductor industry. This project employed a hot filament CVD system to grow synthetic diamond on various substrates.

Experimental Procedure:
Silicon dioxide (SiO$_2$)-coated Si, 3C-SiC coated Si, and 6H-SiC were seeded with nanodiamond slurry solution in an ultrasonic bath for ten minutes. This was done in order to create nucleation centers for diamond growth. The samples were then loaded in the HFCVD reactor. Also, the backside of a nanocrystalline diamond layer removed from silicon was loaded. The filament-to-sample gap was set to 20 mm, and hydrogen (H), methane (CH$_4$), and argon (Ar) gases were introduced. The H$_2$ flow rate was set to 60 sccm and the CH$_4$ flow rate was set to 1 sccm.

When the process pressure (20 torr) and the sample temperature (750°C) were reached, the filament temperature was raised to 2300°C. Growth of diamond was then initiated. After growth, the samples were removed and characterized. Titanium (Ti, 20 nm) and gold (Au, 150 nm) were deposited by electron-beam evaporation to fabricate ohmic contacts while Ni (100 nm) was deposited to make the Schottky contacts. The ohmic contacts were annealed at 950°C for ten minutes in an H$_2$/Ar ambient environment using a tube furnace.

Figures 1 shows the top view of the created device. A Hall effect setup was used to measure mobility, resistivity, and carrier concentration.
Results and Conclusions:
Diamond growth using HFCVD was conducted successfully, as seen in the resulting polycrystalline facets shown on SEM and AFM images. Diamond grown on diamond yielded the largest grain size (~ 7 µm), compared to sizes of 5 µm (Si) and 4 µm (6H-SiC and 3C-SiC) as shown in Figures 2 and 3. Larger grain sizes should translate into improved carrier transport.

Diamond grown on all substrates had a thickness of 12.3 µm. Roughness did not play a huge role in the results since the AFM revealed similar roughness (210-254 nm) for diamond on the various substrates. A Raman spectroscopy graph confirmed the presence of high quality polycrystalline diamond growth due to the diamond peak value of 1332 cm\(^{-1}\) (Figure 4). The full-width half-maximum value was measured to be 15 cm\(^{-1}\), close to diamond’s true value. Ti-Au ohmic and Ni Schottky contacts were successfully fabricated with linear and nonlinear curves, respectively, although the Schottky behavior was not ideal. Hall effect measured a mobility of 221 cm\(^2\)/V-s, resistivity of 0.39 Ω-cm, and carrier concentration of 7.2E16 cm\(^{-3}\). These measurements are similar to previously published data.

Successful diamond growth and electrical fabrication indicates the potential use of these materials in engineering applications. This project is significant for promoting further research of diamond growth and characterization, especially since this novel material has been complex to study over the years.

Future Work:
The barrier heights of various metals on diamond by internal photoemission will need to take place in the future in order to further analyze metal-diamond interfaces in fabricated diamond devices. The doping of diamond needs to be investigated as well. In addition, research must be done on finding ways to grow single crystal diamond in order to generate more advanced electronics. It may also be necessary to see how different metal contacts play a role in the quality of electrical devices.

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