Electronic Properties and Applications of Ultrananocrystalline Diamond

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Diamond has a number of properties that make it ideal for a high performance, high temperature device material. However, whilst the p-type doping of diamond can be readily achieved and has even been made commercial, n-type doping with low activation energy has remained elusive. Substitutional doping with Phosphorus has produced n-type doping but with the very high activation energy of 0.6eV, the only other confirmed candidate being nitrogen at 1.7eV. Co – doping remains controversial, with recent results suggesting Boron – Deuterium complexes as electron donors, but with high activation and low thermal stability.

Ultrananocrystalline diamond is a fine grain (3-5nm) material which is grown from an Ar/CH_4 plasma rather than the H_2/CH_4 chemistry associated with conventional diamond growth. The nanostructure of this material yields a number of unique properties and interesting electronic characteristics. For instance, the addition of nitrogen into the gas phase results in n-type conductivity with low activation energy, in stark contrast to the case of conventional diamond growth. The control of the nitrogen concentration in the gas phase results in control over the materials conductivity, up to near metallic conduction.

This work details fundamental electrical measurements on this material as a function of nitrogen concentration during growth. Hall measurements show true n-type conductivity, confirmed by Seebeck measurements. Increasing nitrogen content in the gas phase results in increased conductivity, with a hall signal becoming measurable at around 10% nitrogen.

In a recent collaboration with the research group of Professor Kohn at the University of Ulm, we have been able to fabricate a novel heterostructure diode, by growing n-type ultrananocrystalline diamond on p-type boron doped single crystal diamond. In this way we are able to take advantage of the n-type nature of the ultrananocrystalline diamond and the blocking capability and high breakdown field strength of the single crystal diamond, which can be readily p-type doped. The resulting structure shows high rectification ratios from room temperature to $1000^{\circ}C$.

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