Defect Control in Diamond Epitaxy for High Temperature Electronics

Franz A. Koeck[1], Maitreya Dutta[2,3], Raghuraj Hathwar[2], Mehdi Saremi[2], Xingye Wang[1], Brianna Eller[1], Manpuneet Kaur Benipal[1], Srabanti Chowdhury[2,3], Stephen M. Goodnick[2], and Robert J. Nemanich[1*]

[1] Department of Physics, Arizona State University, Tempe, AZ 85287-1504
[2] School of Electrical, Computer and Energy Engineering, ASU, Tempe, AZ 85287-5706
[3] Dept of Electrical, Computer and Energy Engineering, Univ. of California-Davis, Davis, CA 95616
*Email: robert.nemanich@asu.edu

There is growing worldwide interest in CVD diamond materials for future high power electronics applications that include power system distribution, electric vehicles and motor control. The properties of diamond that contribute to its value in power electronics include high electron and hole mobilities (>2000 cm^2/V-s), high breakdown field (10 MV/cm), highest thermal conductivity, and low dielectric constant. Besides, as a group IV elemental semiconductor, problems associated with anti-site structural defects in III-V materials do not occur. Moreover, diamond has a single polytype – diamond cubic, which offers improved stability compared to other materials such as silicon carbide.

There has been notable progress on the development of single crystal diamond substrates and with the use of standard microfabrication processes to fabricate diamond devices. However, to fabricate practical devices, high quality epitaxial growth of low defect, high purity intrinsic, p-type and n-type diamond layers must be achieved.

A crucial aspect of fabricating devices is precise control of phosphorus incorporation during homoepitaxial growth. In our laboratory phosphorus doping is achieved using trimethylphosphine (TMP) in a microwave plasma CVD system. For P-doped layers on (111) diamond, results are presented that show the doping concentration can be varied by careful control of the substrate temperature and the TMP gas phase concentration. Utilization of a dual-wavelength pyrometer accurately resolves the surface temperature of the diamond substrate which is only heated by the plasma discharge. For (100) surfaces, P incorporation either shows a very low incorporation efficiency or a very low growth rate. To overcome these limitations a pulsed growth approach is presented which results in a P-incorporation density greater than 1E18 cm-3.

High breakdown voltage devices require low defect, high purity intrinsic diamond layer growth. Results are presented which establish that accurate separation of the plasma discharge from the substrate surface can lead to an adequate growth rate and a substantial reduction in surface defect formation.

The temperature dependence of PIN diodes fabricated using diamond epitaxy have been measured to >300°C. The measurements showed that in (100) diodes the n-type layer is fully depleted and transport is limited by thermionic emission, whereas on (111) the n-type nature and bipolar transport is confirmed with the observation of continuous light emission at forward bias. The simulation program has been used to project the high frequency operation of a BJT. The simulation predicted a nearly constant ft of ~8 GHz as a function of temperature to 500°C.

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