Temperature Dependence of Boron Doping Efficiency

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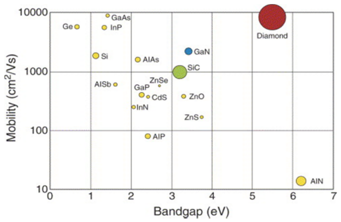
INTRODUCTION

With many superior physical and electronic properties, diamond is an ideal candidate for many materials applications. Diamond has enormous untapped potential in electronics, where its high breakdown voltage and wide bandgap would make it particularly well suited to high-temperature and high-power devices, such as boron doped *p*-type diamond Schottky-barrier diodes.



The graph above shows the combined carrier mobility (electron and hole mobility) of a number of semiconductor materials. The size of the dots is proportional to the thermal conductivity of the materials [Image credit: Element Six]

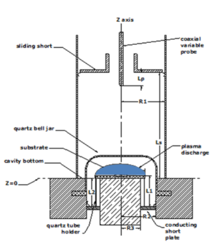
Vertical Schottky Barrier Diode Architecture

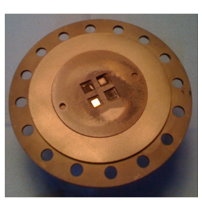
Free-standing, heavily-doped (boron concentrations of > 10^{20} cm^{-3}) *p*-type substrates are a precondition for the higher-power vertical diode architectures, and reliably producing these highly-doped substrates will require high growth rates to reduce growth time, and high doping efficiency from boron in the plasma feedgas to the boron incorporated in the grown crystal.

This work is part of an ongoing effort to deposit high-quality boron-doped single crystal diamond by Microwave Plasma Assisted Chemical Vapor Deposition and characterize the films for electronic applications

DEPOSITION SYSTEM

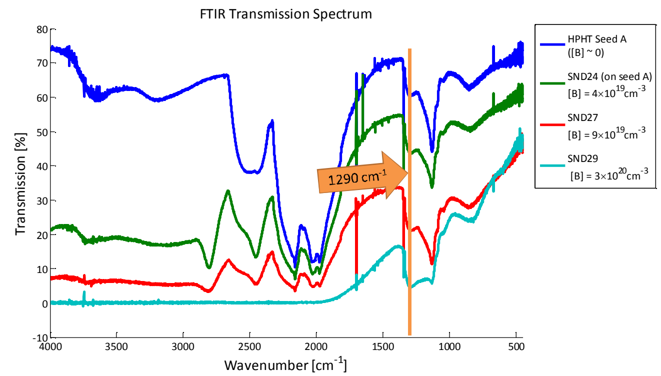
Homoepitaxial doped diamond films are grown by microwave plasma chemical vapor deposition (MPCVD) on 3.5 mm x 3.5 mm high pressure, high temperature (HPHT) diamond substrates with gas chemistries containing hydrogen, methane, and diborane. The MPCVD reactor [1] operates at 2.45 GHz with a molybdenum substrate holder that is water cooled. The seed substrates were acid cleaned and hydrogen plasma etched before deposition. The temperature of the sample during growth is measured by optical pyrometer, and reported here as the set-point temperature to which the input microwave power (and therefore plasma density) was manipulated to achieve.



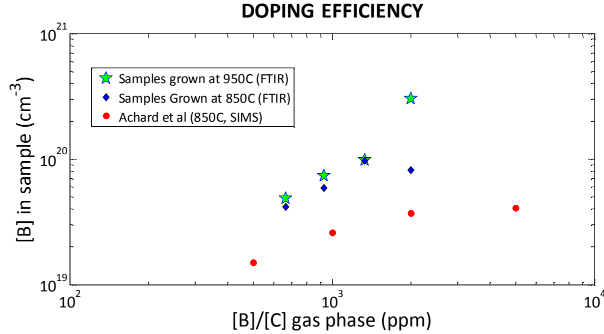


DETERMINATION OF BORON CONCENTRATION - FTIR

One-phonon absorption requires a defect to break the symmetry of the intrinsic diamond lattice. For samples with [B] < 10^{18} cm^{-3}, the one phonon absorption region is dominated by nitrogen absorption features. As boron concentration increases, the boron induced one-phonon absorption becomes the dominant feature at 1290 cm^{-1} (160 meV), and can be used to determine the boron concentration for heavily doped samples, using the relation given in Davies [3]: $[B](cm^{-3}) = 2.13 \times 10^{17} \alpha(1290cm^{-1})(cm^{-1})$



DOPING EFFICIENCY

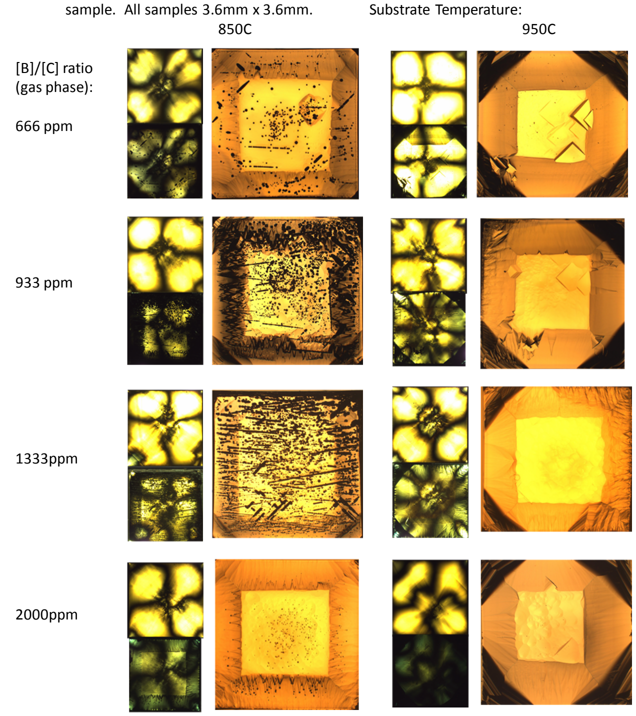


Doping efficiency is shown above graphically for samples of this work grown at approximately 950C, those grown at approximately 850C, and results from the recent literature, which were reported to be grown at 850C with the boron concentration determined by SIMS. The samples grown at 950C show a higher doping efficiency than those grown at 850C for the same reactor feedgas chemistry. Work done on polycrystalline diamond films has shown that the rate of incorporation of the boron dopant into the diamond lattice is dependent on the temperature of the substrate during growth [5], and a similar relationship may also hold for single crystal diamond growth.

Samples grown at 950C show a slightly higher doping efficiency than those grown at 850C

EFFECT OF GROWTH TEMPERATURE ON DEFECT MORPHOLOGY

Samples are shown with birefringence images with equal exposure of the substrate before (top) and after (bottom) as the small images next to the optical micrograph of the grown sample. All samples 3.6mm x 3.6mm. Substrate Temperature:



Samples grown at 950C show fewer and morphologically different defects than those grown at 850C

SUMMARY AND CONCLUSIONS

- Samples of this work show a higher doping efficiency than the saturation limit proposed by Achard *et al* [4], possibly due to the different methods of determinng the boron concentration. Samples grown at 850C show slightly lower doping efficiency than those at 950C, which suggests a temperature dependence to the doping efficiency.
- The defect morphology differs between the samples grown at 950C and those grown at 850C.
- With a higher doping efficiency and lower defect density, 950C is a promising substrate growth temperature for thick heavily doped boron films for electronic applications

References:
[1] Kuo and Asmussen, *Diam. Rel. Mater.* **6**, (1997) 1097. [2] Gheeraert *et al. Diam. and Rel. Mater.* **7** (1998) 1509. [3] Davies in: *The Chemistry and Physics of Carbon,* (1977). [4] J. Achard, *et al. Diam. and Rel. Mater.*, **20** (2011) 145. [5] H. Li, T. Zhang, L. Li, X. Lu, B. Li, Z. Jin, and G. Zou, J. Crystal Growth, **312,** 1986 (2010) [6] S. N. Demlow, I. Berkun, M. Becker, T. Hogan, and T. A. Grotjohn, *MRS Proc*, **1395**, (2012).