

Pulsed Gas Mixtures for Sharp Doping Transitions in Diamond Multilayers

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Introduction Sharp transitions from heavily boron-doped (p^+ , $[B] \geq 5 \times 10^{20} \text{ cm}^{-3}$) to lightly boron-doped (p^- , $[B] \leq 10^{17} \text{ cm}^{-3}$) diamond films organized in multilayers (ML) can be the key technology to build power transistors [1], or optical systems [2]. The most important challenge concern the MPCVD, which must guarantee reproducible boron concentrations and films thicknesses in the ML deposition process. In this study, we focused on the effects of oxygen and boron pluses injections in the gas mixture to shape doping transitions in ML.

Experimental details Diamond samples have been exposed to plasma discharges in our MPCVD chamber fed with trimethylboron (TMB), CH_4 , O_2 , and H_2 . The plasma composition has been analyzed by optical emission spectroscopy (OES). We followed the intensity of OH^* (308 nm), BH^* (433 nm), and C_2^* (515 nm) emission peaks via a miniature spectrometer (USB2000+, Ocean Optics) connected to an optical fiber located at 12 cm of the sample.

The ML deposition process has been divided in six steps, as follow: #1 p^- deposition with $\text{H}_2/\text{CH}_4/\text{O}_2$ (98.8:1:0.2), #2 rinsing with H_2/O_2 (99.8:0.2), #3 pulse of H_2/TMB (99.9:0.1), #4 p^+ deposition, #5 pulse of O_2 , #6 same rinsing as #2. Total gas flow rate, MPCVD chamber pressure, and microwave power were resp. 250 sccm, 140 Torr, and 1.4 kW.

Results & discussions Proportionality between the intensity of C_2^* and deposition rate, and between the intensity of BH^* and B/C in feed gas have been experimentally confirmed. We also demonstrated etchant features of the plasma, in absence of O_2 , characterized by a non-linear intensity of BH^* when B/C ratio was over 80,000 ppm with a carbon fraction below 0.5% in feed gas [3]. Etching creates etch pits at the diamond surface, which break up sharp doping transitions and flat surfaces.

References

- [1] A. Fiori et al., *Appl. Phys. Express* **6** (2013), 045801.
- [2] A. Fiori et al., *Appl. Phys. Lett.* **105** (2014), 081109.
- [3] A. Fiori et al., *Diamond Relat. Mater.* (in preparation).

Consequently, if the concentration of carbon in the gas is dropping faster than boron residual during a rinsing step, then etching features are observed, and smooth slopes in doping transitions can be expected. We suppose that boron oxide precipitates and stay away from the plasma and the sample. The injection duration and flow rate of O_2 must be precisely fit to react with residual boron only, because a possible excess of O_2 in the gas might etch diamond too.

Fig. 1a) shows the SIMS boron profile of a diamond ML, and Fig. 1b) displays the corresponding time-resolved OES, plotted with a reversed timeline for a direct comparison between process steps and SIMS boron profile. In this experiment, steps #3 and #5 had the same injection duration of 18 seconds, and the equivalent thickness of doping transitions were resp. denoted δ^+ and δ^- in Fig. 1a). Step #4 consisted in the injection of $\text{H}_2/\text{CH}_4/\text{TMB}$ (93.94:6:0.06) during 10 minutes. The pulsed injection of TMB (#3) rapidly increased the BH^* intensity. At the opposite, the injection of O_2 (#5) made BH^* and C_2^* intensities to fall. However, the thickness of corresponding doping transitions were about 110 nm and 55 nm, for resp. δ^+ and δ^- .

The pulsed injection of TMB gave a doping slope two times smoother than the transition following the O_2 pulsed injection, but in both cases, the response of the BH^* intensity was quick. This discrepancy between SIMS boron profile and OES data pointed out the different kinetics of chemical reactions at the diamond surface and inside the plasma discharge.

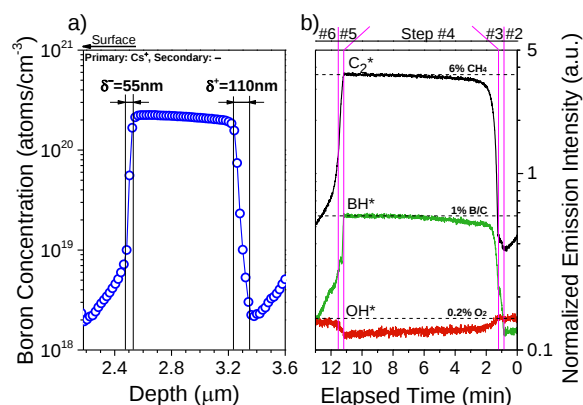


Fig. 1. a) Boron SIMS profile, and b) corresponding time-resolved OES (C_2^* , BH^* , and OH^*).