Controlled Lightly Phosphorus Doped Diamond Homoepitaxy

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1. Introduction

Phosphorus doping has emerged as the principal approach for the growth of n-type diamond. While highly phosphorus doped material is preferred for electrical contacts, lightly doped diamond can provide an approach for new and improved devices. With lightly doped films mobility controlled epilayers can be prepared. Furthermore, quantum-related devices that are based on solid-state spins could be advanced through controlled low (phosphorus) doping.

We present research that demonstrated the viability of in situ and near real-time control of phosphorus doping through the utilization of residual gas analysis (RGA). A custom design enabled the RGA (operating at 10^{-5} Torr) for real time measurement of chamber species during deposition at 100 Torr.

2. Experimental and Results

Homoepitaxial phosphorus doped diamond films were grown on CVD type IIa substrates with (111) surface orientation. An ASTeX style plasma-enhanced chemical vapor deposition system was employed with a custom built, water-cooled sample stage. With a dry pumping solution a base pressure of about 3×10^{-8} Torr was achieved. A 5 kW microwave source was used for plasma generation where process gases included hydrogen, methane and a 200 ppm trimethylphosphine in hydrogen (TMP/H_2) gas mixture as the dopant source. Temperature controlled gas delivery allowed accurate dosing of the dopant into the CVD reactor. An RGA component was utilized to measure in near real-time the composition of the gas chemistry during the doped diamond growth process. From several deposition runs with varying TMP/H_2 flow rates, a comparison with secondary ion mass spectroscopy (SIMS) identified the PH (32 amu) species as an indicator for the doping concentration. With a microwave power of 2500 W, a deposition pressure of 80 Torr, and a CH_4/H_2 ratio of 1% a significant growth rate of about 2 μm/hr was achieved. A controlled PH pressure of about 7×10^{-12} Torr effected a phosphorus incorporation of about 8×10^{16} cm^{-3} as shown in Figure 1. The nitrogen incorporation for the same epilayer was about 3-4$\times 10^{16}$ cm^{-3} as measured by SIMS. Low and ultra-low phosphorus doping was observed to be advantageously affected by a pre-growth process that included a pure hydrogen plasma and monitoring of the residual PH level in the reactor. We will elaborate on the growth process and control of the doping and impurity incorporation utilizing near real-time RGA instrumentation.

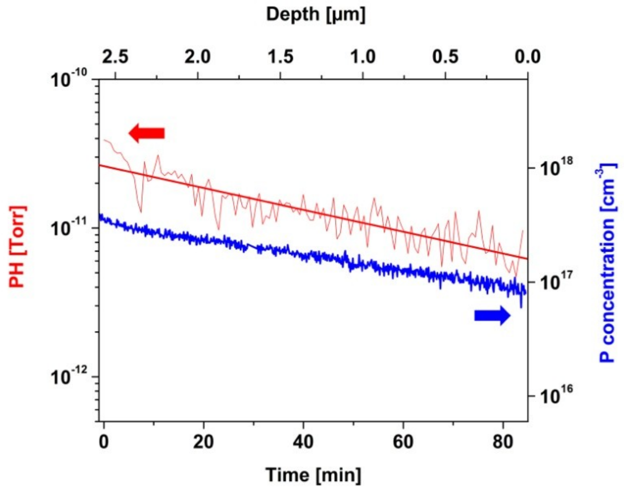

Figure 1. RGA measured PH pressure (red line) and the phosphorus incorporation (blue line) from SIMS of a homoepitaxial phosphorus doped diamond film.

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