Investigation of the Scaling and Control of Microwave Discharges for Diamond Deposition on Substrates of Various Sizes and Shapes

T. A. Grotjohn, J. Asmussen, G. M. Swain and S. Zuo
Michigan State University & Fraunhofer USA Center for Coatings and Laser Applications
East Lansing, MI 48824

A. L. Vikharev
Inst. of Applied Physics, Nizhny Novgorod, Russia

The scaling and control of the microwave plasmas for deposition of diamond is reported in this paper. Two specific questions addressed are (1) how do the plasma properties for diamond deposition scale as the discharge size changes? and (2) how can the plasma discharge be controlled to deposit diamond on irregular shapes?

In this study experiments and computational models have been used to map out the microwave power density of diamond deposition discharges versus various operating parameters. The microwave reactors studied included microwave resonant cavity based systems using predominantly hydrogen based discharges. The experimental power densities were measured as the microwave power absorbed by the discharge divided by the discharge volume as determined from photographs of the discharge. The absorbed power was determined by measuring the incident microwave power and the reflected microwave power from the microwave reactor using calibrated directional couplers and power meters. The data showing the power density versus pressure for various plasma discharge sizes is shown in Fig. 1. The substrate size for the various discharge sizes range from about 2.5 cm diameter substrates for the small discharge size to 15-20 cm diameter substrates for the large discharge size. Fig. 1 shows that as the discharge size increases the power density decreases significantly at a given pressure. Other properties of the discharge versus discharge size will be also presented including plasma gas temperature, atomic hydrogen concentration, and plasma density.

The second portion of this presentation is to examine the behavior of the microwave diamond deposition reactor as diamond deposition is done on irregular shapes such as tools, grids and meshes. This presentation will discuss specific reactor configurations and operating techniques for deposition on irregular shapes. A challenge in depositing on irregular shapes is minimizing/controlling localized heating of the substrate while using a high enough deposition pressure to get useful deposition rates. One technique that allows the deposition pressure to be increased (hence getting good deposition rates) while distributing the plasma over a larger volume to reduce localized heating is to use a pulsed regime for the microwave power coupled into the discharge. The influence of the pulsed regime as compared to the CW regime is studied with respect to changes in the deposition rate and changes in the temperature of the deposition surface. Results show a constant mean specific microwave power and constant substrate temperature in a thermally floating reactor configuration can be maintained in the pulsed regime by increasing the pressure as the duty cycle decreases. Hence, for substrates that require a thermally floating reactor configuration (such as irregular-shaped, non-flat substrates and low thermal conductivity substrates, for which no active substrate cooling or heating can be used) the pulsed regime can be used to increase the deposition pressure and hence the deposition rate while minimizing any overheating the substrate.

Fig. 2 shows data comparing the effect of the pulsed and CW regimes on the substrate temperature in a thermally floating substrate configuration for a microwave plasma reactor. In this set of experiments the substrate used was a 10 cm silicon wafer sitting on a molybdenum substrate holder that was neither actively heated or cooled, i.e. the heating of the substrate and substrate holder occurred do to heat flux from only the plasma discharge. The substrate temperature was monitored with an optical pyrometer. The deposition condition used was a hydrogen flow rate of 400 sccm and a methane flow rate of 6 sccm. The plasma discharge was operated with microwave power levels in a range such that the discharge created fully covered the 10 cm substrate without being so large in volume that it touched the discharge chamber walls. Fig. 2 shows the substrate temperature difference between the CW and pulsed regimes when the reactor is operated at the same mean absorbed microwave power into the discharge. The data is shown for both 40 and 25 Torr. The indicated trend is that as the duty cycle decreases, the substrate temperature difference between the CW and pulsed regimes increases. It should also be noted that as the pulsed regime duty cycle decreases, while holding the mean power constant, the peak microwave power increases as well as the plasma volume. So, it is possible by adjusting the pulsed regime parameters to maintain a constant deposition area and substrate temperature while increasing the pressure.

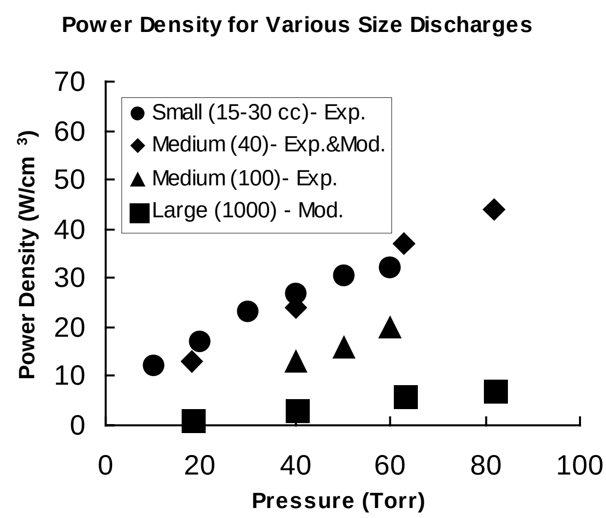

Fig. 1: Discharge power density versus pressure and discharge volume (in cm^3).

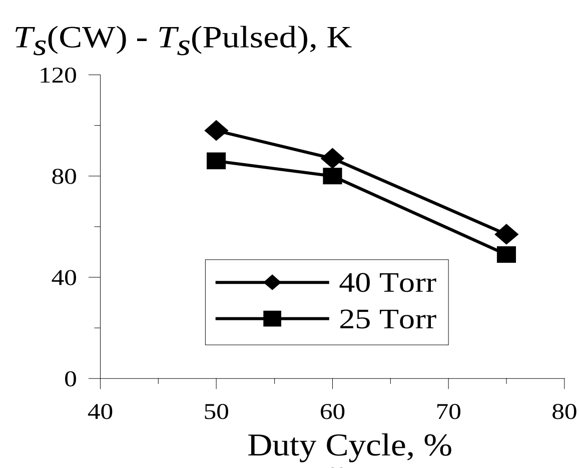

Fig. 2: Substrate temperature difference between CW and pulsed operating regimes.