MICROWAVE PLASMA REACTOR DESIGN FOR DIAMOND SYNTHESIS AT HIGH PRESSURES AND HIGH POWER DENSITIES

J. Asmussen[1,2] K.W. Hemawan[1], J. Lu,[1] Y. Gu,[1]
and T. A. Grotjohn,[1]
[1]*Michigan State University, East Lansing, MI 48824 USA*
[2]*Fraunhofer USA, Center for Coatings and Laser Applications, East Lansing, MI 48824 USA*

It is now widely recognized the CVD synthesized diamond quality and growth rates can be improved by using high power density microwave discharges operating at pressures above 180 Torr. However at high pressures these discharges separate from the walls of the discharge chamber and become freely floating taking on shapes that are related to the shape of the impressed electromagnetic fields. Discharges can even move about the discharge chamber as they react to buoyant forces and to convective forces caused by the gas flows. Thus at high pressures microwave discharges behave very differently from the typical low pressure discharge and require new methods of discharge control and microwave applicator and plasma reactor design. In particular the high pressure plasma reactor system must be able control the size, the spatial location and the shape of the very hot, and spatially non-uniform microwave discharge in such a manner to enable optimal diamond synthesis at high pressures and power densities. The engineering challenge is to develop reactor designs and associated process methods that are both robust and optimized for high pressure and high power density operation and thereby take advantage of the improved deposition chemistry and physics that exist in the high pressure regime. The design and development of two new microwave plasma reactors is described. Each of these reactors is excited with a hybrid "TM013 plus TEM001" mode, and robustly operated in the 200-400 Torr pressure regime. The reactor applicators are tunable and their electromagnetic fields are focused just above the substrate and can be varied and modified by reactor tuning. An intense microwave discharge with absorbed variable power densities of 150-600 W/cm^3 is produced. The adaptable design allows the control of the discharge size, shape and position and thereby allows in situ process optimization; i.e. the discharge can be positioned over the substrate for optimized synthesis. The experimental single crystal diamond (SCD) and polycrystalline diamond (PCD) synthesis performance of these reactors over the 200-400 Torr pressure regime is compared to the performance of commercial reactors operating at lower pressures and lower power densities. In particular, high quality SCD and PCD is synthesized with deposition rates that exceed 100 microns/hr and reactor power efficiencies range from 6 – 25 mm^3 of diamond per kW-h over a 25 mm diameter synthesis area as pressure, power density and gas chemistry are varied. The ability to extend these designs to even higher pressures will also be discussed.