INTRODUCTION

Recently two new microwave plasma-assisted chemical vapor deposition (MPACVD) diamond synthesis reactors [1,2] were designed, built and experimentally evaluated and their performance was compared to earlier MPACVD reactor designs [3]. To take advantage of the improved CVD diamond synthesis conditions that occur within the high pressure regime (160-300 Torr) the two reactors were designed to operate with high discharge power densities and at high pressures. When these reactors operate at high pressures single crystal diamond synthesis occurs over a large range of reactor conditions [1,2] such as: (1) pressure, p = 100–300 Torr; (2) input power, 1–3 kW; (3) flow rates, 400 SCCM; (4) methane to hydrogen concentrations of < 1% to greater than 9%; (5) discharge power densities of 200–1000 W/cm². [4] different substrate holder designs/geometry, and (7) is a variable plasma/substrate position, z. Within the 120–300 Torr operating pressure regime the discharge gas temperature is estimated to vary between 2500–4000 K [4]. In order to efficiently supply the CH₃ and H growth species to the substrate the discharge itself must be located away from the reactor walls and in close contact with the substrate. CVD diamond synthesis typically requires a substrate temperature of 800–1300K. Thus substrate cooling is required. During MPCVD diamond synthesis the microwave discharge supplies both the growth species and thermal energy to the substrate. The design, operation and optimization of these MPACVD reactors is a new, complex, and challenging multi-variable problem. It is important to develop an experimental understanding of the growth species and thermal energy to the substrate. The design, operation and optimization of these MPACVD reactors is a new, complex, and challenging multi-variable problem. It is important to develop an experimental understanding of the growth species and thermal energy to the substrate. The design, operation and optimization of these MPACVD reactors is a new, complex, and challenging multi-variable problem. It is important to develop an experimental understanding of the growth species and thermal energy to the substrate.

EXAMPLE REACTOR ROADMAP – defining the safe and efficient operating regime

When operating with a specific fixed design/geometry, the substrate temperature is a function of both the pressure and the absorbed microwave power. Given a constant input chemistry, the major independent experimental variables, i.e. absorbed microwave power, Pₐbs, and pressure, p, have an experimentally repeatable, single-valued nonlinear relationship with the experimentally measured substrate temperature, Tₛ. Given a specific reactor configuration, gas input chemistry and flow rate, this nonlinear relationship can be measured. The resulting set of curves provide an important data describing the useful experimental diamond deposition regions of the reactor system. Such a set of curves is shown in Fig. 1 and is identified here as the "operating field map" of the reactor. It is at any given constant pressure Pₐbs is varied within the operating regime the resulting absorbed power density - substrate temperature remains approximately constant. This is also shown in Fig. 1.

DIFFERENT MICROWAVE CAVITY REACTOR (MCPR) DESIGNS

1) Reactor A – the benchmark reactor
   - Hybrid TM/submode electromagnetic mode excitation
   - Coated-substrate holder on the "powered electrode" located around the z=0 plane.
   - R₁=5.8cm, R₂=8.49cm, R₃=4.1cm.
2) Reactor B –
   - Substrate holder/cooling stage radius is reduced from 4.1cm to about 1.9 cm, thereby decreasing the area of the powered electrode by a factor of 4-5 over Reactor A.
   - Hybrid TM/submode electromagnetic mode excitation as in Reactor A but a length tunable TEM section.
   - Substrate position at z=0.2 is variable from 0.4mm to 9mm.
   - Reactor now incorporates four tuning variables for matching and process optimization and control, i.e. Lₛ, Lₚ, and L₁.
3) Reactor C –
   - Same substrate holder/cooler size and variable substrate position as Reactor B.
   - The applicator cavity and quartz dome diameters increased by >50%.
   - The excitation of a new hybrid mode, i.e. the TM/submode, that focuses the electromagnetic energy onto the substrate.

A Description of the Experimental Microwave Discharge Behavior Versus Pressure, Power and Reactor Geometry for MPACVD Diamond Synthesis Reactors

J. Lu a, Y. Gu a, and J. Asmussen a, b

a Michigan State University, Department of Electrical & Computer Engineering, East Lansing, MI 48824
b Fraunhofer USA, Center for Coatings and Laser Applications, East Lansing, MI 48824

REFERENCE


OBJECTIVE

To experimentally understand the behavior of the MCPR versus the many experimental and design variables. In order to develop an understanding of the reactor behavior we experimentally measure and plot the nonlinear performance of the MCPR versus reactor design, i.e. a set of experimental "road map" curves are measured that describe the reactor's nonlinear performance versus the many experimental input and design variables.

REACTOR DESIGN VARIABLES

- Reactor size
- Powererode electrode size
- Powererode holder design
- Powererode power position – z

EXPERIMENTAL VARIABLES

Q Input Variables
- Sample holder design
- Flow rate – 400 SCCM
- CH₃H, fixed at 3% in roadmap measurement

Q Internal Variables
- Substrate temperature, Tₛ (900–1400°C)
- Plasma volume, V_p, (4–10 cm²)
- Absorbed power density, Pₐbs, discharge volume (200–1000 W/cm²)

REACTOR PERFORMANCE [1-3]

SCD synthesis is a multi-variable optimization problem – when holding substrate size and flow rate (~400 SCCM) constant the major variables are pressure, CH₃H, substrate temperature, and reactor design. A multi-dimensional plot is necessary to evaluate different reactor designs.

- Growth rates versus pressures for Reactor A, B, and C (N₂<0.5). (Reaction 1)
- Reduction of powered electrode area and the increase in pressure increase the deposition rate.

SUMMARY

- The authors have experimentally observed the different substrates and reactor operating regimes; i.e. the reactor operating roadmap has been defined. Within this same and efficient operating regime, the discharge is sufficiently large to cover the substrate but it is small enough to not waste power and also not touch the walls of the quartz dome. (Reaction 1)
- SCD may be readily synthesized at 160–300 Torr within this safe and efficient operating regime. High quality type IIa diamond crystals have been produced in these reactors. (Reaction 1)