Design and Modeling of a Microwave Plasma Enhanced Chemical Vapor Deposition System at 2.45 GHz

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Abstract: *Solid thin films developed by a microwave plasma-enhanced chemical vapor deposition (MPECVD) system have excellent electrical properties, good substrate adhesion, and excellent step coverage. Due to these advantages, MPECVD films have been widely used in very large-scale integrated circuit technology, optoelectronic devices, MEMS, and other fields. The MPECVD method is one of the promising candidates for synthetic CNTs due to low temperature and large area growth. Recently, this technique has gained popularity in graphene and diamond film fabrication. This paper discusses the design of an MPECVD chamber operated at 2.45 GHz of frequency using a finite element method simulation. The design consists of a coaxial waveguide and a cylindrical chamber at the center connected using 4 identical slots in each direction. For the magnetic coupling, slots placed at the bottom of the central cavity.* TM_{011} *mode in the inner chamber is employed to generate the plasma at 2.45GHz. In addition, we consider the effects of input power and gas pressure on plasma density.*

Keywords: Microwave plasma; MPECVD chamber; FEM.

Introduction

Solid thin films developed by a microwave plasma-enhanced chemical vapor deposition (MPECVD) system have excellent electrical properties, good substrate adhesion, and excellent step coverage. Due to these advantages, MPECVD films have been widely used in very large-scale integrated circuit technology, optoelectronic devices, MEMS, and other fields. The MPECVD method is one of the promising candidates for synthetic CNTs due to low temperature and large area growth. In this system, the plasma consisting of ionized gas species and electrons is ignited and sustained by applying high power microwave at high frequency and a thin film can be deposited at a lower temperature. The commonly used diamond film manufacturing methods include hot filament CVD (Chemical Vapor Deposition), MPECVD, DC plasma-jet CVD, and oxy-acetylene combustion flame. Using the MPECVD system has many advantages such as the contamination of diamond film by evaporation of hot wire is avoided with the usage of many kinds of reactive gases. The microwave power is adjusted continuously and smoothly so that the deposition temperature can change continuously and stably. Through the structural adjustment of the MPECVD reaction chamber geometry, a large-area and stable plasma sphere can be generated in the deposition chamber which is conducive to the large-scale and uniform deposition of diamond film. The paper discusses the design of an MPECVD chamber operated at 2.45 GHz of frequency using finite element method (FEM) simulation that produces a stable TM_{011} mode at the plasma chamber filled with argon gas at a variety of gas pressure and input power. The detailed geometry structure and the results will be discussed.

Simulation Model and Results

MPECVD Simulation Model: The design of an MPECVD chamber consists of a coaxial waveguide with radius of 16.27 cm as the outer radius which was tuned in such a way that there is formation of 8 peaks with the input given. This waveguide is then coupled with a cylindrical chamber located at the center of the coaxial waveguide using four coupling slots in each direction. The coupling slots are tuned and placed in the bottom of chamber as shown in Fig. 1 such that a good TM_{011} mode at 2.45 GHz is obtained in the cylindrical plasma chamber. At the beginning, the chamber is filled with argon gas and a pressure of 1 Torr and an input power of 1200 Watts to the waveguide were set.

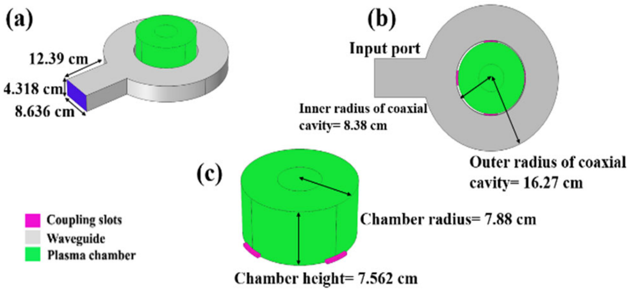

Figure 1. (a) 3D model of an MPECVD, (b) top view of the MPECVD showing coupling slots, and (c) 3D view of the cylindrical chamber and coupling slots.

Simulation Results: The model is first tested with injecting a microwave of 1200 watts through the input port of the waveguide and without any gas injection in the plasma chamber to find the correct geometry parameters to get TM_{011} mode resonant at 2.45 GHz in the chamber. The field patterns of TE mode in the coaxial waveguide and chamber for top and side views are shown in Fig. 2.

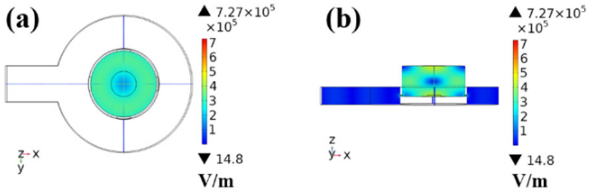

Figure 2. (a) Top and (b) side views of electric field norm in the MPECVD system for the TM_{011} mode operation.

The argon gas is added to the plasma chamber and the initial electron density is set to 1e17 m^{-3}. The electron temperature is set as 4 eV, and initial gas temperature is set to 300K. The run time taken to reach a steady-state was about 0.01 second. The electron density and electron temperature plots are shown in Fig. 3 and Fig. 4, respectively. The maximum electron density can reach up to 2.93e17 m^{-3}, while the electron temperature decreases to 1.04 eV.

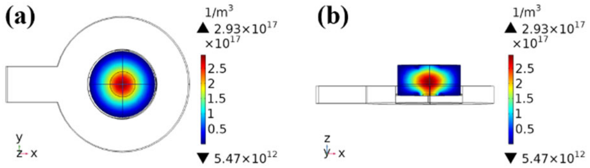

Figure 3. (a) Top and (b) side views of electron density in the MPECVD system for the TM_{011} mode operation.

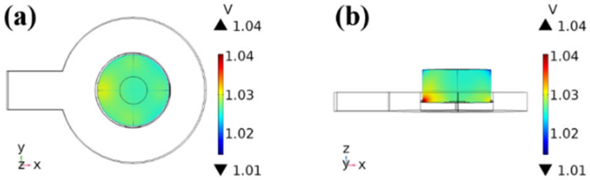

Figure 4. (a) Top and (b) side views of gas temperature distribution in the MPECVD model.

As shown in Fig. 5, at the time of 0.01 s, the gas temperature reaches 310K. Initial studies show that the spatial arrangement of the coupling slots between the waveguide and chamber plays an import role in determining the resonating mode in the plasma chamber while this issue needs to be further investigated.

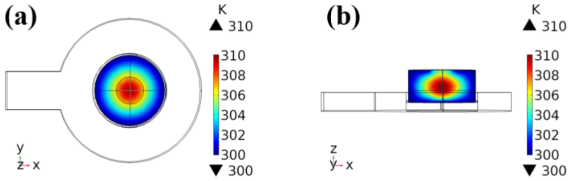

Figure 5. (a) Top and (b) side views of gas temperature distribution in the MPECVD model:

Conclusion

The studies are ongoing to get the steady state for a long run time for TM_{011} mode and the effects of gas pressure and input power on the MPECVD system are studied in detail to find out their operating characteristics for some industrial applications such as diamond film and graphene growth. The further study on the coupling slot arrangement and central cavity size may give us a better understanding on the MPECVD design to optimize the operation.

Acknowledgment

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