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A dome-shaped cavity type microwave plasma chemical vapor deposition reactor for diamond films deposition

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ABSTRACT

In this paper, a new type of microwave plasma chemical vapor deposition (MPCVD) reactor possessing a novel dome-shaped resonant cavity is described. Such a MPCVD reactor is required for efficient preparation of diamond films. It will be shown that by adopting a design outlined in this paper, a MPCVD reactor fulfilling all different requirements for reliable, long-time operation at high input microwave power levels could be optimized. Experimental results will be given showing that with the new MPCVD reactor, an input microwave power of up to 10 kW at 2.45 GHz could be applied, and at an input power of 8.5 kW, uniform and transparent polycrystalline diamond film of high quality and high purity could be deposited on 2 inch diameter silicon substrates, at a deposition rate of about 3.5 μm/h.

1. Introduction

Microwave plasma chemical vapor deposition (MPCVD) is the most widely used technique to synthesize high quality diamond films [1–3], since the technique possesses various advantages ranging from good controllability, highly stable operation to clean environment free from contamination.

Last decades have witnessed great progress being made in developing the MPCVD diamond films deposition technique. To this development, progressive improvements made on MPCVD reactors made the most contributions. As the deposition rate of diamond films by using the MPCVD technique is ordinarily low, especially when large area diamond films are being deposited, various MPCVD reactors have been invented, to increase the microwave power levels input into a MPCVD reactor and hence to enhance the efficiency of the MPCVD technique. Actually, with the microwave power increasing, the gas pressure in the deposition chamber should also be increased, in order to couple the microwave energy into the MPCVD reactors. It has been known that a simultaneous increase in both the microwave power and the gas pressure is the most effective way to enhance the efficiency of diamond films deposition.

But on the other hand, the levels of microwave power which could be input into a MPCVD reactor is primarily limited by the dielectric window through which the microwave energy will be introduced into the chamber [4]. As an essential element of a MPCVD reactor, the microwave window not only allows coupling of microwave energy into the reactor, but also delimit a reduced pressure region for plasma ignition. Proper design of the microwave window would allow us to select a single region of maximum electric field in the reduced pressure region near the substrate surface where diamond films are to be deposited. The plasma should be ignited only in such a region and formation of parasitic plasmas should be avoided. As the dielectric windows are generally made of quartz material and the plasma gas inside the reactors is primarily hydrogen, damage (etching as well as overheating) of the quartz windows is always a serious concern in designing MPCVD reactors [5,6].

Up until now, various types of MPCVD reactors have been developed and used in depositing diamond films. But all of these MPCVD reactors have their problems. For example, some MPCVD reactors use quartz bell jars as their microwave energy feeding windows [5,7–11], and in these circumstances, input microwave power levels of the reactors will be strictly limited by the etching and the overheating of the bell jars. For the ellipsoidal cavity type MPCVD reactors [11] developed at the Fraunhofer Institute, Germany, large diameter quartz bell jars are accommodated so that the walls of the bell jars are somewhat moved away from the plasma and the input power into the reactor could be higher. However, when the input power level is further increased beyond 6 kW, the

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etching problem could reappear. The non-cylindrical resonant cavity type MPCVD reactor [12,13] developed by ASTEX company (now called SEKI company) ingeniously designed a clamshell-shaped cavity, with the quartz window incorporated beneath the deposition chamber. In such a way, the etching problem of the window material is eliminated and input power to the reactor could also be higher. However, as the geometric shape of the clamshell reactor is so complex, not only its design is complicated, but also a capability of being regulated during its operation is lost. This regulatability would be very desirable, since it is directly related to the optimization of plasma distribution inside a MPCVD reactor.

Generally speaking, a MPCVD reactor for diamond films deposition should possess the following four characteristics:

(1) It should be capable of being operated at high input microwave power levels over long deposition times.
(2) The microwave window should be designed in such a way that damage of the window would be no more a problem, even when high input microwave power is coupled.
(3) It should be capable of being regulated during its operation, so that the plasma distribution in the reactor could be conveniently optimized.
(4) The sealing of the quartz window should be reliable, so that a clean environment for diamond deposition is ensured and maintenance work needed is minimal.

Recently, we have designed a new cylindrical cavity type MPCVD reactor [14]. Its features include adoption of a ring-shaped quartz window avoiding the window etching problem and its simple geometrical shape allowing regulation of the cavity during diamond films deposition. Afterward, modification was made on this reactor so that contamination problem caused by deposition of carbon impurities on the top of the cavity could be avoided [15].

Along with this improvement, a new dome-shaped cavity type MPCVD reactor has been materialized. In this paper, we describe the design of the dome-shaped cavity type MPCVD reactor. We will describe step by step our designing strategies, and at the same time, we will show that all the prerequisites listed above for a MPCVD reactor have been balanced met. Experimental results will be given showing that the reactor has performed satisfactorily in depositing diamond films at high input microwave power levels, and the capability of the reactor to deposit high quality diamond films has been demonstrated.

2. Evolution of our cylindrical cavity type reactor to a dome-shaped cavity type MPCVD reactor

In Fig. 1 is shown schematically the evolution process of our new dome-shaped cavity type MPCVD reactor from our early cylindrical cavity type MPCVD reactor.

Initially, the cylindrical cavity type MPCVD reactor [14] shown in Fig. 1(a) was designed in our laboratory. This reactor has been designed emphasizing that the reactor should possess both the capabilities of being run at high input power levels and of being regulated during its operation. It could be seen from Fig. 1(a) that the resonant cavity of the MPCVD reactor is composed of primarily a cylindrical cavity and a movable plunger. Beneath the substrate holder situates the ring-shaped quartz window, just as in the case of the clamshell-shaped cavity type reactor [12]. An obvious advantage of such a design is that the quartz window is well protected from plasma etching. Therefore, the reactor is inherently able to be run at high microwave power levels. Another characteristic of our cylindrical cavity type reactor is that as the shape of the reactor is geometrically simple, regulation mechanism could be

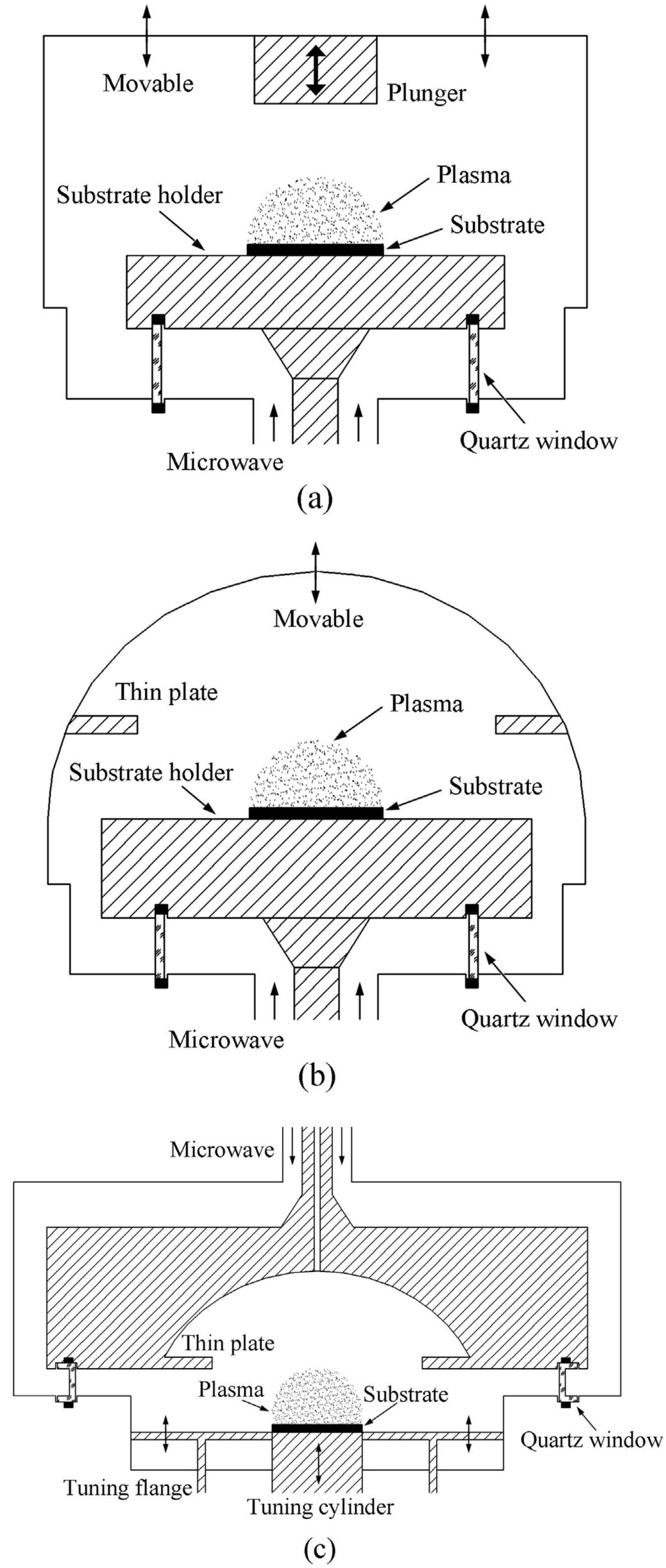

Fig. 1. Schematic cross-sectional views of (a) the cylindrical cavity type reactor, (b) intermediately improved reactor and (c) the dome-shaped cavity type reactor.

incorporated into the reactor. This means that performance of the reactor could be optimized during diamond films deposition. Simulation results revealed that the resonant mode of microwave inside the reactor is primarily a TM_{02} mode [14]. Above the