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Design and Construction of 2.45 GHz Microwave Plasma Source at Atmospheric Pressure

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Abstract

In this paper, we have designed and constructed the simple microwave plasma source (MPS) at atmospheric pressure in laboratory scale. A 2.45 GHz magnetron tube from a commercial microwave oven was utilized as the microwave source. Two types of MPS system were presented. MPS type I consists of magnetron tube connected to waveguide, a 3-stub tuner, a simple plasma torch region and a shot plunger. The MPS type II consists of magnetron tube and a tapered waveguide. The magnetron power supply for these systems was constructed. The measurement of the microwave power output was obtained by using calorimetric method. We can easily generate plasma at atmospheric pressure with argon as a plasma gas by using an auxiliary igniter. The plasma system is simple, compact and economical.

Keywords: Microwave plasma source; 2.45GHz magnetron; Magnetron power supply; Simple plasma torch

1. Introduction

The plasma state is generated when a gas is subjected to sufficient energy to break down its molecular integrity and dissociate it into ions, electrons and other sub-atomic species. Photons are generated during recombination. The initial interest in thermal plasma technology occurred in the 1960. Plasma sources are required for a wide range of technological such as etching, cleaning, plasma chemistry, surface modification, cutting, thin film technology, textile, etc[1]-[3]. Atmospheric pressure plasma source have been utilized as a tool for modifying polymer and metal surface [4]-[5].In this paper, two types of the simple microwave plasma source at atmospheric pressure have been constructed by using the magnetron tube from a commercial microwave oven. The prototype of MPS type I consists of a rectangular waveguide connected to a magnetron tube operated at the 2.45 GHz, a 3-stubtuner, waveguide applicator and a tuning plunger. The magnetrons used in this work were manufactured by Samsung Electronics, model 2M218. Therefore, this plasma system is simple, compact and economical. In MPS type I, the geometrics of all parts of this system are described. The length of MPS type I can be pre-adjusted by a tuning plunger. The experimental set-up block diagram of the MPS type I is shown in Fig. 1.

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The waveguide used in the prototype of MPS type II is tapered to effectively deliver microwave power into the simple torch region. The experimental set-up block diagram of the MPS type II is shown in Fig.2. The power transferred in the rectangular tapered waveguide is calculated from the Pointing theorem. The microwave power before entering into tapered waveguide is given by

$$P_i = \frac{E_0^2 ab}{4Z_{TE}} \quad (1)$$

The power inside the taper is given by

$$P_T = \frac{E_T^2 a(b/n)}{4Z_{TE}} \; ; \; n = 1, 2, 3, \ldots \quad (2)$$

Where *E0* and *ET* are the maximum electric field strengths in the waveguide before and after entered into the taper, are the width and height of the waveguide cross section and *abTEZ*is the characteristic waveguide impedance. If *n*=4, equation (2) become

$$P_T = \frac{E_T^2 a(b/4)}{4Z_{TE}} \quad (3)$$

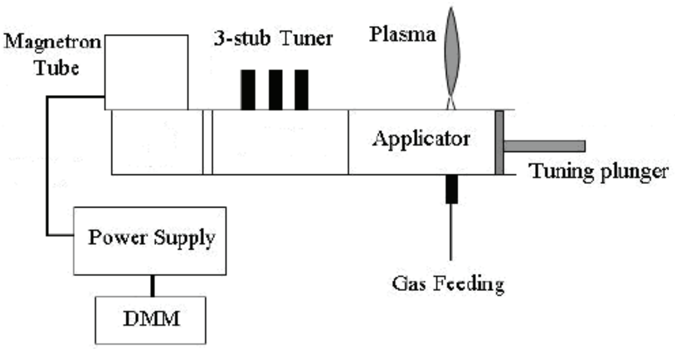


Fig. 1 The block diagram of the simple microwave plasma source type I

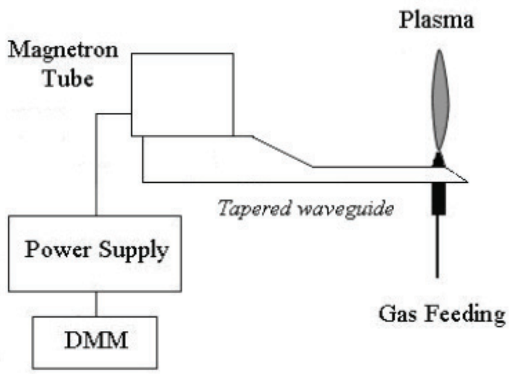


Fig. 2 The block diagram of the simple microwave plasma source type II

From equation (1) and (3) with $P_i = P_T$,

$$E_T = 2E_0 \quad (4)$$

Therefore, the electric field strength at the torch region for tapered waveguide is 2 times higher than that of incident wave. It means that the reducing of the height of a waveguide gives us an increase in the electric field strength even with the same microwave power.

2. Material S and Methods

2.1 Waveguide for type I

An air-filled copper rectangular waveguide WR340 (86x43 mm2) was designed and constructed to guide the microwave with dominating mode, . *TE*10

2.2 3-stub tuner

A 3-stub tuner was used for impedance matching by progressively inserting each metallic stub into the waveguide. In this work, a stub tuner was made from a micrometer fitted on the rectangular waveguide.

2.3 Waveguide applicator

A schematic diagram of the rectangular waveguide applicator is given in Fig. 3. The applicator is a section of waveguide fitted with a sliding short circuit, or a movable tuning plunger. The applicator served as a plasma confinement chamber passing centrally through the waveguide. Microwaves enter the applicator and are reflected from the plunger at the rear where boundary conditions require the electric field to be zero. The plasma is easiest to initiate when the superposition of incident and reflected waves form a standing wave pattern with a maximum centered at the plasma torch. Once the plasma has been initiated, the plunger position is adjusted to give a minimum of reflected power.

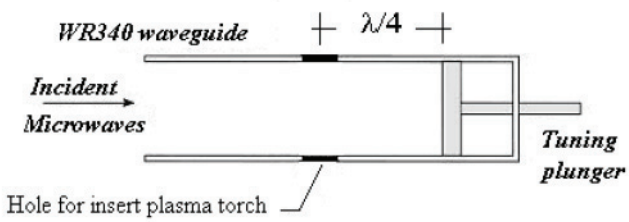
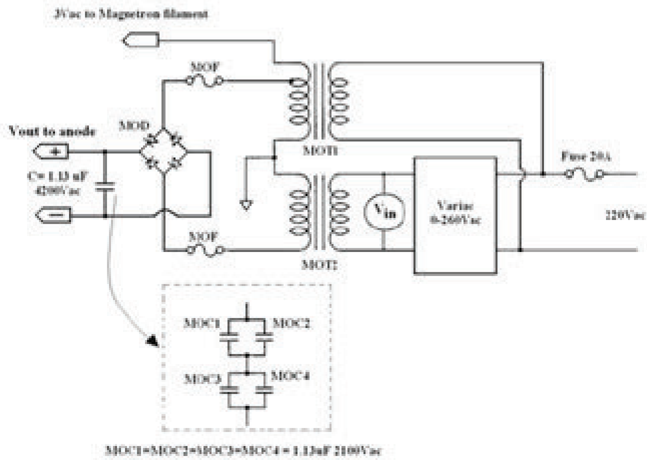


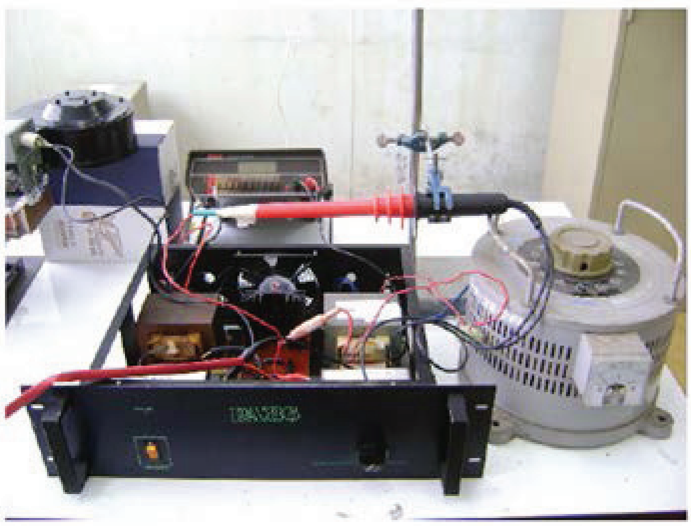
Fig. 3 Waveguide applicator with a tuning plunger for MPS type I

2.4 The magnetron power supply

To operate home microwave oven magnetrons, approximately 4kV electric voltage should be applied to the magnetron cathode. To construct a power supply that the voltage output can be varied from 3,300V to 6,600V, two microwave oven transformers (MOT) and 0-260 Vac transformer were used. The bridge rectifier for high DC output voltage was constructed by using 4 microwave oven diodes (MOD) and a microwave capacitor (MOC), and was cooled by an air-cooling system.The output from MOT1 is fixed at 3,300V, whereas the MOT2 produces an output voltage between 1,000 and3,600V. The picture and schematic diagram of the experimental setup are shown in Fig.4a and 4b, respectively.



(a)



(b)

Fig. 4 (a) Schematic and (b) Picture of Magnetron power supply.

2.5 The microwave power calibration

In this work, the calorimetric method was used to measure the microwave power. This method based on the complete conversion of incoming microwave energy into heat. The microwave power is calculated from the heat of water load, as it absorbs microwave power. *Pmw*The power absorbed by the water load, $P_{water\ load}$ is calculated from the following equation

$$P_{mw} = P_{water\ load} = \frac{(m_w c_w + m_c c_c)(T_f - T_i)}{t} \quad (4)$$

Where *mw* is the mass of water load, *Cw* is the specific heat of water, Mc is the mass of water container,

c_c is the specific heat of water container,

T_i, T_f are the initial and final temperature of water load

and t is the exposure time of water load to microwave radiation.

2.6 Simple Plasma torch

A simple plasma torch for producing the plasma flame of both MPS types at atmospheric pressure was constructed. The schematic diagram of the simple plasma torch is shown in Fig. 5.

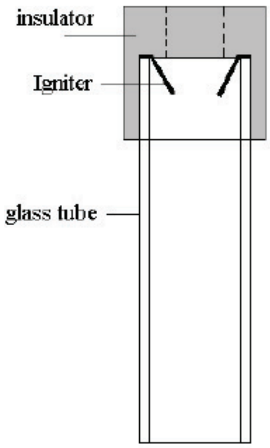


Fig.5 The simple plasma torch

MPS type II

The photograph of MPS type II is shown in Fig. 6. It consists of the magnetron tube connected to one side of the tapered waveguide. In this system, the simple plasma torch was inserted into the tapered wave nears the end of the waveguide.

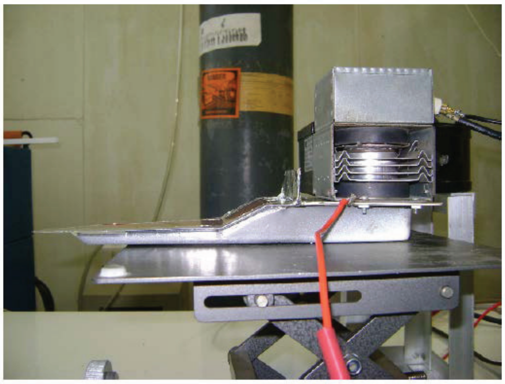


Fig. 6 Photograph of MPS type II

3. Results and Discussion

(1) The magnetron operated at 250 W was coupled directly to the applicator via 3-stub tuner for several hours without any problem. This could means that the system could be run continuously at 250 W.

(2) The linear relation of input and output voltage of magnetron power supply is shown in Fig.7.

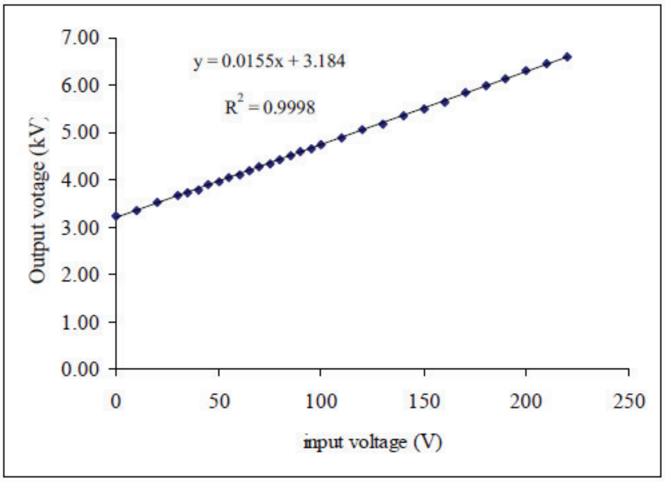


Fig.7 Input and Output voltage of magnetron power supply

(3) The relation of average microwave power and input voltage for MPS type I is shown in Fig.8. The threshold input voltage for radiation of microwave power is about 37 V. This correlation can be later used to estimate the power delivered to the plasma. The microwave power increases in polynomial function with input voltage. However, the power is nearly linear to the input voltage if started at 45 V as shown in Fig.9

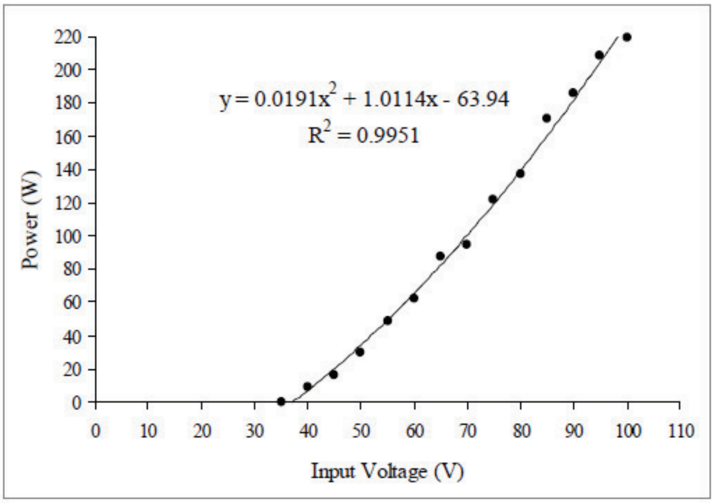


Fig.8 Relation of microwave power and input voltage

(4) Both systems can be generated plasma at atmospheric pressure with argon as the discharge gas but the power used for the MPS type II is 30% less than that of type I.

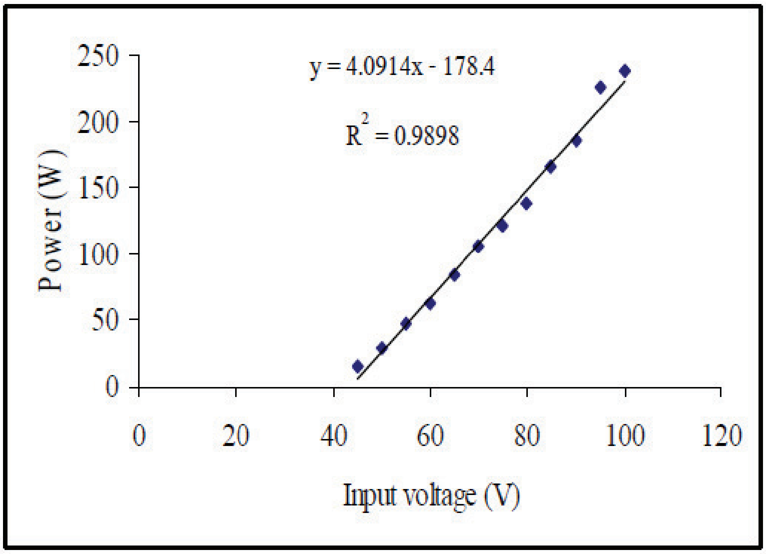


Fig.9 Relation of microwave power and input voltage started at 45V.

4. Conclusion

We have successfully designed and constructed the microwave plasma source with a 2.45 GHz magnetron tube as used in a commercial microwave oven. It is a simple, compact and economical plasma device. The system utilizes a high voltage power supply so that the magnetron can generate a microwave radiate continuously. The output power can be adjusted from 0-250W making it very easily and different from commercial microwave oven. The plasma at atmospheric pressure can be made by both systems and the plasma torch will be developed in the further work because the simple torch in this work has a problem of thermal runaway.

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