Development of uniform line-shaped plasma under long wavelength evanescent microwave (LWEM) for PDP processing

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Abstract: *High density microwave plasmas based on electrode less discharge have been studied and developed for large area plasma processing in manufacturing industries, such as large area Plasma Display Panel (PDP) and Liquid Crystal Display (LCD), surface modification of thin PET film, semiconductor manufacture and elemental analysis. Such plasma processing provides improved and desirable surface properties. The present paper describes the development of novel line-shaped plasma under Long Wavelength Evanescent Microwave (LWEM) and its characteristics such as electric field pattern, plasma density and Ion saturation current density were measured by using planar Langmuir probe. Furthermore results shown that a uniform electric field pattern is observed inside a waveguide for the generation of uniform long line-shaped plasma. The generated plasma has uniformity of about 7 % for 40 cm length were obtained at 4 Torr He plasma with total input power of 1.4 kW in a twin power supply case. In addition, the present results indicate that uniform plasma with uniformity is 7.6% along 40 cm line shaped plasma and the same is 3.7% along 30 cm in Z axial distance at 20 mTorr in Ar plasma.*

Keywords: Electric field; evanescent region; long line-shape plasma; Langmuir probe.

Introduction

Recently, it has been necessary to develop a large area high-density plasma sources for PDP processing, liquid crystal display panel manufacturing industries and surface modification of large-thin films [1-3]. Among the various type of plasmas such as Inductively Coupled Plasma (ICP), Electron Cyclotron Resonance Plasma (ECR), helicon etc., presently investigated plasmas are one of the most promising candidates from the view points of cost performance, compactness and feasibility of enlargement of high density homogenous plasma. On the other hand, atmospheric pressure plasmas have also been investigated [4,5]. Microwave generated plasmas have been receiving a great deal of attention, because of their outstanding properties [1,6]. Microwave plasmas have an advantage in the high-pressure region because high-density line-shaped plasma ignition is possible without electrodes and eliminating the process contamination. Excitation is very efficient, so that high plasma densities and radical concentrations are achievable. On the other hand, 2.45 GHz magnetrons are inexpensive as compared to RF generators. Microwave plasmas operated at atmospheric pressure, particularly waveguide-based plasma have been the subjects of increased attention during the last decade [7,8]. Such interest comes from their potential and actual use in various applications, including excitation sources for elemental analysis, lighting, and purification or remediation of gas effluents detrimental to the environment [9].

A uniform electric field and ambipolar diffusion is necessary for uniform line shaped plasma generation. However, the wavelength of the microwave is restricted to approximately 12 cm in free space. The wavelength (λ_g) of a microwave in a waveguide is described as follows [10]

$$\lambda_g = \frac{\lambda_0}{\sqrt{\mu_r \varepsilon_r}\sqrt{1-\left(\lambda_0 / 2a\right)^2}} \qquad \ldots(1)$$

In eqn (1) λ_g, λ_0 and a are the wavelength in waveguide, wavelength in free space and width of the waveguide respectively. μ_r-permittivity and ε_r-permeability. In this work we introduce a new type of high-density line shaped plasma source utilizes two microwave power supplies, which is called as twin power supply case. The total microwave power mentioned throughout this paper is the sum of the input power of two power supplies. In this paper we investigated the optimum operating parameters for line shaped plasma generation by expanding the wavelength in a narrow waveguide. The operating parameters are waveguide width (a), quartz tube insert distance (D_{id}) input power (P) and quartz tube-probe distance (D_{sp}). Plasma strike power in relation to the gas pressure was measured in the pressure range of 1

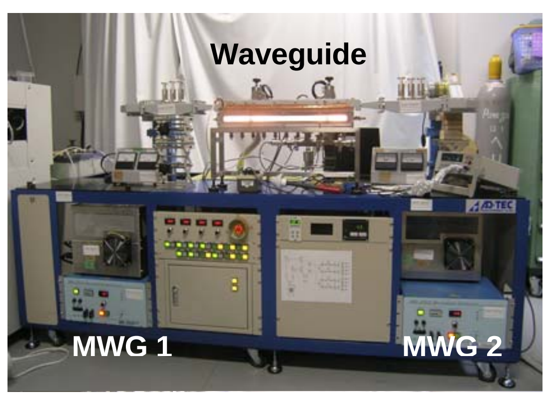

Figure 1. Photograph of the line plasma system

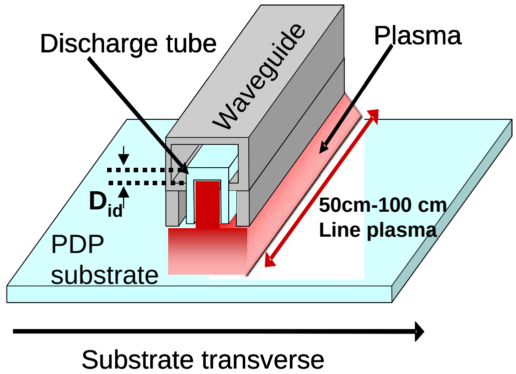

Figure 2. Concept of the line shaped plasma

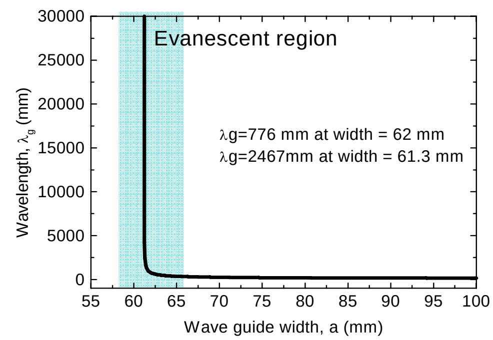

Figure 3. Calculated wavelength (λ_g) in the waveguide

Torr to 760 Torr for He plasma. Electron density profiles were measured at various discharge tube-probe distance (D_{sp}) for 4 Torr He plasma. Further, Ion saturation current density (J_i) profiles have also been measured for Ar plasma at low pressure of 20 mTorr and results were presented.

Experimental setup

Photograph of the line plasma system is shown in Figure.1. 2 numbers of microwave generators (IMG-2503, IDX Corporation, Japan) mentioned as MWG 1 and MWG 2 were used with a frequency of 2.45 GHz and maximum output power of 3 kW. Microwave power was fed through water-cooled isolator and three-stub tuner for impedance matching. We used a narrow rectangular waveguide with internal dimensions of 500 mm length, 62 mm width and 5 mm height. Both end of this waveguide was connected with tapered waveguide with dimensions are 96mm×27mm at the input side and 62mm×5mm at the output side. WST-AD standard, TE_{10} mode based E and H-corner type waveguide was connected on between both side of tapered waveguide and power supply input side. Adjusting the detachable aluminum plate can vary the width of the waveguide. The height of the waveguide was decreased to increase the power density inside the waveguide. Such a waveguide can generate a high electric field than that of a conventional waveguide. Aluminum plate has many holes of diameter of 3 mm in 1 cm interval about length of 50 cm was fixed on the top of the rectangular waveguide for measuring the internal electric field of the waveguide. The whole waveguide was connected to the discharge chamber, which is evacuated using a scroll pump, and achieved a base pressure in the order of 10^{-3} Torr. Chamber contains the port for gas injection. Quartz tube was used as a discharge tube in between the waveguide and discharge chamber.

A coaxial cable that has an outer diameter of 1.4 mm and impedance of 50 ohms was used as an electric field measurement probe. The stripped core wire was 1mm in diameter and 2mm in length. This coaxial cable was inserted in quartz tube with diameter of 2.8mm. The electric probe was inserted into the waveguide through the hole on the top plate of the waveguide. The output signal from the electric probe was connected to digital multimeter (Advantest:AD 7461A) through a crystal diode detector (Nihonhoshuka).

Plasma diagnostics system consists of a Langmuir planar probe, ±100V Bipolar power supply (BWS 120-2.5, Takasago Ltd, Japan), Digital multimeter (Advantest: AD 7461A) and PC controlled data acquisition system. A Langmuir planar probe is a cylindrical tungsten wire of 1mm in diameter and is connected to the chamber through 0.25inch sweglok port. In order to avoid the effect of microwave noise on probe measurements, noise filters are used to cover the signal cables (NEC-Busteraid:3GF(10)). Figure.2 shows the concept of line shaped plasma in a large area surface treatment. In this case the long line shaped plasma generation system is fixed, but we can process the large area substrates by moving the substrates axially below the downstream of the plasma. This is the key point for large area surface treatment system. In our experiment, discharge area of quartz tube inside the waveguide slit was selected as 0, 1.5 and 2.5 mm and it is denoted as quartz tube insert distance (D_{id}) throughout this paper.

Results and Discussion

Characterization of the narrow waveguide: The calculated wavelength (λ_g) of the microwave in the waveguide is shown in Figure. 3. The waveguide width of WST-AD is 96 mm. However λ_g increase rapidly when increase in the waveguide width (a) i.e less than 63mm. The cutoff width of the waveguide is 61.3mm. When width becomes narrow we can achieve a very long wavelength over 1000mm. At width of 62 mm λ_g is 776 mm and decrease the width as 61.3 mm the wavelength become longer as 2467 mm. This region is useful to generate the long line shaped plasma and it is called as Evanescent region of microwave.

Electric field (EF) pattern: We measured the EF pattern inside the waveguide in the evanescent region, with D_{id} of 0.5, 1.5 and 2.5 mm at several input powers. Figure. 4 shows the EF pattern inside the waveguide for twin power supply case. The width of the waveguide is 56 mm

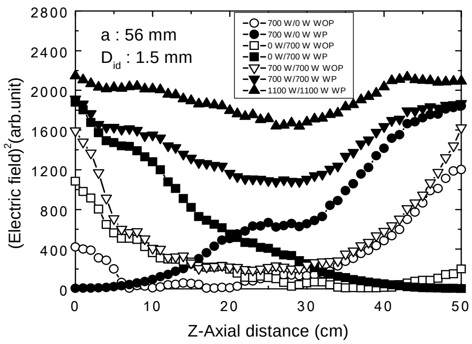

Figure 4. Variation of electric field on the Z axial distance in the narrow waveguide for twin power supply. Total Microwave power is 1.4 kW in He plasma at 4 Torr.

and quartz tube insert distance (D_{id}) inside the waveguide is 1.5 mm. The open symbols show the results of EF pattern in the waveguide before plasma generation using only one power supply. Solid circles and solid rectangular symbols show the EF pattern in the waveguide after He plasma is generated at gas pressure of 4 Torr with one power supply on both side and operated separately. However, the EF pattern is not uniform along 50 cm length in the above condition. Solid triangle shows the EF pattern in the waveguide after plasma generation under twin power supply case is almost uniform at total microwave input power of 1.4 kW. When increase the microwave input power from 1.4 kW to 2.2 kW, the EF pattern becomes uniform along 50 cm length in Z axial distance. It noted that the optimum condition for generating the uniform line shaped plasma by fixing the waveguide width and input power at quartz tube insert distance of 1.5 mm.

Strike power: Figure.5 shows the plasma strike power in relation to the chamber pressure in the range of 1 Torr to 760 Torr for He gas for twin power supply case. Plasma strike power is constant for a pressure ranged from 1 to 100 Torr, however the trend becomes linear when we increase the pressure from 100 Torr to 760 Torr. Plasma strike power at atmospheric pressure of 760 Torr is about 4 kW of total microwave power i.e 2 kW power on both side of waveguide. Our system has an advantage of wide range of operating pressure from few Torr pressure to atmospheric pressure, where expensive vacuum installations can be avoided.

Plasma density (Uniformity): Electron density (Ne) was measured by using Langmuir probe for the above mentioned operating conditions. Figure.6 shows the dependence of plasma density on the Z-axial distance along the 50 cm line plasma is presented for He plasma at 4 Torr and total microwave input power of 1.4 kW for several distances between the discharge tube and probe. In figure, 0 and 50 cm is near the wall of the chamber and plasma density is seems to be low due to the plasma recombination to the chamber wall. As seen from the figure plasma density profile strongly depends on the

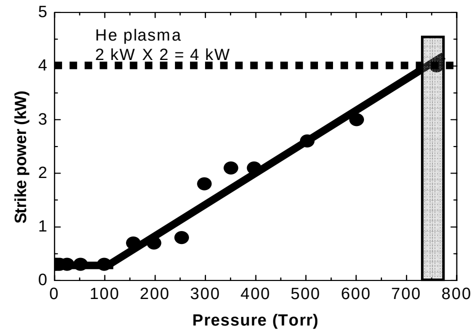

Figure 5. Variation of strike power for different He gas pressure.

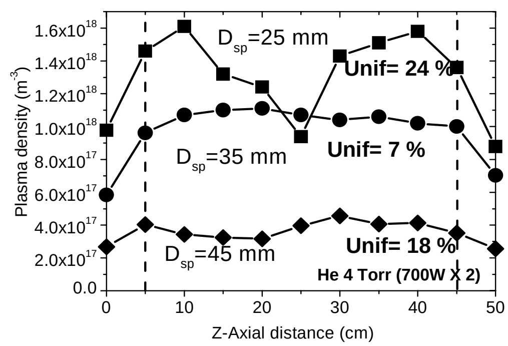

Figure 6. Variation of plasma density at different Z axial distance for three different probe distance for He plasma at 4 Torr.

discharge tube and probe distance (D_{sp}). At lower D_{sp} of 25 mm, plasma density is seen to be lower at the center of the plasma (25 cm) and D_{sp} of 35 mm gives uniform plasma density profile between Z-axial distances of 5 to 45 cm along 50 cm line shaped plasma. Further increase in the D_{sp} to 45 mm leads to the slight increase in the plasma density at the center. Uniformity percentage of the plasma density along 40 cm i.e. Z-axial distance between 5 to 45 cm is calculated using conventional formula of Unif %=(Max-Min)/(2*Ave) * 100. It is significant to note that at D_{sp} of 35 mm, plasma uniformity is better and obtained the value of 7%. Uniform long line-shaped plasma generation is important for the highly reliable results in PDP processing.

Further, we investigated the plasma generation at pressure less than 1 Torr and results reveals that Ar plasma can be generated at low pressure of 10 mTorr to 1 Torr, However He plasma cannot be generated at pressure lower than 200 mTorr. We attempt to measure the ion saturation current density profile along the 50 cm line plasma using Langmuir probe at negative bias voltage of –70 V. Figure 7 shows the ion saturation current density at D_{sp} of 40 mm with total microwave input power of 2.8 kW in a twin power supply case for Ar plasma at 20 mTorr. From the graph is it significant to

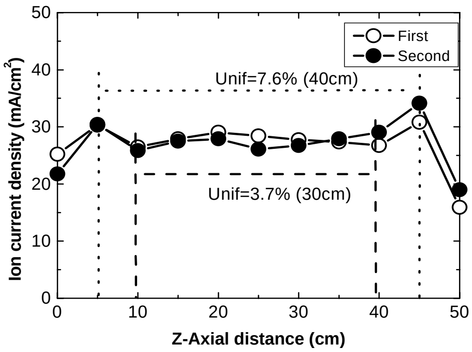

Figure 7. Variation of Ion saturation current density at different Z axial distance for Ar plasma at 20 mTorr.

note that uniformity percentage is 7.6% along 40 cm line-shaped plasma and the same is 3.7% along 30 cm.

Conclusion

50 cm line plasma system was developed and its characteristics were studied.

Electric field pattern inside the waveguide before and after plasma were measured and optimized the condition for uniform line-shaped plasma generated at waveguide width of 56 mm, total microwave input power of 2.2 kW in a twin power supply case and quartz tube insert distance (D_{id}) of 1.5 mm for He plasma pressure of 4 Torr.

Plasma strike power for the He plasma in the power range of 1 Torr to 760 Torr is presented. He plasma until 200 mTorr can be generated. However Ar plasma can also be generated in the low pressure until 10mTorr. Wide range of operating pressure from low pressure to atmospheric pressure plasma has advantage in processing.

Better uniformity of 7 % was obtained in the length of 40 cm for He plasma at 4 Torr with total microwave input power of 1.4 kW using twin power supply in line shaped plasma and also studied the performance of the Ar plasma at 20 mTorr. It is significant to note that the uniformity percentage is 7.6% along 40 cm line shaped plasma and the same is 3.7% along 30 cm in z axial distance. Using this 50 cm line-shaped plasma will carry out large area surface modification and CVD processing.

Acknowledgement

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