Production and Control of VHF Excited Plasmas by Superposing Two Standing Waves

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The method of superposing the standing waves is the idea to generate VHF excited plasmas with excellent uniformity for large area processing. To get such plasmas, we generate two standing waves on the electrode, control the places of their own antinodes, and then, we superpose them. By using this method, VHF pure hydrogen plasmas are produced for various conditions. According to the photographs of produced plasmas and measurements of plasma parameters, it is confirmed that VHF excited plasmas with higher uniformity are well synthesized compared to the plasmas generated by the usual method.

Keywords: VHF plasmas, superposing the standing waves, uniformity, large area

1. Introduction

Radio frequency (RF) discharge plasmas at 13.56 MHz have been used widely in the field of the material processing, especially in the hydrogenated amorphous silicon (a-Si:H) films and the thin film transistors (TFTs) [1-2]. The treated substrate size will enlarge in size to achieve improvement of the productivity and low cost. To this end higher deposition rates and plasma of excellent uniformity have required.

Recently, it is reported that a higher deposition rate of amorphous silicon (a-Si:H) films is achieved in Very High Frequency (VHF:30-300MHz) excited plasmas [3-5]. VHF excited plasmas have characteristics of higher electron density and lower electron temperature compared to that of RF discharge plasmas. However, it is hard to obtain excellent uniformity for large area in VHF range. With the increase of the frequency, the wavelength approaches the dimension of the electrode and standing waves are generated on the surface of parallel plates and feed lines. Due to these standing waves, distribution of electric field intensity is inhomogeneous. As a result, deposited films become non-uniform. To solve this problem, several methods have been reported [5-7]. However, it is an open question to generate uniform VHF excited plasmas.

Recently, we have reported VHF excited hydrogen plasmas using new idea [8-9]. This idea is "The method of superposing the standing waves". In this method, some standing waves (two waves in our study) are generated on the electrode, the places of their own antinodes are controlled spatially, and then, these waves are superposed [8-9]. In this paper, we study further generation and characteristics of the VHF excited plasmas. Control of axial distribution of plasma parameters and pressure dependence of plasma parameters are discussed.

2. Experimental set-up

Figure 1 shows a schematic diagram of the experimental apparatus ((a) front view, (b) side view). The vacuum chamber is 310 mm in diameter and 400 mm long. In the vacuum chamber, rod electrode and flat plate are installed. Rod made of aluminum is 20 mm in diameter and 270 mm long. Flat plate made of aluminum is 100 mm wide and 300 mm long. The distance of the rod electrode and flat plate is 10 mm. Both ends of the rod electrode are connected with co-axial cables to impress VHF voltage at the frequency of 200 MHz. VHF excited plasmas are produced between the rod electrode and the flat plate.

To generate two standing waves independently, VHF voltage is pulse modulated and is impressed to the electrode alternating with duty 50 % (shown in Fig.2). One standing wave W1 is generated by pulse train which repeats on and off (see Fig.2 (b)), and the other standing wave W2 is generated by pulse train which repeats off and on (see Fig.2 (c)). The modulation frequency of the pulse train is 1 kHz, and its duty ratio is 50 %. To control the places of their own antinodes, the phase difference between two high frequency voltages are changed with phase shifter.

The characteristic features of generated plasmas are monitored by using digital camera. The plasma

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parameters, i.e. electron density N_e and electron temperature T_e, are measured with a Langmuir probe. The distance d between the rod electrode and a probe tip is 35 mm.

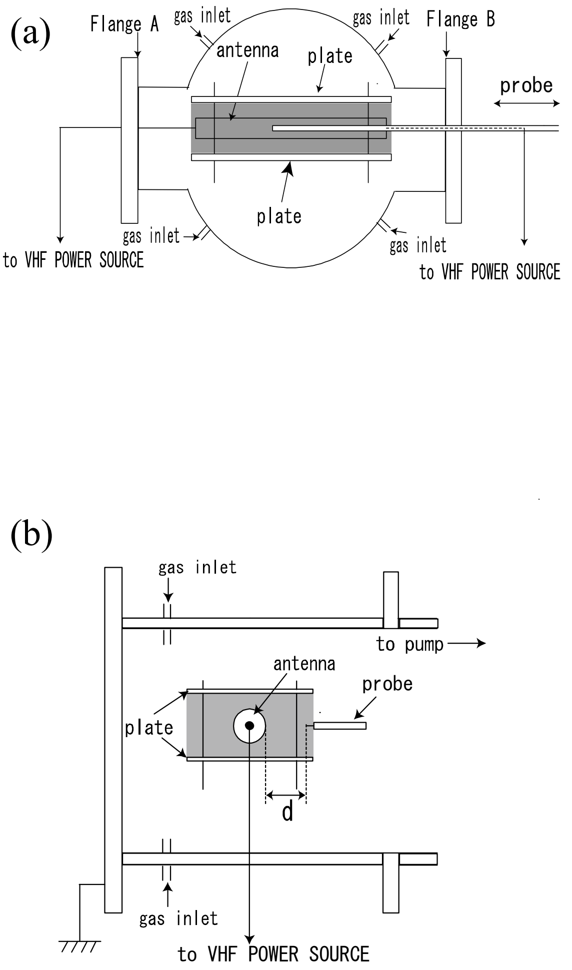

Fig.1 Schematic diagram of the experimental apparatus: (a) front view and (b) side view.

3. Experimental results and discussion

At first, we demonstrate the application feasibility of our superposition method for producing uniform VHF excited plasmas. The pressure of hydrogen is 10 mTorr, and applied VHF power is 100 W from the both ends of the rod electrode, amount to 200 W.

Figure 3 shows photographs of VHF excited plasmas for three different cases. First two plasmas are produced using only one standing wave. The place of antinode of one standing wave (W1) is adjusted at the left in Fig.3 (a). The place of antinode of another standing wave (W2) is adjusted at the right in Fig.3 (b). Fig.3 (c) shows the photograph of the plasmas produced superposing both W1 and W2 shown in Figs.3 (a) and (b), respectively. According to the results, the region of the visible emission of VHF excited plasmas is varied by changing the place of antinode of standing waves. Namely, we can spatially control plasma production and to synthesize well the uniform plasmas.

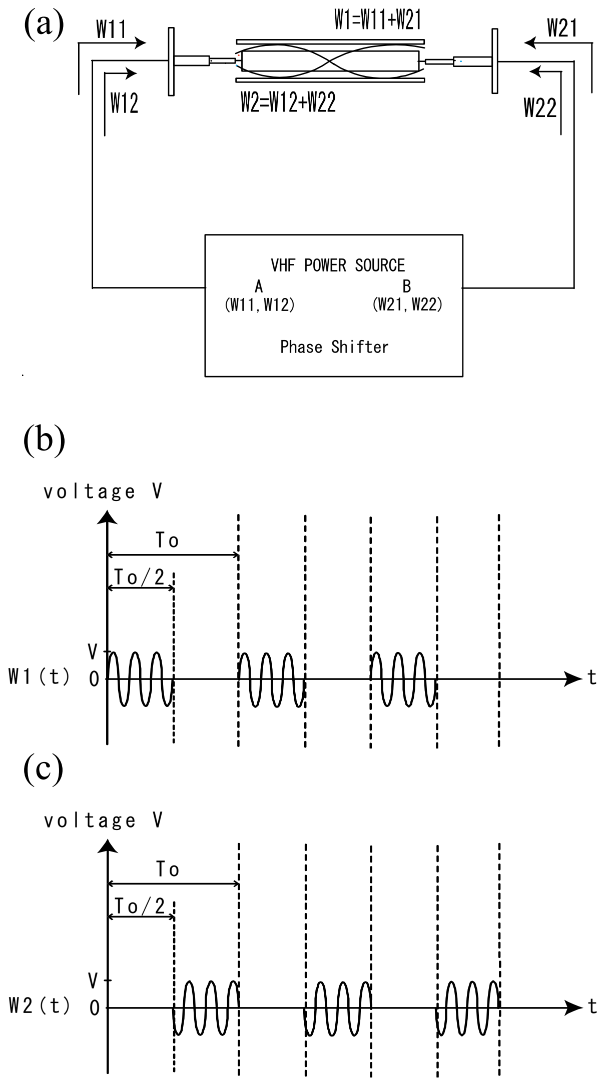

Fig.2 Schematic diagram of pulse operation for VHF plasma production: (a) A rod-plate electrode and VHF power system, (b) timing of power supply for W1, and (c) timing of power supply for W2.

Figure 4 shows typical examples of axial distributions of N_e corresponding to the plasmas shown in Fig.3. These are time averaged axial distributions measured with the Langmuir probe. In plasmas produced by only W1 adjusted at the left, N_e is high in the left side. On the other hand, in plasmas produced by only W2 adjusted at the right, N_e is high in the right side. As is shown clearly, N_e of VHF excited plasmas with superposing W1 and W2 has uniform distribution. For reference, a typical example of N_e distribution obtained at different pressure (i.e. p = 5 mTorr) is also plotted.

Although N_e is decreased with changing pressure, pattern of an axial distribution has nearly the same form. Then, it is confirmed that the method of superposing two standing waves is useful.

(a)

(b)

(c)

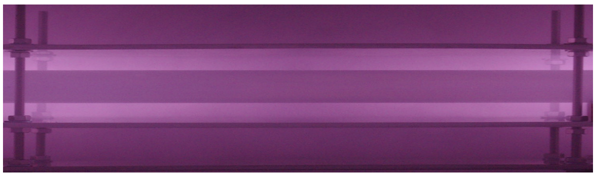

Fig.3 Photographs of the produced VHF plasmas: (a) plasmas produced by one standing wave (W1 adjusted at the left), (b) plasmas produced by another standing wave (W2 adjusted at the right) and (c) plasmas produced by superposing two standing waves (W1 and W2). Experimental conditions are as follows: Applied VHF power for W1 and W2, W_{VHF} =100 W and hydrogen gas pressure p = 10 mTorr.

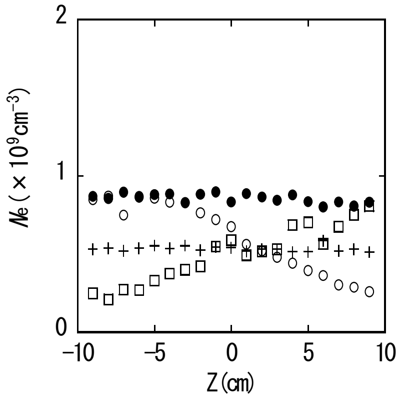

Fig.4 Axial distribution of electron density N_e corresponding to the plasmas shown in Fig.3.: ○ (W1 adjusted at the left), □ (W2 adjusted at the right) and ● (superposing W1 and W2). For reference, another example of *N*e distribution is also plotted where p = 5 mTorr; + (superposing W1 and W2).

Next, we further test production and control of the synthesized plasmas with changing the place of antinode. A certain example is shown in Fig.5. Figure 5 (a) is a photograph of the plasmas with superposing two different standing waves (i.e. W1 adjusted at the center and W2 adjusted at the center). Figure 5 (b) is a photograph of the plasmas, where W1 is adjusted at the middle in the left hand side and W2 is at the middle in the right hand side. According to the results, emission of VHF excited plasmas can be observed between electrodes all around.

Figure 6 shows axial distributions of electron density N_e and electron temperature T_e corresponding to the photographs of plasmas shown in Fig.5 and Fig.3 (c). Axial distributions of N_e are varied and synthesized by superposing two standing waves when the places of two antinodes are changed.

(a)

(b)

Fig.5 Photographs of the produced VHF plasmas: (a) plasmas produced by two standing waves (W1 adjusted at the center and W2 adjusted at the center) and (b) plasmas produced by two standing waves (W1 adjusted at the left middle and W2 adjusted at the right middle). Experimental conditions are as follows; W_{VHF} = 100 W and p = 10 mTorr.

It is VHF excited plasmas by superposing W1 adjusted at the center and W2 adjusted at the center that N_e is the highest within three cases. This highest N_e accords with the brightest emission of plasmas in Fig.5 (a). Although plasmas shown in Fig.3 (c) is approximately uniform, N_e is lower than others two cases. This is partly caused by diffusion effect of produced plasmas. In plasmas shown in Figs.5 (a) and (b), plasmas are produced mainly in the center region and produced electrons are diffused in the plasma region (i.e. from the center to the edge). On the other hand, in plasmas shown in Fig.3 (c), plasmas are produced mainly in the edge region, and then only a half of electrons are diffused in the plasma region (i.e. from the edge to the center). Another half of electrons may be lost outside of the plasma region. At any rate, the method of superposing the standing waves can control plasma production and axial distribution of electron density.

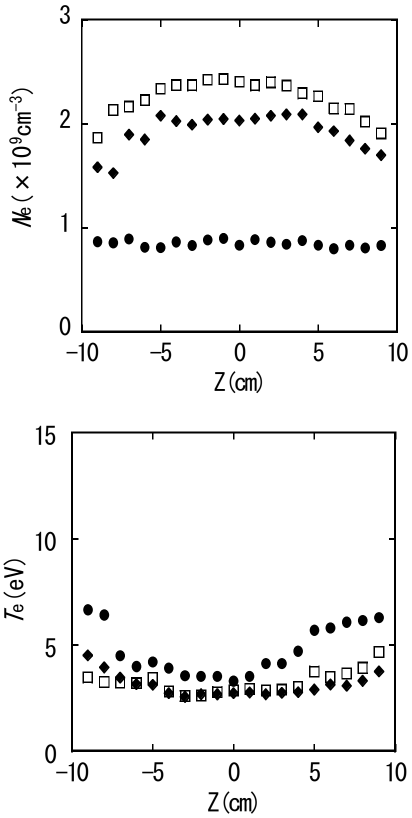

Fig.6 Axial distributions of electron density N_e and electron temperature T_e : ● (W1 adjusted at the left and W2 adjusted at the right), ◆ (W1 adjusted at the left middle and W2 adjusted at the right middle) and □ (W1 adjusted at the center and W2 adjusted at the center). Experimental conditions are as follows: W_{VHF}= 100 W and p =10 mTorr.

Finally, pressure dependence of plasma parameters (N_e and T_e) is studied, where two standing waves (i.e. W1 adjusted at the left and W2 adjusted at the right) are present. The probe is set at the center, i.e. Z = 0. As is shown clearly in Fig.7, with increasing gas pressure, N_e is increased and T_e is also decreased sharply. This pressure dependence is the same as the usual relationship. The ratios of N_e and T_e at two different pressures 8 and 4 mTorr are as follows: the ratio of N_e (8 mTorr) / N_e (4 mTorr) is about 5.2 and the ratio of T_e (8 mTorr) / T_e (4 mTorr) is about 0.2. Then, the products $N_e \cdot T_e$ for two different pressures have nearly the same values. So, power deposition and then coupling between the VHF power source and the rod-plate electrode system may not be varied largely with changing pressure. In addition, the emission of VHF excited plasmas becomes bright with increasing pressure and VHF excited plasmas can be produced with keeping nearly the same uniformity as shown in Fig.4 even if the pressure of hydrogen is changed within the present experiment.

For characteristics of VHF excited hydrogen plasmas, previously, it was reported that N_e increased and Te decreased when excitation frequency was increased up to 100 MHz [4]. However, the pressure dependence of N_e and T_e at frequency of 65 and 100 MHz are different from the present our results. Namely, N_e tends to decrease and T_e tends to increase with increasing pressure of 40-200 mTorr. So far, this difference has been not yet clarified experimentally although frequency and pressure range are different from each other and then the trapped electrons in the bulk plasma may play important role.

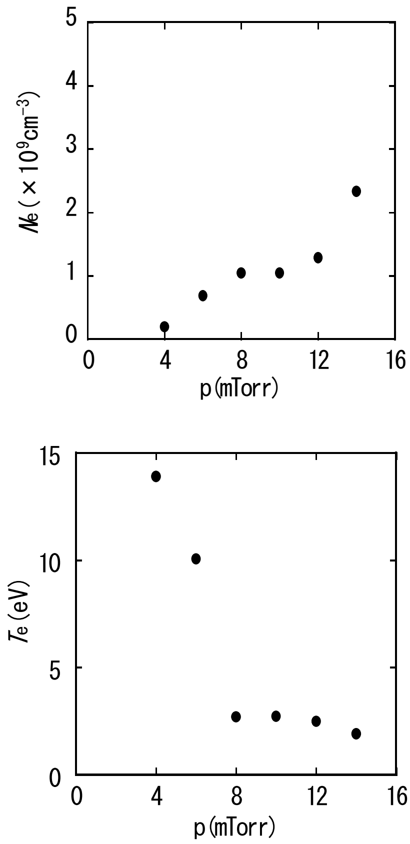

Fig.7 Pressure dependence of electron density N_e and electron temperature T_e, corresponding to plasma production shown in Fig.3 (c), i.e. W1 adjusted at the left and W2 adjusted at the right. Experimental conditions are as follows: W_{VHF}= 100 W and axial probe position Z =0 cm.

Now, we test the present method using two electrodes system. As like one rod electrode case, it is confirmed that generation of VHF excited plasmas and its axial distribution are well controlled by superposing two standing waves.

4. Summary

VHF excited hydrogen plasmas are produced with superposing two standing waves and the electron density and the electron temperature are measured with the Langmuir probe. The method of superposing the standing waves can spatially control plasma production and produce uniform VHF excited plasmas.

In the future, we further test the present method using longer and multi-rod electrode system. We will discuss the characteristics of the VHF excited plasmas for developing large area VHF plasma sources.

5. References

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