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Plasma and impedance characteristics of internal linear antennas for flat panel display applications

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Abstract

The trend towards large area substrates motivated by flat panel display industries has accelerated the development of the large size plasma sources. In this study, two types of linear internal-type inductively coupled plasma source enabling the production of large area high density plasma, that is, a serpentine-type and a double comb-type were investigated and their characteristics of plasma and impedance were compared. The use of the double comb-type antenna showed higher root-mean-square current, higher plasma density, and lower antenna resistance compared to that of the serpentine-type antenna as the rf power increased from 600 to 5000 W. By the application of 5000 W of rf power with 2 Pa Ar, a high plasma density of $2.2 \times 10^{11}/\text{cm}^3$ with the plasma uniformity of 8% for the size of 880×680 mm could be obtained for the double comb-type antenna. The improved characteristics of the double comb-type antenna compared with the serpentine-type antenna appear to be from the higher inductive coupling and less standing wave effect compared to the serpentine-type antenna.

Keywords: Flat panel display; Thin film transistor; Plasma processing and deposition

1. Introduction

In the manufacturing of thin-film transistor/liquid crystal display for the next generation, it is very important to produce a uniform plasma over the large substrate area at low gas pressures [1–3]. *Low gas pressures are generally used to minimize the contamination, to improve step coverage, etc.* [4]. Currently, in the plasma processing of flat panel display (FPD), capacitively coupled plasma is mostly widely used due to its ability to scale up to large area substrate sizes. *But, it has disadvantages such as the difficulty in controlling the ion energy and ion flux bombarding the surface separately, high plasma potentials, etc. in addition to low processing rates or low throughputs due to the low plasma density and low dissociation rate compared to high density plasma sources* [5]. Also, the standing wave effect may limit the processing substrate size no larger than to 7th generation glass size.

Various high density plasma sources such as inductively coupled plasma (ICP) sources, helicon wave plasma sources, surface wave plasma etc. [6,7] are studied for the application to the FPD processing, and among these sources, inductively coupled plasma (ICP) sources are most widely investigated because of their simple physics and scalability compared with the other high density plasmas sources, therefore, uniform large-area plasmas can be produced relatively easily [2,8,9]. Among the various ICP sources studied for the next generation FPD device processing, internal linear ICP sources show benefits compared to the conventional spiral-type external ICP sources. It is because they can solve the problems related to the thick dielectric material required for the transmission of electromagnetic wave from the antenna in the conventional external ICP systems by installing the linear antenna inside the vacuum chamber [10]. Instead, the internal ICP sources show other practical problems such as higher electrostatic coupling of the antenna with plasma. Due to the exposure of the high voltage rf antenna to the plasma through a thin dielectric material, the high voltage sustained at the antenna is

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transferred to the plasma and it could increase the plasma potential and result in unstable plasmas having frequent arching due to the anomalous rise of the plasma potential [11–13].

In this study, a double comb-type antenna was applied for the internal ICP for the improvement of the characteristics such as stability, plasma potential, plasma density, etc. and its plasma and impedance characteristics were compared with those by the conventional serpentine-type antenna generally used for the linear internal-type ICPs.

2. Experiment

Fig. 1 shows the schematic diagram of the experimental apparatus used in the experiment. The plasma processing chamber was designed as a rectangular form for FPD applications and the inner size of the chamber was 1020 × 830 mm and the substrate size was 880 × 680 mm (about 4th generation glass size). As shown in Fig. 1, for the ICP generation, two different arrangements of internal linear antennas, that is, a serpentine-type antenna (a) and a double comb-type antenna (b) were applied. In the case of the serpentine-type antenna, five linear antennas (S-shape) were embedded in the vacuum chamber and each linear antenna was connected in series. The length of the serpentine-type antenna from the rf power input position to ground position was approximately 7 m. However, in the case of the double comb-type antenna, the rf power was connected to the five parallel antennas alternatively from the opposite ends as shown in the figure. The other ends of the each antenna were connected to the ground, therefore, a double comb-type internal antenna was formed. The length from the rf power to the ground was approximately 1.2 m for the double comb-type antenna. The linear antenna was made of 10 mm diameter copper tubing with the outside shielding by quartz tubing. The outside diameter of the quartz tubing was 15 mm and the thickness was 2 mm. 13.56 MHz (0~5 KW) rf power was fed to the antenna through a conventional L-type matching network for both of the antenna types.

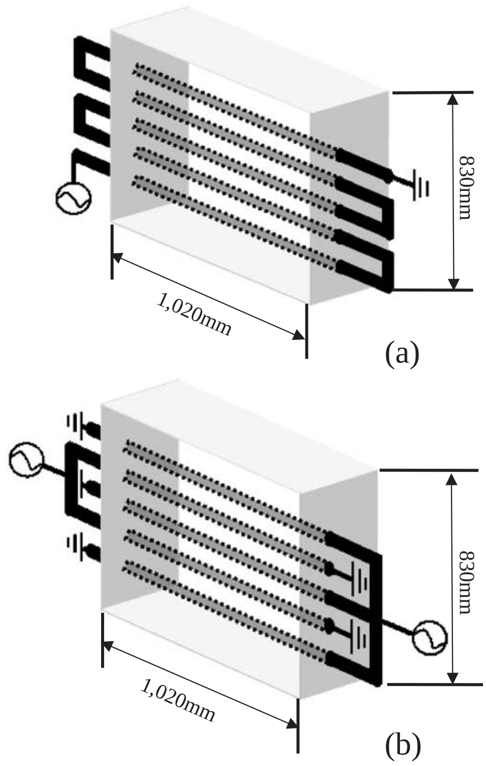

Fig. 1. Schematic diagram of two different types of internal linear ICP sources used in this experiment. (a) A conventional serpentine-type antenna and (b) a double comb-type antenna.

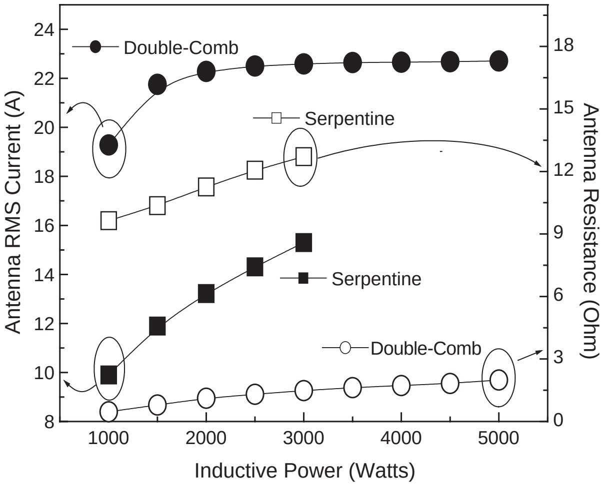

Fig. 2. RMS currents and resistances of two types of the antennas measured using an RF plasma impedance analyzer as a function of rf power from 1000 to 5000 W at 2 Pa Ar.

The plasma characteristics of the internal ICPs such as plasma density, plasma potential, ion saturation current, and plasma uniformity for the both of the antennas with Ar gas were measured using a Langmuir probe (Hiden Analytical Inc.) located 7.5 cm below the antenna and along the vertical centerline of the chamber. To observe the electrical characteristics of the internal antennas, an rf plasma impedance analyzer (V-I probe, MKS Instruments, Inc.) was installed between matching box and internal antenna and its root-mean-square (RMS) current and impedances were measured.

3. Results and discussion

Fig. 2 shows the RMS current and resistance from the antenna to the plasma measured as a function of rf power to the antenna using an rf plasma impedance analyzer. The impedance analyzer was located between the matching network and the rf power input position of the antenna. 2 Pa of Ar was used to generate the plasma. As shown in the figure, the RMS current for the double comb-type antenna was in the range from 19 to 23 A while that for the

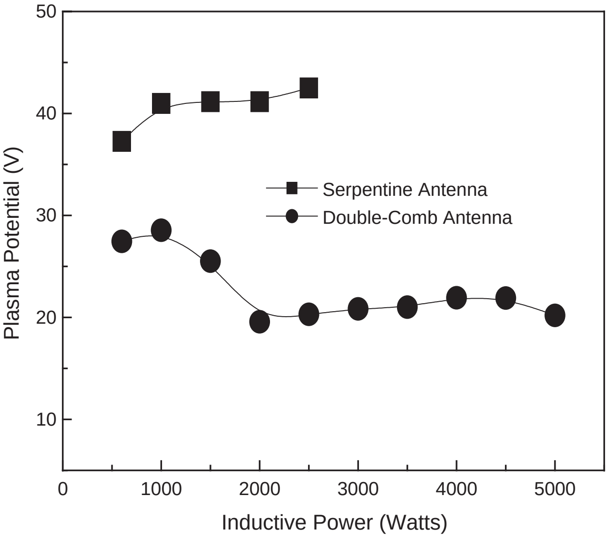

Fig. 3. The plasma potentials of two types of the antennas using a Langmuir probe as a function of rf power from 6000 to 5000 W at 2 Pa Ar.

serpentine-type antenna was in the range from 9 to 15 A when rf power was operated from 1000 to 3000 W. Therefore, the RMS current at a given rf power was generally higher for the double comb-type antenna compared to the serpentine-type antenna.

In the case of resistance shown in the Fig. 2, the double comb-type antenna showed the lower than 3 Ω while the serpentine-type showed 9∼12 Ω *due to the length of the total antenna from the rf power to the ground even though the resistance measured by the impedance probe is the real part of impedance containing the resistance of the antenna and the resistance of the plasma.* It is believed that, due to the lower resistance of the antenna for the double comb-type, more current can flow to the antenna at a given rf power, therefore, more inductive coupling is possible for the double comb-type. In the case of the serpentine-type antenna, it was difficult to operate at the rf power higher than 3000 W due to the unstability of the plasma and arcing. Therefore, no data could be obtained above 3000 W while the plasma with the double comb-type antenna was stable even at 5000 W. Also, the antenna length from the rf power input position to the ground for the double comb-type antenna is much shorter than the wavelength of the 13.56 MHz rf power while the length for the serpentine-type can be comparable to the wavelength of the rf power. Therefore, the standing wave effect that can cause a uniformity problem of the plasma may not be observable for the ICP source with the double comb-type antenna.

Fig. 3 shows the plasma potentials measured at the center of the chamber and 7.5 cm below the antenna with 2 Pa Ar as a function of rf power using a Langmuir probe. As shown in the figure, the plasma potential was increased from 37 to 45 V as the rf power was increased from 600 to 2500 W for the serpentine-type antenna. However, in the case of the double comb-type antenna, the plasma potential initially decreased from about 28 to 20 V when the rf power was increased from 600 to 2000 W, and the further increase of rf power to 5000 W did not change the plasma potential significantly. The initial decrease and stabilization of the plasma potential to a low voltage for the double comb-type antenna appears from the transition from capacitively coupled plasma to the inductively coupled plasma. In the case of the serpentine-type antenna, due to the high plasma potentials and the increase of the plasma potential with the increase of rf power, the plasma appeared to become unstable and show arcing when the rf power was higher than 3000 W. *It is known that, when the capacitively coupling is dominant, at a given power, a high voltage is induced on the antenna and the power is delivered to the plasma by the high sheath potential developed at the sheath region of the plasma. However, when the inductive coupling is dominant, a higher current is induced on the antenna and the power is delivered by the time varying magnetic field generated by the current of the antenna not by the sheath potential, therefore, there is less potential drop between the sheath and the plasma for the inductive coupling. Therefore, lower plasma potential obtained at the power higher than 2000 W for the double comb-type antenna appears related to the transition from the capacitive coupling to the inductive coupling.*

Fig. 4 shows plasma density and ion saturation current measured using the Langmuir probe at the center and 7.5 cm below the antenna as a function of rf power with 2 Pa of Ar for the serpentine-type antenna and the double comb-type antenna. As shown in the figure, the increase of rf power from 600 to 2500 W increased the plasma density from $2\times10^{10}/\mathrm{cm}^3$ to $1\times10^{11}/\mathrm{cm}^3$ for the serpentine-type antenna and from $3\times10^{10}/\mathrm{cm}^3$ to $1.5\times10^{11}/\mathrm{cm}^3$ for the double comb-type antenna and, in the case of the double comb-type antenna, the continuous increase of rf power to 5000 W increased the plasma density almost linearly to

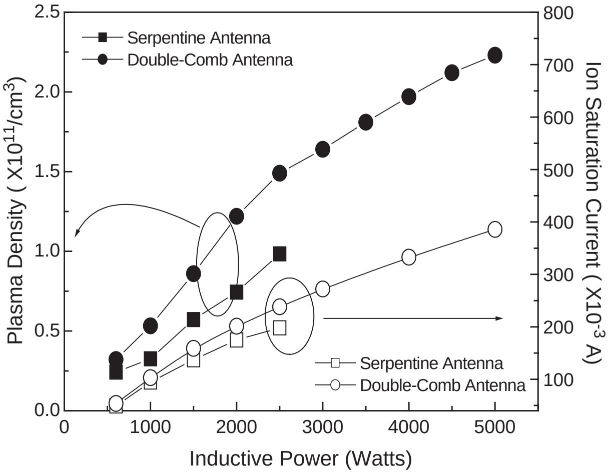

Fig. 4. Plasma densities and ion current densities of the two types of the antennas measured by a Langmuir probe at the center of the chamber and 7.5 m below the antenna as a function rf power from 600 to 5000 W. The operation pressure was maintained at 2 Pa Ar.

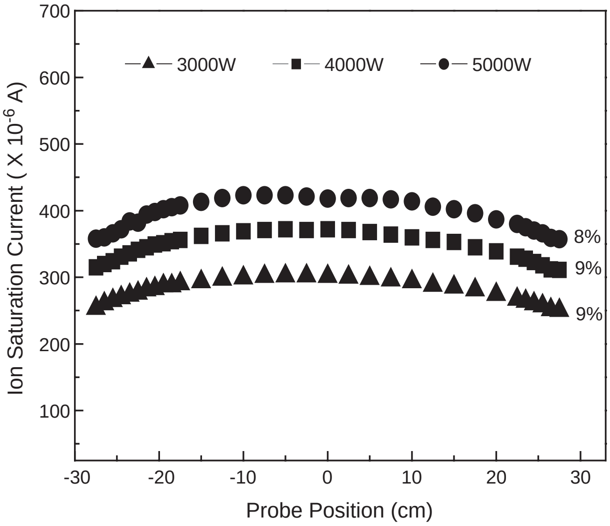

Fig. 5. Plasma uniformity of the double comb-type antenna measured 7.5 cm below the antenna as a function of RF power from 3000 to 5000 W with 15 mTorr Ar. Ion saturation current measured using a Langmuir probe biased at −60 V was used as the estimation of plasma density.

2.2×10^{11}/cm^3. Therefore, at a given rf power, the double comb-type antenna showed higher plasma density compared to the serpentine-type antenna possibly due to the more inductive coupling by higher antenna current at the same rf power as shown in Fig. 2. Also, in the case of the double comb-type antenna, the plasma density was increased continuously without saturation until 5000 W of rf power was applied. In fact, the power density at the 5000 W is still low as 0.59 W/cm^2, compared to the power density used for the plasma processing which is higher than 2 W/cm^2, therefore, it is believed that the plasma density will be increased continuously if the rf power higher than 5000 W is applied to the antenna. In the figure, the ion saturation currents measured by biasing the Langmuir probe at −60 V are also shown. The ion saturation currents measured as a function of rf power showed the similar trend as the plasma potentials. Therefore, using the ion saturation currents measured by the probe, the uniformity of the plasma in the chamber for the double comb-type antenna was measured.

Fig. 5 shows the ion current density measured as a function of position perpendicular to the antenna lines shown in the Fig. 1 at 7.5 cm below the antenna. The uniformity of the ion current density was measured for the double comb-type antenna with 2 Pa of Ar and for the rf power from 3000 to 5000 W. As shown in the figure, the ion current density was lower near both sides of the chamber walls due to the diffusion of the ions to the chamber wall. The measured uniformity of the plasma was about 8∼9% which is acceptable for the plasma processing of the FPD in general.

4. Conclusions

In this study, to develop a linear internal-type ICP source that can be applied to the next generation FPD processing, the plasma characteristics of the ICP source with a double comb-type antenna were investigated and its characteristics were compared with those of the ICP source with the serpentine-type antenna which is conventionally used as the antenna for the linear internal ICP source. By using the double comb-type antenna compared to the serpentine-type antenna, higher RMS current to the antenna, therefore more possible inductive coupling to the plasma, could be obtained due to the low resistance of the antenna at a given rf power. The plasma potentials for the double comb-type antenna were lower than those for the serpentine-type antenna, therefore, more stable plasma could be obtained. The high plasma density of 2.2×10^{11}/cm^3 and a good plasma uniformity of 8% could be obtained for the ICP with the double comb-type antenna at 5000 W of rf power. This double comb-type antenna does not have the standing wave effect due to the short length of the antenna from the rf power to the ground, therefore, it is believed that the ICP source with the double comb-type antenna can be applicable as the high density plasma source for the next generation FPD processing.

Acknowledgments

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