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Effect of Pressure on Inductively-Coupled Plasmas Sustained with Multiple Low-Inductance Internal-Antenna Units

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We studied effect of pressure on inductively-coupled plasmas sustained with multiple low-inductance internal-antenna units. With increasing pressure, the plasma densities on the substrate folder increased to attain a plasma density of 1.4×10^{11} cm^{-3} at an argon pressure of 13 Pa. The plasma potential and the potential drop decreased drastically with decreasing Ar pressure. These dependencies are related to changes in the electron temperature and the antenna RF voltage. The ion energy distributions considerably decreased with increasing Ar pressure. The peak energies of the distributions depended more strongly on pressure and corresponded to the magnitude of plasma potential. The FWHM of the distributions decreased with lowering the antenna RF voltages by decrease in Ar pressure.

Key words: Plasma, ICP, Internal-antenna, Large area, plasma source

1. INTRODUCTION

In fabrications of flat panel displays (FPDs) such as thin-film transistor liquid-crystal displays (TFT-LCDs) and microelectronics devices, there is a steady growth in size of substrate for reduction of the production costs. [1] In the case of TFT-LCD, mother glass substrates are expected to be larger than 3000 x 3000 mm^2 within a few years. [2]

For plasma processing of the substrates, development of high-density plasma reactors is desired to realize the high production throughput. The development of large-area plasma reactors has been attempted using various plasmas. Among the various plasma reactors, inductively coupled plasma (ICP) reactors have been widely investigated due to their simplicity and scalability to large areas [3–6].

However, considering design issues for plasma production with high-frequency (HF) power sources to scale the reactor size exceeding a meter, power deposition profiles and hence process profiles become inherently nonuniform especially due to standing wave effects and/or edge effects, which can not be avoided with increasing reactor size when the reactor employs power coupling devices (inductive antenna) with a scale length equivalent to or as long as the 1/4 wavelength of the HF-power transmission [7-10]. Furthermore, the increase in antenna size and hence increase in antenna impedance causes a high antenna RF voltage, and it lead a high plasma potential by the increased capacitive coupling. [11]

In order to solve these constraints associated with large-area reactors, we have developed inductivity-coupled plasma (ICP) generation techniques with multiple low-inductance antenna (LIA) units, which can produce high-density plasma with low potential by low voltage operation [12]. Previous experiments using cylindrical reactor with multiple LIA units resulted in stable source operation to attain plasma densities as high as 10^{11} - 10^{12} cm^{-3} and the plasma potential as low as 13 - 14 V in high density plasmas has been achieved for argon plasmas [13,14]. Furthermore, deposition of μc-Si films for TFT-LCD using rectangular reactor with multiple LIA units was demonstrated, and highly crystallized μc-Si films with a crystalline volume fraction of over 90% were deposited on glass substrates at the substrate temperature of 300°C with high deposition rate of up to 70 nm/min. [2]

In this paper, we report effects of pressure on properties of inductively-coupled Ar plasmas sustained with multiple internal- antenna units.

2. EXPERIMENTAL

Schematic diagram of the chamber with a set of eight LIA units is shown in Fig. 1. The LIA unit consists of a

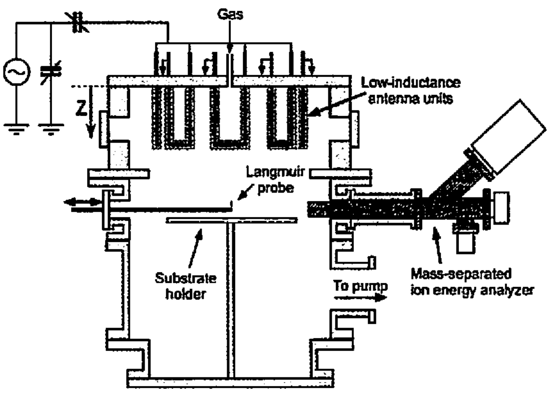

Fig. 1. Schematic diagram of chamber with multiple low-inductance antenna units.

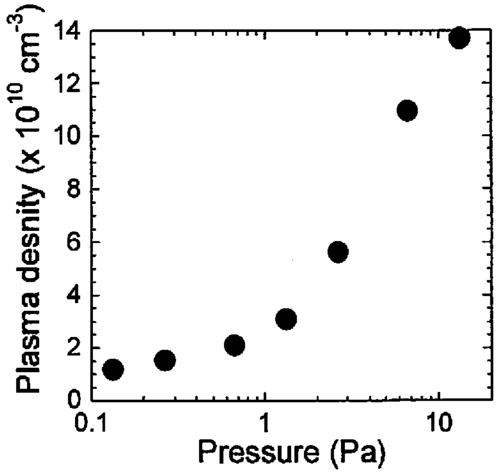

Fig. 2. Pressure dependence of plasma density for argon plasmas at RF power of 1000W.

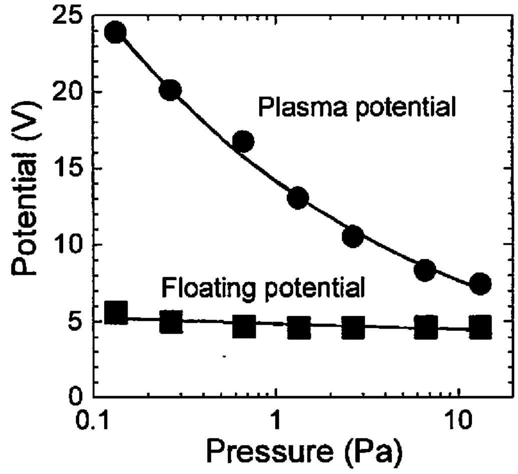

Fig. 3. Pressure dependence of plasma and floating potential for argon plasmas at RF power of 1000W.

U-shaped antenna conductor, which was fully covered with dielectric tubing for complete isolation from the plasma [12, 13]. Eight LIA units with a 70 mm width and a 160 mm height were mounted on the top flange of the discharge chamber and coupled to a 3000 W RF power generator at 13.56 MHz via a matching network. Each LIA unit was connected in parallel to the matching network. This chamber had a 500 mm inner diameter and a 200 mm height, which was connected to a diffusion chamber made of stainless-steel vessel with a 500 mm inner diameter and a 400 mm height. The substrate holder was placed at a distance of 297 mm from the top flange.

For this experiment, z axis is taken along the axis of the discharge system as illustrated in Fig. 1. so that the z = 0 position lies in the inner surface of the top flange and the positive z values are taken in top-to-bottom direction. Plasma parameter was measured with a cylindrical Langmuir probe which was inserted radially at an axial position of z = 280 mm below the top flange. Ion energy distributions in Ar plasmas were measured with a mass-separated ion energy analyzer (Hiden, EQP500), which had a grounded sampling orifice, mounted on sidewall as shown in Fig. 1.

3. RESULTS AND DISCUSSIONS

Pressure dependence of plasma density at an RF power of 1000W measured at the radial center of the chamber at z = 280 mm is shown in Fig. 2. The plasma densities increased with increasing RF power to attain a plasma density of 1.4 x 10^{11} cm^{-3} at an argon pressure of 13 Pa. The results show that high-density plasmas as high as 10^{11} cm^{-3} can be obtained at the downstream region in the condition of high pressure.

Figure 3 shows dependence of plasma potential and floating potential on Ar pressure at an RF power of 1000 W. With increasing Ar pressure, the plasma potential decreased from 24 V at 0.13 Pa to 7 V at 13 Pa, while floating potential is almost constant with a slight increase from 5 to 6 V.

Variation of potential drop from the plasma potential to the floating potential is shown in Fig. 4. The potential drop is equivalent to the energy of ion bombardment during the film growth by plasma chemical vapor deposition (plasma CVD) on non conductive substrates such as glass and polymers. With increasing Ar pressure, the potential drop decreased from 18.3 V at 0.13 Pa to 2.8 V at 13 Pa. These results regarding of plasma density, plasma potential and potential drop show that ICPs driven by multiple low-inductance antenna units are suitable as plasma sources with high density and low potential for high-speed deposition of high-quality films with markedly reduced plasma damage.

Figure 5 shows dependence of electron temperature on Ar pressure at a RF power of 1000 W. With increasing Ar pressure, the electron temperature considerably decrease from 4.1 eV at 0.13 Pa to 1.4 eV at 13 Pa. The decrease of electron temperature is considered to be attributed to enhance the coupling of power to the plasma with increasing Ar pressure. Furthermore the decrease

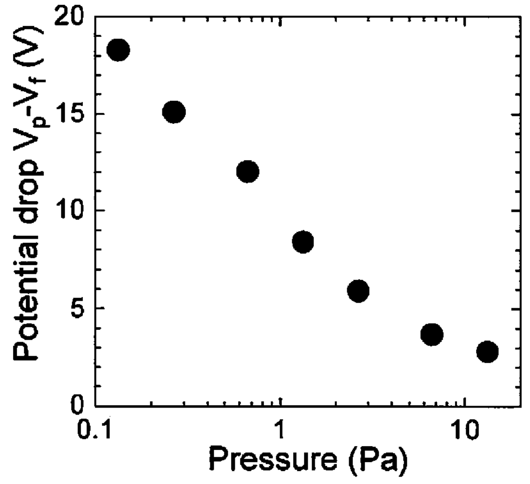

Fig. 4. Pressure dependence of potential drop for argon plasmas at RF power of 1000W.

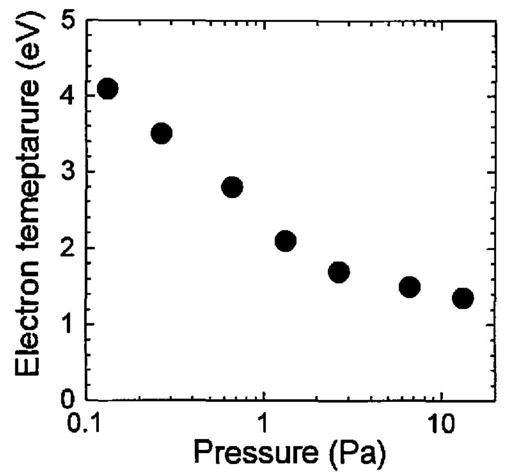

Fig. 5. Pressure dependence of electron temperature for argon plasmas at RF power of 1000W.

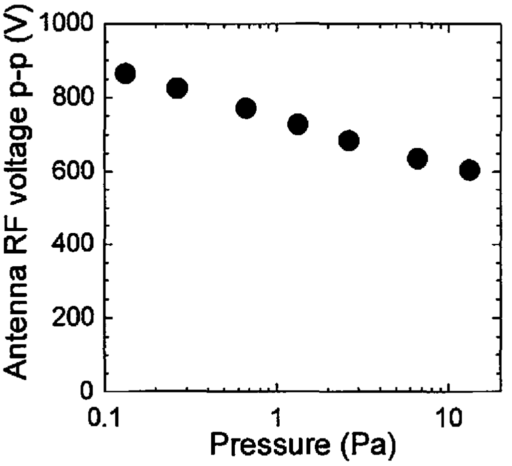

Fig. 6. Pressure dependence of peak-to-peak antenna RF voltage for argon plasmas at RF power of 1000W.

of electron temperature contributed to a suppression of the plasma potential and a lowering of the potential drop [15].

Figure 6 shows dependence of peak-to-peak antenna RF voltage on Ar pressure at a RF power of 1000 W. With increasing Ar pressure, the antenna voltage exponentially decrease from 865 V at 0.13 Pa to 603 V at 13 Pa. The antenna RF voltages in this study were significantly smaller than those obtained using a hemispherical multi turn antenna (8000 V)[16] and a double half-loop antenna (2000 V)[11]. The reduction in antenna RF voltage by decreasing antenna inductance in this study is expected to decrease the potential fluctuation due to capacitive coupling between the antenna and the plasma, which may lead to the suppression of electron loss to grounded walls. Furthermore the reduction in antenna RF voltage with increasing Ar pressure is considered to be partly attributed to lower the plasma potential as shown in Fig. 4. [13]

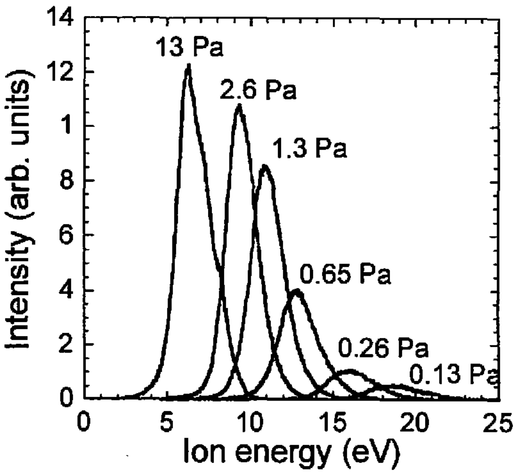

Fig. 7. Variation of kinetic energy distribution of argon ions at RF power of 1000W as a parameter of argon pressure.

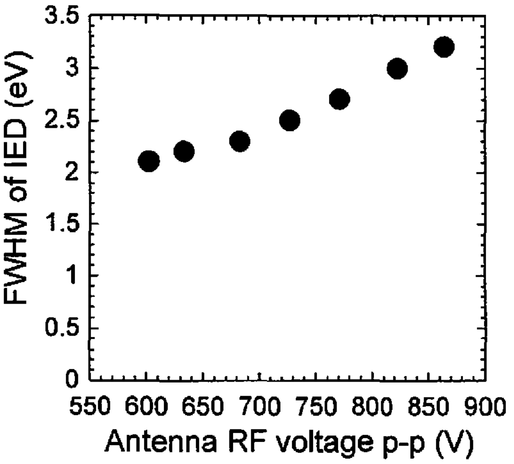

Fig. 8. Variation of full width at half maximum (FWHM) of ion energy distributions (IED) as a parameter of antenna RF voltage.

Figure 7 shows variation of ion energy distribution (IED) of Ar ions in argon plasmas sustained in an Ar pressure range of 0.13 -13.3 Pa. With increasing Ar pressure, peak values of IEDs of Ar ions decrease from 19 V at 0.13 to 6 V at 13Pa Pa and the peak energies of the distributions depend more strongly on pressure. The IEDs of Ar ions have peaks which correspond to the magnitude of plasma potential as shown in Fig. 3. Full width at half maximum width (FWHM) of the IEDs decreases from 3.2 eV at 0.13 Pa to 2.1 eV at 13Pa with decreasing Ar pressure.

To investigate effects of the antenna RF voltages on the IEDs, variation of the FWHM on the antenna RF voltages, which was obtained from pressure dependence of the antenna RF voltages and the FWHM in the IEDs as shown in Figs. 6 and 7, was plotted as shown in Fig 8. The FWHM of the IEDs was reduced with decreasing the antenna RF voltages. These results exhibit that the decrease in the antenna RF voltages and hence the decrease in the potential fluctuation lead to the lowering in the capacitive coupling between the antenna and plasma, resulting in reduction of the FWHM in the IEDs.

4. CONCLUSIONS

We studied effect of pressure on inductively-coupled plasmas sustained with multiple low-inductance internal-antenna units. With increasing Ar pressure, the plasma densities on the substrate folder increased to attain a plasma density of 1.4×10^{11} cm^{-3} at an argon pressure of 13 Pa. The plasma potential and the potential drop decreased drastically with decreasing Ar pressure. These dependencies are related to changes in the electron temperature and the antenna RF voltage.

The ion energy distributions considerably decreased with increasing Ar pressure. The peak energies of the distributions depended more strongly on pressure and corresponded to the magnitude of plasma potential. The FWHM of the IEDs decreased with lowering the antenna RF voltages by decrease in Ar pressure.

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