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Large Area Plasma for LCD Processing by Individyally Controlled Array Sources

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Abstract

Large area plasma source has been built for LCD etcher by an array of 2× 2 ICP sources. Since only one RF power supply and one impedance matching network is used in this configuration, any difference in impedances of unit RF antennas causes unbalanced power delivery to the unit ICP. In order to solve this unavoidable unbalance, unit antenna is designed to have a movable tap, with which the inductance of each unit can be adjusted individually. The plasma density becomes symmetric and etch rate becomes more uniform with the impedance adjustment. The concept of adding axial time-varying magnetic field to the single ICP source is applied to the array ICP source, and is found to be effective in terms of etch rate and uniformity .

Keywords : large area plasma, array of ICP sources, etching, LCD

1. Introduction

As glass substrate becomes larger in size and the minimum feature size shrinks in recent TFT-LCD technology, dry etching becomes more and more important. RIE reactors which have commonly been used are limited in their etch performance in terms of etch rate and uniformity for next generation TFT-LCD processing. Thus, it is required to have a large area plasma source with high density and good uniformity, which can handle substrates larger than 110×120 cm[1, 2, 3]. Inductively coupled plasma (ICP) with planar RF antenna is a good candidate because of its ability of scaling up and higher plasma density at low process pressure[1]. Obtaining large area plasma simply by enlarging RF antenna diameter is not the effective way because larger and longer antenna has larger series impedance. Large area ICP plasma has to have a large dielectric window which should be covered by RF antenna. If a single antenna is used, its length becomes longer, which in turn causes larger series impedance. It will cause more power loss and potential drop in the antenna. Larger window also requires thicker dielectric layer to the antenna in order to sustain high chamber vacuum, which reduces the power coupling efficiency[2].

Connecting several small unit antennas together in parallel to cover large area of dielectric window can reduce the series impedance less than that of one large antenna for the same area. This scheme of large area ICP plasma can increase the power coupling efficiency and thus plasma density. However, there is an intrinsic problem of power unbalance among the antennas due to small impedance deviation from each other. It can cause non-uniform plasma density distribution[2]. Therefore, it is necessary to have a solution to balance the impedances of all antennas individually[4].

In this work, a 2×2 array ICP source is built for large plasma generation. The antenna of each ICP source is designed such that its impedance can be adjusted individually. The uniformity of Ar plasma is measured

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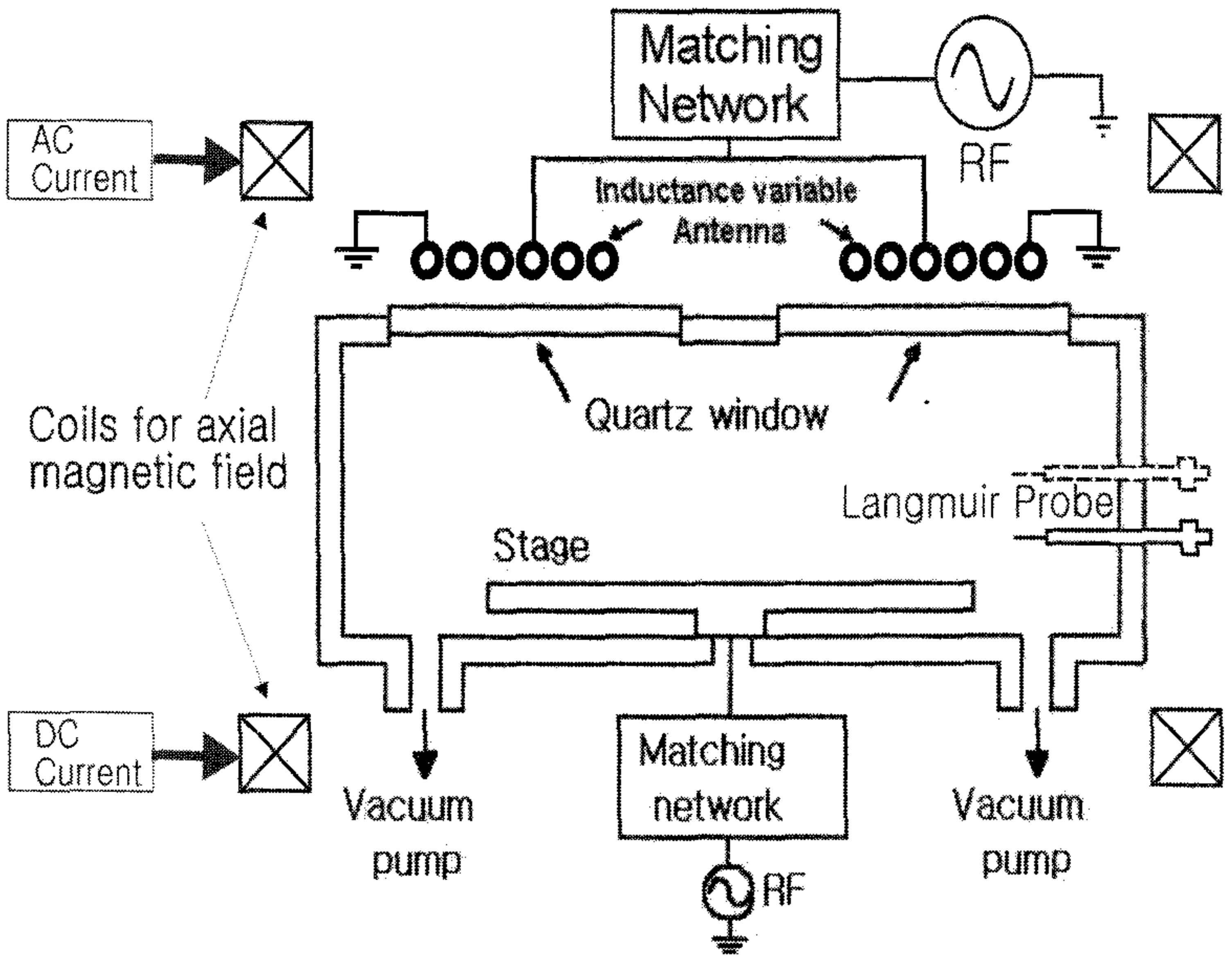


Fig. 1. Schematic diagram of 2×2 array ICP with an axial magnetic field.

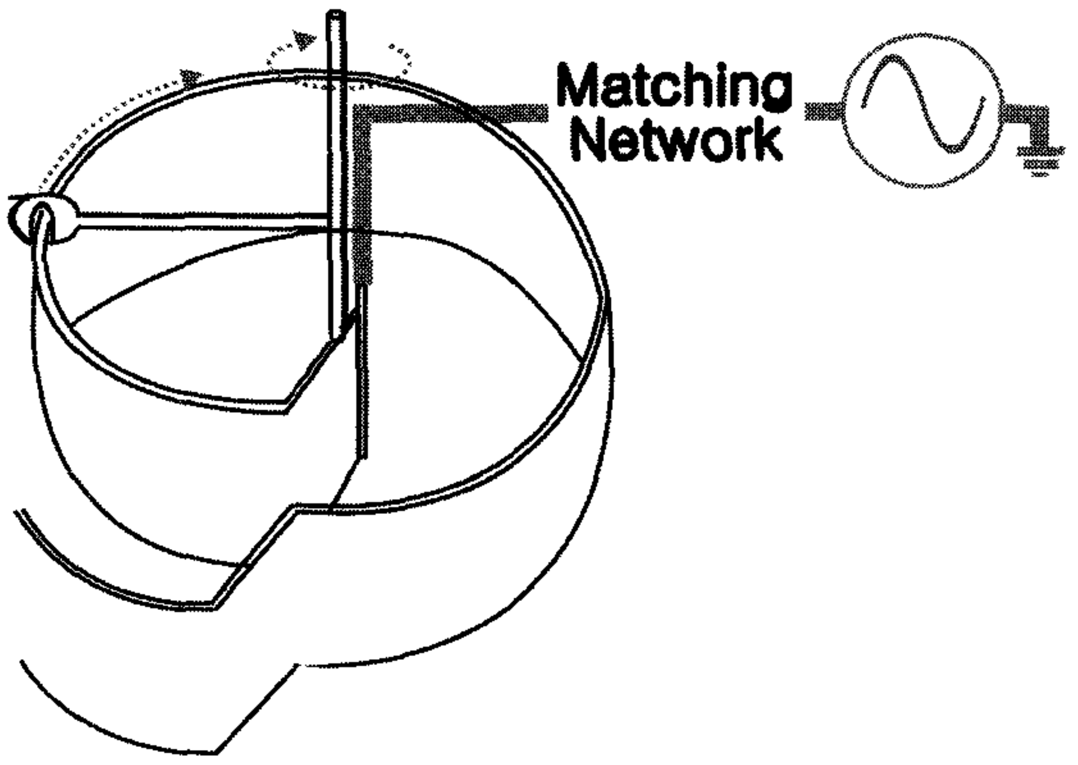


Fig. 2. Unit RF antenna with a movable tap to adjust the impedance.

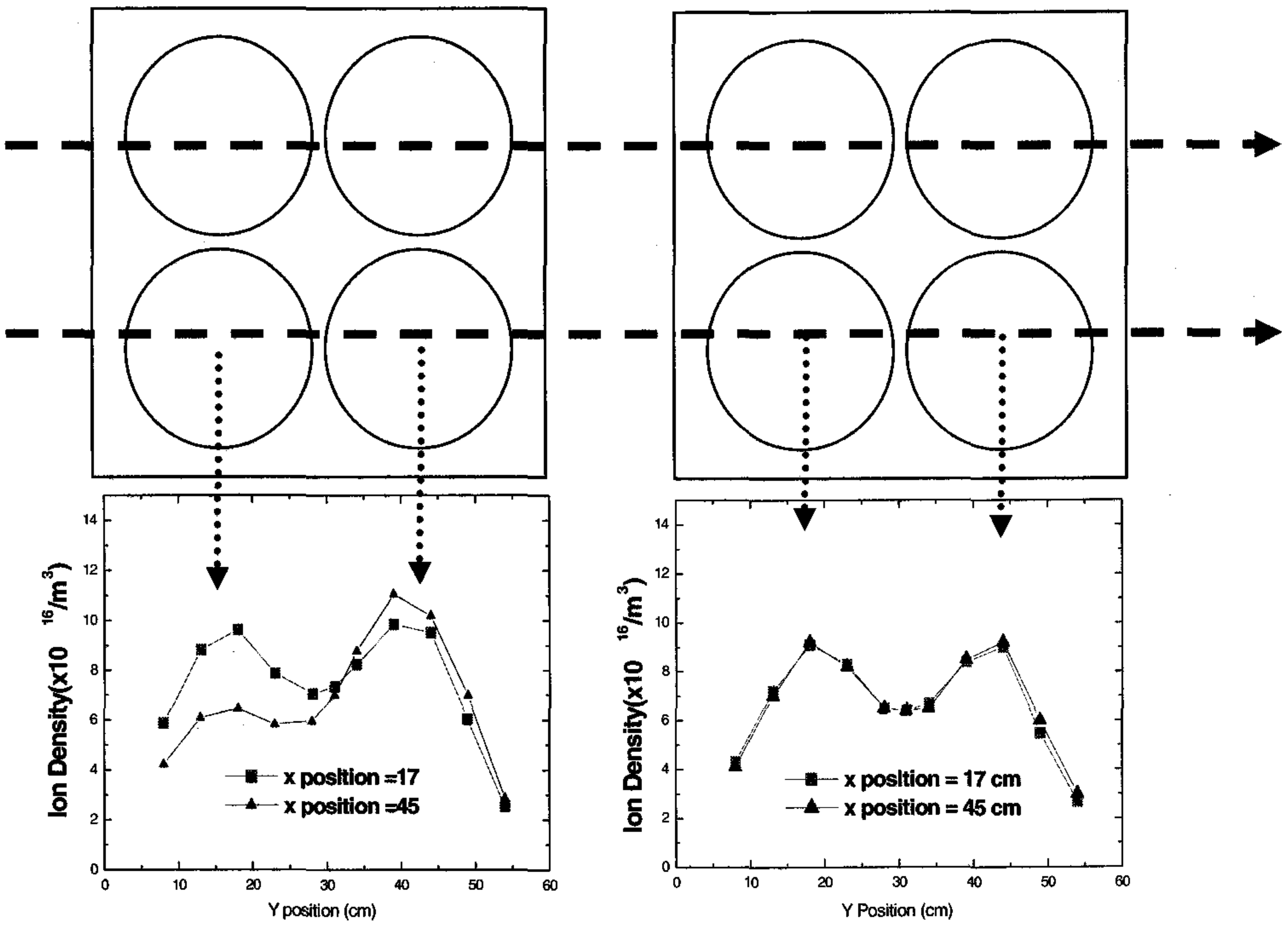
across the chamber and etch rate uniformity of photoresist in O_2 plasma is measured and compared. Effects of time-varying axial magnetic field to this array ICP is also investigated [2].

2. Experimental and Results

2.1 RF antenna with directly adjustable impedance

Four spiral antennas are arranged as a 2×2 array on top of 620×620 mm reactor. One RF power of 13.56 MHz is connected to all four antennas through one matching network[1]. A substrate holder of 300×350 mm glass has an independent 13.56 MHz RF power for dc self-bias. Fig. 1 shows the schematic diagram of the etch chamber. It also shows a pair of Helmholtz coils to provide axial magnetic field. The current to the upper coil can be changed while the current to the lower coil is constant.

Even if shape, size and material of all four RF antennas are kept the same, there still exists impedance difference among them at high frequency due to uncontrollable parasitic impedance. This difference causes unbalanced power delivery to unit sources, and plasma densities of unit sources become different. Thus, conventional spiral shape RF antenna is modified to have a movable tap as shown in Fig. 2. The diameter of the



(a) Before impedance adjustment

(b) After impedance adjustment

Fig. 3. Plasma density profiles of the 2×2 array ICP at two x-positions; (a) before and (b) after impedance adjustment. Four circles are dielectric windows of RF antenna to the etching chamber.

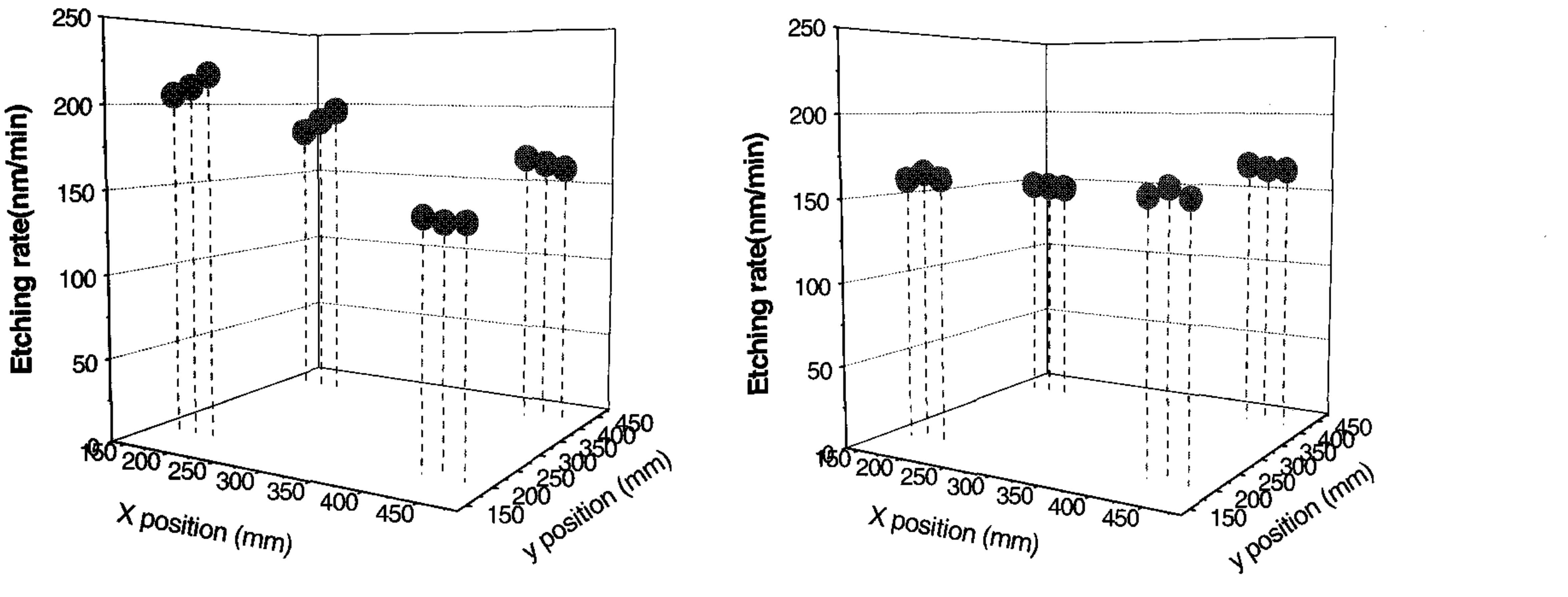
antenna is 150 mm and spiral shape 3.5 turn copper coil is coated with silver to improve electrical conductivity. The inductance of each antenna can be controlled by adjusting the position of the tab and altering the RF current path. Table 1 shows the impedance measured at different tap position by LCR meter. By rotating the tap by one turn, the impedance can be reduced by 17 %.

Table 1. Inductance of unit antenna at different tab position.

Tab position	Home	1/2 turn	1 turn	3/2 turn
Inductance	1.31 μH	1.23 μH	1.09 μH	0.98 μH

Plasma density distributions of 2x2 array ICP without impedance adjustment are first measured by Langmuir probe positioned at 7 cm below from top of the reaction chamber and plotted in Fig. 3-a. Ion densities of all four unit sources are different from each other as shown in Fig. 3-a. They are ranging from 6×10^{16} cm^{-1} to 11×10^{16} cm^{-1}. Because of slight difference in impedance among the four antennas, the power delivery to all unit sources is unbalanced. When the adjustable antennas are used instead, the impedances of four unit antennas can be controlled individually to have the same value. The results are plotted in Fig. 3-b, where the ion densities of all four unit sources show the same shape with the peak density of 11×10^{16} cm^{-1}. This symmetric density profile is the result of the impedance balance among the RF antennas of the array ICP.

The improvement of the balancing and uniformity is also observed in etching of organic photoresist thin films by oxygen plasma. Photoresist is spin coated on the 350x300 mm glass substrates. 100 sccm oxygen is fed in the reaction chamber at 20 mTorr. Total RF power to the four unit source is 800 W, and the RF power to the substrate holder for dc self-bias is 250 W. Oxygen ions are accelerated by the dc self-bias, and the energetic oxygen ions react with organic films in anisotropic etching mode. Fig. 4 –a shows the etch rates obtained when there is no adjustment in antenna impedance. Near 4 different unit sources the etch rates vary from 130 nm/min to 220 nm/min. However, when the impedances are adjusted using the direct adjustable antenna, the etch rate ranges from 160 to 170 nm/min. The improvement in the etch uniformity is very noticeable.



(a)

(b)

Fig. 4. Etch rates of photoresist in oxygen plasma; (a) before and (b) after impedance adjustment.

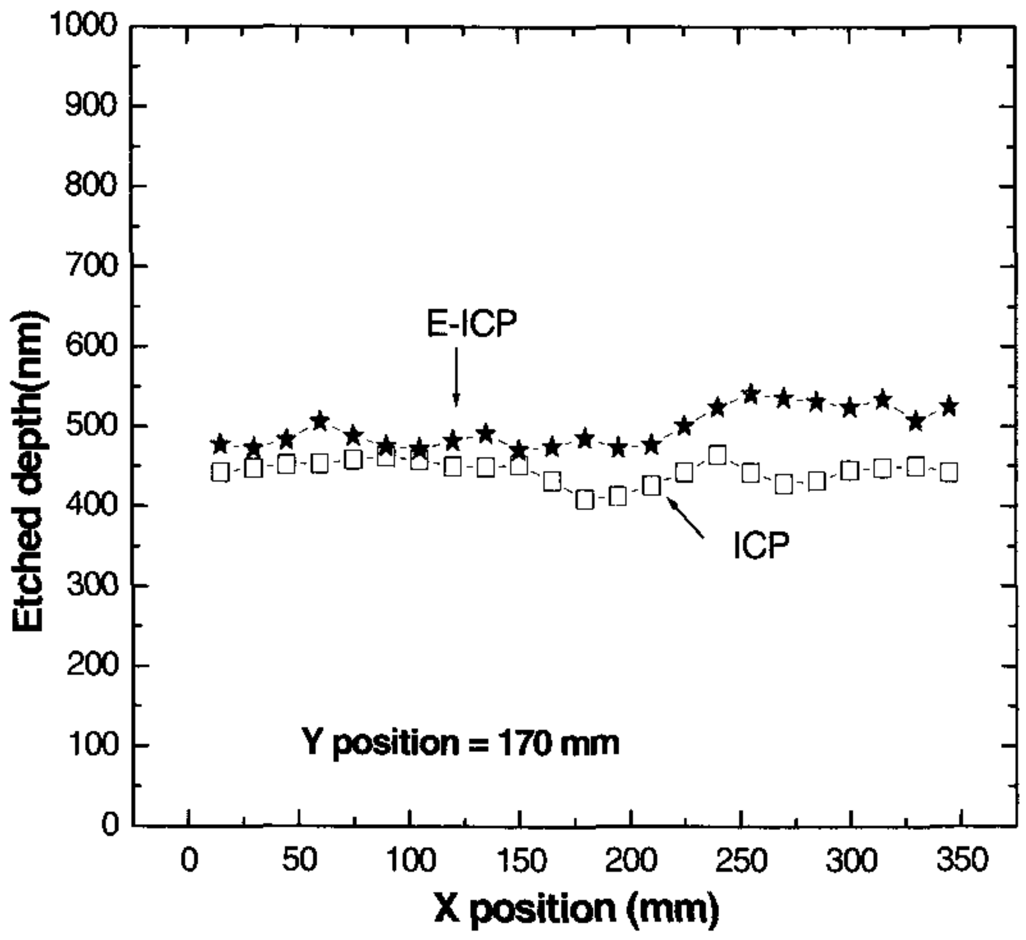


Fig. 5. Photoresist etch rates by the array ICP with and without the axial magnetic filed. ICP with the axial magnetic field is called as E-ICP.

2.2 Axial magnetic field to the 2×2 array source

Fig. 1 also shows a pair of Helmholtz coil to provide the axial magnetic field to the array ICP source. When the upper coil has sinusoidal current (ac current) while the lower has constant dc current, the axial component of the resulting magnetic field at the middle of the reaction chamber is changing in time depending on the frequency of the ac current. This additional axial magnetic field has been added to the ICP, which is called as E-ICP, and its performances have been studied for oxide etching, anisotropic photoresist etching and isotropic photoresist ashing [5, 6]. On all of the previous studies, the axial magnetic field has been applied to the single ICP source, which has a single RF antenna. Thus, the effect of the E-ICP concept is tested in this array source. Fig. 6 shows the etch depths after three minutes of etching. The total RF power to all unit source is 600 W, and the frequency of the upper coil current is 40 Hz. As in the other cases, the overall etch rate is increased by 10 %, and the uniformity gets better [5, 6]. Thus, the effects of axial magnetic field is confirmed in the array ICP configuration.

3. Summary

By adjusting the impedances of unit RF antennas individually, the 2×2 array ICP sources can have symmetric and balanced plasma distribution. The anisotropic etching of photoresist by balanced array source shows very high uniformity of better than 5 %. Addition of time varying axial magnetic field can further improve the etching characteristics, and it proves that the addition of magnetic field is effective to the array antenna configuration as well as to the single antenna.

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