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Novel Internal Linear Inductively Coupled Plasma Source for Flat Panel Display Applications

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In this study, using two different types of linear internal type inductively coupled plasma sources with a serpentine-type antenna and a novel double-comb type antenna having the size of $1020 \times 830\,mm^2$, the characteristics of their plasmas were compared as the application to the flat panel display manufacturing. The use of the double-comb type antenna instead of the serpentine-type antenna showed two times higher plasma and radical densities, and more stable plasma when rf power higher than 2000 W was applied. By the application of 5000 W of rf power with 15 mTorr Ar, a high plasma density of $2.2 \times 10^{11}/cm^3$ with the plasma uniformity of 8% could be obtained for the double-comb type antenna. The increase of plasma density, radical density, and plasma stability for the double-comb type antenna compared to the serpentine-type antenna appears from the higher inductive coupling and less standing wave effect compared to the serpentine-type antenna.
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KEYWORDS: high density plasma, large area, display, etching

1. Introduction

For the etching of thin film transistor-liquid crystal display (TFT-LCD) devices, and especially for the next generation TFT-LCD device processing, dry etching methods are replacing wet etching methods due to the better control of critical dimension, better repeatability, less environmental impact, easier automation, etc. Also, for the dry etching plasma sources, to improve the throughput of the TFT-LCD device processing, high density plasma etching sources are preferred compared to conventional capacitively coupled plasma sources due to their higher processing speed.

To apply for the TFT-LCD device processing having extremely large area substrate size, various high density plasma sources have been recently studied using an array of helicon sources,[1)] an inductively coupled plasma (ICP) source composed of large loop,[2)] ICP sources composed of internal antennas,[3,4)] etc. Among these sources, internal-type ICP sources do not require a huge dielectric window on the wall of the processing chamber which is prerequisite for transmitting electromagnetic field to the plasma from the source antennas. Therefore, these internal-type ICP sources can be more easily applicable to the next generation TFT-LCD substrate size in addition to the easier and cheaper fabrication of the processing chamber.

Currently, various internal-type ICP sources utilizing serpentine-type antennas have been reported for the applications of large-area TFT-LCD processing[5–7)] and semiconductor processing.[8)] However, in the case of TFT-LCD processing, due to the long length of the serpentine-type antenna close to operating rf wavelength and its high impedance, it is difficult to remove the standing wave effect and the plasma unstability as the chamber size becomes larger and larger.

For the operation of serpentine-type antennas, a traveling wave can be launched to remove the standing wave effect, however, it is known to be difficult to match the source to the input power due to the various capacitors used to launch the traveling wave.[3)] Otherwise, as the internal-type ICP antennas, short linear antennas should be used to remove the standing wave effect and to decrease the high impedance due to the long length of the antenna as investigated by Setsuhara *et al.*[9)] In this paper, as one of the methods using short internal antennas to remove the standing wave and to have low impedance, a novel internal-type antenna (double-comb type antenna) has been utilized and the characteristics of the source such as plasma density, uniformity, and etch characteristics were compared with the conventional serpentine antenna as the application to the next generation large-area TFT-LCD processing.

2. Experiment

Figure 1 shows the schematic diagram of the experimental apparatus used in the experiment. As shown in the figure, the plasma processing chamber was designed as a rectangular form for flat panel display (FPD) applications and the inner size of the chamber was $1020 \times 830\,mm^2$ and the substrate size was $880 \times 680\,mm^2$. As shown in Fig. 1, in the case of a serpentine-type antenna, five linear antennas were embedded in the vacuum chamber and each linear antenna was connected in series. However, in the case of a novel antenna (double-comb type antenna), five parallel antennas were connected to the rf power supply 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 linear antenna was made of 10 mm diameter copper tubing with the outside shielded 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.

Ar plasma characteristics such as plasma density and plasma uniformity of the internal-type ICP sources were measured using a Langmuir probe (Hiden Analytical ESP) located 7.5 cm below the antenna and along the vertical centerline (A–A′ in Fig. 1) and the horizontal centerline (B–B′ in Fig. 1) of the chamber. RF rms voltages and DC quartz voltages were measured by a high voltage probe (Tektronix, P6015A) through an oscilloscope. Oxygen radical intensity measured by optical emission spectroscopy (OES, SC Tech. PSM-403) was used to observe the characteristics of photoresist film etching. Photoresist etching characteristics were investigated using 3-μm-thick photoresist (AZ-GXR601) deposited on the glass and using O_2 instead of Ar. The etch rate was measured at the center of the substrate. For the photoresist etching, the substrate was

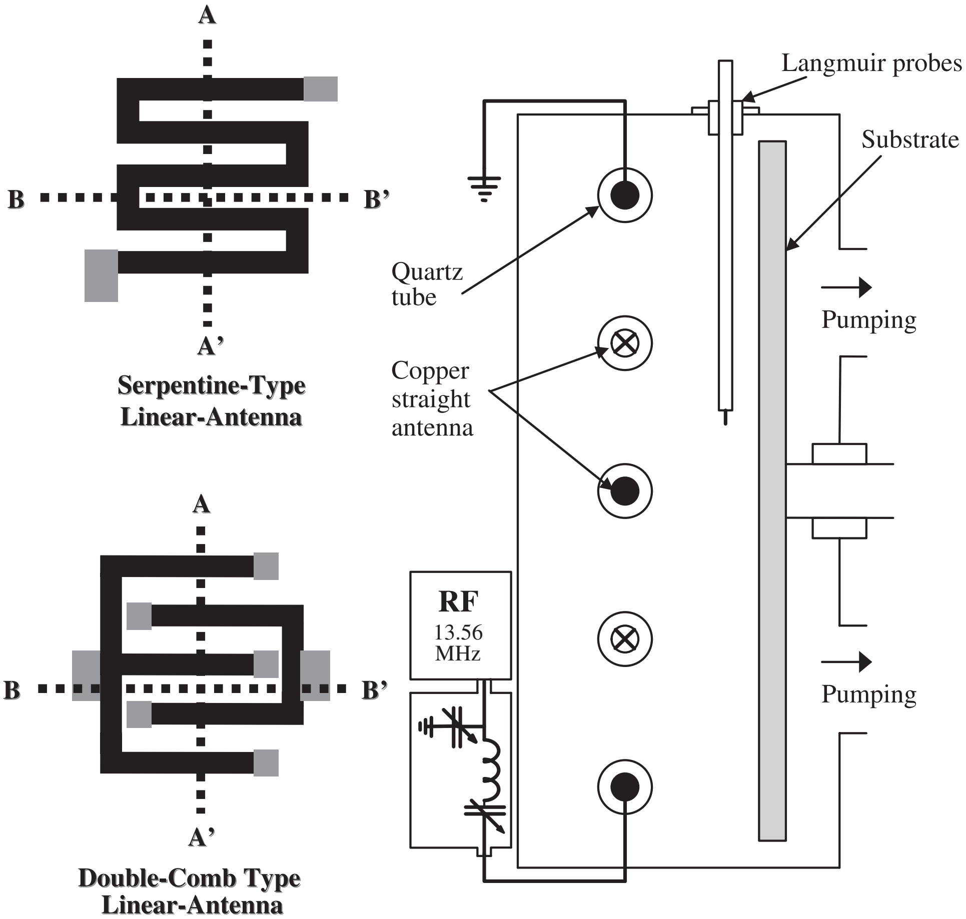


Fig. 1. Schematic diagram of inductively coupled plasma system and two types of internal linear antennas used in the experiment.

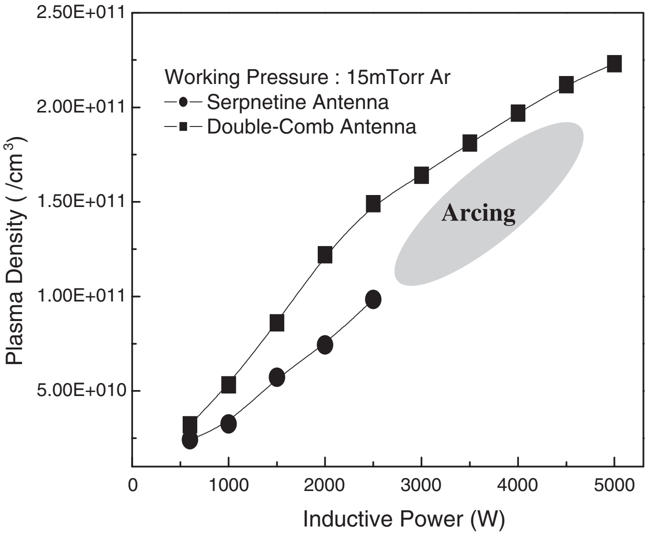
located 6 cm below the antenna and −35 V of bias voltage was applied to the substrate through a separate rf power supply (12.56 MHz, 0–2 kW) and a matching network. The substrate temperature was kept at room temperature. The photoresist etch rate was estimated by measuring the step heights of the photoresist before and after the etching with a stylus profilometer (Tencor Alphastep 500).

3. Results and Discussion

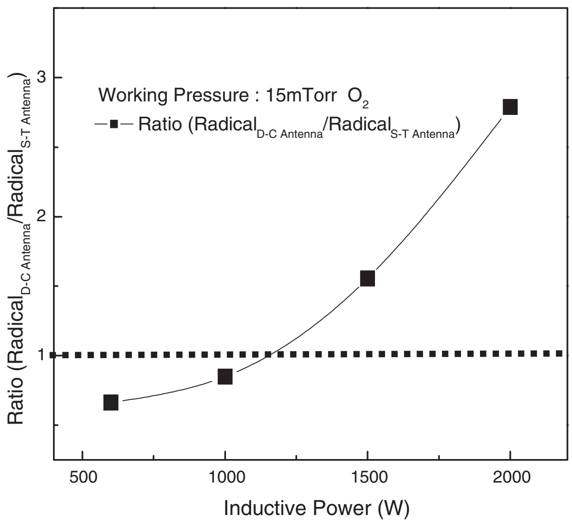
Figure 2(a) shows the effect of inductive power on the Ar plasma density for the serpentine type antenna and the double-comb type antenna. The inductive power was varied from 600 to 5000 W at 15 mTorr of Ar. The plasma density was measured using a Langmuir probe located at the center of the chamber and 7.5 cm below the antenna. As shown in the figure, when the serpentine-type antenna was used, the plasma density was increased with the increase of rf power and the plasma density of about $1 \times 10^{11}/\text{cm}^3$ could be obtained at 2500 W of rf power. However, when the applied power was higher than 2500 W, the plasma became unstable by showing arcing possibly due to the high electrostatic coupling between the antenna and the plasma. When the double-comb type antenna was used instead of the serpentine-type antenna, the plasma density of about $1.5 \times 10^{11}/\text{cm}^3$ which is higher than that obtained by the serpentine-type antenna could be obtained at 2500 W. Also, until 5000 W of rf power was applied, the plasma density was increased almost linearly with the increase of rf power and the plasma was remained stable. The rf power higher than 5000 W could not be applied due to the limit of rf power supply. At the 5000 W, as shown in the figure, the plasma density of $2.2 \times 10^{11}/\text{cm}^3$ was obtained. Therefore, the use of double-comb type antenna instead of the serpentine-type antenna showed the increased plasma density and stability of the plasma.

Using oxygen instead of Ar, the differences in the radical density between the serpentine-type antenna and the double-comb type antenna were compared. Figure 2(b) shows the ratio of oxygen atomic intensity between the serpentine-type antenna and the double-comb type antenna as a function of the inductive power. The optical emission peak from oxygen atom (775 nm) was measured using an optical emission spectrometer for the inductive power from 600 to 2000 W and at 15 mTorr of oxygen. As shown in the figure, the ratio of oxygen atomic emission intensity, which is an estimate of the ratio of oxygen atomic density, was increased with the increase of rf power, and, at 2000 W of rf power, the ratio was close to 3. Therefore, the use of double-comb type antenna instead of the serpentine-type antenna showed the increase of both plasma density and the radical density at high power conditions.

Using 15 mTorr oxygen and by applying −35 V of dc-bias voltage to the substrate, the photoresist etch rate was investigated for both of the antenna types as a function of inductive power from 600 to 5000 W and the results are shown in Fig. 3. As shown in the figure, the photoresist etch



(a)



(b)

Fig. 2. (a) Ar ion density measured by a Langmuir probe at 7.5 m below the each antenna as a function of inductive power from 600 to 5000 W at 15 mTorr Ar. (b) The ratios of oxygen atomic emission intensity (775 nm) measured using optical emission spectroscopy for the double-comb type antenna and the serpentine-type antenna.

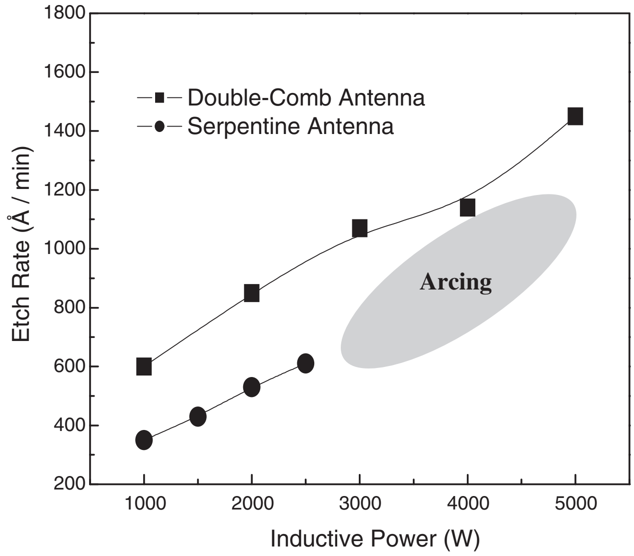


Fig. 3. Photoresist etch rates as a function of inductive power for 15 mTorr O_2 and at −35 V of dc-bias voltage in two type antenna.

rates were generally low due to the low dc-bias voltage used in this experiment, however, the increase of rf power to the antenna increased the photoresist etch rate almost linearly for both of the antenna types. The double-comb type antenna showed photoresist etch rates higher than two times compared to the serpentine-type antenna at the same rf powers due to its higher plasma density and higher radical density. Also, for the serpentine-type antenna, the photoresist etch rate could not be measured due to the arcing at the inductive power higher than 2500 W.

To find the differences obtained between the two types of antennas, the rf rms voltages induced along the antenna line on the sidewall of the chamber were measured for 15 mTorr of Ar and 2000 W of rf power and the results are shown in the Fig. 4(a). The rf voltage was measured using a high voltage probe (Tektronix P6015A). As shown in the figure, the rf rms voltage measured for the serpentine-type antenna was varied significantly along the antenna line while the voltage measured for the double-comb type antenna did not show significant variation. Also, the rf rms voltages measured for the serpentine-type antenna were generally higher than those measured for the double-comb type antenna. (In fact, in the case of double-comb type antenna, the antenna voltage was not measured along the antenna line, however, as shown in the figure, the antenna voltages were lower and antenna voltage distribution was more uniform along the chamber sides for the double-comb type antenna.) The higher rf voltage and significant variation of the voltage for the serpentine-type antenna appear to be from higher impedance and possible standing wave effect due to the longer length of the antenna line from the power input to the ground. At the same input power, due to the low impedance, higher rf current will flow to the double-comb type antenna and will generate higher time-varying magnetic field to induce higher electric field in the plasma for electron heating by the following Maxwell equation.

$$-\frac{\partial B}{\partial t} = \nabla \times E$$

Therefore, the higher plasma density and higher radical density with the double-comb type plasma appear related to the more efficient inductive coupling to the plasma due to the higher induced electric field in the plasma.

When an inductively coupled plasma source was used with dielectric cover, due to the rf voltage on the antenna line, capacitively coupling in addition to the inductive coupling is induced. To measure the degree of capacitively coupling, the dc voltage induced on the dielectric surface was measured at the location close to the power input as a function of the inductive power from 250 to 2500 W at 15 mTorr of Ar and the results are shown in Fig. 4(b). As shown in the figure, the dc voltage induced on the surface of the dielectric covering the antenna was increased with the increase of rf power up to about 1250 W and was remained similar with the further increase of inductive power for both of the antenna types. However, the induced dc voltage was

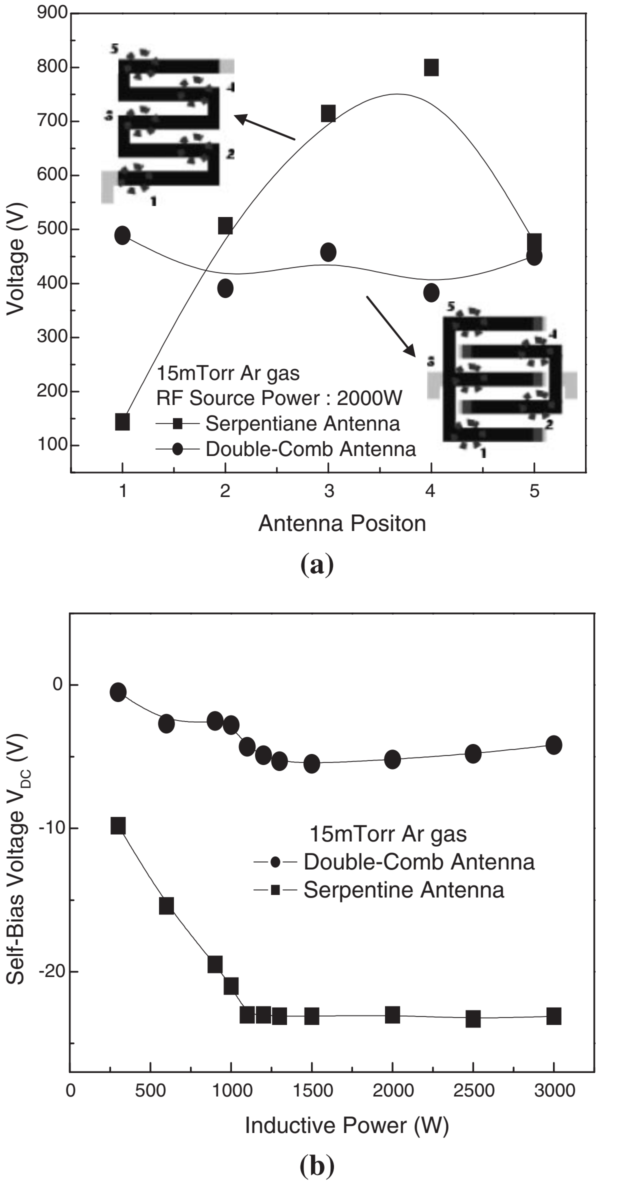


Fig. 4. (a) RMS voltage measured on the antenna line along the sidewall of the chamber for the double-comb type antenna and the serpentine-type antenna for 15 mTorr Ar and 2000 W of inductive power. (b) DC voltages induced on the dielectric surface covering the antenna line measured at the location close to the power input as a function of inductive power at 15 mTorr Ar for two types of antennas.

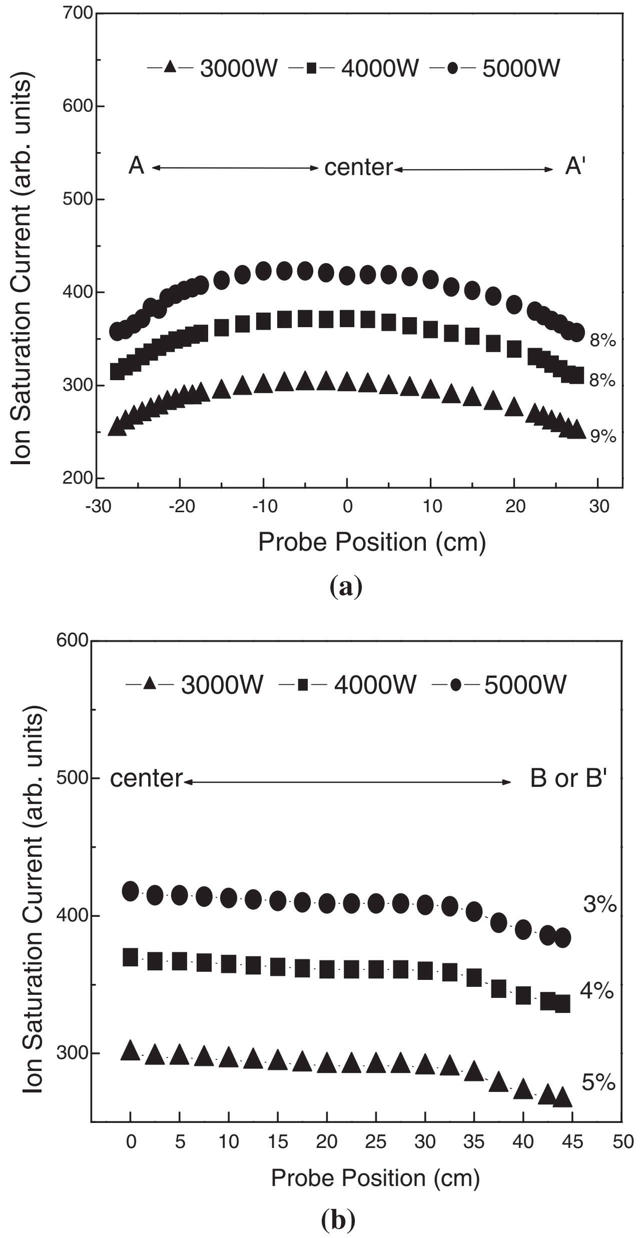


Fig. 5. Plasma uniformity measured 7.5 cm below the each antenna as a function of inductive power from 3000 to 5000 W for 15 mTorr Ar: (a) for the A–A′ and (b) for the B–B′ in Fig. 1. Ion saturation current measured using a Langmuir probe was used as the estimation of plasma density.

about four times higher for the serpentine-type antenna indicating more significant capacitively coupling. The higher dc voltage induced on the surface of the dielectric covering the antenna line could result in higher sputtering loss of the dielectric surface and more contamination by the sputtered dielectric material. In addition, the higher antenna voltage for the serpentine-type antenna not only increases the higher dc voltage on the surface of the dielectric covering the antenna line but also decreases the stability of the plasma because of higher electric field at the sheath region by increasing the possibility of arching.

Figure 5 shows the ion currents measured 7.5 cm below the double-comb type antenna using a Langmuir probe along the vertical centerline (A–A′ in Fig. 1) and the horizontal centerline (B–B′ in Fig. 1) line of the chamber for the rf power from 3000 to 5000 W and at 15 mTorr Ar. The ion currents were measured as the estimation of the plasma density. As shown in the figure, the uniformity of the plasma measured along the A–A′ of the chamber was about 9% while that measured along the center-B (or B′) was about 5% at 3000 W. In the case of 5000 W, the uniformity of the plasma measured along the A–A′ was about 8% and that measured along the center-B (or B′) was about 3%. Therefore, the uniformity of the plasma measured along the antenna line was better than that measured across the antenna line. If the uniformity of the plasma over the substrate area is considered, the uniformity was less than 9% for the experimental conditions used in this study.

4. Conclusions

In this study, the effects of two different types of linear antennas for internal inductively coupled plasma sources such as a serpentine-type antenna and a double-comb type antenna on the plasma characteristics were compared and their possibility for the application to a large area (880 × 680 mm^2) TFT-LCD processing was investigated.

By the application of rf power higher than 2500 W, plasma densities higher than $1 \times 10^{11}/cm^3$ could be obtained for the both of the antenna types. However, the use of the double-comb type antenna instead of the serpentine-type antenna showed higher plasma and radical densities and more plasma stability. When 15 mTorr oxygen was used with −35 V of dc-bias voltage, the double-comb type antenna showed photoresist etch rates higher than two times compared to the serpentine-type antenna at the same rf powers due to its higher plasma density and higher radical density. By the application of 5000 W of inductive power with 15 mTorr Ar, a high plasma density of $2.2 \times 10^{11}/cm^3$ with the plasma uniformity of 8% could be obtained for the double-comb type antenna. At the same rf power, the rf voltages along the antenna line and the dc voltages induced on the dielectric covering the antenna were lower for the double-comb type antenna. Therefore, the increase of plasma density, radical density, and plasma stability for the double-comb type antenna compared to the serpentine-type antenna appears related to higher inductive coupling and less standing wave effect compared to the serpentine-type antenna due to the shorter length of the antenna.

Acknowledgments

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