ELECTRODE TEMPERATURE IN PLASMA PROCESS

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INTRODUCTION

When a material is exposed in plasma, its temperature increases due to surface bombardment, chemical reaction, and radiation. Heat build-up is an essential concern when sample materials are heat or temperature sensitive. Many factors affect the temperature of parts in a chamber. They include the material's thermal conductivity, the orientation of the parts (are they directly on the shelf or in carriers) and plasma process conditions such as input power, plasma treatment time, gases, gas flow rate, and the frequency of the generator.

To minimize heat build-up, process optimization must be done balancing all of the above parameters.

Usually the substrates are placed on the powered electrode or the grounded electrode during the plasma process. Therefore, the temperature of the electrode can be used to estimate the temperature of the substrate. In this report, the influence of plasma conditions, such as input power, operating pressure, and distance between the electrodes, on the temperature of electrodes is discussed.

EXPERIMENT

All of experiments were run in March PX-1000. In this system, the work surfaces or shelves for sample processing are the electrodes. The Eight-Point Irreversible Temperature Indicators made by Cole-Parmer Instrument Company was used to measure the electrode temperature during the plasma process. The size of the powered and ground electrode was 13.5" × 16.5" and 16" × 18", respectively. Argon was used as the plasma processing gas and the electrode distance was 6 inch unless indicated.

RESULTS AND DISCUSSION

Electrode Temperature Comparison

Figure 1 shows the relationship between electrode temperature and plasma treatment time under different plasma conditions. It is clear that the temperature of the powered electrode raises faster than that of the ground electrode. The faster rise on the powered electrode is due to the DC bias on the powered electrode. The self DC Bias results in strong ion bombardment on the surface of the powered electrode. Due to this strong ion bombardment, the temperature increases faster than that on ground electrode. Note, the temperature required to achieve significant temperatures on both the ground and powered electrode is typically much longer than the standard plasma processing times. Thus temperature concerns due to processing time are often not significant.

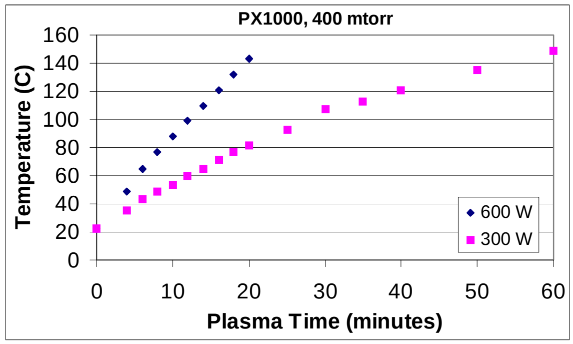

Figure 1. Electrode Temperature Comparison. Plasma conditions: 600 W, 400 mtorr

Effect of plasma input power

The data in Figure 2 indicates that the temperature of the powered electrode increases faster at higher input power (600 W) than at lower input power (300 W). This is due to the fact that the ion density increases with increasing input power, resulting in high-density ion bombardment and energy transfer to the electrodes. Thus, higher power processes results in higher temperature conditions.

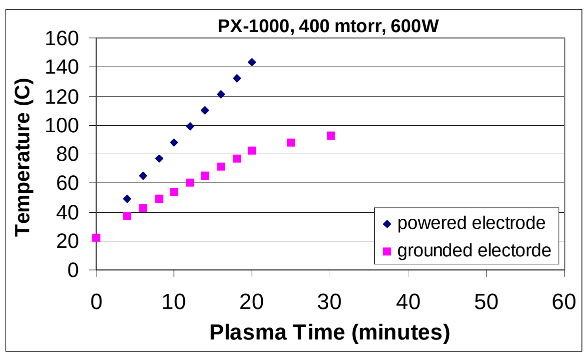

Figure 2. Effect of power on the temperature of the electrode.

Effect of operating pressure

The influence of operating pressure on the electrode temperature is shown in Figure 3. Both the temperature of the powered and the ground electrode (G) were monitored. It is clear that the temperature of the electrode raises faster at high operating pressure than at low operating pressure. The reason is mainly attributed to the plasma energy density. With the increase of operating pressure, the volume of the plasma glow discharge shrinks. Thus the local plasma energy density increases between the electrodes resulting in the faster temperature increase on the electrodes.

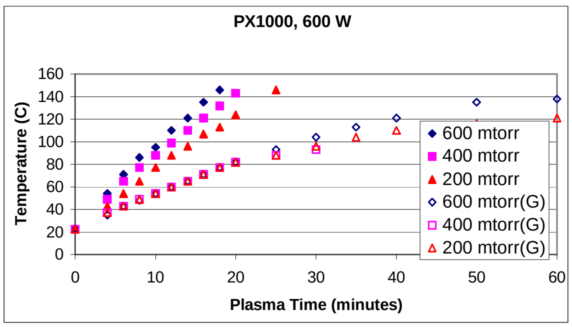

Figure 3. Effect of system pressure on the temperature of the electrodes.

Effect of electrode distance

The effect of electrode distance on the temperature of electrodes is shown in Figure 4. The electrode distance is 2 inch and 6 inch respectively. It indicates that the narrower the gap of the electrodes results in higher temperature of the electrodes. One reason is that there is a higher plasma energy density between the electrodes with narrower electrode gap. The other reason can be attributed to the narrower distance of electrode causing a larger higher barrier to heat dissipation.

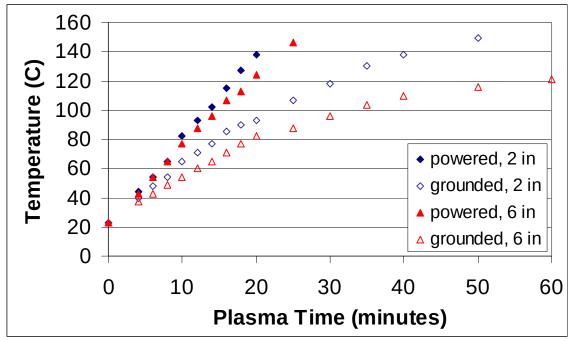

Figure 4. Effect of electrode distance on temperature of electrodes. The plasma conditions are 600 W and 200 mtorr.

Effect of electrode area

The influence of electrode size on temperature of electrodes is measured and the result is shown in Figure 5b. In this experiment, four work shelves were used, two of them were used as powered electrodes and the other two were used as ground (See Figure 5a). The powered and ground electrodes were alternated with the top electrode being grounded. The electrode distance was 2 inches. The total electrode area was doubled to evaluate electrode area effects. (See Figure 5a).

It is shown in Figure 5 that the temperature of electrode depends on the electrode area for a given total power input. The electrode's temperature rises slower when the power is distributed between multiple electrodes as opposed to a single pair of electrodes. The observation is due to the energy density per unit area increasing with the decrease of electrode size. High energy density indicates high ion bombardment and radiation, therefore, causes the rise in temperature.

Figure 5a

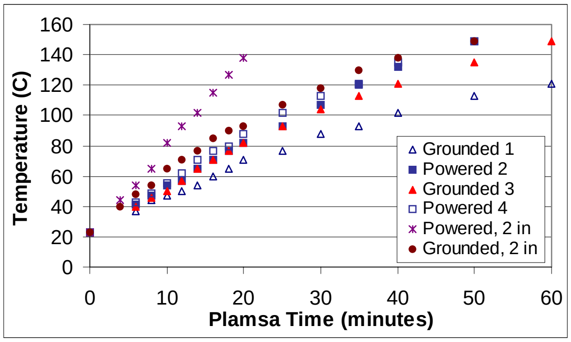

Figure 5. The influence of electrode area on temperature of electrodes. Plasma Conditions: 600 W, 200 mtorr. (a) Electrode configuration and (b) Result comparison.

The effect of plasma volume on temperature was also evaluated. The input power density was kept constant between the electrodes, but the number of electrodes pairs was changed from two to one (6 inch gap for single pair electrodes compared to a 2 inch gap for two pair electrodes). The data in Figure 6 indicate a similar result to that displayed in Figure 5, that the energy density per unit area increases with the decrease of electrode size. The high energy density indicates high ion bombardment and radiation, therefore, causing the rise in temperature. Therefore, the electrode size is one of essential factors to control the temperature of electrode.

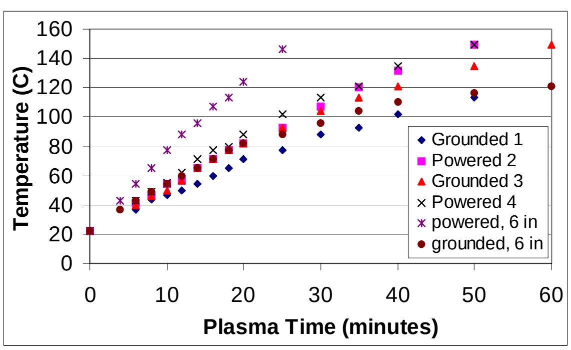

Figure 6. The influence of electrode area on temperature of electrodes under the same volume between electrodes. Plasma conditions: 600 W, 200 mtorr.

SUMMARY

Temperature of electrode (or substrate) is effected by the power, pressure, and operating time. Since various systems are designed differently, it is difficult to generalize for all plasma systems. The following is the rule of thumb for the concern of plasma temperature.

Power:	The higher the power, the higher the temperature.
Time:	The longer the time, the higher the temperature.
Electrode distance:	The larger electrode distance, the lower substrate temperature.
Electrode size:	The bigger electrode size, the lower electrode temperature.

Most processes can be kept under 100 °C by operating under 300 watts of power and keeping the process time under 20 minutes if no cooling system is used. Processing time should be kept to about 10 minutes and power to about 300 watts if temperatures of under 60 °C need to be maintained. The cooling system, which circulates fluids to the surface of the work area, maybe needed if longer plasma treatment time and low substrate temperature is necessary.