Ignition of Peripheral Plasma in Capacitive Discharges

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***Abstract*—Ignition of peripheral plasma was examined in low-pressure (100-mtorr) RF capacitive coupled plasma by means of kinetic and fluid models. Plasma density and potential profiles are presented to visualize peripheral-plasma ignition. A dielectric gap size is an important parameter for a dense and stable plasma source.**

***Index Terms*—Capacitive coupled plasma (CCP), modeling, peripheral plasma.**

LOW-PRESSURE RF capacitive coupled plasma (CCP) has been widely used in the semiconductor industry. Experimental and numerical efforts have led to understanding of RF CCPs. Recent commercial devices have dielectric rings for the purpose of pumping gas, separating a main discharge region and a peripheral region. Plasma ignition at the peripheral region affects the plasma impedance, which breaks the matching condition [1] and produces low-frequency oscillations [2]. More importantly, these unstable operations can damage the devices during plasma processing.

In this paper, the ignition conditions of the peripheral region were presented by using a 2-D particle-in-cell model coupled with a Monte Carlo collision model (PIC/MCC), called xpdp2 [3], and a fluid model [4]. Discharge geometry is shown in Fig. 1. Grounded wall is represented in gray, RF electrode in red, and dielectric rings in white. The dielectric rings separated the discharge space into three different regions: main, slot, and peripheral regions. Electrons and ions were considered as charged particles, assuming a uniform background argon gas at a pressure of 100 mtorr. The 2-cm gap size and 27-MHz frequency were applied for the PIC/MCC model, whereas 3 cm and 13.56 MHz were chosen for the fluid model, which are typical parameters for the commercial chambers [1], [2].

Fig. 1(a) and (b) show the plasma density and particle distributions, respectively, for a discharge voltage of 500 V. The high applied voltage, which is preferable for high-density plasma, can ignite the plasma not only at the main discharge region but also at the auxiliary region such as the peripheral region and the dielectric slots. However, it needs to sustain the plasma only at the main discharge region where plasma processing occurs. The unstable operation caused by the peripheral plasma can damage the microsystems on the substrates during plasma processing. On the other hand, the operation with 200 V generated the plasma only at the main discharge region, as shown in Fig. 1(c), which is a preferable condition. However, even in 200 V, the peripheral plasma was sustained, when the space charges initially resided in the auxiliary region. This hysteresis was also found in the experimental work of Lieberman *et al.* [1]. Fig. 1(d) shows the radial potential profiles along the line that is parallel to the powered electrode at the midgap height [Fig. 1(a), dashed line]. When the plasma was limited in the main discharge region, the large potential barrier existed at the dielectric slot region, confining energetic electrons. The relatively flat potential profile in the case of 500 V allowed electrons to access the auxiliary region by the diffusion process.

The confinement of plasma was also captured by our separate simulations with the fluid model. The electron-density profiles are shown in Fig. 1(e) and (f) to show the dielectric-gap-size effect. The 300-V applied voltage and 13.56-MHz frequency were considered for different dielectric gap sizes. With 0.5-cm gap size, the plasma was strongly confined at the main discharge region. The increased gap size of 1.5 cm allowed the plasma to ignite at the peripheral region. The shrinking of dielectric gap enables the discharge to stably operate without the ignition of the peripheral plasma. However, the large dielectric gap is better to avoid the gas pressure gradient near the dielectric rings. There is a tradeoff between the uniform gas density and stable operation in determining the dielectric gap size. Thus, the dielectric gap size has to be considered as an important aspect during the chamber design to satisfy less gas density gradient and stable operation without the ignition of the peripheral plasma.

In summary, the RF CCPs with the dielectric rings were examined to visualize peripheral-plasma ignition by means of PIC/MCC and fluid models. The plasma was ignited at the peripheral region with the applied voltage of 500 V. The ignition condition at the applied voltage of 200 V depended on the initial condition such as remaining space charges at the peripheral region. The properly designed chamber with adequate dielectric width can achieve dense and stable discharges without ignition at the peripheral region.

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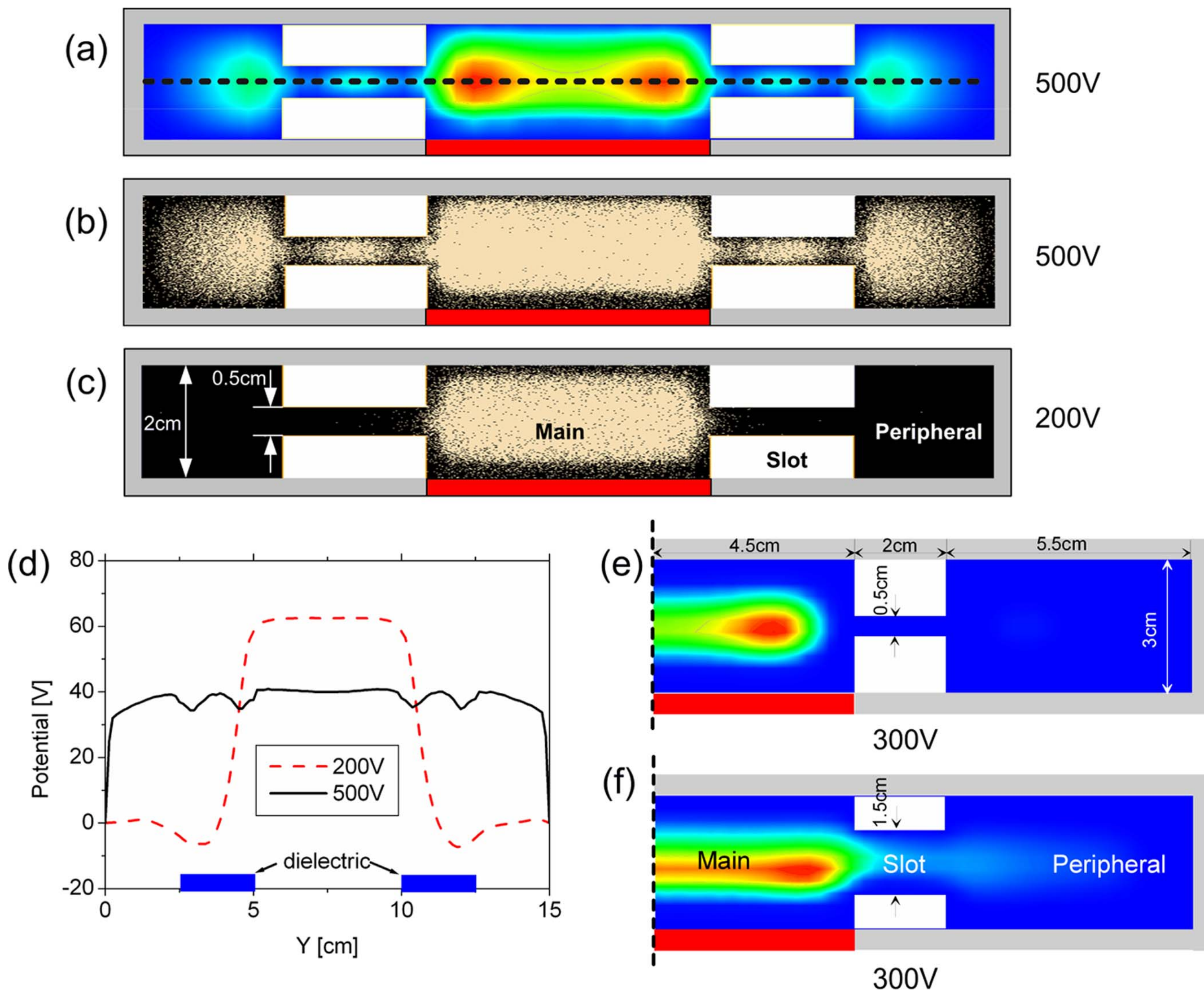

Fig. 1. Peripheral plasma ignition. (a)–(d) PIC/MCC results with 200- and 500-V applied voltages and 27-MHz frequency. (e) and (f) Fluid results with 300-V applied voltage and 13.56-MHz frequency. (a) An ion-density profile when the peripheral region ignited for 200 V. (b) An ion-distribution profile for 500 V. (c) An ion distribution in the case of confined plasma for 200 V. (d) Potential profiles across the discharge center. (e) and (f) Electron-density profiles with different dielectric gap sizes.

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