Voltage Distribution on Electrode in Large PECVD Device

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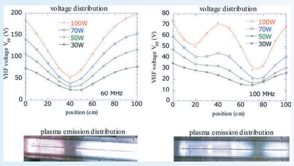
Introduction

In recent years, large-area high-quality thin film deposition technologies with high throughputs have been required for manufacturing of, for example, flat panel displays and solar cells. Large-scale plasma enhanced chemical vapor deposition (PECVD) processes can meet such requirements. In a large PECVD device, the sizes of electrodes for plasma production may be comparable with the wave lengths of input power. In such a system, standing waves of surface voltage may be formed on the powered electrode, which typically causes plasma non-uniformity. Such problems can be avoided if the electrode shapes, locations of power supply points, and waveforms of input power are optimized based on careful modeling of the system.

In this work, we consider a capacitively coupled large-area PECVD system with the driving frequency of VHF range for amorphous Si deposition. To design a power supply system that can minimize such nonuniformity, we have extended a linear transimission line model proposed by Satake et. al. to an time dependent nonlinear model by adopting simple fluid models for plasmas.



Satake et.al.
Plasma Sources Sci. Technol. 13(2004) 436-445

r_p and l_p are obtained from simple plasma fluid model with no ionization, uniform electron and ion densities, and uniform external electric field E.

$$r_p = \frac{m_e \, d\nu_e}{n_e e^2}, \qquad l_p = \frac{m_e \, d}{n_e e^2}, \qquad c_s = \epsilon 0 \frac{w}{s}.$$

Objective

・Study of time evolution of non-uniform voltage distribution on the powered electrode in a large-area very-high-frequency (VHF) capacitively coupled plasma processing system based on a one-dimensional transmission-line model with an equivalent-circuit model of the plasma.

Model

One dimensional TLM

$$L \frac{\partial I(x,t)}{\partial t} + R I(x,t) + \frac{\partial V(x,t)}{\partial x} = 0, \qquad V(x,t) = L_p\left[-\frac{\partial I}{\partial x}\right],$$

$$L_p[j] = \frac{2}{c_s}\int_0^t j(x,t)\,dt + r_p j(x,t) + l_p \frac{\partial j(x,t)}{\partial t},$$

L : line inductance par unit length.
R: line resistance par unit length.

$$R = \frac{\rho}{2\pi r \delta_s},$$

$$L = \frac{\mu_0}{2\pi}\left(\log\left(\frac{1+\sqrt{1+r^2}}{r}\right) - \sqrt{1+r^2} + r\right).$$

L_p: linear operator representing potential drop in plasma region.

r_p: plasma resistance.
l_p: plasma inductance.
c_s: sheath capacitance.

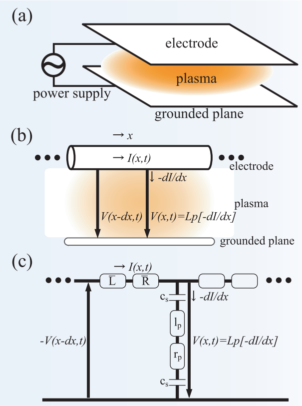
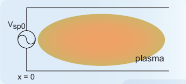


Fig.1 A schematic diagram of a VHF PECVD device and Transmission line model.

Calculated Results

1 point power supplied



Wave Form

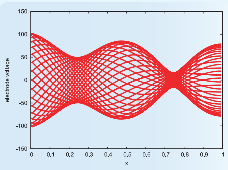


Fig.2 Voltage distribution.

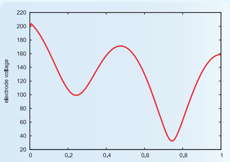


Fig.3 Peak-to-peak voltage distr.

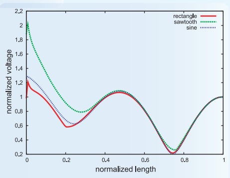


Fig.4 Peak-to-peak voltage distribution for various wave-forms of input power.

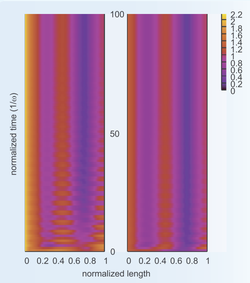
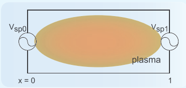


Fig. 5 Spatio-temporal evolution of peak-to-peak voltage distribution.

2 points power supplied



Phase
Frequency

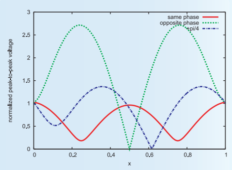
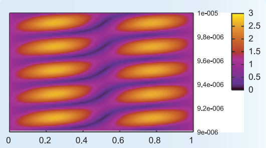


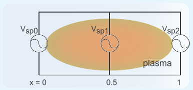
Fig.6 Peak-to-peak voltage distribution for various phase of input power.

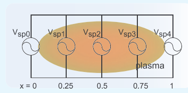


100MHz 95MHz

Fig.7 Beating mode appeared in spatio-temporal evolution of peak-to-peak voltage distribution.

3 & 5 points power supplied





Amplitude
Frequency

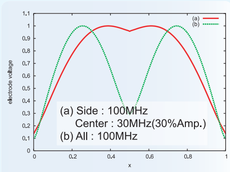


Fig.8 Peak-to-peak voltage distribution.

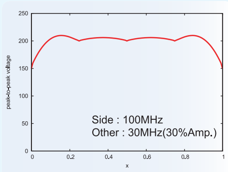


Fig.9 Peak-to-peak voltage distribution.

Conclusions

Time evolution models for large-area VHF PECVD plasma processing systems are solved based on transmission-line models with equivalent-circuit plasma models.

1-point power supply: Standing waves are formed in the peak-to-peak voltage distribution. Three types of input wave-forms (sine, sawtooth, rectangular) are studied, however the normalized peak-to-peak voltage distribution are hardly different except thier transient time. This is because the plasma eliminates the contribution from the high-frequency components.

2-point power supply: An uniform voltage distribution could not be achieved by the control of the phase of driving frequency. When the driving frequency set to 100MHz and 95MHz, a beat wave whose frequency is 5MHz is clearly seen. The position of minimum voltage moves from left to right on the electrode.

3-point power supply: The voltage distribution is improved by the control of the amplitude and the frequency of power supply. However, the region where the voltage is uniform is not sufficiently wide.

5-point power supplies: Electric potential uniformity over 90% range of the electrode is achieved by the control of the amplitude and the frequency.

Acknowledgments

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