# Fluid study on uniformity in capacitively coupled silane mixture discharges

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**Abstract:** A two-dimensional fluid model coupled with an electromagnetic transmission line model is used to study a capacitively coupled silane mixture discharge. At 27.12 MHz in a chamber with the radius more than 1 meter, the standing wave effect on the radial uniformity is investigated with the increase of the gas pressure. The deposition rate dependent on the plasma properties is analyzed, in comparison with the corresponding experiment results.

**Keywords:** fluid model, large chamber, standing wave effect.

## 1. Introduction

Radio frequency capacitively coupled plasmas (RF CCPs) are widely used in solar cell industry. In recent years, with the increase of the wafer size and driving frequency for the purpose of higher production efficiency, uniformity problems due to the electromagnetic effects have attracted much attention. As the driving frequency increases, the electromagnetic wavelength within the chamber will be shortened and becomes comparable to the chamber dimension. With the interference of two oppositely traveling waves from the electrode edge to the center, the powered electrode is no longer equipotential, and the electric field amplitude between the electrodes will be a distribution of high center - low edge, which is called the radial standing wave nonuniformity [1]. Thus, the standing wave effect will cause the significant inhomogeneity in the plasma density and film thickness [2], [3]. Especially, for higher production efficiency, the chamber diameter of solar cell production equipment is usually more than 1 meter, which means that the standing wave effect can not be neglected any more. So it would be required to offer insight into the electromagnetic mechanism and optimize the discharge parameters to realize uniform plasma and higher deposition rates, based on theoretical analysis and simulation validation.

## 2. Results and discussions

In this work, we investigate a capacitively coupled silane/hydrogen mixture discharge at 27.12 MHz based on a two-dimensional fluid model[4] coupled with an electromagnetic transmission line model[5]. For the simulation case, the radius, thicknesses and gap of electrodes are 140 cm, 1cm and 1.6 cm with a spacing of 5 cm from the sidewall. Among this, the voltage amplitude is 100 V, and the pressure ranges from 1 Torr to 4 Torr with 1% content of silane. The experimental chamber is a square with a side length of 2 m, and the experimental data are measured along the diagonal on the grounded electrode with other conditions are similar to the simulation case.

The periodically averaged spatial distribution of the electron density for 1-4 Torr are given in figure 1. At 1 Torr, the electron density peak locates in the region between the electrode edges and the sidewall, while at higher pressure, the electron density shifts to the radial center between the two electrodes. This indicates that the standing wave effect is significantly enhanced with the increasing pressure in the case of larger chambers and 27.12 MHz in contrast to the previous studies [6] in smaller chambers at higher frequencies. As the pressure is increased, the plasma density increases and the relative permittivity of the plasma becomes larger, giving rise to the increase of the surface wave number with the decrease of wave length. The skin depth also decreases with the increasing plasma density, but still larger than the half of electrode gap which means the skin effect will not dominate [1],[7].

As shown in figure 2, the electric potential is flat in the bulk between electrodes and high in the region between the electrode edges and the sidewall at 1 Torr compared to those at higher pressure. Thus, the discharge is dominated by the electrostatic edge effect which means the electron power abortion will be enhanced at the edge region, suggesting an edge high electron density distribution. As the pressure is increased, the radial gradient of the electric potential between the electrodes becomes increasingly large and the region with flat potential shrinks to the radial center, due to the decay of the surface wave wavelength. The discharge is transformed from the electrostatic edge effect dominated to the electromagnetic standing wave effect dominated. Therefore, the ionization rate becomes stronger in the radial center due to the efficient electron power absorption and brings a higher density of electron, ions and neutral radicals, resulting in the higher deposition rate in the radial center. As the pressure is increased, the deposition rate will be lower and lower in the edge region than that of the radial center (as shown in figure 3), which is due to the decay of the electrostatic edge effect. The deposition rate increase significantly in the radial center with the increasing pressure in lower pressures (1-3 Torr), with the increase of the ions and radicals densities. While, in higher pressures (3-4 Torr), the deposition rate shows almost no increase with the increasing pressure in the radial center, which reason can be summarized as that the ions and radicals fluxes reaching the electrode surface decrease due to the reduction of the potential drop in sheath and the diffusion coefficient, although the ions and radicals densities increase. In the 1-4 Torr range, the simulation results show good agreement with the experimental data. In addition, the H radical density at the edge region is significantly lower compared with the other particles, which may result in less H in the film at the edge.

## 3. Conclusion

In this study, a two-dimensional fluid model coupled with an electromagnetic transmission line model is used to study a capacitively coupled silane mixture discharge in a chamber with the radius more than 1 meter at 27.12 MHz. As the pressure is increased, the electron density maxima shift from the region between the electrode edges and the sidewall to the radial center region between the two electrodes. The discharge is transformed from the electrostatic edge effect dominated to the electromagnetic standing wave effect dominated, which will lead to non-uniform electron power absorption, electron density and ionization rate in the radial direction. Ultimately, this results in a nonuniformity of deposition rate, which shows good agreement with the experimental data. In the future, we will study more about this nonuniformity with different discharge parameters and discuss how to optimize.

## 4. Acknowledgements

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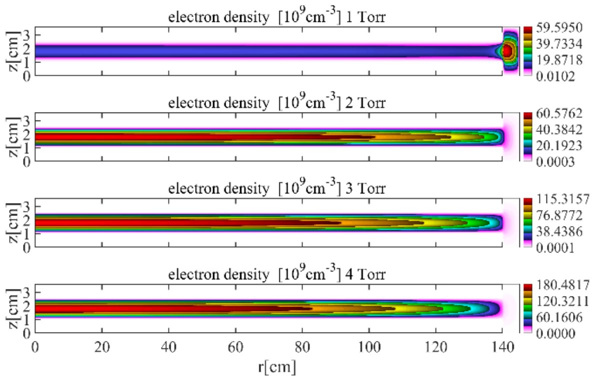


Figure. 1. Periodically averaged spatial distribution of electron density for $r$ =140+5 cm, $z$ =1+1.6+1 cm, $f$ =27.12 MHz, $V$ =100 V, $SiH_4/SiH_4+H_2$= 1%.

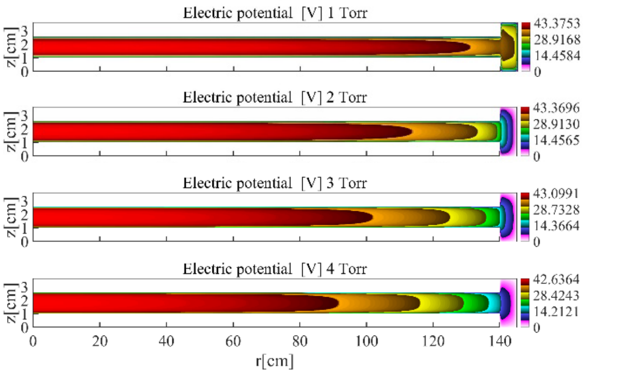


Figure. 2. Periodically averaged spatial distribution of electric potential for the same discharge conditions as in figure 1.

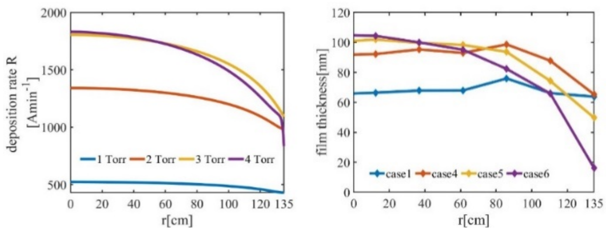


Figure. 3. Simulated deposition rates obtained from fluid model (left) and some experimental data provided by Suzhou Maxwell Technologies (right).