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OPTIMIZATION OF PLASMA UNIFORMITY USING HOLLOW-CATHODE STRUCTURE IN RF DISCHARGES*

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AGENDA

- Introduction
- Review of experiments
- Description of “HPEM”
- Simulation results and analyses
  - Electron density distribution
  - Electron sources
  - Electron temperature distribution
  - Influence of pressure and cathode width
- Conclusion

INTRODUCTION

- Obtaining good uniformity in high density plasmas is an important goal in microelectronic processing, especially for large wafers and for cases requiring high etching selectivity.

- Edge effects in the reactor can cause non-uniformity in reactants.

- Use of electrodes having co-axially grooved geometries can produce high density plasmas. The plasma perturbation produced by geometry can result in good discharge uniformity.

- The goal of this study is to understand the mechanism for obtaining improved uniformity from electrode design.

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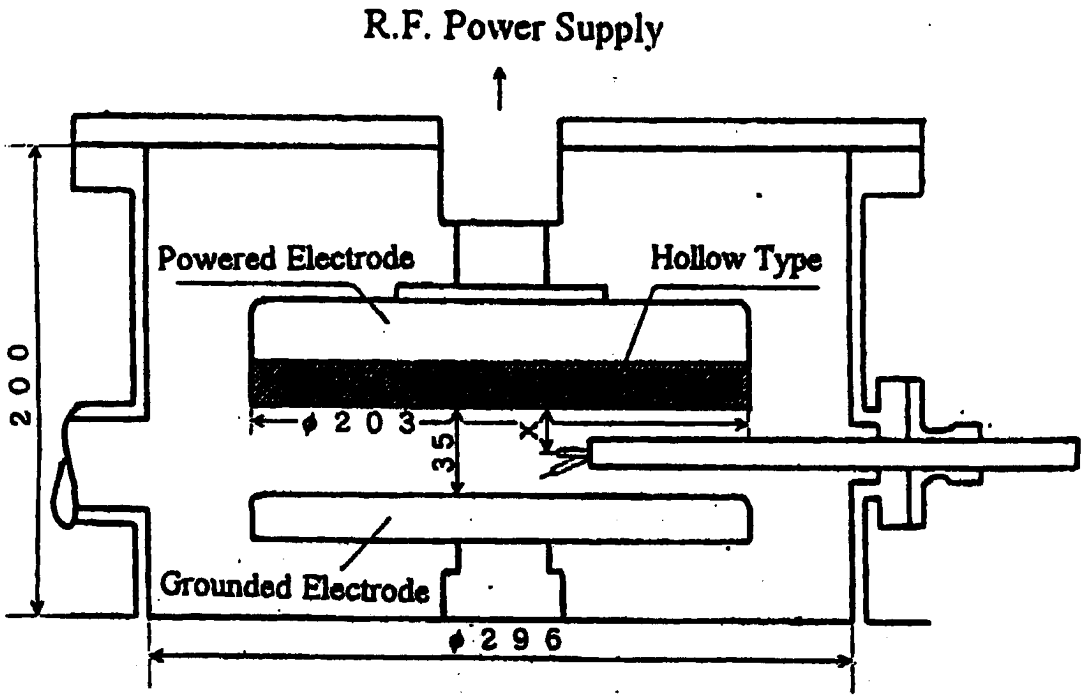
EXPERIMENTAL PROOF OF PRINCIPLI

- **The concept of using a grooved electrode to improve discharge uniformit has been proposed by M. Sugawara and T. Asami.**

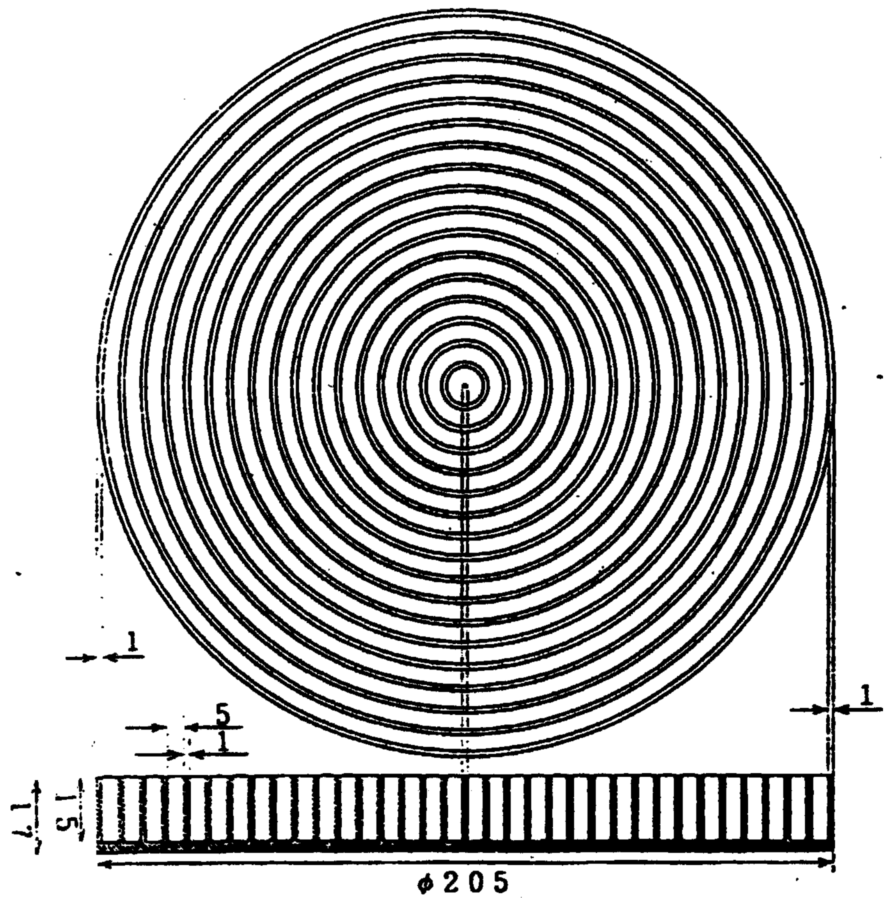
- **Reactor schematic and experimental conditions.**



- **Parrallel-plate reactor**
- **Plate separation: 35 cm**
- **rf (13.56 MHz) power**
- **Ar gas**
- **Pressure: 130 mTorr**

• Ref.: M. Sugawara, T. Asami, *Surface & Coatings Technology*, 73 (1995) 1

GROOVED ELECTRODE GEOMETRY



- Hollow-cathode like electrode
- Co-axial vertical grooves
- Groove width: 5 mm
- Original groove depth: 15 mm

• Ref.: M. Sugawara, T. Asami, *Surface & Coatings Technology*, 73 (1995) 1

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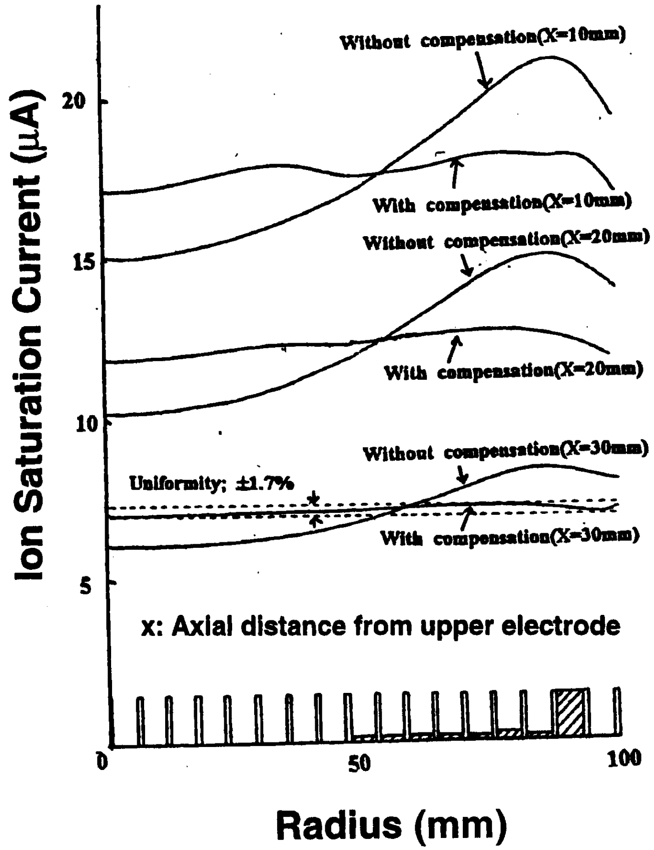
EXPERIMENTAL RESULTS

- Ion saturation current distributions were measured for electrode geometries with and without groove compensation.

- Before optimizing the grooves, ion current peaks at the edge of the reactor.

- With proper design of the groove depth near the peak current region, the uniformity of the ion current distribution improves.



- Ref.: M. Sugawara, T. Asami, *Surface & Coatings Technology*, 73 (1995) 1

INTRODUCTION TO “HPEM”

- In this study the “HPEM” was used to investigate the mechanisms whereby grooves influence uniformity.

- General description
  - modular program
  - low pressure condition (1 mTorr to 10 Torr)
  - for plasma etching and deposition
  - 2-d azimuthally symmetric model

- Main modules in HPEM
  - Electromagnetic Module (EMM), for calculating electromagnetic fields and magneto static fields.
  - Electron Energy Transport Module (EETM), for solving electron temperature and electron impact reaction coefficients.
  - Fluid-chemical Kinetics Simulation (FKS), for computing the plasma species densities and electrostatic potential.

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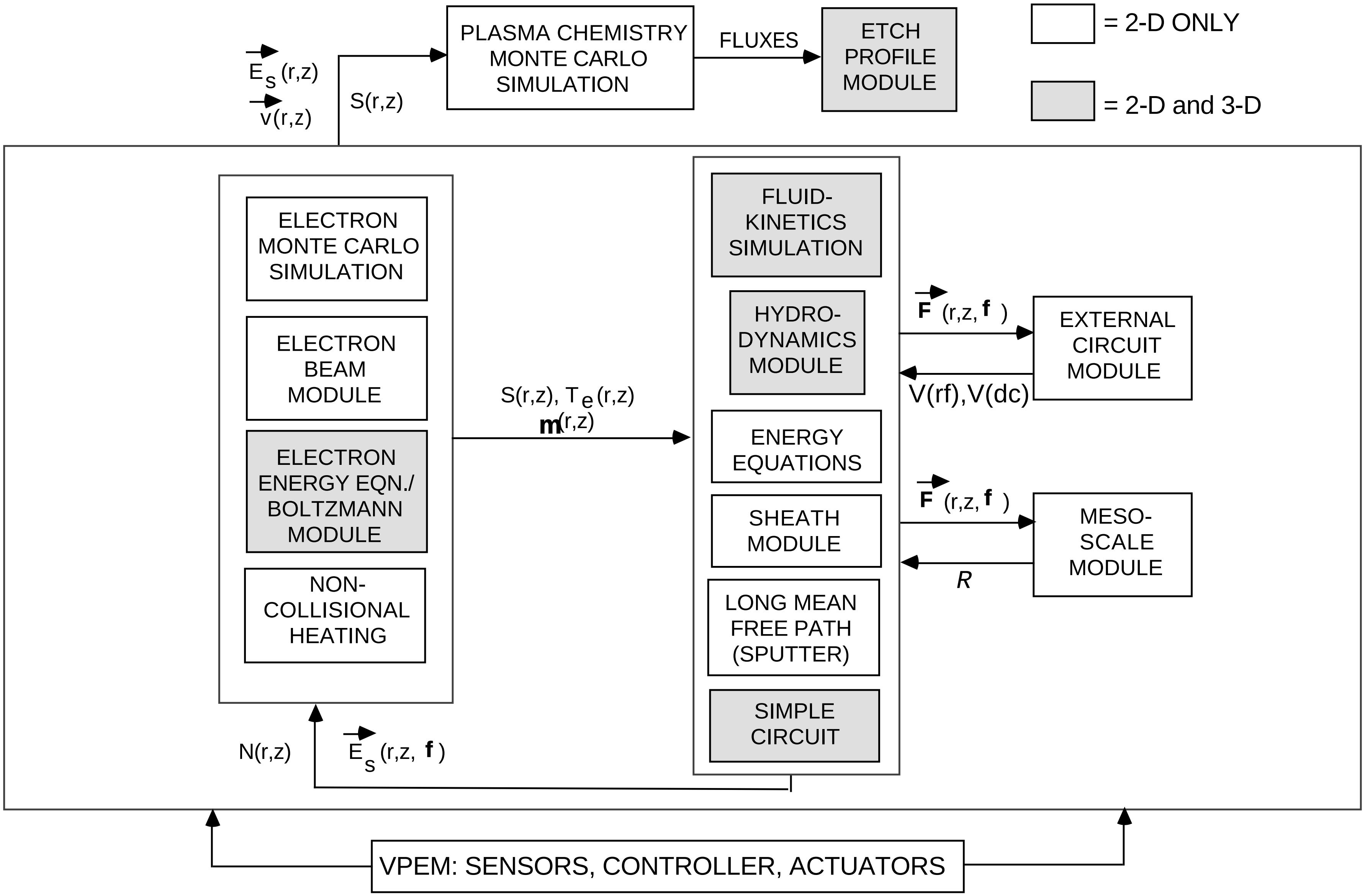
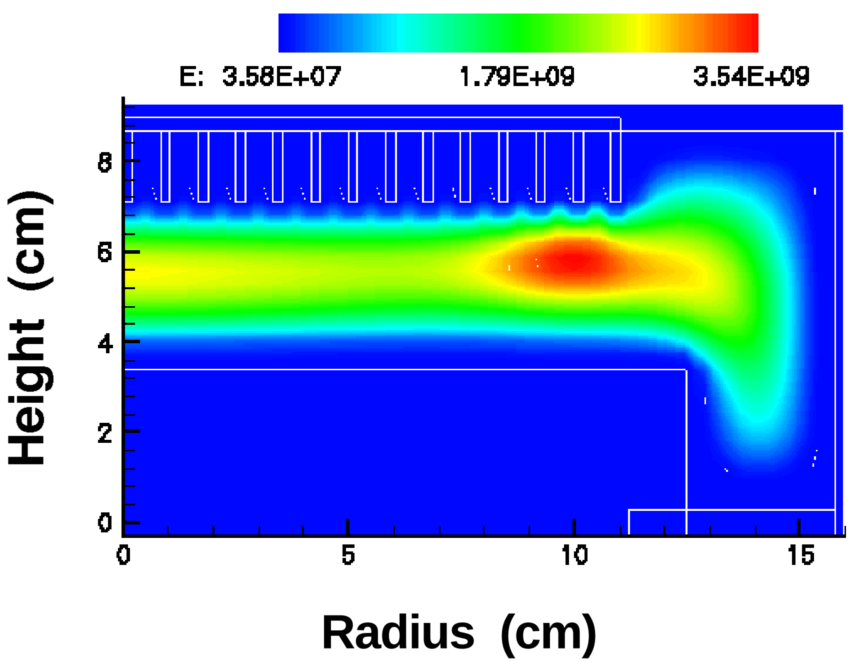
SCHEMATIC OF 2-D/3-D HYBRID PLASMA EQUIPMENT MODEL



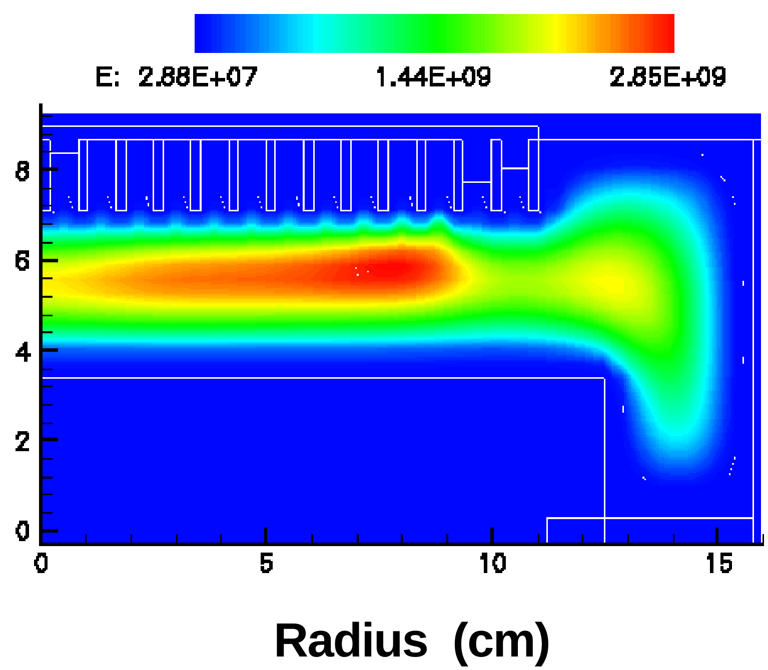
ELECTRON DENSITY DISTRIBUTION

- Before electrode geometry modification:
  Electron density peaks near the edge of the reactor.
- After decreasing the depth of the grooves close to the peak density area:
  The electron density gets more uniform.

- Original electrode



- Modified electrode



- Ar, 130 mTorr, 13.56 MHz, 100 v amplitude

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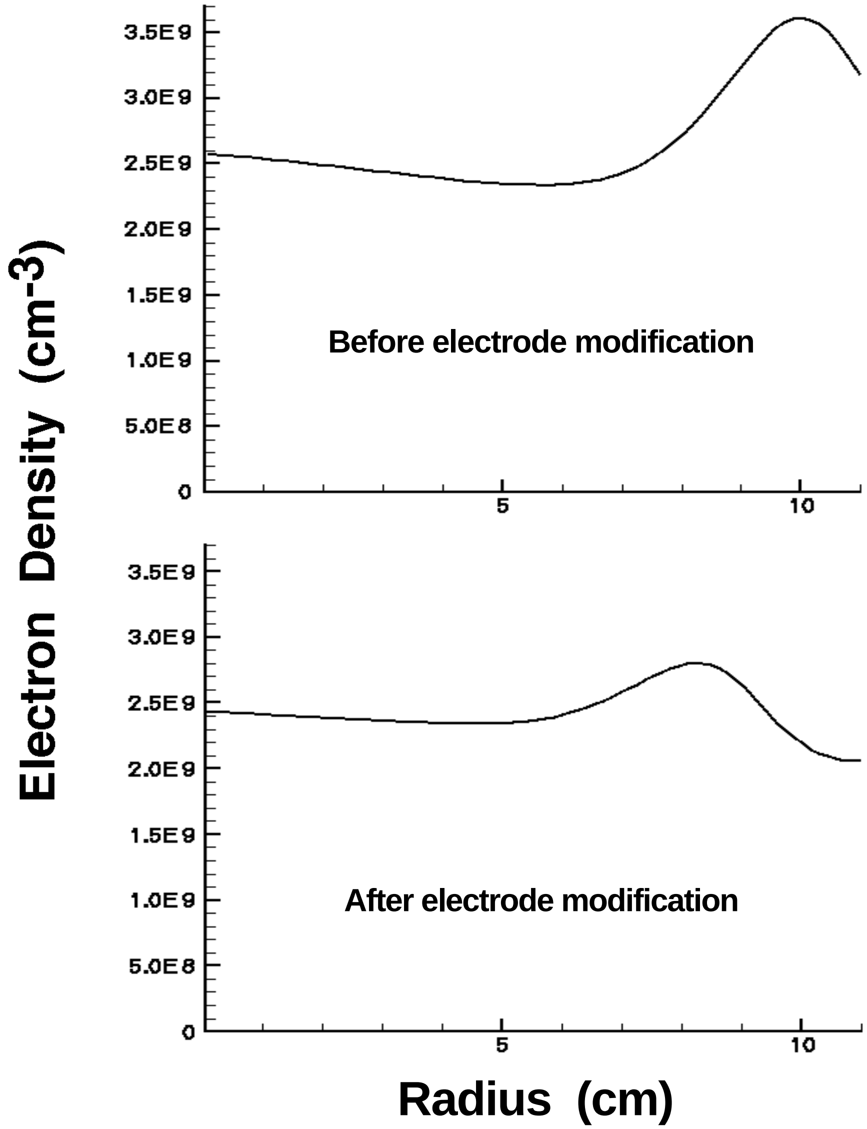
ELECTRON DENSITY DISTRIBUTION (cont.)

- Radial electron density distribution in the middle-plane between two electrode plates.

- With proper modification of the electrode geometry, the electron density distribution line is flattened.

- Simulation results agree very well with the experimental data.



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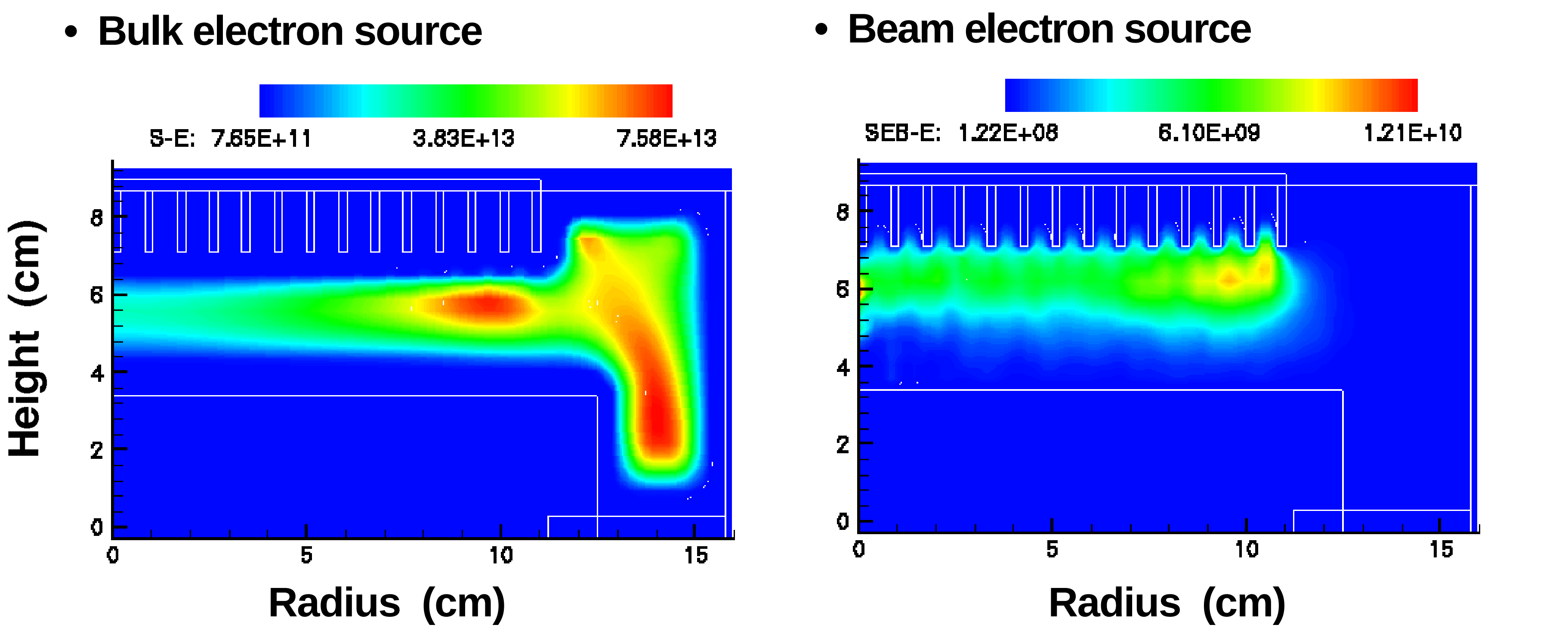
ELECTRON SOURCES

- Hollow-cathode effect of the grooved electrode can be one source of electrons.
- Compared with normal source, the source due to secondary electron emission from grooved electrode seems to be much smaller and thus less important. This is because *p d*=0.065 torr-cm is below the acceptable threshold for hollow cathode operation.
- The hollow aperture to hollow wall area ratio is low.



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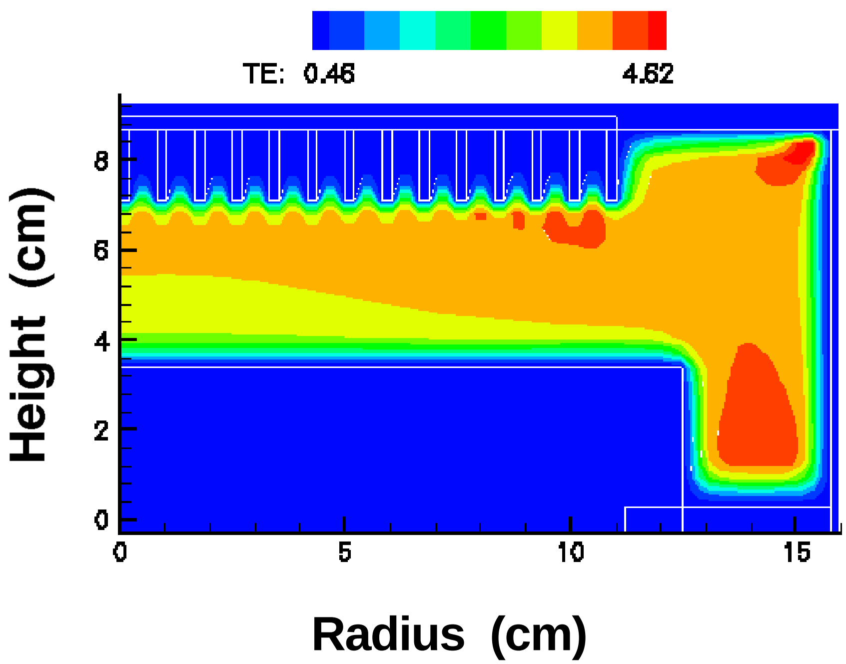
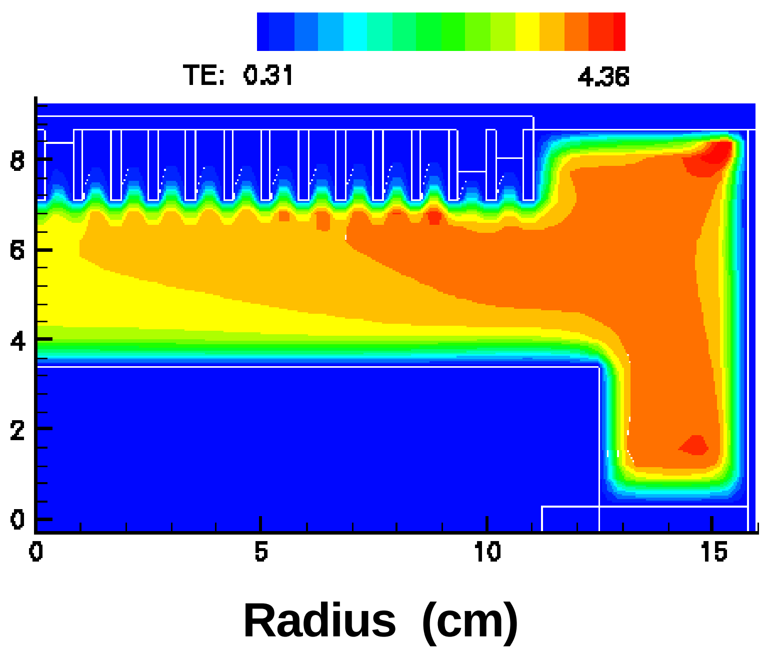
ELECTRON TEMPERATURE DISTRIBUTION

- Before electrode geometry modification, there is a peak Te close to the peak electron density region.
- After reducing the depth of the grooves near this region, the peak Te area is depressed, and the peak shifts a bit to a smaller radius.

a) Original electrode



b) modified electrode



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MECHANISM of UNIFORMITY IMPROVEMENT

- **For original reactor, corner effect causes local high Te area near the edge of the electrodes, which produce higher electron density at that region.**

- **The reduction of the groove depth close to the peak Te area actually decreases the electron diffusion loss area to the wall.**

- **To keep local electron generation--loss balance, the Te near the area must drop down, so the peak Te area is depressed.**

$$\frac{\partial(Ne)}{\partial t} = n_e k_{ion} n_{gas} V - \frac{D_a n_e}{\Lambda^2} A$$

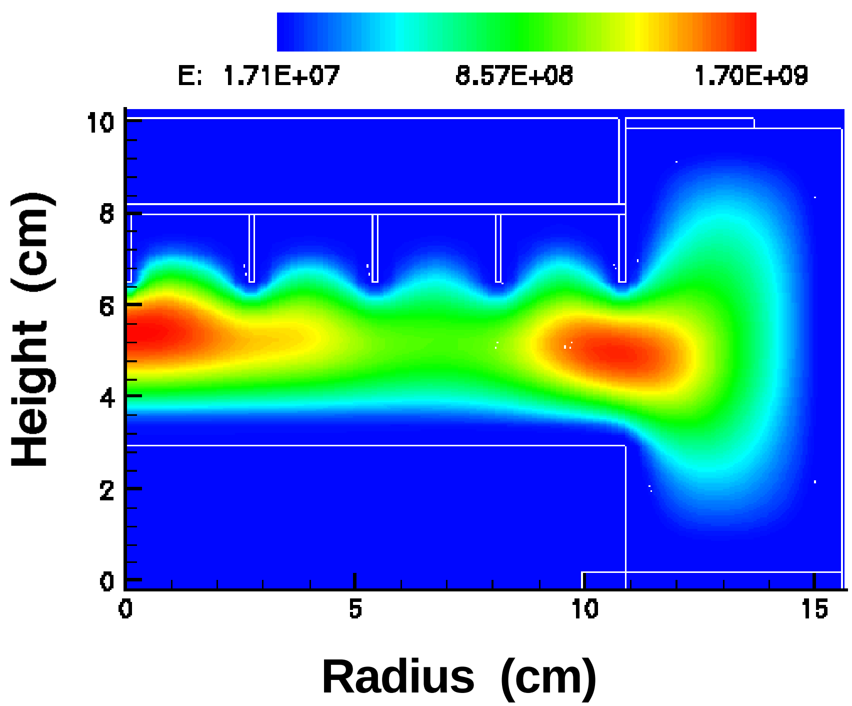
$$k_{ion} = <\sigma\nu> \quad Te^{\alpha}$$

- **A more uniform Te distribution at last leads to the more uniform distribution of electron density.**

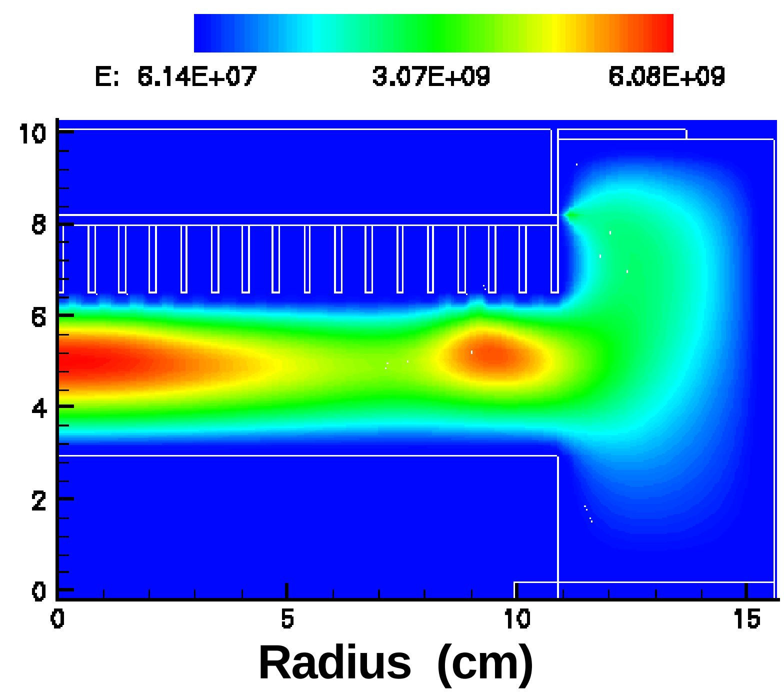
INFLUENCE of PRESSURE and GROOVE WIDTH

- **The electron density has different distribution for electrode with different groove width, or for different gas pressure condition.**
- **Increasing pressure or increasing groove width have similar effects on the electron density distribution.**

- **$D = 4D_{(original)}$, P = 130 mTorr**



- **$D = D_{(original)}$, P = 260 mTorr**



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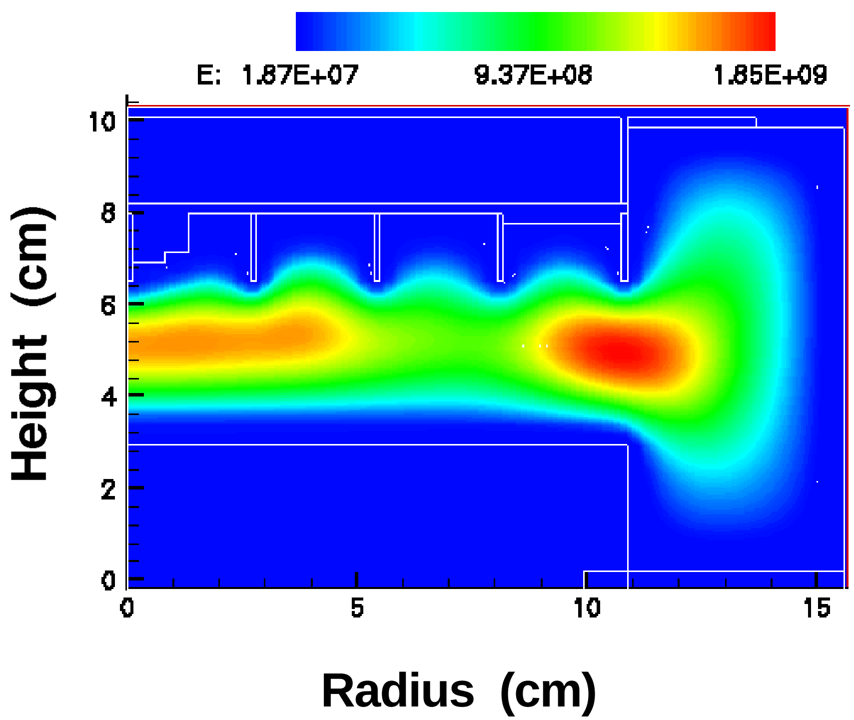
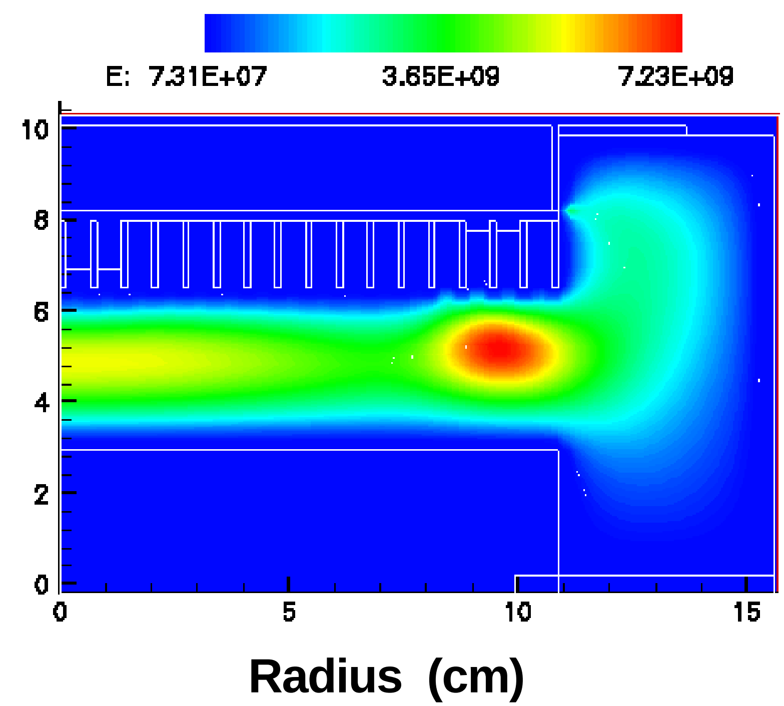
ELECTRODE MODIFICATION EFFECT

- **Electron density distribution after electrode geometry modification.**
- **Proper electrode modification based on original electron density distribution can improve the uniformity.**

• D = 4 D $_{(original)}$ P = 130 mTorr



• D = D $_{(original)}$ P = 260 mTorr



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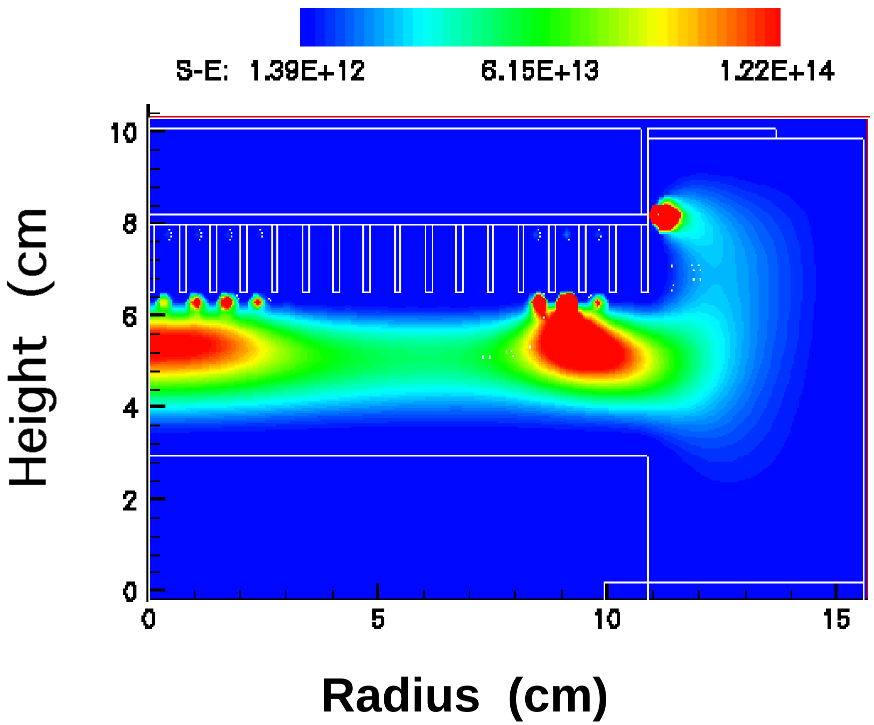
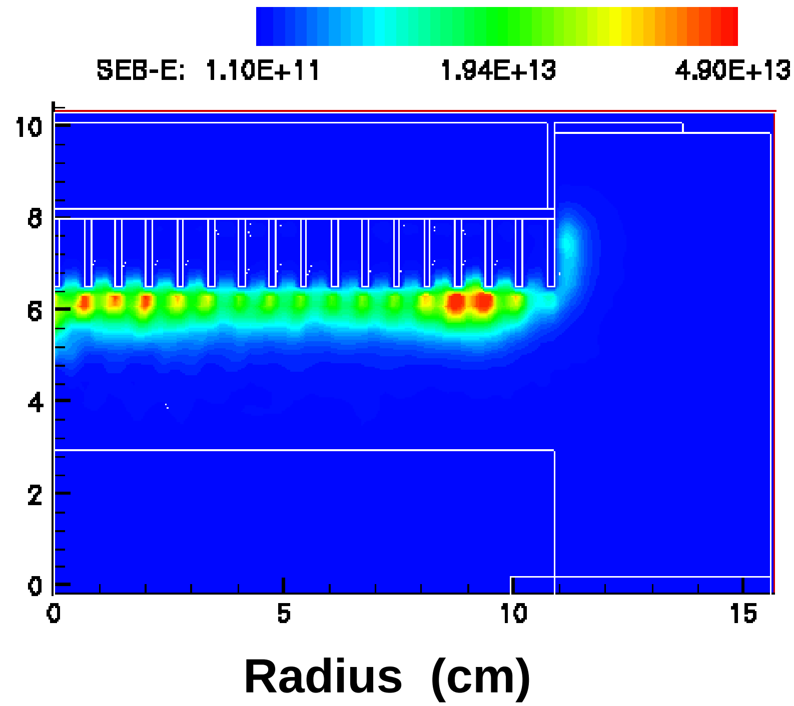
ELECTRON SOURCES

- D = D(original), P = 260 mTorr
- Bulk electron source has two peak regions.
- Beam electron source occupies larger fraction of the total source.

- Bulk electron source



- Beam electron source



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CONCLUSION

- An rf parallel plate reactor with a grooved electrode has been used to obtain uniform discharge processing.

- By adjusting the groove depth geometry, we can optimize the uniformity of the discharge.

- Simulation results demonstrate the change of electron density uniformity with the variation of electrode geometry.

- These results suggest that optimizing the local electrode groove depth can improve the electron temperature distribution, thus leading to better plasma uniformity.