Kafrelsheikh University
Faculty of science
physics Department

### Thesis Title

# "Simulation of Geometrically and Electrically Asymmetric Plasma Discharges"

***By***


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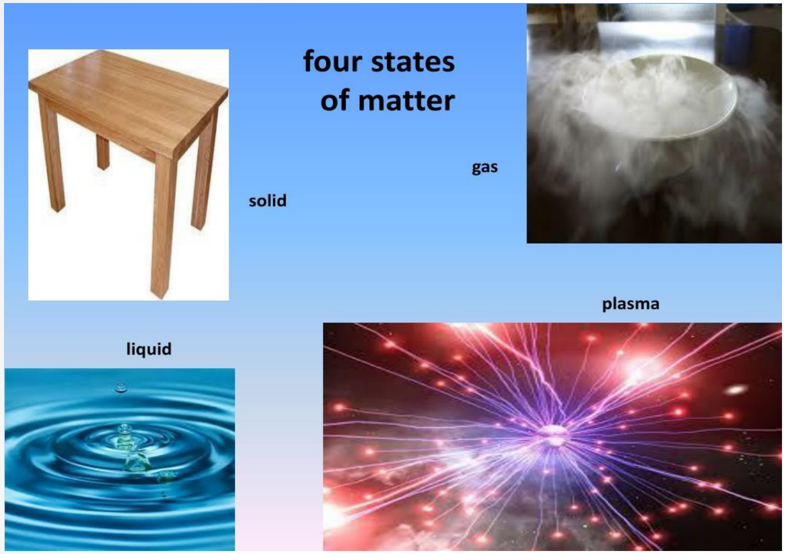
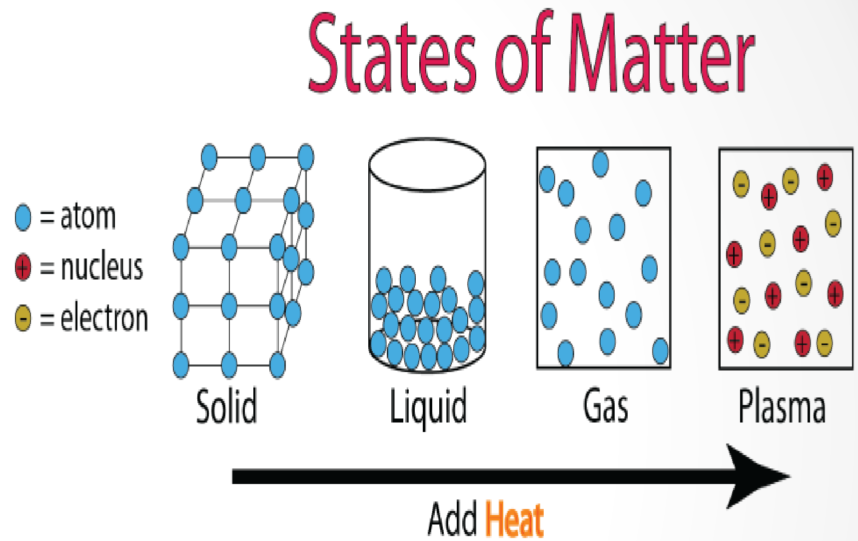
# Introduction to plasma




- Plasma
  - very high KE - particles collide with enough energy to break into charged particles (+/-)
  - gas-like, variable shape & volume
  - stars, fluorescent light bulbs

# HOW TO GENERATE PLASMA

## Capacitively Coupled Plasma

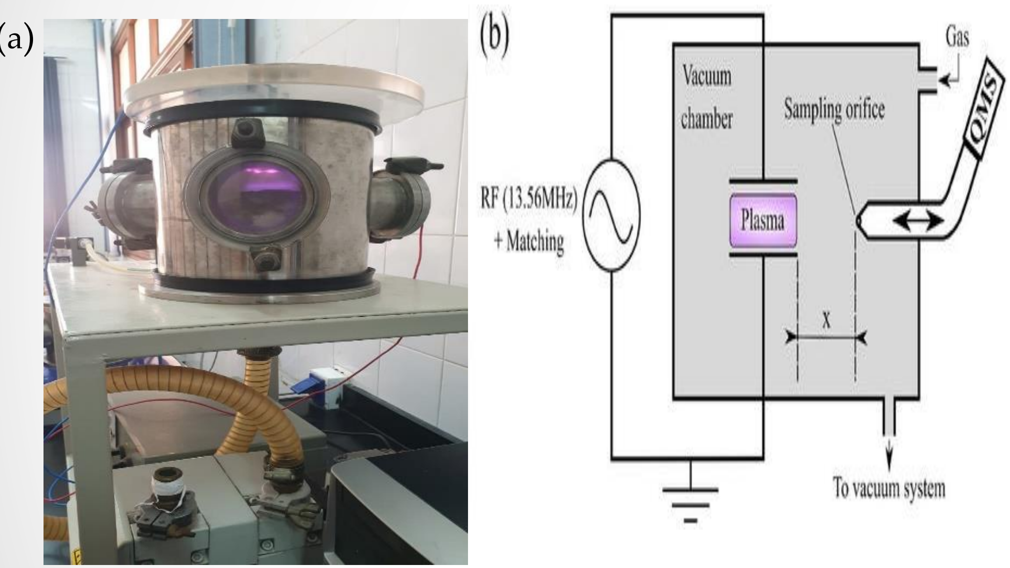



**Fig.(1):** Schematic of capacitively coupled plasma system

## Inductively Coupled Plasma

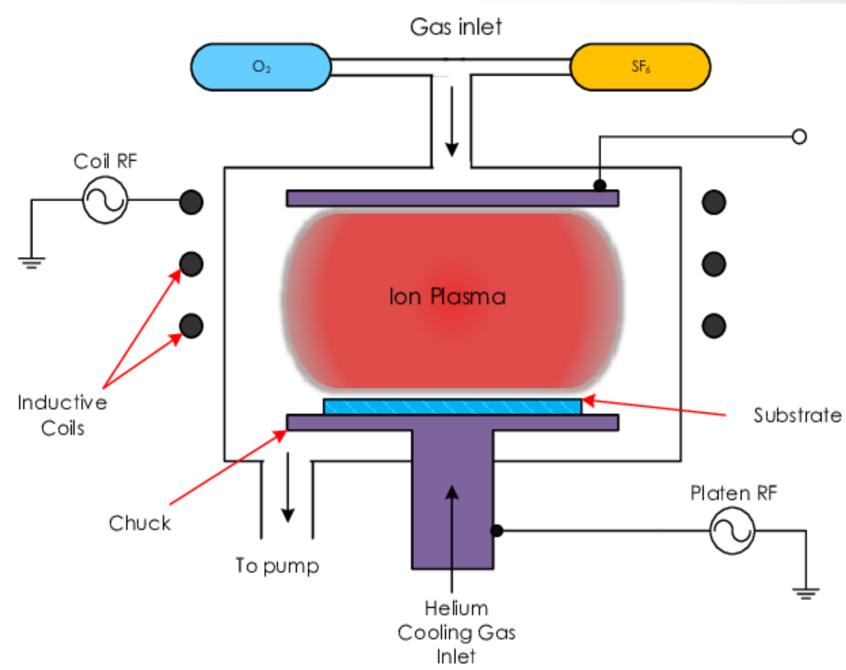



**Fig. (2):** Schematic of inductive coupled plasma system

# Capacitively coupled plasma

- A **capacitively coupled plasma** (**CCP**) It essentially consists of two metal electrodes separated by a small distance, placed in a reactor. The gas pressure in the reactor can be lower than atmosphere or it can be atmospheric.

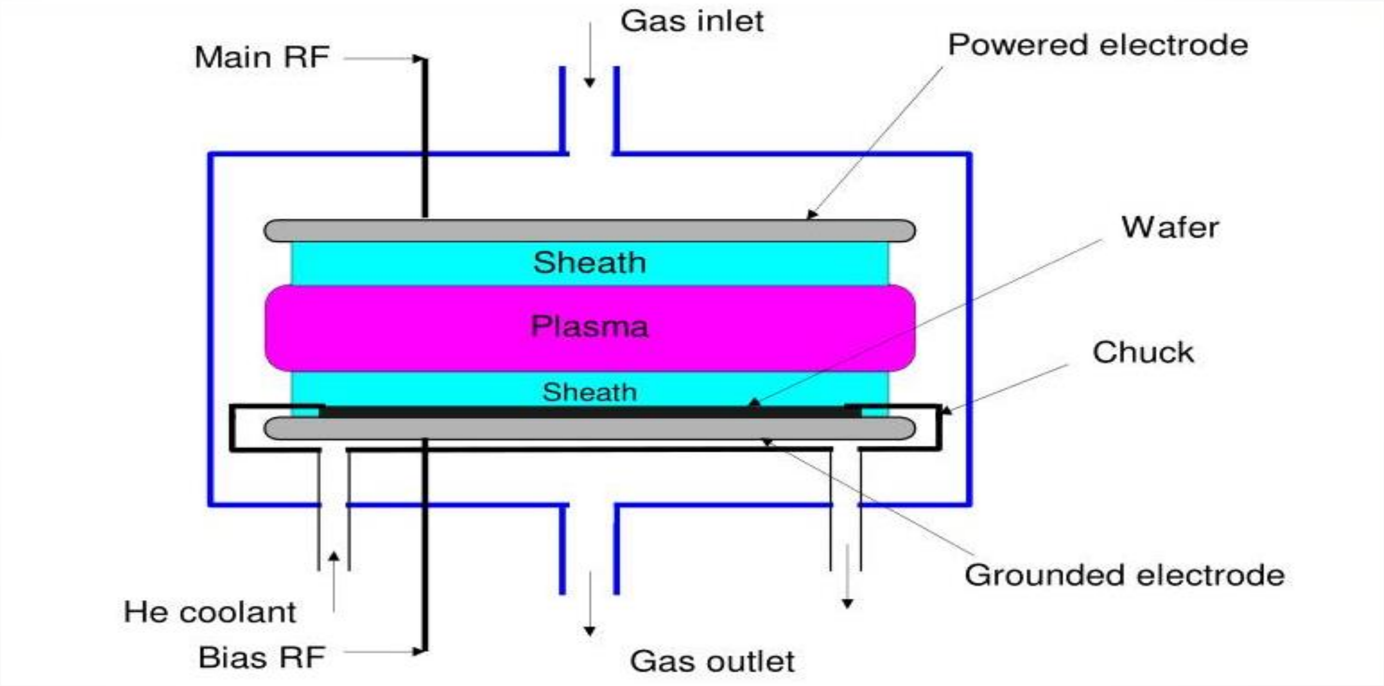



**Fig.(3):** A schematic of a capacitive discharge.

# Objective of the work

- Study numerically, the geometrically and electrically asymmetric discharges at different conditions employing a Particle-in-Cell code.
- Plot the results and making statistical analysis for the ion energy distribution, ion angular distribution, the sheath potential, plasma particles fluxes, and the charge distribution.
- Concluding the results in form of empirical formula to correlate the degree of asymmetry of the discharge on the plasma and the reactor parameters.

# Simulation Method

Particle-in-Cell method: It is a computationally expensive tool, where the plasma dynamics is calculated based on the solution of the equation of motion of plasma particles in a self-consistent way with plasma fields.

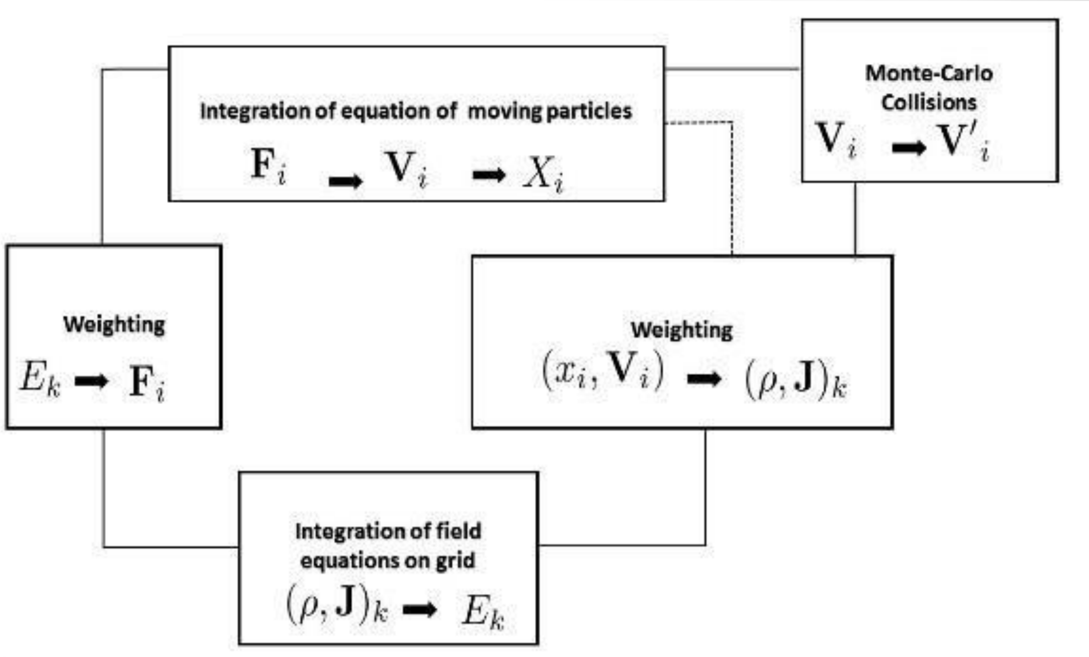



**Fig.(4):** A schematic flow chart of PIC modules. The dashed lines are to short cut Monte-Carlo calculations for collisionless plasma.

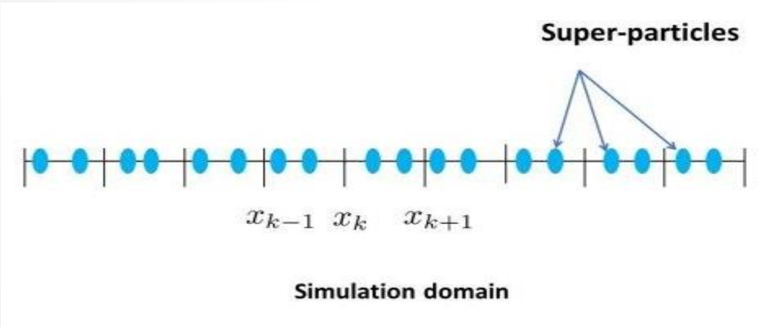
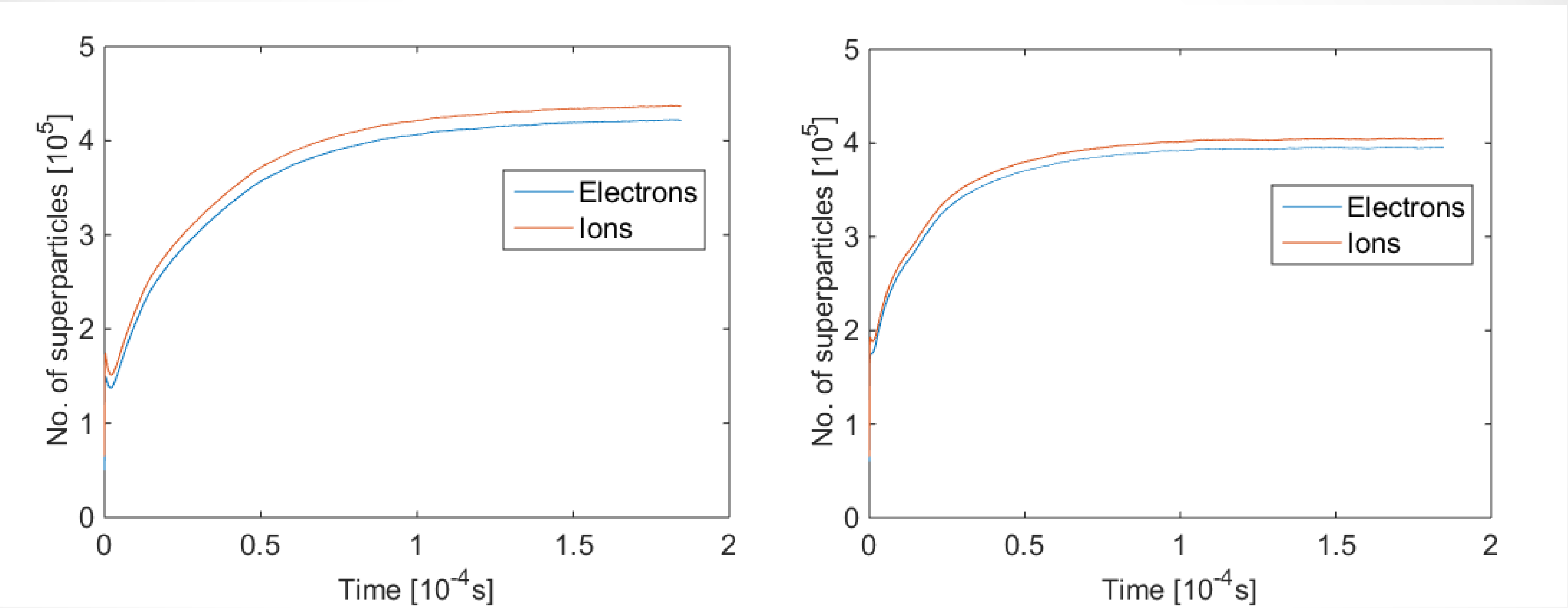



**Fig.(5):** The discretization of the simulation domain into kth grids.

# Convergence




(a)

(b)

**Fig.(6):** (a) Convergence for gap size 0.03 between the two electrodes, (b) Convergence for gap size 0.04 between the two electrodes.

# Geometrically asymmetric plasma

- Industrial plasma sources are often geometrically asymmetric, i.e., the surface areas of the powered and grounded electrode, A.p. and A.g., are not equal.

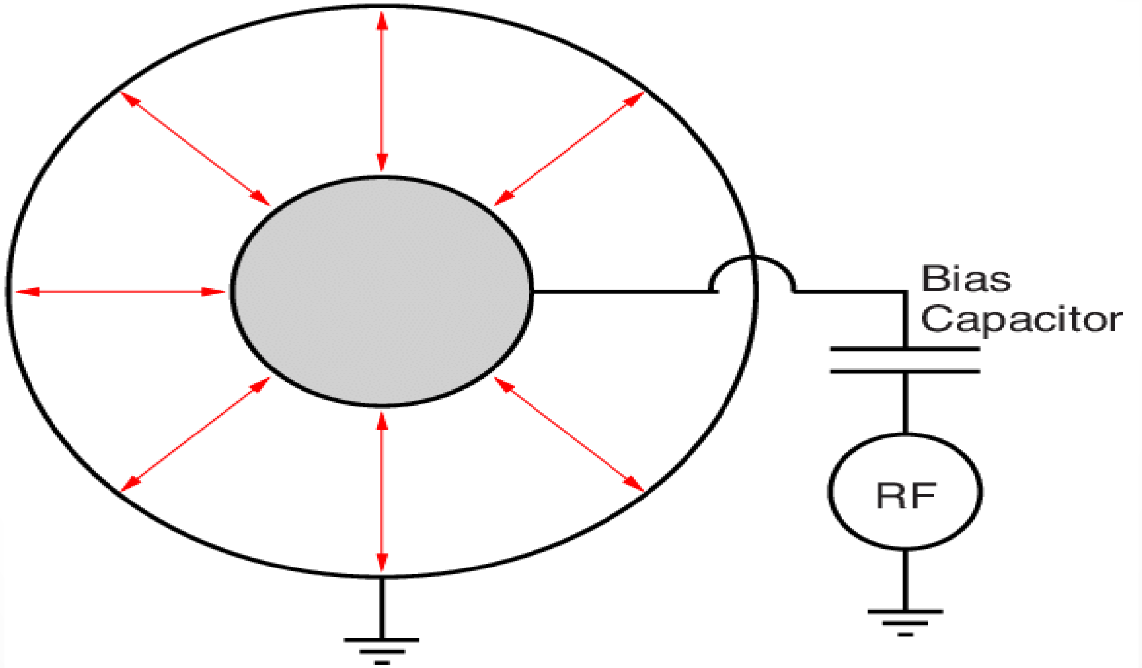



**Fig.(7):** Sketch of the discharge geometry including the rf current paths arrows.

# *Pre-results*

**6.1** pre-result for geometrically asymmetric Capacitively Coupled Plasma.

**Table (1):** represents input parameters for geometrically asymmetric CCP with inner electrode 0.02 m and number of grids 229

| Gap size[m] | Number of RF cycles[Hz] |
|---|---|
| 0.03 | 5000 |
| 0.04 | 5000 |
| 0.05 | 5000 |
| 0.06 | 5000 |
| 0.07 | 5000 |
| 0.08 | 5000 |
| 0.09 | 6000 |
| 0.1 | 6000 |
| 0.11 | 7000 |
| | |

# The first case

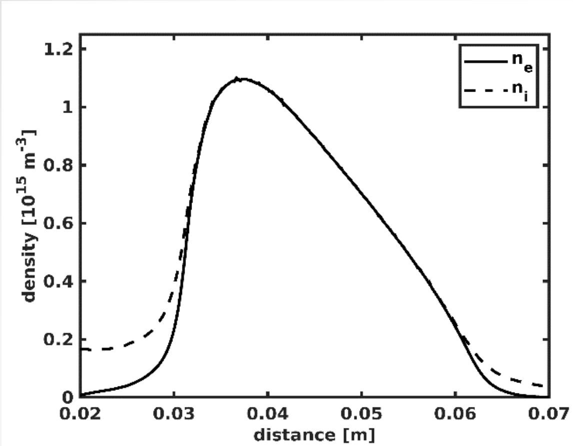



**Fig.(8):** Represents the density of ions and electrons in respect to the distance away from the electrodes.

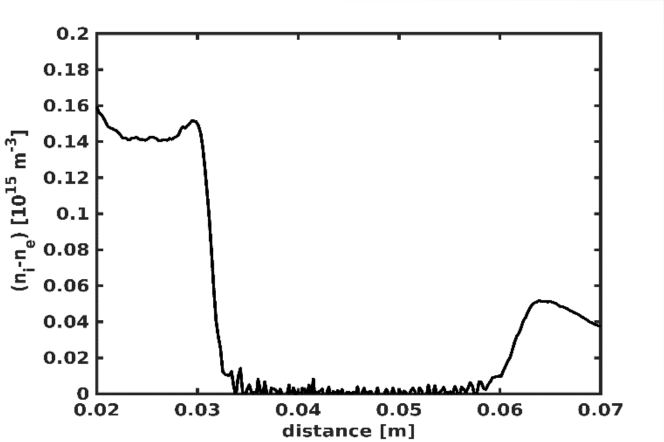



**Fig.(9):** Represents the electric field of the inner and outer electrodes.

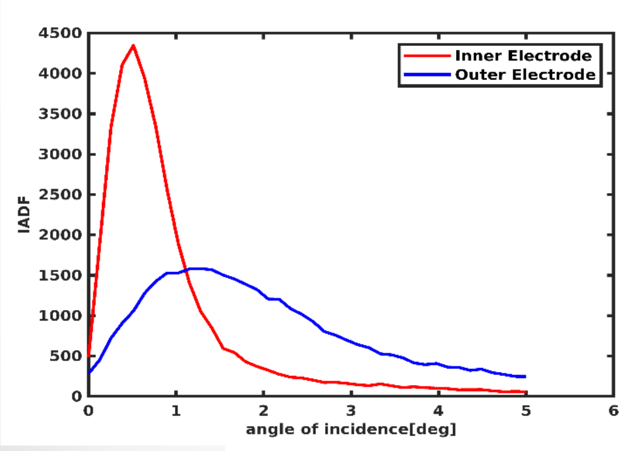



**Fig.(10):** Represents the ion angular distribution function as a function of angle of incident ions on the inner and outer electrode.

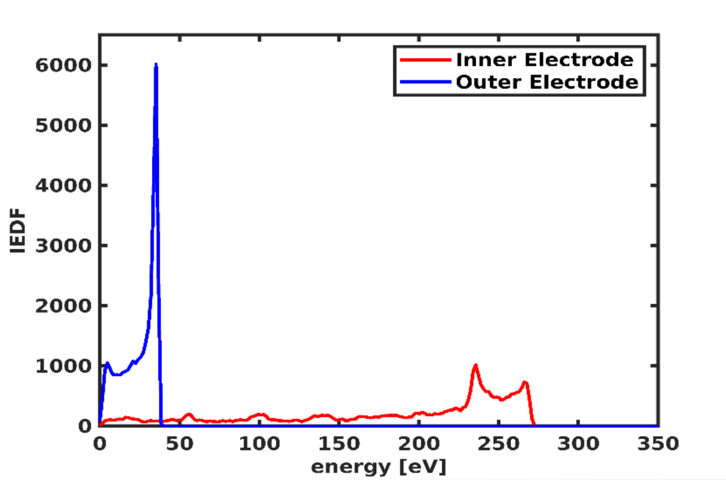
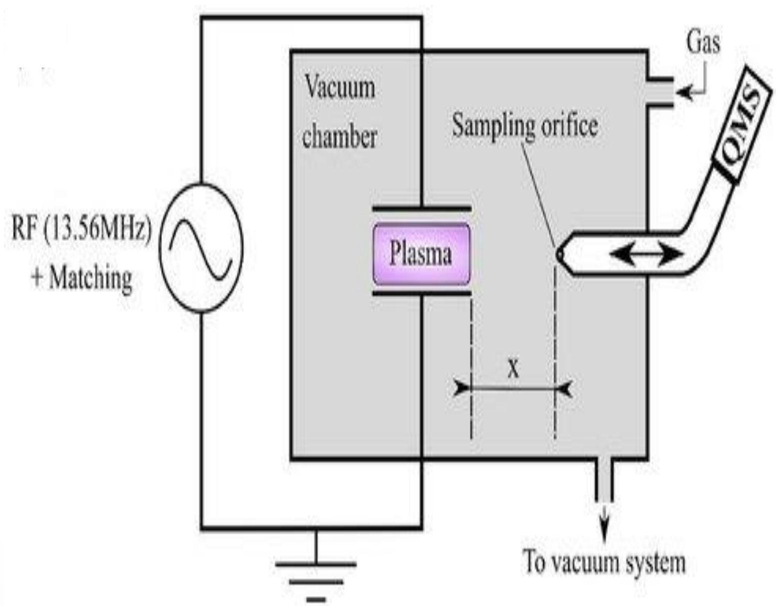



**Fig.(11):** Represents ion energy distribution function as a function of energy.

# Electrically asymmetric plasma

- A dual-frequency voltage source of 13.56 MHz and 27.12 MHz is applied to the powered electrode and the discharge symmetry is controlled by adjusting the phase angle θ between the two harmonics.




Schematic of capacitively coupled plasma system

# 6.2 Pre- result in Electrically Asymmetric CCP

Comparison between the five runs with phase shifts 45°, 135°, 180°, 225°, 270°. For phase shift 45° we have

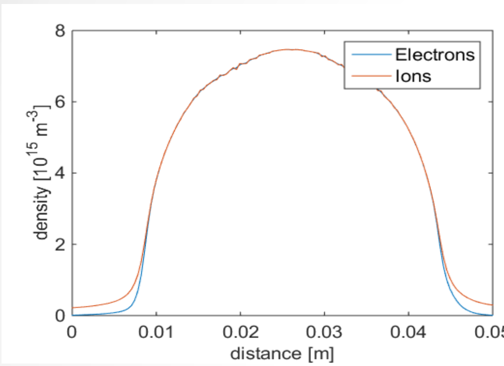



**Fig.(12):** Represents the density of ions and electrons in respect to the distance away from the electrodes.

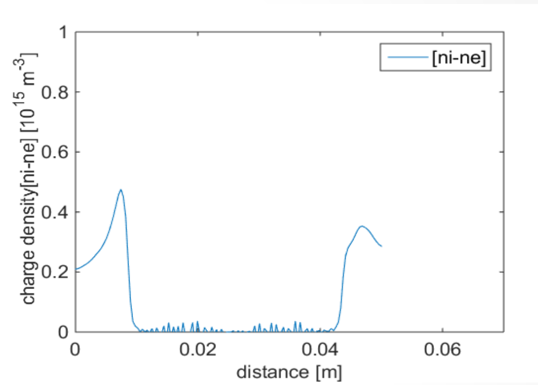



**Fig.(13):** Represents the electric field of the inner and outer electrodes.

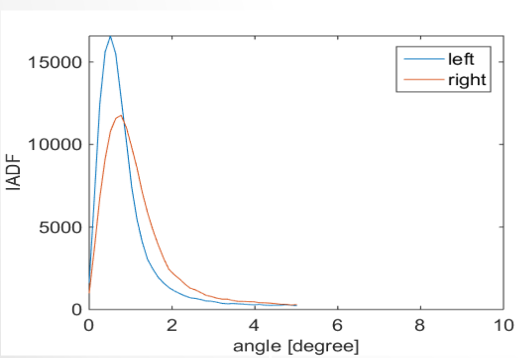



**Fig.(14):** Represents the ion angular distribution function as a function of angle of incident ions on the inner and outer electrode.

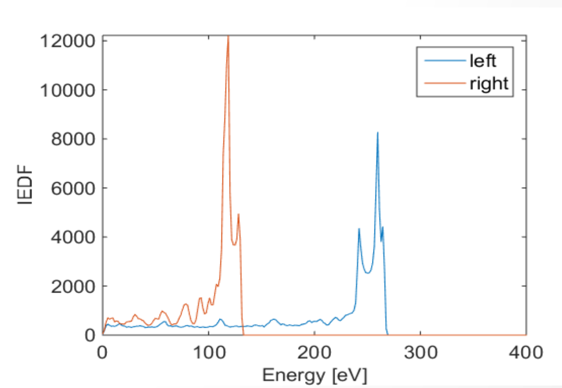


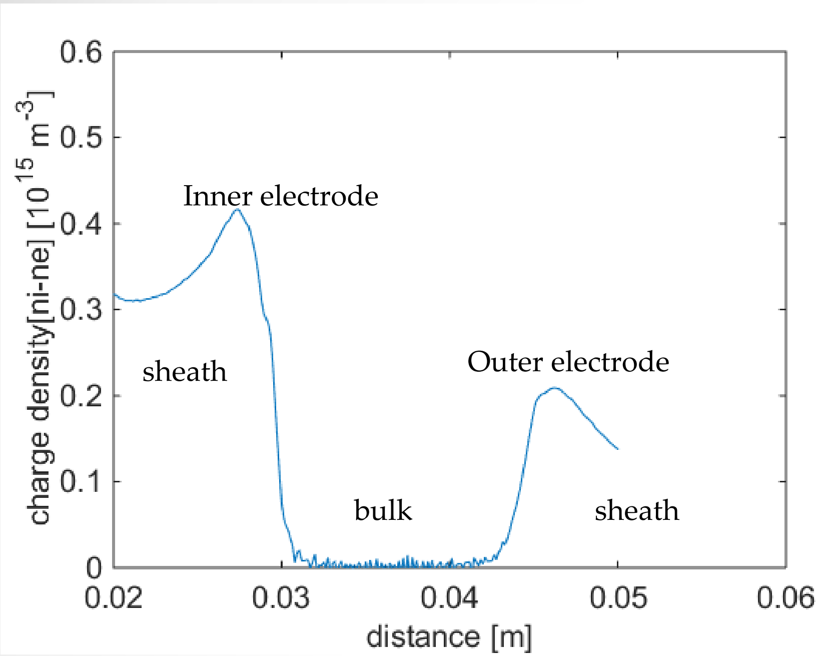

**Fig.(15):** Represents ion energy distribution function as a function of energy.

# Geometrically and Electrically asymmetric Capacitively Coupled Plasma

**Table (2):** represents input parameters for geometrically and electrically asymmetric CCP with Left electrode frequency1= 27.12 [MHz], left electrode frequency2 = 13.56[MHz]
, number of grids= 229 and radio frequency cycles= 5000 Hz.

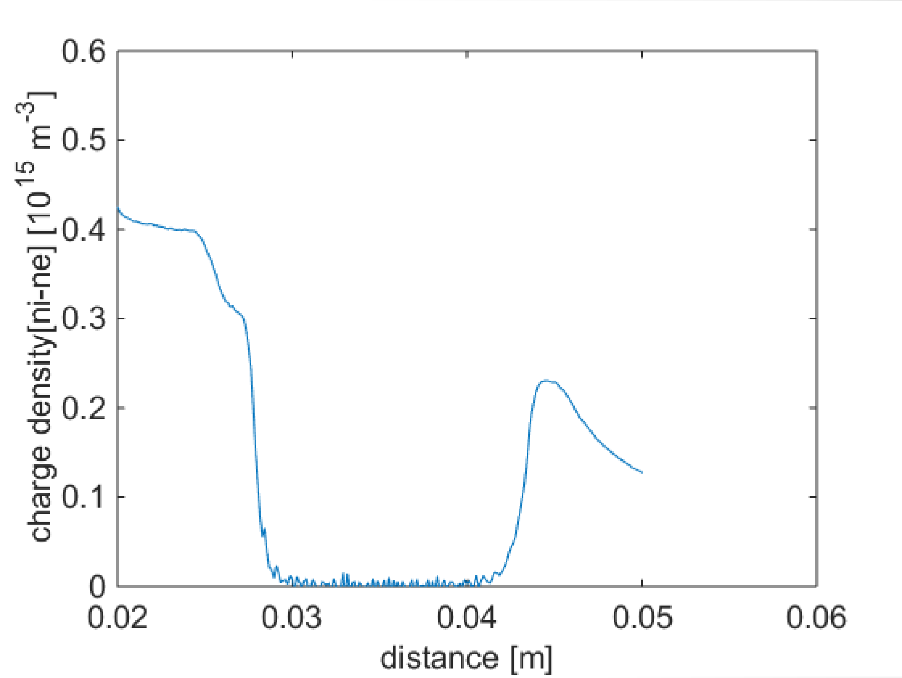
| Gap between the inner and outer electrode [m] | Inner electrode [m] | Phase angle [degree] |
|---|---|---|
| **0.03** | 0.02 | 0º |
| **0.03** | 0.02 | 45º |
| **0.03** | 0.02 | 90º |

# Charge Density Comparison




Phase angle= 0º

(a)



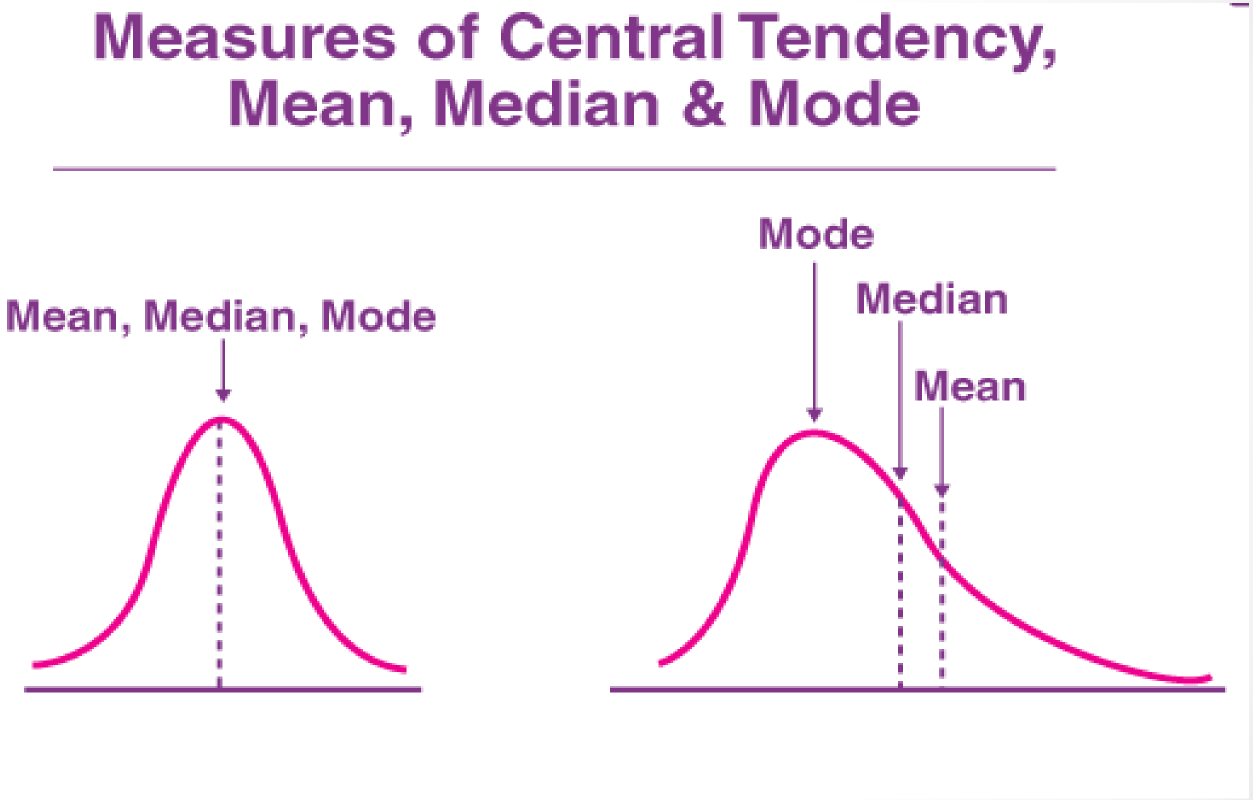

Phase angle = 45º

(b)

**Fig.(16):** represents the electric field of the inner and outer electrodes. (a) for phase angle= 0º**.** (b) for Phase angle = 45º

# Statistical Analysis

- Mean
- Median
- Mode
- Variance
- Standard deviation



# Moments

Statistical Moments: the shape of boundary segments can be described quantitatively by using statistical moments, mean ,variance and higher order moments as skewness and kurtosis.

**For ungrouped data:**

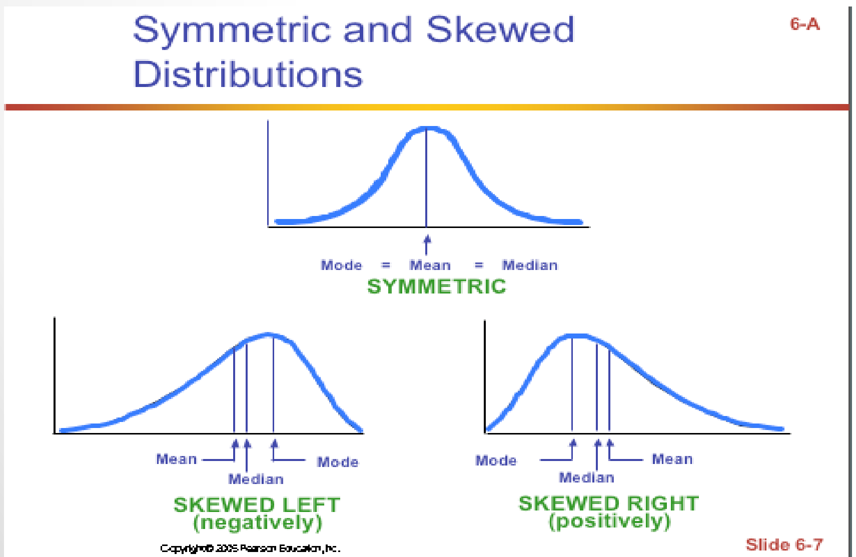
$\mu_r = 1/n * \sum (x - \bar{x})^r$ r=1,2,3,4….

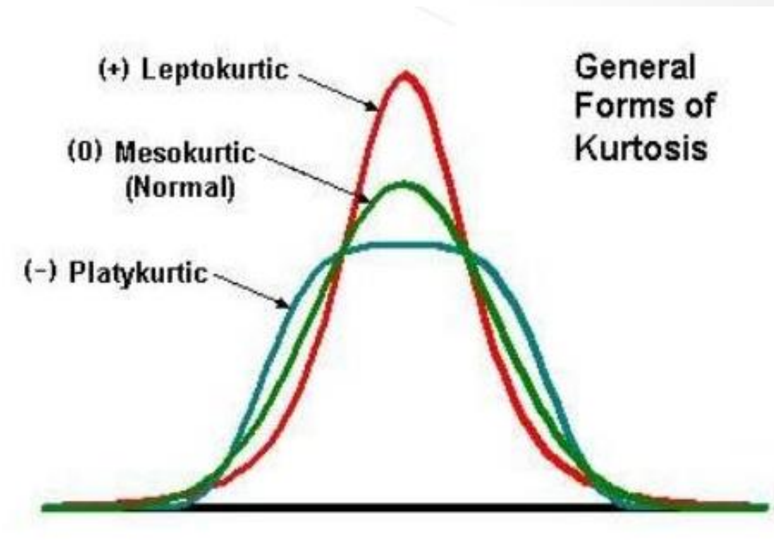
## Co-efficient of Skewness and Kurtosis using Moments

- Co-efficient of Skewness $$\beta_1 = \frac{\mu_3^2}{\mu_2^3}$$
- Kurtosis $$\beta_2 = \frac{\mu_4}{\mu_2^{\,2}}$$

# Skewness and Kurtosis

| Sr. No. | Skewness | Kurtosis |
|---|---|---|
| .1 | It indicates the shape and size of variation on either side of the central value. | It indicates the frequencies of distribution at the central value. |
| .2 | The measure differences of skewness tell us about the magnitude and direction of the asymmetry of a distribution. | It indicates the concentration of items at the central part of a distribution. |



# Geometrically asymmetric discharges are visited to quantify an accurate empirical formula.

- The analytical models expect an inverse relation between the sheath potential and the electrode area with different powers ($V_{sh} \propto A^{-\alpha}$ ).

- The matrix sheath model, Child collisionless sheath model, and Child collisional-sheath model expect a power (a) of 2, 4, and 2.5, respectively.

- Particle-in-Cell simulation expects a power of ~ 0.53.

# Calculation of alpha

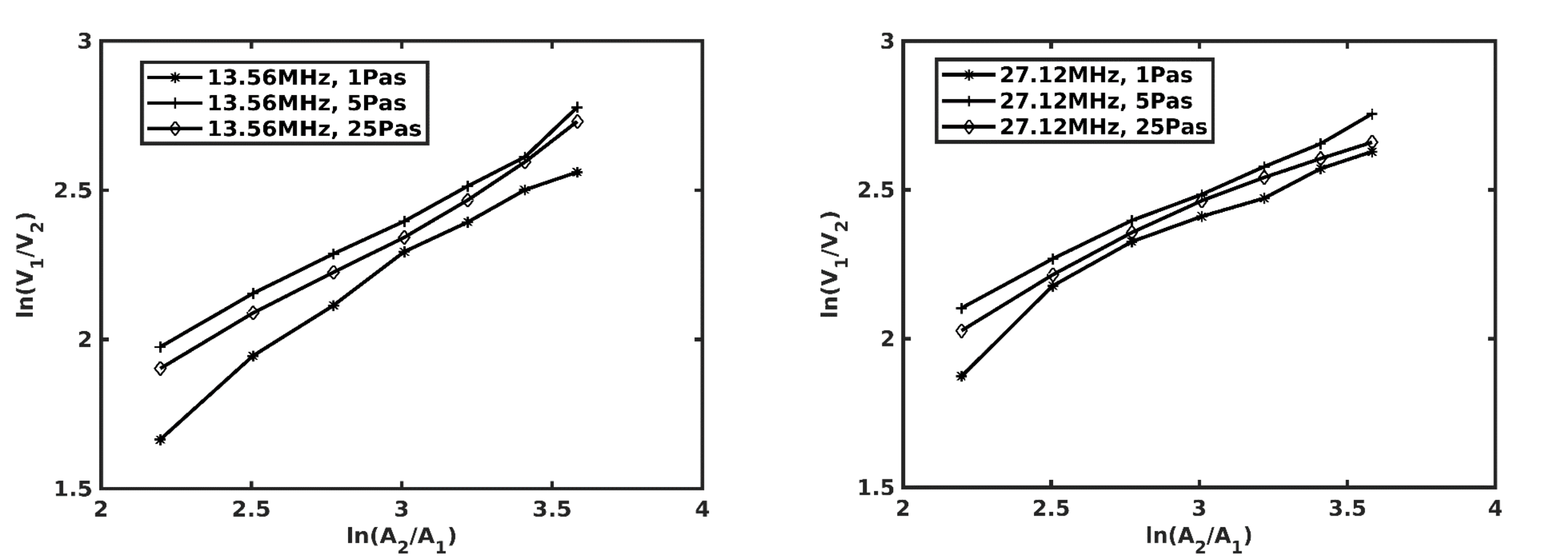



Fig. 17 (Left) The sheath potential as a function of the electrode area at pressures 1, 5, and 25 Pas and a driven frequency of 13.56 MHz. (Right) The electrode potential as a function of the electrode area at pressures 1, 5, and 25 Pas and a driven frequency of 27.12 MHz.

# Deposition of $Al_2O_3$ on FTo substrates by DC Magnetron Sputtering.

- We prepare (Al2O3) films on substrate of FTo by using plasma magnetron sputtering technique.
- We study the structural and optical properties for the prepared films with different thicknesses.

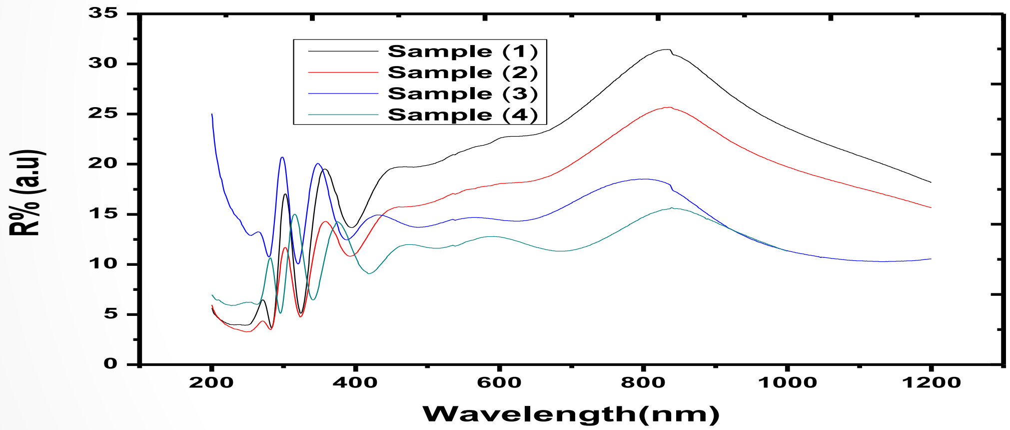



Fig. (18): The reflectance spectrum of Al2O3 films in different mediums.

# In summary

- Particle in cell method is employed to simulate geometrically and electrically asymmetric Capacitively Coupled Plasma.
- Simulated results are with good agreement with other published papers.
- The parameters for the simulation were validated with the curves of convergence.
- Simulated results for geometrically and electrically asymmetric CCP showed that there are asymmetry and that ions hit the inner electrode with higher energy than outer electrode.
- The sheath of inner electrode is larger than outer electrode. Substrates over the inner electrode may allow plasma etching.
- Statistical analysis calculated to get an empirical formula.
- Calculate the empirical formula power.
- Formation of $Al_2O_3$ films by DC Magnetron Sputtering.

Thank you