The effect of cathode rings changes on the confinement process of IEC device

Ghammas H., Nasrabadi M N*

Faculty of Physics, University of Isfahan, 81746-73441, Isfahan, Iran
*Email: mnnasrabadi@ast.ui.ac.ir

Abstract

Inertial electrostatic confinement is a method of generating nuclear fusion in which nested electrodes are used to accelerate ions toward the center of the device in order to perform a fusion reaction. Poor ion confinement in conventional IECs is the main reason for achieving fewer fusion reactions. Multi-grids devices are demonstrated through a particle in cell simulation that allows ions to pass indefinitely in a collisionless regime and improved the confinement times. Experiments were also performed to confirm this progress. In this work, the simulation is performed based on the number of rings forming the cathode grid. The effect of cathode transparency, which is due to the number of rings, on the confinement process is also investigated. Finally, the results are displayed on graphs such as electric field, ion density and kinetic energy.

Keywords: Cathode grid, Transparency, Ion density, Rate of reaction

Introduction

The inertial electrostatic confinement (IEC) device is a fusion device that accelerates ions generated toward the center to perform a fusion reaction. This is done by using an electric field caused by applying a potential difference between two electrodes. This device typically consists of two electrodes, an external electrode called an anode which is connected to ground, and an internal electrode called a cathode connected to a high negative voltage [1,2]. The cathode grid usually consists of several rings, which indicates the transparency of the grid. In previous works, the effect of grid transparency on the electric field has been simulated and performed experimentally. We now want to predict the effect of grid transparency on the other parameters using the particle in cell (PIC) method.

Simulation of device structure using PIC code

To investigate the effect of grid transparency and also the complex behavior of ions within the IEC spherical device, we performed PIC simulations using the XOOPIC code [3]. The simulation parameters used in this work are given in Table 1. The simulations are based on experiments performed on a device at MIT [4] and in sync with the simulations performed by Mc Guire [5].The background gas is argon and when the ion injector is turned on, argon ions are injected into the chamber. The reason for choosing argon as the gas to be tested is that the peak of the electron bombardment ionization cross section for this gas is in the range of 100-150 eV electron energy. This low cross-sectional area facilitates testing, which is useful for improving the device. Argon gas reactions are given in Table 2. In this regard, we simulate the effect of cathode transparency on confinement. On the other hand, the following equation can be used to calculate the value of transparency of the grid [6]:

$$\eta = 1 - \frac{N\omega}{2R_C} \qquad (1)$$

Where η represents the value of the grid transparency, N is the number of rings, ω is the thickness of the rings, and R_C refers to the radius of the grid. The transparency value of each grid is calculated and included in Table 3.

Results and discussion

Figure 1 shows the position of ions in the device. As can be seen from the figure, the position of the ions in an 8-rings (c) device has better symmetry than other devices. Figure 2 shows the electric field inside the device. The 4-rings device (a) with a value of $9.9 \times 10^5 \frac{V}{m}$ has the highest value among the other two devices. This causes the electric field in the center of the device to decrease as the rings gradually increase. The correctness of this can now be confirmed by the following equations. The radial potential profile can be obtained from the following equation [4]:

$$\phi = \left(\frac{9 I_i \alpha^2}{16\pi\varepsilon_0}\sqrt{\frac{m_i}{2e}}\right)^{2/3} \qquad (2) \qquad\qquad I_i = \frac{I_{meas}}{(1-\eta^2)(1+\gamma)} \qquad (3)$$

Where α is a geometrical factor and I_i is the recirculation ion current. As the transparency increases, the value of I_i decreases and therefore the potential should decrease. This reduction also reduces the electric field, which confirms the simulation results. Kurt in his experiments with different material for grids, concluded that as the number of rings increases, the electric field decreases [7]. In Figure 3, although the amount of potential decreases with increasing number of rings, the E_k increases as a result and the reaction rate also increases. Figure 4 shows that the ion density in an 8-rings device is $2.94 \times 10^{15}\ 1/m^3$, which is the highest value among other devices. This value is higher than the maximum measured ($2 \times 10^{14}\ 1/m^3$) in a 4-rings device [5].This issue indicates that the ion density increases with the number of rings. The following equation confirms this subject [6]:

$$n_{i0} = \frac{\eta}{(1-\eta^2)(1+\gamma)} \frac{I_{meas}}{4\pi {r_0}^2 e\sqrt{2e\phi_0/m_i}} \qquad (4)$$

Figures 5 shows the charge density value inside the device.

Tables

Table 1. Geometry of IEC device

Parameters	**Values**
Anode radius	250 mm
Grid radius	50 mm
Skin depth of grid	5 mm
Background gas	Argon
$V_{Cathode}$	-50 kV
V_{Anode}	0 kV
Pressure	3×10^{-2} mTorr
Current	20×10^{-6} A

Table 2. Reactions in the simple argon model

(1)	$e + Ar \rightarrow e + Ar$	(Elastic Scattering)
(2)	$e + Ar \rightarrow e + Ar^{*}$	(Excitation)
(3)	$e + Ar \rightarrow e + Ar^{+} + e$	(Ionization)
(4)	$Ar^{+} + Ar \rightarrow Ar + Ar^{+}$	(Charge Exchange)
(5)	$Ar^{+} + Ar \rightarrow Ar^{+} + Ar$	(Elastic Scattering)

Table 3. Three types of cathode grid

n	4-rings	6-rings	8-rings
η	80%	70%	60%

Figures

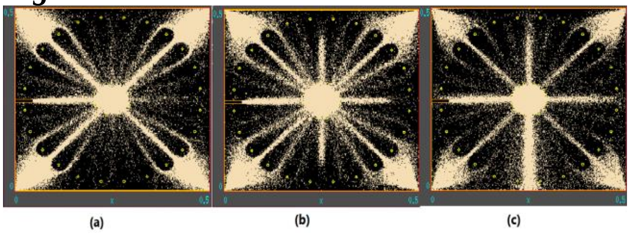

Figure 1. x-y phase space of ion for 4-rings (a), 6-rings (b) and 8-rings (c) device.

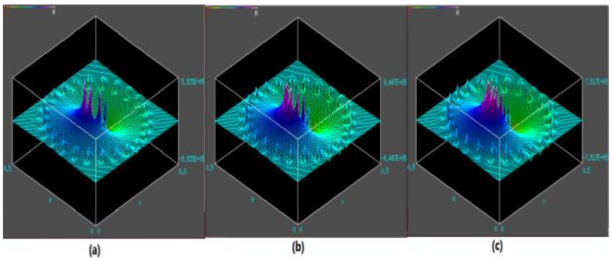

Figure 2. Electric field in the direction x for 4-rings (a), 6-rings (b) and 8-rings (c) device.

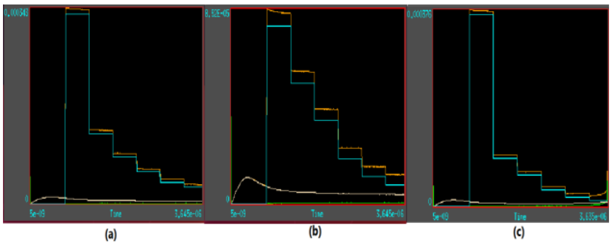

Figure 3. Kinetic energy of particles for 4-rings (a), 6-rings (b) and 8-rings (c) device.

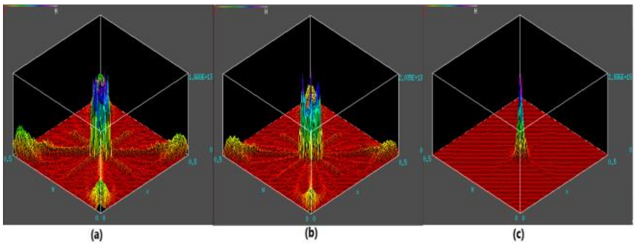

Figure 4. Number of ion for 4-rings (a), 6-rings (b) and 8-rings (c) device.

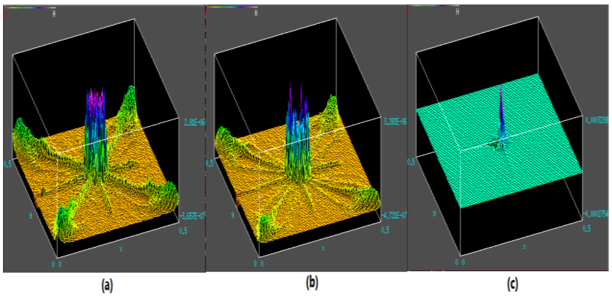

Figure 5. Charge density for 4-rings (a), 6-rings (b) and 8-rings (c) device.

Conclusions

In this work, experimental data confirmed the simulation results. These results show that the electric field and the electric potential decrease with decreasing transparency, but at the same time the density of ions and consequently the reaction rate increases.

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