Comparative simulation studies of plasma cathode electron (PCE) gun

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Comparative simulation studies of plasma cathode electron (PCE) gun

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Abstract. Pseudospark discharge based plasma cathode has capability to provide high current density electron beam during discharge process. In this paper an effort has been made to simulate the breakdown processes in the pseudospark discharge based plasma cathode electron gun. The two-dimensional plasma simulation codes VORPAL and OOPIC-Pro have been used and results are compared. The peak discharge current in the plasma cathode electron gun is found to be dependent on aperture size, hollow cathode dimensions, anode voltage and seed electrons energy. The effect of these design parameters on the peak anode current has been analysed by both the codes and results matches well within 10% variation. For the seed electron generation an electron beam trigger source is used to control the discharge process in the hollow cathode cavity. The time span of trigger source has been varied from 1-100 ns to analyze the effect on the peak anode current.

1.Introduction

The pseudospark (PS) discharge is recognized as unique type of discharge [1] which is capable of producing electron beams with highest combined current density and brightness of any known type of electron source [2-6]. The PS discharge based plasma cathode electron (PCE) gun has potential applications in microwave generation, electron beam melting, welding, surface treatment, plasma chemistry, radiation technologies, laser pumping, and where material cathode cannot be used. This type of gun has longer life as compared to that of material cathode. PS discharge is a specific type of gas discharge, which operates in hollow cathode geometry on the left-hand side of the Paschen curve with axially symmetric parallel electrodes and central holes on the electrodes [7].

There are two mechanisms to generate pseudospark discharge; one is self-breakdown discharge that follows the Paschen's curve for breakdown of gases. Another mechanism is triggering discharge in which some initial electrons are provided to start and stimulate the discharge process. In triggered discharge process breakdown of gases can be achieved below the required voltage as calculated by Paschen's curve. In our case typically 1x1011 seed electrons are injected at the centre of the cavity of the hollow cathode with appropriate energies to initiate the discharge. It is fixed for all simulation data in the present analysis. The initial electron which comes from trigger source collides with the gas molecule and generates low density discharge and accelerates towards anode leaving a cluster of positive ions which further acts as virtual anode. Due to this virtual anode formation electric field start penetrating inside the hollow cathode structure and stimulate further

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discharge process. This penetrating electric field helps to create dense plasma with high current density. By this method current can be achieved from few amperes to several thousand amperes using suitable dimensions of PCE-gun [8].

In this work an effort has been made to simulate breakdown processes in the PS discharge based PCE-gun. The two-dimensional plasma simulation codes VORPAL and OOPIC-Pro are used and results are compared. It has been found that the peak current arriving at the anode depends on the hollow cathode dimensions, potential applied at the anode and average velocity of the seed electrons.

In this simulation study secondary electrons generation due to wall impact by electrons is also considered [9].

2. Model Description

The simulation study has been carried out through the two-dimensional electrostatic kinetic particle-in-cell (PIC) simulation codes VORPAL and OOPIC-Pro developed by Tech-X Corp. Both the codes use elastic and ionizing collision using Monte Carlo Collision (MCC). A cross-section model is taken from the Tech-X Corp. in-built library for the electron ionization process. The input parameters like trigger position, seed electron velocity, gas pressure, time constant, etc. are kept similar in both the codes. The schematic view of the model used in the simulation is given in Figure 1. This model has fixed hollow cathode height, $Ymax=50$ mm and $d= 5$ mm separation between anode and cathode. The hollow cathode length is also fixed, $D+W = 37$mm where W is the hollow cathode thickness and D is depth of the hollow cathode. The hollow cathode dimensions have been varied to check the dependency of the peak current on these parameters. The position of the trigger source is kept constant for all the operating parameters. The trigger source is used to supply the seed electrons for the initiation of the discharge process in the hollow cathode. The injection period of the seed electrons is kept 1ns for high energetic electrons and 10 ns for low energy electrons. The seed electron velocity is varied in two cases corresponding to 1keV kinetic and 2.5eV thermal energy and 100eV kinetic and 2.5eV thermal energy respectively. Argon gas has been used in the PCE-gun for all the operating conditions. The neutral gas is kept at room temperature and operating pressure is kept 60 Pa. The applied potential at the anode is varied from 0 to 10 keV to analyse its effect on the peak anode current.

3. Simulation Results

The variation of the applied potential and anode current at different times is shown in figure 2. At the starting of the simulation, the anode current is very small but when the voltage starts penetrating inside the hollow cathode cavity, the potential difference between anode and cathode starts decreasing and the current starts increasing [5]. It has been observed that the peak amplitude of anode current changes with change in the hollow cathode dimensions.
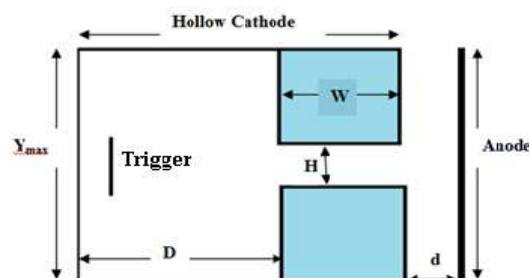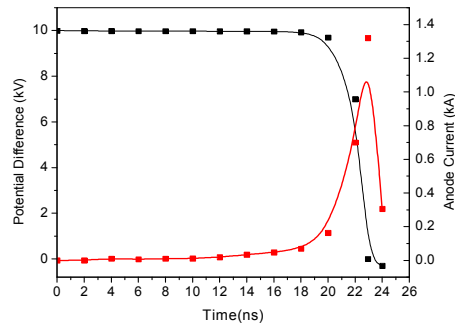

Figure 1. Simulation model for PCE Gun

**Figure 2.** Variation of potential and anode current

using VORPAL

Figure 3 shows voltage penetration inside the hollow cathode cavity. The applied electric field accelerates seed electrons which generate ions and also extract the electrons out of the hollow cathode, leaving behind a net positive charge region. This positive charge region grows inside the hollow cathode cavity and acts as a virtual anode. The electric field penetration inside the hollow cathode vicinity is due to the virtual anode formation.

(a)

(b)

(c)
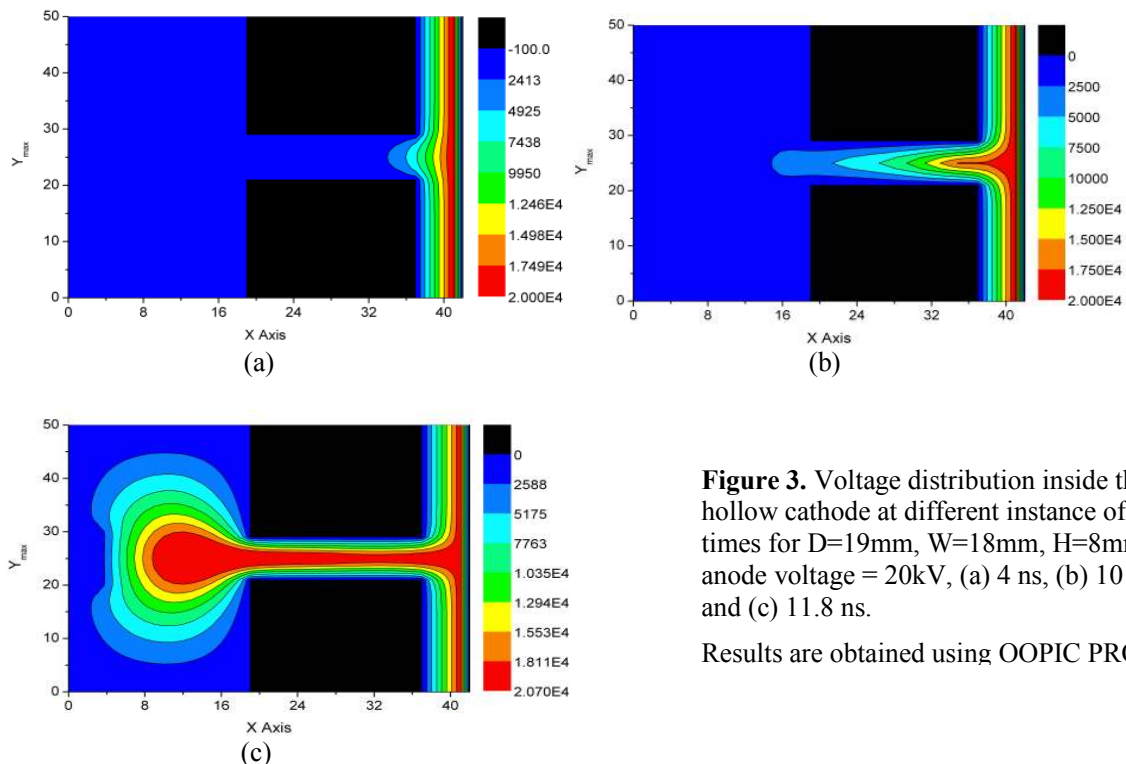
Figure 3. Voltage distribution inside the hollow cathode at different instance of times for D=19mm, W=18mm, H=8mm, anode voltage = 20kV, (a) 4 ns, (b) 10 ns, and (c) 11.8 ns.

Results are obtained using OOPIC PRO

The anode current variation with the velocity of the seed electron change is shown in the figure 4. It is found the more energetic seed electron energy leads more anode current. In fact, increase in the seed electrons energy generates denser plasma due to the more collisions between neutral atoms and electrons.

(a)   (b)
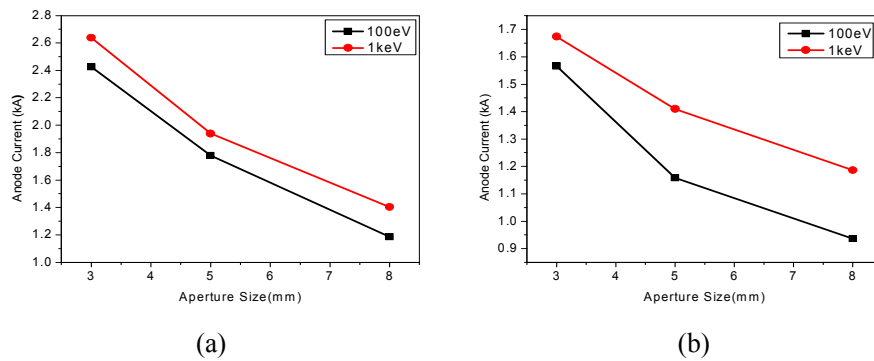
Figure 4. Anode current at different energy of seed electron for D=32mm, W=5mm, (a) anode voltage=10 kV, (b) anode voltage= 20 kV

The variation of the peak anode current with aperture size of the hollow cathode at different dimensions of the PCE-gun is shown in figure 5. In this figure the results obtained by two codes are also compared which matches well within 10% variation. In all the cases the anode current amplitude decreases with increase in aperture size due to less discharge time and density.

(a)   (b)

(c)   (d)
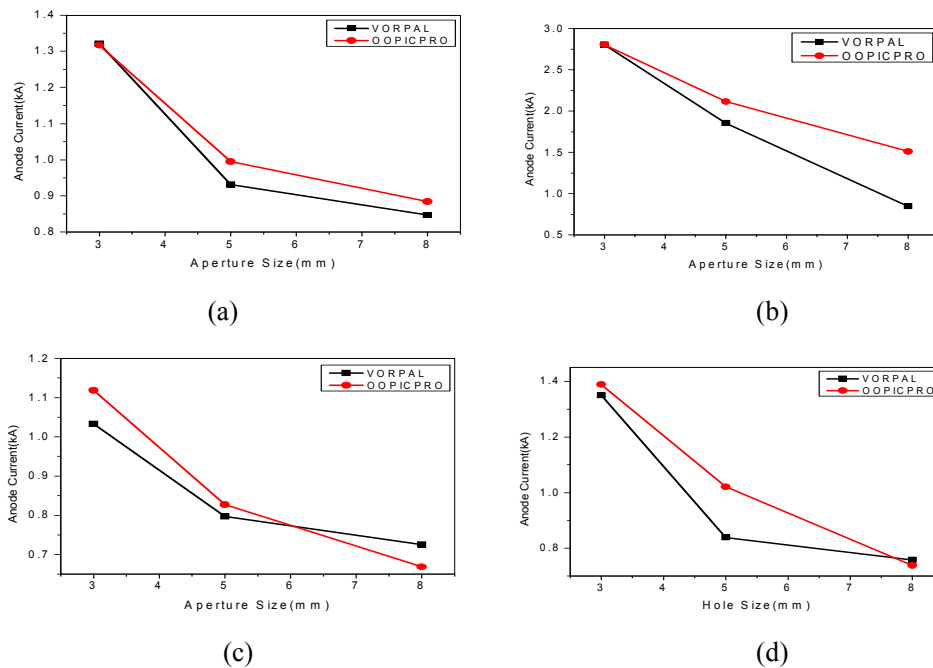
Figure 5. Comparison of peak anode current for different aperture sizes by both the softwares OOPIC Pro and VORPAL (a) D=19 mm W=18 mm, anode voltage =10 kV, (b) D=19 mm W=18 mm, anode voltage =20 kV, (c) D=32mm W=5 mm, anode voltage =10 kV, and (d) D=32 mm W=5 mm, anode voltage =20 kV

4.Conclusion

The change in peak anode current by variation in the input parameters –like, seed electron velocity, hollow cathode depth, hollow cathode width, aperture size and anode voltage has been analysed by 2-D PIC simulation codes VORPAL and OOPIC-Pro. Both the codes show good agreement in the variation of the peak anode current. The virtual anode formation in the hollow cathode basically leads to penetrate the electric field inside the hollow cathode vicinity. It is found that the increase in seed electrons velocity generates denser plasma.

5.References
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