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NEUTRALIZATION AND FOCUSSING OF PULSED BEAMS WITH HIGH CURRENT DENSITIES*

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Abstract

The intense pulsed ion beams with energies about 70 keV produced by the multiplate chamber(MPC) under low gas pressure are extracted from the cathode hole. High power densities are evidently proved by the craters with diameters about 15 micrometers or less on the surface of metallic targets. The major processes of beam production and propagation could be explained by the factors of the field escalation effects in the MPC; fast charge neutralization by the simultaneous introduction of electrons on surfaces in close proximity to the beam; bunching of time of flight and focussing of the plasma lens. It is expected that the processes described above could be used experimentally for simulation of intense pulsed ion beams propagating in the low gas pressure.

Introduction

The development of intense pulsed ion beam generators has been stimulated by their potential applications to controlled thermonuclear fusion programs, material testing, direct pumping of gas and chemical laser.[1] The transporting behavious of intense heavy ion beams with energies of about GeV. have been theoretically investigated.[2] Because appropriat accelerator facilities are not available many essential problems of heavy ion fusion can not be experimentally investigated.[3]

An inertial fusion scheme with low energy heavy ions was proposed recently.[4] To produce the pulsed heavy ion beams in a spherically focused array, using time-of-flight(TOF) is the basic idea. Besides the production of pulsed beams, the beam transportation and focussing, energy deposition of beam bombarding the target are more important subjects. The aim of our investigation is to determine whether a heavy ion beam with energy of below 100 keV can be transported in low pressure gas with high efficiency, to hit a submilimeter target. We are interested primarily in the propagation of a self-pinched ion beam which is produced by using a MPC under low pressure gas.[5]

Production of pulsed ion beams

A MPC with central hole of 1 to 2 mm in diameter is filled with the low pressure gas of about 10 Pa (Fig. 1). The electrode plates are 1 to 2 mm apart. According to Paschen's law $U_b=f(p.d)$, where U_b is the breakdown voltage of the gap, p is the gas pressure, d is the gap distance, the geometry of the MPC makes the chamber such that the electric strength of each gap between the vicinal plates is higher than the strength of total chamber by the factor $p.d_p \ll p.d_c$, here d_p is the distance between the vicinal plates; d_c is the total length of the MPC.

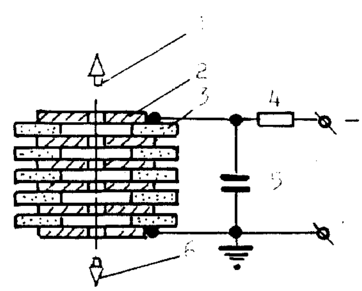

Fig. 1 Multiplate chamber
1. Ion Beam
2. Metallic Plates
3. Insulating plates
4. Charging Resistor
5. External Capacitor
6. Electron Beam

After applied voltage reaches a certain value, a so-called pseudo-spark discharge takes place in the MPC.[6] The processes of MPC discharge could be described in such a way: if one takes the MPC as many gaps in series, the gaps breakdown one after another from the cathode to the anode sequentially, therefore, the maximum electric field will appear on the gap near the anode due to the voltage of capacitor C_{ext} does not change obviously during the discharge processes under the condition of $C_{ext} \gg C_g$, here C_g is the equivalent capacitance of the gap between adjacent plates. The discharge processes of so-called "vacuum diode" will take place in the gap near the anode. Such effects obtaining a high electric field to creat a field emission through a low initially average field, may be called the effect of field escalation.[7] Fig. 2 schematicly shows the production of the electron beams and ion beams.

The voltage V_{max} appears on the gap near the anode can be proximally estimated as following

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$$V_{max}= C_{ext}/(C_g+C_{ext})\cdot V_o$$

where V_o is the applied voltage initially on total MPC, C_g is the equivalent capacitance of the gap near the anode. The well-focused, high current ion beams as well as electron beams were observed outside the cathode hole and the anode hole of the MPC respectively.

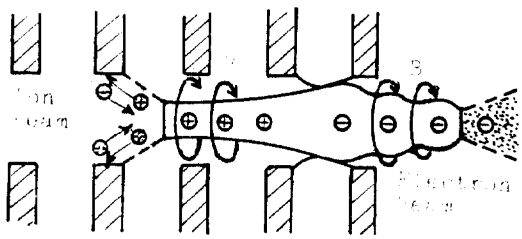

Fig. 2 Schematic diagram of "vacuum diode" processes in a MPC

The concluded discharge processes of the MPC are summarized as following: applied voltage on the MPC reaches certain value; field escalation effect; field emission of the cathode; explosion of surface whisker; formation of the cathode plasma; creation of the anode plasma; generation of self-pinched electron beam and focussing ion beam.

Neutralization and focussing of intense pulsed ion beams

A tiny crater as small as 15 micrometer in diameter produced by the bombardment of ion beam pulses was observed on the surface of metallic target (Fig. 3). It is known that for intense ion beams, propagation is impossible in the absence of electrons. For instance, the

Fig. 3 A scanning electron micrograph of a crater on the carbon steel specimen bombarded by the pulsed ion beams with high power densities

unneutralized space-charge potential for a uniform beam in a vacuum is

$$\Phi_m=2\pi e n_i S^2$$

where n_i is beam ion density, S is the distance between beam axis and internal surface of the conducting tube. The beam will blow up in approximately a distance $S(W_b/e\Phi_m)$, where W_b is the beam energy.[8] For the geometry of the MPC, the electrons can be produced by the secondary emission from bombardment of the surface of electrode plates by the ions of the beam head, or from the plasma created by the the ionization of beam ions in the volume of the central hole of the MPC.

As the ion beams travel in the environment of low gas pressure, the bound electrons in the heavy ions acquires energy by Coulomb interaction with the gas nucleus, therefore, the beam ions undergo stripping, which results in an increase in beam current. After stripping of heavy ions, the total beam current should be $I_b=Z_{eff}I_o$, where I_o is the injected beam curret, and Z_{eff} is a function of the ion position in the gas medium, given by

$$Z_{eff}=\sum ZN_Z / \sum N_Z$$

here N_Z is the number density of beam ions with charge Z, and the sum is performed over all charge state. In the example of the self-pinch effect, the magnetic force which is responsible for pinching the ion beam is proportional roughly to Z^2_{eff}.

For the nonrelativistic ion beams, the bunching of time-of-flight is an important factor to elevate the beam current density. an attempt to make a numeric simulation failed in overcoming difficulties with the complicated situation of the beams involving multiply ions, the variable geometry of the MPC and lack of the data of the ionization cross section, however, the ion beams with energy below 100 keV could be compressed in time by a large factor.

The recombination of energetic beam ions makes beam particle losses and creates scattered neutral diffusion beams which surround the central beam (Fig. 3).

So far, one can make a conclusion that the self-pinch of intence pulsed ion beams with energies below 100 keV takes place with the effects as following

. Magnetic self-focussing of ion beams is initiated in the gap near MPC anode which behaves as a "vacuum diode"

. Space charge neutralization by the electrons produced by the surface secondary emission and by the plasma electrons

. Current density increase due to the stripping

. Bunching of time of flight for such nonrelativistic ion beams

After passing through the cathode hole, the envelop of ion beam expands rapidly due to the decrease of the electron density and the repulsion of the beam space charge and beam-gas molecular interaction etc..

Conclusion

As an intense pulsed ion beam source, the multiplate chamber with simple geometry and high efficiency can generate heavy ion beams with current density of more than 10^4 A/cm^2.[2,6] A variety of ions, such as gaseous ions H^+, He^+, N^+, O^+, Ar^+ and metallic ions Al^+, Fe^+, Ti^+, Cu^+, Ag^+, Ta^+ etc., can easily be produced. The MPC could be used as an ion implanter of pulsed beam with high current densities to carry out the material testing and modifications, and it may also work as a low-energy injector of pulsed ion beam into post-acceleration system.

Based on the experimental results discussed in this paper, it is expected that the processes of neutralization and focussing of pulsed ion beams can be used to check the theoretical model of the self-pinching of heavy ion beams and to find a reasonable configuration of beam transporting system.

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