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PROPAGATION OF INTENSE PULSED ELECTRON BEAMS WITH ENERGIES BELOW 80 KEV

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Abstract

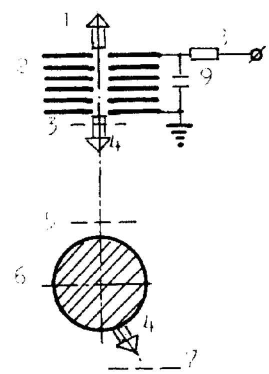
The transporting behaviours of intense pulsed electron beams in the low pressure gas are experimentally investigated. The results presented in this paper show that the self-pinching of electron beams in the ambient pressure about 10 Pa for nitrogen, air etc., takes place. After bombardment of single beam pulse, a interference-like fringe having a pattern of colored rings appears on the surface of witness film, thus one can make a dedution of the space configuration during the propagation of the pulsed electron beam. As a result of beam deflection by an external magnetic field, the configuration-space instabilities of the self-contracting plasma of electron beam occur, therefore, the beam filament effect is evidently observed. Such intense pulsed electron beams are extracted from anode hole of a multiplate chamber behaving as a foilless "vacuum diode" with high efficiency. Many attractive potential applications are expected for the electron beams.

Introduction

As intense pulsed electron beam generators are of interest for material studies, inertial confinement fusion reaction, direct pumping of gas and chemical lasers, generation of X-rays, microwave and infrared radiation, it is necessary to know the transporting behaviours of the pulsed electron beam passing through the neutral gases. For intense pulsed electron beams with energies below 80 keV, it is hard to carry out the experimental observation of their propagation in the low pressure gas due to the electron energy too low to penetrate through the anode foil which normally used to seperate the so-called "vacuum diode" from the drift tube with low pressure gas. This problem can be solved by using a multiplate chamber which behaves as a foilless vacuum diode, to produce intense pulsed electron beams.[1] In order to understand the behavior of electron beam, Lawson formalism is taken to describe the radial equation of motion for a beam electron.

Experimental description

The nanosecond-pulsed electron beams with electron energies below 80 keV and curret densities about $10^6 A/cm^2$ can be produced by a multiplate chamber (MPC) due to the escalation effect(Fig. 1).[2] The electron beams are directly injected into a drift chamber filled with low pressure gas about 10 Pa. In order to observe the magnetic self-pinching effect of intense pulsed beams, the metallic targets and witness films are placed on several positions along the beam trajectory. The witness films consist of Mylar foils covered by thin layer of dimethyl yellow or pentamethoxyl red.



1. Ion beam
2. Multiplate chamber
3. Metallic target
4. Electron beam
5. Witness film 1
6. Magnetic field
7. Witness film 2
8. Charging resistor
9. Capacitor

Fig. 1 Intense pulsed electron beam generator and the propagation of the electron beam under low pressure air.

The crater on the metallic target sputtered by a series of electron beam pulses proves that the electron beam is of self-pinching and with high power density (Fig. 2).

Fig. 2 Crater produced by sputtering of a series of electron beams on an iron target.

In the environment of the gas pressure about 10 Pa, the pulsed electron beams propagate with high efficiency due to rapid space-charge neutralization to create beam self-pinching, therefore, the current neutralization should not been important owing to the background density too low to produce the return current which can effectively reduce the important of magnetic self-field effects. Under the assumption of paraxial approximation, the radial equation of motion for an electron with the beam radius r_o is

$$\frac{d^2r}{dz^2} = 2\frac{\nu r}{\gamma r_o^2}\frac{(1-f_e-\beta^2)}{\beta^2} \qquad (1)$$

where ν the so-called Budker parameter, is defined as the number of electrons per classical electron-radius length of the beam, γ is the usual relativistic factor, $\beta = V_z/c$, V_z is the injected electron speed, c is the speed of light, $f_e = n_i/n_e$ is the fractional charge neutralization by a background of stationary ions.[3]

A single beam pulse with energy of some 55 keV and current density of about 10^6 A/cm^2, after passing through 60 mm in the low pressure air, was used to bombard a witness film. The interference-like fringes having the form of colored rings which converge toward a center emerged on the surface of witness film (Fig. 3). From the rings of the interference-like pattern, one can make a dedution of the

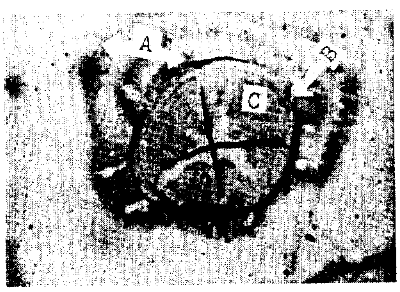


Fig. 3 An interference-like pattern on the surface of witness film.

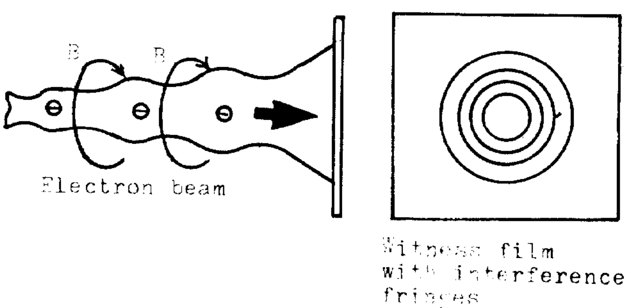


Fig. 4 Schematic interpretation of the evolution of the space configuration during the propagation of electron beam.

evolution of the space configuration during the propagation of intense pulsed electron beam(Fig. 4).

From the experimental results mentioned above, the processes of the propagation of the electron beam in unionized background gas with pressure about 10 Pa, can be envisaged into following stages:

- divergence of beam envelop: $0 < f_e < (1-\beta^2)$, the front of pulsed beam expands rapidly due to space charge repulsion,part of beam electrons is lost to the tube walls (Fig. 3, region A).
- radial force neutralization: $f_e = (1-\beta^2)$, for the beam to drift without expansion, only fractional space-charge neutralization is required. In this case, an equilibrium radius of beam envelop is temporarily reached(Fig. 3, equilibrium radius B).
- beam self-pinching: $(1-\beta^2) < f_e < 1$, the radius of beam envelop starts to pinch with a radial oscilation of sinusoidal wave. For $f_e = 1$, the electron beam is fully neutralized, Eq.(1) becomes

$$\frac{d^2r}{dz^2} = -2\frac{\nu r}{\gamma r_o^2} \qquad (2)$$

the wave length of sinusoidal solution is

$$\lambda = 2\pi r_o/(2\nu/\gamma)^{1/2} \qquad (3)$$

From Fig. 3, region C, we can infer that the radius of beam collapses due to beam losses and reduction of beam current. The swelling area and the craks show that the power density is relatively high at central region.

Much more informations can be obtained in the photograph of beam spots (Fig. 5), a variety of instabilities of beam plasma, such as sausage instability, kink instability and flute instability etc., of the evolution during the propagating of electron beams can be derived from the physical patterns of the beam spots.

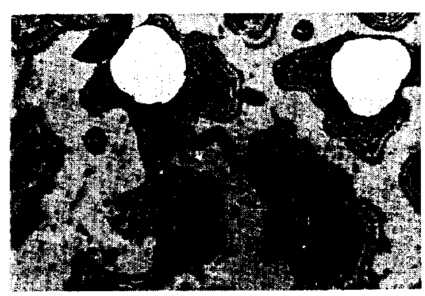


Fig. 5 The photograph of electron beam spots. x54

While passing across a magnetic field, the electron beam would become unstable due to the perturbance exerted by the magnetic field. Considering the terms of the energy distribution of beam electrons, the interaction between beam and its wake fields on the wall of the drift tube, the effect on the beam contraction of the synchrotron radiation of the electrons in the self-magnetic field created by the beam current and so on, the physical pattern of the propagation of electron beam passing across the magnetic field is rather complicated.[4,5] As a result of the beam deflection caused by the external magnetic field, the configuration-space instabilities of a self-contracting plasma of the electron beam occur, therefore, the beam filamentation were evidently observed on the surface of the witness 2 located at the position across the trajectory of the electron beam (Fig. 6). Many tiny burning spots sized up 5-12 micrometers in diameter show that the beam splits into filaments, each of which self-pinches and the purely growing perturbations center on points of enhanced beam density which magnetically attract nearby beam electrons and repel secondary electrons produced by the ionization effects of beam electrons.

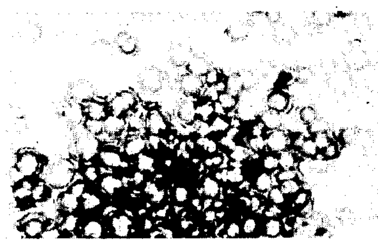


Fig. 6 Beam filamentation owing to the perturbation of across magnetic field. x416

Conclusions

The intense pulsed electron beams produced by the multiplate chamber, with energies below 80 keV can be used to carry out the experimental investigation of the propagation of pulsed electron beam in an environment of low gas pressure. The evolution of space-configuration of propagating electron beam could be deduced from the interference-like pattern on the surface of witness bombarded by a single beam pulse, therefore, a variety of instabilities of beam plasma can be derived with the physical pattern of beam spots.

Fxperimental results presented in this paper provide a good view of beam filamentation due to the perturbance exerted by across magnetic field. The time development of space configuration of beam propagation is left to take futher investigation.

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