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TRANSPORT CONTROL OF INTENSE ELECTRON BEAM USING INSULATOR GUIDE

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Abstract

We present a new interesting feature in an intense-electron-beam transportation system using an insulator guide: the ion extraction from a plasma generated at the insulator surface is self-regulated by the net space charge of the electron beam in order for the effective charge neutralization. This paper also presents a numerical study on a plasma generation effect at the insulator guide surface on an intense-electron-beam transportation through the insulator beam guide. The plasma at the insulator surface is generated by the local electric field which is created by beam electrons. The ion extraction from the plasma is delayed by the plasma-generation time. The simulation results present that 1) the head of the electron beam pulse is used to generate the plasma, and 2) the electron beam transport efficiency is not fatally but slightly degraded.

Introduction

In order to utilize pulsed power technologies and particle beams effectively,[1-5] we proposed a new system[4,5] for an intense-electron-beam transportation by using an insulator guide: a fraction of beam electrons hits the insulator surface, and generates a local electric field, which induces local discharges. The local discharges produce a plasma at the insulator surface. By the electron beam net charge, ions extracted from the plasma at the insulator surface expand over the transport guide region which is covered by the insulator beam guide. Then the ions are extracted from the guide region by the electron beam charge into the outer region which is not covered by the insulator. After the ion expansion into the outer region, the beam charge is neutralized effectively by the ions in the whole transport region. Consequently, the electron beam propagates through the short insulator beam guide.

Intense-Electron-Beam Transport

In this paper we present numerical simulation results for the intense-electron-beam transport using the insulator guide.

The simulation results show that the following interesting feture of self-regulated effective charge neutralization: the ion extraction from the plasma generated at the insulator surface is controlled by the beam net charge.[5] Consequently advantages of our system are 1) the self-regulated charge neutralization, and 2) the simplicity of the system.

This paper also presents a numerical study on a plasma generation effect at the insulator guide surface on an intense-electron-beam transportation through the insulator beam guide. The ion extraction from the plasma is delayed by the plasma-generation time. Consequently the electron beam charge neutralization is also delayed by it. However the simulation results present that only the head of the electron beam pulse is used to generate the plasma, and the electron beam transport efficiency is not fatally but slightly degraded.

Figure 1 shows a model for electron beam transportation in a vacuum through the insulator beam guide. The self-regulated charge neutralization is a unique feature in the transportation system. However, the current is not neutralized. Therefore the beam is pinched by the self-magnetic field. In order to prevent the pinching, an external parallel static magnetic field is required.[4] We study the plasma generation effect on the intense-electron-beam transportation by a computer simulation.

Our simulation model employed is as follows: we assume that the phenomenon concerned is cylindrically symmetric. In this work, we employ the following plasma generation model: a magnitude of electric field is monitored, and a local plasma is generated at each mesh at the insulator beam guide surface, when the magnitude of electric field at the guide surface is beyond the threshold[2] for a local discharge which generates the plasma. We also assume that the plasma consists of protons and electrons, and that the thickness of the plasma layer is infinitesimal; a sufficient amount of plasma is generated at the insulator surface so that the charged particles emitted from the insulator inner surface are limited by the space charge.[1] The beam outer radius coincides with the inner radius of the insulator. We assume that the outermost boundaries of the computational area are conductors. In this study, we carry out a particle-in-cell (PIC) simulation.[6] The PIC code used is a 2.5-dimensional one. The field components (E_r, E_z, B_θ), and the particle position and velocity $(r, z, v_r, v_\theta, v_z)$ are solved by using the Maxwell equations and the relativistic equation of motion. In the system an external parallel static magnetic field B_{z0} is applied. At the time $t = 0$, the transport area is in a vacuum. The beam-parameter values employed in this paper are as follows: for the input electron beam wave form the maximum current is 25 kA, the maximum particle energy 150 keV, the pulse width 200 ns, and the rise and fall times are 20 ns. The beam radius r_b is 3.0 cm. The average longitudinal speed v_{z0} of the beam electrons injected is determined by the input wave form, and the beam temperature is 10 eV. The average v_{z0} is 0.63c at $z = 0$. Here c is the speed of light. At the beam entrance, that is, $z = 0$, the beam electrons pass through cylindrically symmetric ring slits with an aperture ratio of 70 %; the aperture ratio is defined as (the total slit aperture area)/(the total area of πr_b^2). The transport computation area is $0 \leq z \leq Z_l$ (= 10.0 cm) and $0 \leq r \leq R_l$ (= 5.0 cm) (see Fig. 1). The relative permittivity of the insulator beam guide is 5.[5] The external parallel static magnetic field B_{z0} is 0.20 T. By using the parameter values, the peak magnetic field at the beam outer radius is estimated to be 0.17 T, which is comparable to B_{z0}. The threshold for a local discharge which generates the plasma is assumed to be 1×10^7 V/m.[2] The peak electric field generated by the electron beam is 7.93×10^7 V/m at the insulator inner surface.

The particle maps for the beam electrons and the particles emitted from the insulator inner surface are shown in Fig. 2. The plasma is generated until 11.5 ns in this case. After that, the ions extracted from the insulator inner surface expand over the transport area. The beam electrons are transported through the volume in which the extracted ions exist. The ion cyclotron radius is sufficiently large compared with the beam radius[4]. Therefore the ions expand over the transport area. Figure 3 presents histories of total space charges of the beam electrons and the ions in the transport region. During the first 120 ns, the ions emitted are expand over the whole transport region. After that, the beam electrons are transported well. Figure 3 also shows the self-regulated feature of the system. The electron beam current wave forms are shown in Fig. 4. Figures 4(a) and 4(b) show the current wave forms at $z = 4$ cm and $z = 8$ cm, respectively. The transport efficiency, which means a ratio of the electron beam total charge to the total input charge injected at $z = 0$, is 47.8 % at $z = 4$ cm and 44.1 % at $z = 8$ cm. The transport efficiency is slightly degraded compared with the previous results [5] in which the plasma generation effect is not included: in the case without the plasma generation effect, the transport efficiency was 63.3 % at $z = 4$ cm and 58.1 % at $z = 8$ cm. When we change the threshold of the local discharge to 0.5×10^7 V/m, the plasma is generated at the insulator surface before 6 ns, and the transport efficiency is 52.2 % at $z = 4$ cm and 49.3 % at $z = 8$ cm.

Conclusions

In this paper, we studied the plasma generation effect on the electron beam transportation through the insulator beam guide. The time lag of the plasma formation is numerically included in the present study. The simulation results present that 1) the self-regulatred charge neutralization, 2) the head of the electron beam pule is used to generate the plasma, 3) the electron beam transport efficiency is not fatally but slightly degraded, and 4) the simplicity of the system. Consequently, the electron beam propagated efficiently through the insulator beam guide.

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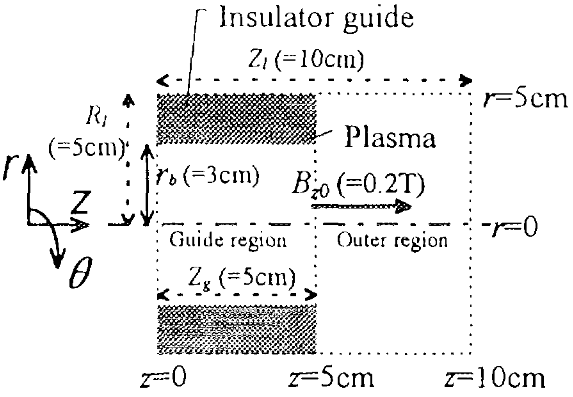
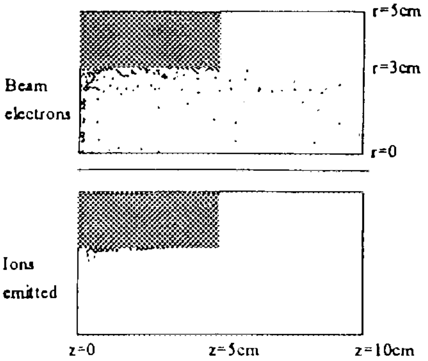
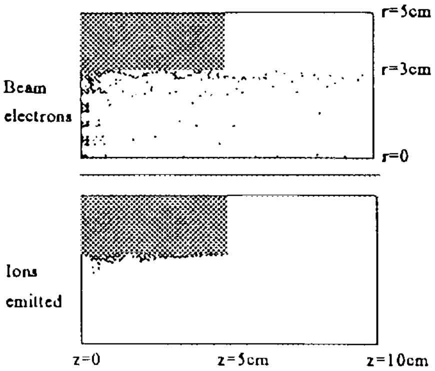


Fig. 1 Electron beam transport through an insulator beam guide. The beam radius r_b is 3.0cm. The insulator guide length Zg is 5cm. The external parallel static magnetic field is applied. A fraction of beam electrons hits the insulator surface, and generates a local electric field, which induces local discharges. The local discharges produce a plasma at the insulator surface. By the electron beam net charge, ions extracted from the plasma at the insulator surface expand over the transport guide, and neutralize the electron beam space charge in a self-regulated manner.

(a) t = 11 ns



(b) t = 11.5 ns



(c) t = 130 ns

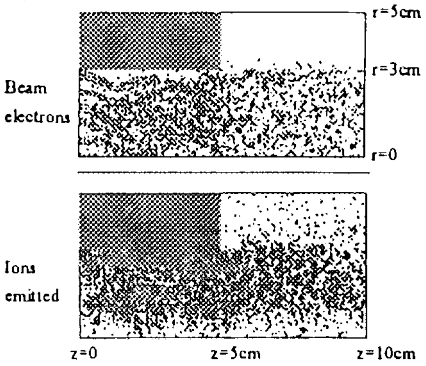


Fig.2 Particle maps: (a) at t=11 ns, (b) at t=11.5 ns and (c) t=130 ns. The upper map shows the beam electrons and the lower shows the ions emitted from the insulator inner surface. During the first 11.5 ns, the plasma generated covers the whole insulator surface. In this case the threshold for the local discharge which generates the plasma is assumed to be 1×10^7V/m.

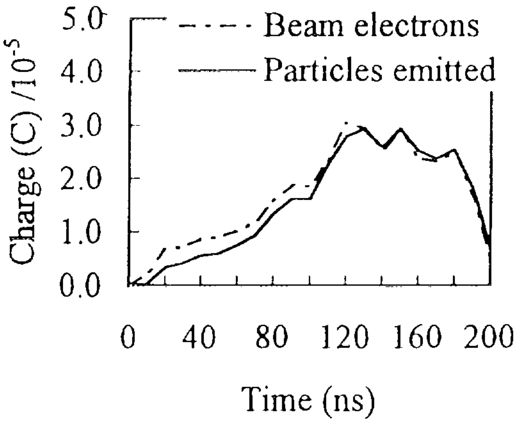
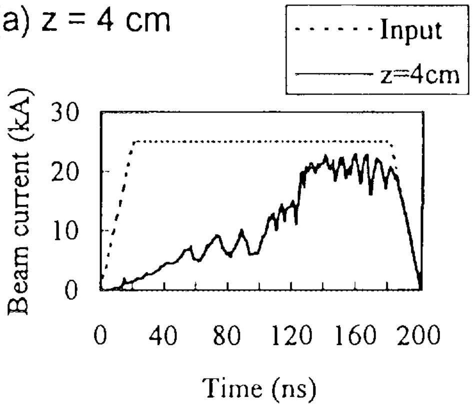


Fig.3 Histories of the total space charges of the electrons and the ions in the transport region. The ions emitted neutralize the electron beam space charge in a self-regulated manner.

(a) z = 4 cm



(b) z = 8 cm

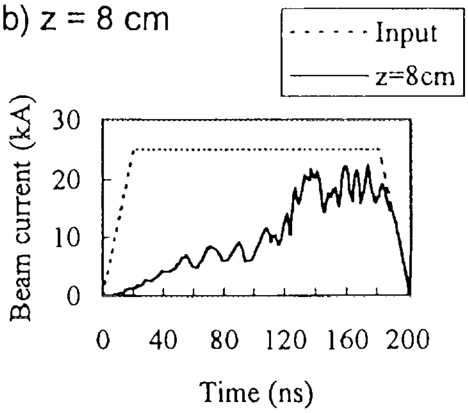


Fig.4 Electron beam current wave forms: (a) at z=4 cm and (b) at z=8 cm. The transport efficiency is 47.8% at 4 cm and 44.1% at 8cm.