HIGH GRADIENT OF WAKW FIELD TRIGGERED BY PSEUDO SPARK ELECTRON BEAM

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Abstract

The pseudospark discharge is referred to the gas discharge on the low pressure of the Paschen curve. The pseudospark discharge offers a wide area of application such as pseudospark switches for medium and high current up to 100kA, and voltage or a source of a nanosecond pulsed electron beams with current raise to 10^{10} A/s and current density up to 10^{10}A/m^2. When the intense electron beams of 200 μ m diameter pass through a low pressure gas, these will produce a plasma wakefield with high gradient > 5GeV/m which can trap and accelerate hot electrons that are moving in the right phase at nearly the phase velocity of the plasma wave. This field is similar to the wakefield formed by interaction of high intensity and ultra-short laser pulse with plasma. Accelerated and trapped electrons energy is measured by replacing aluminum absorbers or sensitive film in the path of the deflection charged particles.

1 INTRODUCTION

As modern high-energy accelerator is very immense and its price very high, it encourages people to discover different new methods of acceleration. Wakefield triggered by high power super short pulsed laser beams can be used to accelerate charged particles where electric field gradient is higher than the common radio-frequency electric field accelerator by about 4 orders. Pseudospark discharge can produce a nano second pulsed electron beam with rising rate of 10^{10} A/s, current density up to 10^{10} A/m^2 and total current up to several hundreds of kA. When this electron beam passes through low-pressure gas it creates a very high electric field gradient similar to plasma wake field produced by laser.

2 EXPERIMENTS

A multi-gap pseudospark discharge device filled with a low pressure gas under external direct current- voltage discharge, would follow Paschen curve, and breakdown from total glow discharge to the spark-like discharge in the gap near to the anode. As we know that the electric field concentration near cathode hole is the source of self sputtering and self pinched intense electron beam emission, therefore the pseudospark electron beams have not only a high rising rate of current but also a very steep current collapse Fig 1.

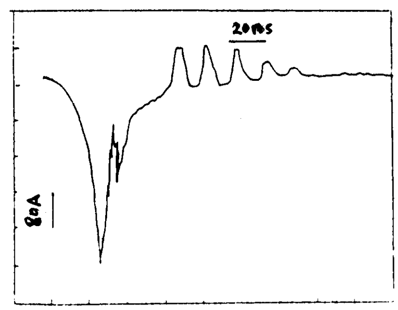

Fig 1. pseudospark pulsed electron beam current wave

In order to observe the spectrum structure of pulsed electron beams extracted from the multigap pseudospark chamber (MPC), we replace a permanent magnet paralleled to the path of the electron beam with background gas oxygen or argon at 10 Pa as in the Fig 2.

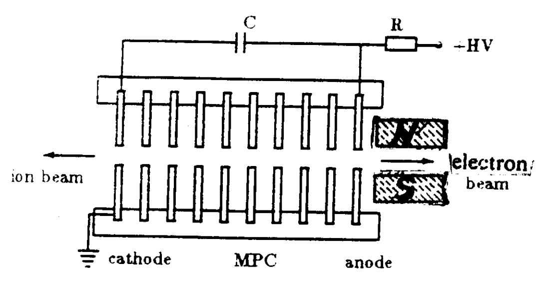

Fig 2. Experiment Set up

The pseudospark electron beam with energy of 40 keV after crossing deflection magnet field incident on a sensitive film or a metallic target Fig. 3. From the photograph Fig. 3. It can be seen that the central beam having magnetic-self contraction and current density up to 10^{10} /cm^2. The electron beam energy at the center is about 20 keV which has made the film burn through. There are some high energy electrons with high magnetic rigid at point A. Also, there are large quantity of scattering electrons which can not form self contraction due to the rapid space charge neutralization.

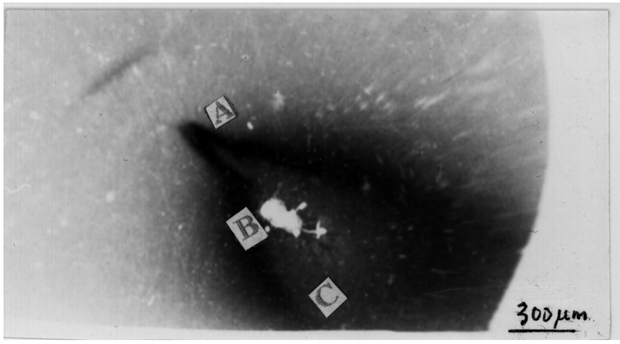

Fig. 3. Pulsed electron beam after deflection cross the magnetic field (A) high energy point, (B) Center region, (C) low energy region

3 BEHAVIOR OF THE PRODUCED BEAM

The analysis of the space configuration during the propagation of the pesudospark pulsed electron beam in unionized background gas with a condition of low pressure 10pa, leads one to assume that a spatial electric charge neutralization can be created, thus a magnagtic self-contraction effect. Much more information can be obtained about the propagation of the electron beam through a magnetic field in spite of the fact that the physical pattern of the propagation is very complicated. However, looking at the film surface effected, one can summarize the most interesting phenomena of the incident beam after crossing permanent magnetic field. It is found that the beam becomes unstable due to the perturbance exerted by the magnetic field. Different spots due to the beam splitting into filaments each of which self pinch, and clear deflection of the beam filaments was observed on the film surface. For further understanding of the behavior of the electron beam propagation we must study the equation of motion of electron and introduce it as radial force equation which is given else where [2][3] $F_r = 4\pi^2 / r\int(1-f_e-\beta^2)\, n_e\, r\, dr$. The equation of motion of the electron beam of radius r_0, may be simplified and given by $d^2r / d^2z = 2\nu\, r / \gamma r_0\, (1-f_e-\beta^2) / \beta^2$ where ν = Budker parameter, $\gamma = 1/(1-r^2/c^2)^{1/2}$ Specific parameter, $\beta = V_z / C$ where V_z electron velocity to z direction, $f_e = n_i / n_e$ where n_i and n_e being ion and electron density respectively.

1) If the beam is unneutralized, $0< fe< (1-\beta^2)$. The force is radially outward and the beam is expands rapidly du to the space charge repulsion and will be a different beam lost in the surrounding of the mean beam Fig 4. A.
2) The amount of fractional space charge neutralization required for $F_r = 0$ is given by $f_e=(1-\beta^2)$, which is known as equilibrium condition, so the beam propagates in almost constant radius as in Fig 4. b.

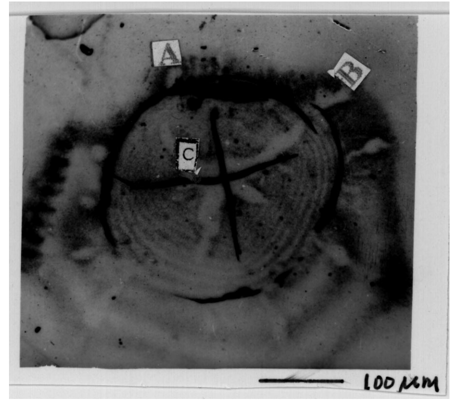

Fig 4. Beam spots on the target surface

3) If the neutralization fraction is $(1-\beta^2)<f_e<1$ this means that there will be no more beam expansion in the beam propagation and the beam starts pinching in the radial direction until the electron beam is fully neutralized . For f_e= 1 electron becomes oscillating as a sinusoidal wave and it's equation of motion becomes $d^2 r / d^2 z = -2\, \nu/\gamma.\, r_0^2$ where the solution of the sinusoidal wave equation being $\lambda = 2\pi r_0 / (2\nu/\gamma)^{1/2}$, and much more information can be obtained from the photograph and by looking at the beam spots Fig 4c. The radius of the beam becomes more collapsible due to the increasing of the plasma density, the beam losses. The clear cracks, due to the shock of the high power beam density can be seen at the central region of the sensitive film. Different spot size and a variety of instabilities, such as kink instability and flute instability, were found from the physical patterns of the beam spots in target surface Fig 5.

Fig 5 . Electron Beam spots on Target Surface

In Ref. [1], Prof. J. Christinsen et al. had detect electrons with energy up to 583 keV while the pseudospark electron beams pass through the low pressure gas. From the energy spectrum of the electron emission along radial direction one can see that the higher the electron energy, the faster the electron propagate and indicates the intense peak in the spectrum, which may attributed to the electron beam accelerated by pseudospark wakefield. There are two high intense electron peaks in the energy spectrum Fig.10 of [1]. One of the peaks it's attributed to the faster electron in the head of the extracted beam from the pseudospark.

The electrons which vibrating in the plasma wave direction can not be accelerated by wakefield. These electrons which not vibrate in plasma wave could be captured or trapped by the plasma and move at the same group velocity in the same direction with the plasma wave, they can be accelerated continuously and obtain very high energy within a very short distance. This sort of electrons are coming from the electrons accelerated by electron beam collective field, and the scattering electrons in the main electron beam or from the electrons emitted from the metal structure and accelerated by plasma - wave wakefield.

4 CONCLUSION

This is a new way to study the wakefield acceleration for pulsed electron beam, with very high electric field either to vertical direction or to traverse direction, whose value can be up to 100GeV/m. So by pseudospark discharge we can obtain super - short impulse electron beam induced wakefield, x- ray pulses and high brightens radiation and it provide a new effective method to investigate laser super-short pulse dynamics. However more much work must be done on the acceleration mechanism of pseudospark electron beam wakefield. It is notified that there are some similarities between this and the physical mechanism of the plasma lenses under the self-magnetic contraction effect.

5 ACKNOWLEDGMENTS

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6 REFERENCES

[1] Stark R, Christiansen J, Frank K. et al., 'Pseudospark Produced Pulsed Electron Beam for Material Processing', IEEE Trans PS, 1995, PS23:258.

[2] Jiang X L, Jiang S C., 'propagation of Intense pulsed Electron Beam with Energies Below 80keV', IEEE Trans NS, 1985, NS 32:2492.

[3] Jiang X L, Han J, 'Field Escalation Effect in the Pulsed Ion Beam Sources Based on the Pseudospark Discharge', Rev Sci Instrum, 1992,63:2420.

[4] Wagner R, Chen SY, Maksimchuk A, Umstadter D, 'Electron Acceleration by a laser wakefield in a Relativistically Self-guided Channel', Phys Rev Lett 1997, 78: 3125.

[5] Nakajima K, Fisher D, Kawakubo et al., 'Observation of Ultrahigh Gradient Electron Acceleation by a Self-Modulaewd Intense Short Laser Pulse', Phys Rev Lett. 1995, 74:4428