THE POSSIBILITY OF ACCELERATION OF IONS BY A ELECTRON BEAM WHICH GENERATED BY A MAGNETRON GUN WHEN TRANSITION TO PLASMA MODE

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When the magnetron gun is switched to high-current plasma mode, a singularity of the current pulse on the collector is observed. This singularity is that the current is opposite to the voltage. An acceleration of ions by the electron beam is known. Therefore, the assumption is made that the detected singularity corresponds to the accelerated ions.

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INTRODUCTION

Among the collective methods of ion acceleration, of particular interest is the acceleration by direct electron beams in the plasma. This interest is related to the simplicity of realization on the one hand, and on the other hand, to the lack of a satisfactory theory of the phenomenon. The latter give possibilities for optimization of the acceleration process by experiment include computer experiment.

Anomalously fast ions were recorded episodically in plasma systems in the presence of electron beams since the 1930s [1]. For the first time a systematic study of the acceleration of ions in electrical discharges and the formation of high-current electron beams from plasma was undertaken by Plyutto and co-workers [2 - 5]. According to the data of this group, the maximum ion energies can exceed 10…100 times the average electron energy and reach 4…5 MeV for protons and 10…20 MeV for carbon ions at electron energy of 200…300 keV [3, 4]. Acceleration of light ions is observed with short-time (~ 10^{-7}s) voltage pulses across the gap [4]. Such results are already of practical interest, since the energies achieved are sufficient for many nuclear reactions to occur.

A little later, accelerated ions were also detected when relativistic electrons were injected into a neutral gas [5].

A longitudinal magnetic field sometimes suppresses the acceleration process somewhat, but the possibility of accelerating ions in a longitudinal magnetic field is preserved [6].

Like many initial experiments in this field, the experiments described below did not detected accelerated ions, but some of their features indicate that effective ion acceleration could take place.

1. DESCRIPTION OF THE EXPERIMENTS

During the experiments, the "Rassvet" facility was used to test the magnetron gun in the secondary emission mode [6]. The facility was subjected to additional changes associated with obtaining high currents. The facility scheme is shown in Fig. 1.

In carrying out the experiments, the desired residual gas pressure was established by controlling the evacuation by the valve. The pressure was monitored by a vacuum gauge. For simplicity, these elements are not shown in the scheme. Then, the storage capacitor 11 was charged from the source 10 to the corresponding voltage. The voltage was controlled by the kilovoltmeter 8. The current was started by turning on the magnetic field in the coils of magnetic field 4. The results were recorded on an oscilloscope 13 and a digital camera 16. The operating pressure range was limited from above by ignition of discharge without magnetic field. From the bottom, it was limited by the absence of excitation of the discharge with the magnetic field turned on.

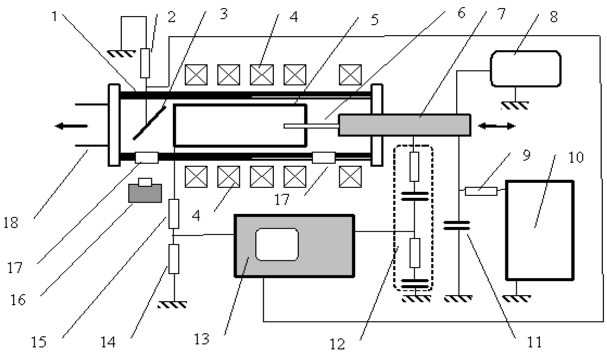

Fig. 1. The experimental facility: 1 – tube vacuum chamber (ceramic insulator); 2 – signal resistor of collector current; 3 – collector; 4 – coils of pulse magnetic field; 5 – tube anode (stainless steel) l=50 cm; 6 – cathode; 7 – cathode holder; 8 – high-voltage voltmeter; 9 – charging resistor; 10 – high-voltage source; 11 – storage capacitor; 12 – capacitor-resistor divider; 13 – digital oscilloscope; 14 – signal resistor of anode current; 15 – anode loading resistor; 16 – digital photographic camera; 17 – optical windows for observation; 18 – tube for vacuum pumping

2. RESULTS OF THE EXPERIMENTS

The oscillograms of the current to the collector and the voltages on the gun are shown in Figs. 2, 3. Both oscillograms indicate a rapid increase in current after the appearance of a relatively small seed current. The difference in the experimental conditions for the oscillograms in Fig. 2 is the inclusion of a current-limiting resistor in the cathode circuit [7]. This causes an important difference in the results. In the first case, the current to the collector does not change the direction.

However, in Fig. 3, the current flows in the direction opposite to the applied voltage (marked by the arrow). The current is accompanied by an oscillation of its magnitude. The results of two consecutive launches of current pulses are indicated: *a*, *b*. Startups are carried out under the same initial conditions. The time between starts is 2 minutes. The difference is change in the division scale for the voltage. Comparison of the oscillograms *a* and *b* illustrates the excellent pulse repeatability. The good repeatability was observed with other pulse parameters.

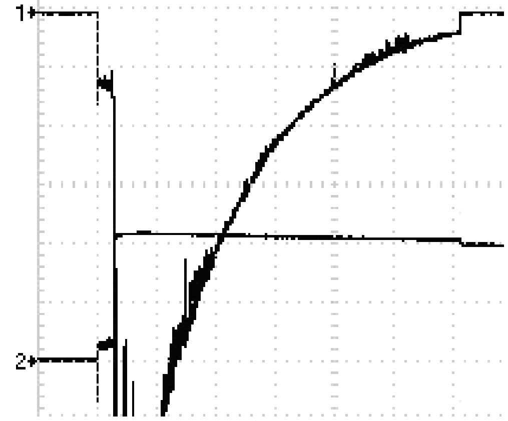

Fig. 2. The oscillograms of the collector current 1(top) 2A/div; and voltage 2 (bottom) 10 kV/div. There is the limiting resistor of 2 kΩ in the cathode circuit. Time scale is 1ms/div. The first 0.2 ms after the appearance of the current the generation of the beam is in the secondary emission mode

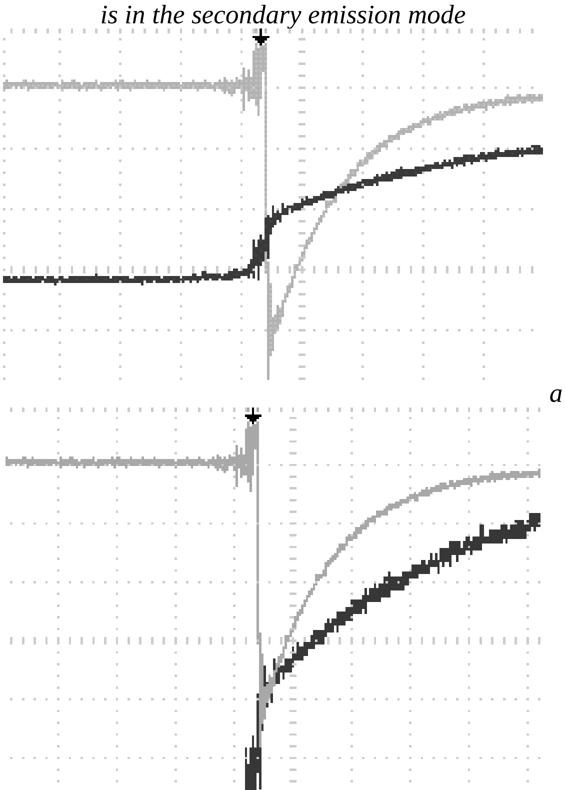

Fig. 3. The gun was tested without a current limiting resistor. Collector current (top), 100 A / div; and voltage (bottom) a) – 5 kV/div, b) – 2kV/div. Time scale is 2.5 μs/div. The starting voltage is 9.4 kV, the storage capacitor is 0.2 μF, the residual gas pressure (air) is 0.12 Pa. The impulse of the current opposite to the voltage is indicated by an arrow

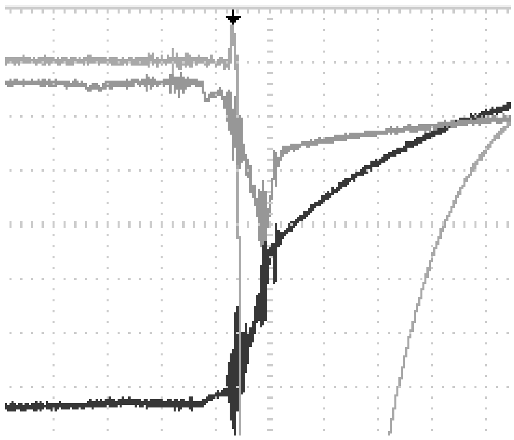

Fig. 4. The gun was tested without a current limiting resistor. Collector current (top), 100 A/div; and voltage (bottom) 2 kV/div. Anode current is in the middle. Time scale is 2.5 μs/div. The impulse of the current opposite to the voltage is indicated by an arrow

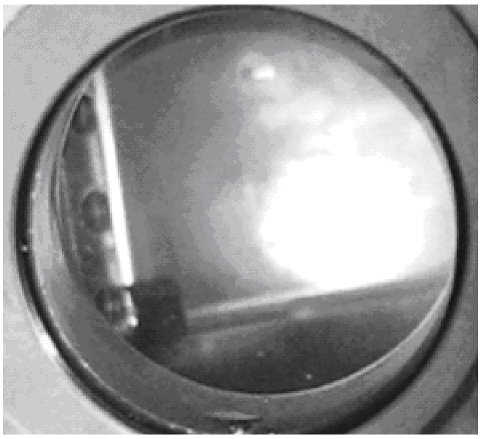

Fig. 5. A trace of the incident electron beam in the collector as glow under its influence. Diameter of window aperture 40 mm Diameter of brightly shining area is about 20 mm

On Fig. 4 is shown the high-current mode in which a positive current pulse is almost none accompanied by oscillations and has a somewhat higher value. It also the current pulse at the anode of the magnetron gun is shown. It can be seen that an appreciable current to the anode begins somewhat earlier than the appearance of a positive pulse at the collector. A positive pulse on the collector is accompanied by intense oscillations of the anode current.

Fig. 5 shows the glow of the collector under the action of an incident electron beam. The diameter of the brightly glowing region is about 20 mm.

3. DISCUSSION OF THE RESULTS

The process of ion acceleration in an electron beam according to the theory and most experiments is considered as it have threshold on the beam current [8]. Therefore, it can be assumed that the beam current (2.5 A) in the case of Fig. 2 was insufficient to capture and accelerate the ions. In the following case (Fig. 3), the current before the positive ejection reached 30 A, which was sufficient to capture the ions and their appearance at the collector. The appreciable oscillations required in this version of the theory for its realization [8] serve as an indirect confirmation of the possibility of ion acceleration. Acceleration is usually associated with rapid changes in significant currents with high current density [3], which is also characteristic of the experiments performed. In another series of experiments, a positive ejection was observed on the collector without significant oscillations of the collector current. This case is reflected in Fig. 4. However, in this case the oscillations are observed at the anode current simultaneously with the appearance of a positive pulse on the collector.

In all known cases of ion acceleration by electron beams, for example, described in articles [1 - 6], ion acceleration is associated with explosive emission and its unstable behavior [9]. The excellent repeatability of the current excitation process indicates that the acceleration process is probably not related to the appearance of cathode spots. The possibility of a high-current emission regime in a magnetic field without the formation of cathode spots has been studied in detail in [10]. Such a regime, where the explosive emission is suppressed, can provide an improvement in the repeatability of the acceleration process. Repeatability is important both in itself and as a condition facilitating the optimization of the process in order to ensure the competitiveness of this method of acceleration in practice. In addition, repeatability will help overcome one of the main disadvantages of ion acceleration by electron beams, the broad energy spectrum of accelerated ions.

4. DEVELOPMENT PROSPECTS

Control of the excitation of the current by a magnetic field was used in the experiments in order to simplify their implementation. To accelerate ions, the best option is to excite the current by applying a voltage pulse. In this case, it is possible to substantially increase the pulse frequency. Thus, the average current of the accelerated ions will be increased. Naturally, it is possible to directly control the magnitude of the magnetic field at the moment of excitation of a strong current. This approach automatically makes it possible to increase the initial concentration of the filling gas. By starting the magnetron gun in the secondary emission mode [11] at the voltage pulse slope [12], it is possible to lower the initial pressure down to a high vacuum. The voltage on the gun in the secondary emission mode can be increased up to relativistic value [13]. In this case, the beam current increases, and in prospects the energy and current of the accelerated ions. Finally, there are indications that in the high-current regime there is emission, which keeps the cathode from erosion [10]. In this case, the plasma is protected from contamination by the cathode material. One of the possible mechanisms of such emission with a high current density can again be a secondary electron-electron emission [14]. By using special systems of filing, it is possible to achieve the desired distribution of the gas concentration along the propagation path of the electron beam. The use of a special magnetic system [15] makes it possible to obtain a beam of smaller diameter with a zero generalized angular momentum. An electron beam from such a gun can propagate in plasma without a magnetic field as well as from a gun without of a magnetic field. All this provides ample opportunities for searching and optimizing the process of ion acceleration, which previously did not exist.

CONCLUSIONS

Indirect proof for the existence of collective ion acceleration by a high-current electron beam generated by a magnetron gun is obtained. However, for establish of the existence of such a process, direct experiments on the registration of accelerated ions are necessary. The main advantage can be the repeatability of experimental results, which opens the way to an adequate theoretical interpretation. Successful theory opens the way to optimizing the simplest collective method of accelerating and expanding its use. In addition, the advantages of this approach may be a smaller spectra width of ion energy, simplicity of implementation, and a longer lifetime of the device.

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ВОЗМОЖНОСТЬ УСКОРЕНИЯ ИОНОВ ПУЧКОМ ЭЛЕКТРОНОВ, СОЗДАВАЕМЫМ МАГНЕТРОННОЙ ПУШКОЙ ПРИ ПЕРЕХОДЕ К ПЛАЗМЕННОМУ РЕЖИМУ

С.А. Черенщиков

При переходе магнетронной пушки в сильноточный плазменный режим обнаружена особенность импульса тока на коллекторе. Эта особенность состоит в том, что направление тока противоположно напряжению. Известно ускорение ионов в направлении электронного пучка. Поэтому сделано предположение, что обнаруженная особенность соответствует ускоренным ионам.

МОЖЛИВІСТЬ ПРИСКОРЕННЯ ІОНІВ ПУЧКОМ ЕЛЕКТРОНІВ, ЯКИЙ СТВОРЮЄТЬСЯ МАГНЕТРОННОЮ ГАРМАТОЮ ПРИ ПЕРЕХОДІ ДО ПЛАЗМОВОГО РЕЖИМУ

С.О. Черенщиков

При переході магнетронної гармати до потужнострумового плазмового режиму виявлена особливість імпульсу струму на колекторі. Ця особливість полягає в тому, що струм є протилежним напрузі. Відомо прискорення іонів у напрямку електронного пучка. Тому зроблено припущення, що виявлена особливість відповідає прискореним іонам.