A STUDY OF ELECTRON STRINGS AND THEIR USE FOR EFFICIENT PRODUCTION OF HIGHLY CHARGED IONS [1]

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1 INTRODUCTION

This project is devoted to studies of the physics of electron plasmas and is based on the use of an Electron Beam Ion Source (EBIS) as a main instrument for the studies. In the normal mode of EBIS operation every electron passes the ion trap region only once. The idea to use it many times by repeated electrostatic reflections in a strong magnetic field was discussed and even tried many years ago on the basis of an usual construction of an EBIS electron gun. Then, starting in late 1993 these attempts were continued using a new gun-repeller construction and some interesting preliminary results were obtained [1,2,3,4]. In particular the phase transition to a so-called electron string state in a one component electron plasma was observed very recently. This project aims at investigating electron strings and their possible use in ion sources.

The considered field of studies in plasma physics is quite new. That is why the collected information about the string state itself as well as about the phase transition is poor. In particular, there is not available such fundamental physics information as: -the necessary conditions for phase transition to the electron string state and the frames for its stability; -the characteristic times for the electron string formation after the beam of primary electrons is switched on and for its decay after the beam is switched off; -electron density and electron energy distributions in the string; - the difference between the pure electron string and the electron string, filled with ions;- there are no theoretical description of the string state and the phase transition to this state.

So, the main objectives of this project are the collection of experimental information about the electron string, the creation of a theoretical model of electron strings and their use for production of highly charged ions.

[1] Status report on INTAS 96-0255 project

Using the string gain in the creation of the electron space charge of the virtual cathode in the gun it is in principle possible to overcome the cathode-anode gap electrical stability limit and produce an extremely high effective electron flow density. Such a possibility is expected to be tested experimentally.

Four teams from the four laboratories indicated above, are involved in realization of the joint Project, which was supported by the International Associations in 1997 for two years starting September 1, 1997.

2 REFLEX MODE OF EBIS OPERATION

The normal mode of EBIS operation is now well known. The reflex mode is based on a construction of the gun, which has the cathode consisting of two parts: the electron emitter itself and a larger cold dummy cathode, surrounding the emitter, the focusing electrode and the anode. The reflector is made similar to the electron gun, except the emitter, which is absent. An orifice in the electron repeller (analogous to the dummy cathode) is used to extract the ions. The gun and the reflector are situated on the axis of the solenoid magnetic field on both sides of the solenoid in the points where the field B is equal about 1/20 Bmax. To study the reflex mode, a more negative voltage than the cathode voltage is usually applied to the repeller and to its focusing electrode. During a previous study of the reflection mode of EBIS operation it was found [2,3] that the dependencies of the emitted electron current, accumulated in an EBIS ion trap, and the extracted ion charge on the heating power have sharp changes similar to changes of parameters in cases of various phase transitions. Namely, there is a region of the cathode heating power where the electron current and the extracted ion charge are different in the cases when the heat power increases and when it decreases. There are two values of the heating power where the electron current suddenly decreases while the positive charge increases and vice versa. As such peculiarities in electron current and ion charge behavior were usual in various experimental conditions, the hypothesis of the phase transition from the multibeam state of the repeatedly reflecting electron system to the so-called electron string state of this system was proposed [3].

3 CURRENT RESULTS

In fig.1 one can see the ion current pulses of highly charged argon, extracted from the source Krion-2 in the reflex mode of operation before the phase transition (lower trace) and after the phase transition to the electron string state (upper trace). In the latest experiments with the source Krion-2 the effective number of electron reflections achieved was 3200.

Recently the transition itself into the string state was observed for the first time. The drift tube structure of the Krion-2 source was used as a "pick-up" electrode to measure a rapid change of the number of electrons in the structure while the cathode heating power was slowly changed.

The expected negative pulse was observed using triggering of an oscilloscope by the pulse itself. The usual shape of the pulse is represented in fig.2. It shows a great reorganization in the community of multiply reflecting electrons during about 20 μs, leading to a big increase of the electron life time in the system.

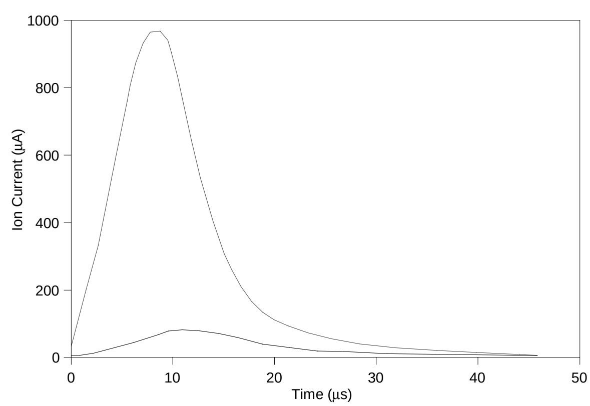

Fig.1. Ar ion current pulse as measured from RefEBIS Faraday cup before the phase transition (lower trace) and after the phase transition (upper trace) to the string state.

Performing systematic triggering employing the pulse itself is difficult. We improved the triggering by using a pulsed mode of the electron gun operation. The emitted electron current was controlled by the pulse of negative potential of the false cathode relative the emitter potential. Fig. 3 (left) shows the sequence of the electron accumulation current pulses inside the 8 cm section of the drift tube structure. Fig. 3 (right) displays the corresponding pulses of the electron current collected on the gun and the reflector anodes. The initial emitted electron current was controlled by the heat power injected into the gun emitter surface.

In Fig. 3 one can see in the beginning the normal accumulation of the multiply reflected electrons inside the drift tube structure, and the corresponding delay in the saturation of the anode current. Under the definite emitter current the second accumulation pulse appears and correspondingly at the same time the anode current decreases. This observation is a sign of the electron string formation which occurs earlier when the initial current is higher.

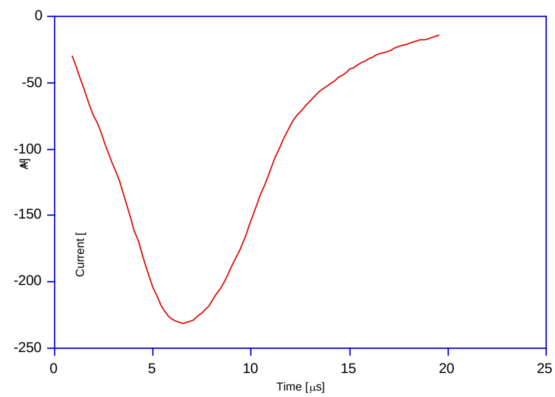

Fig. 2. The induced electron current pulse from the drift tube structure during the phase transition.

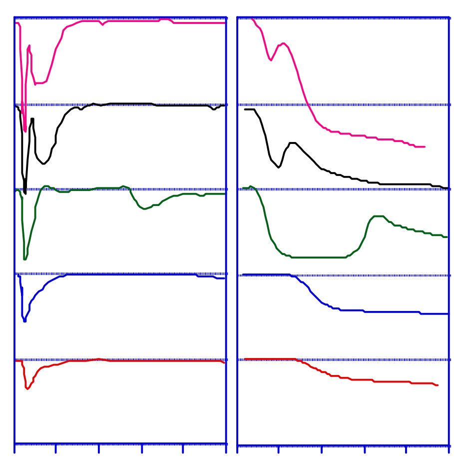

Fig. 3. The sequences of the electron accumulation pulse (left) and the anode current (right). The heat power to the electron gun emitter is increasing upwards in the diagram.

In Fig. 4 (left) the electron accumulation pulse which is barely detectable is displayed with 1.4 mA electron current for the beam. This is compared to the large signal from the string mode (fig. 4 right) – with the same electron current collected on the anodes. For the string mode, the gain in number of electrons inside the structure is 300 times that of the beam mode.

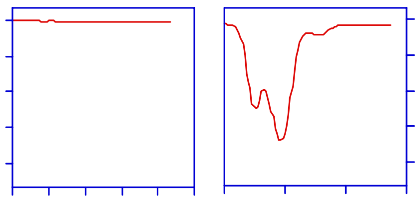

Fig. 4. The electron accumulation pulse (left) compared to the string mode pulse (right).

The first measurements of the bremsstrahlung from string electrons on nitrogen ions indicates the presence of a very small amount of electrons with energy higher than that initially provided by the electron gun. These studies are, however, in a very early stage but will provide the basis of future studies.

4 DESIGN OF AN ELECTRON GUN WITH VIRTUALLY HIGH EMISSION CURRENT DENSITY

Besides saving spent electron beam power, oscillating electrons may also provide immersed flow of focused electrons with considerably higher current density than obtained with available modern cathodes. Those electrons, which return to the cathode will not reach the cathode surface, if they have converted even a minor part of their original energy into the transverse direction. In this case they still contribute to the space charge in front of the cathode, limiting the emission. However these electrons need not to be replaced by emission from the cathode, therefore the gun may be designed for a much higher current density than available by conventional thermal emission. In order to investigate this property of reflected electrons we have chosen IrCe as electron emitter, which can deliver about 100 A/cm^2 at reasonable life times [5]. The limitations to gun design then is set by electrical breakdown: At 100 kV/cm we designed an electron gun emitting 1000 A/cm^2 from a convex shaped emitting surface, largest radius of the focusing electrode and even higher fields on the anode, which is a well established design for electron beam welding guns at 10 A/cm^2. The electrodes of this design are shown in Fig. 5, where the cathode is almost invisible. In order to perform a reliable simulation with a mesh type program [6], a field line in Fig. 5 (lower dashed line) is used to replace the influence of the outer part in a calculation with refined mesh of the inner part (Fig. 6). This simulation then gives reliable answers for the current density, the focusing characteristics and the surface fields.

At MSL a test EBIS is under construction. This will allow us to investigate the physics described above without disturbing the physics experiments at CRYSIS.

At IAP, computer simulation of the special electron gun, devoted to the production of extremely high density of an electron flow has been accomplished and in ISTOK laboratory the manufacturing technology of such guns is under the development.

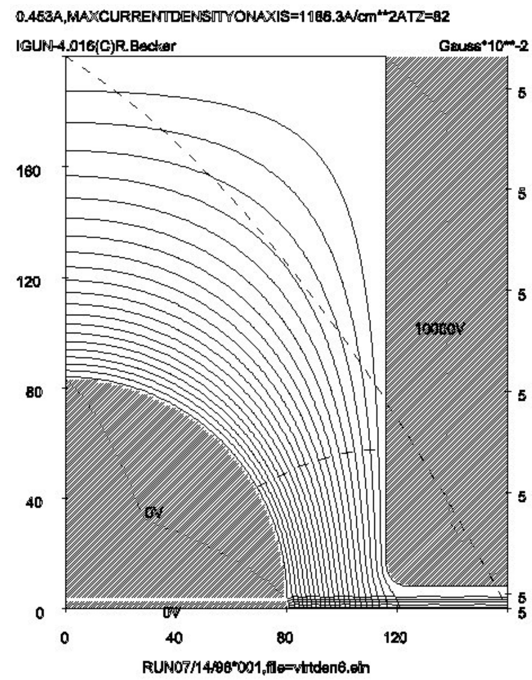

Fig. 5. Simulation of the electron gun for 1000 A/cm^2 as a whole, showing the field line (lower dashed line) to cut out the cathode part for a simulation with finer mesh in Fig. 6

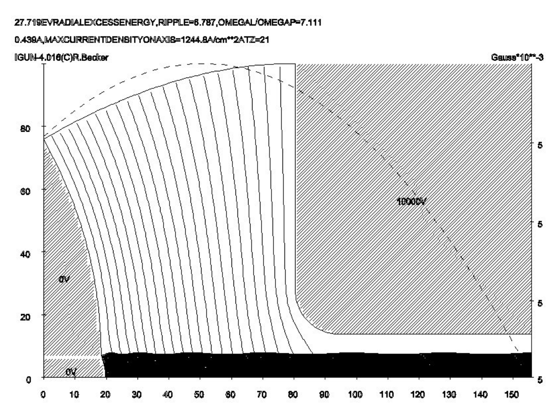

Fig. 6. Simulation of the electron gun of Fig. 5 with higher mesh resolution in the vicinity of the Z-axis.

5 REFERENCES

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