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THE RESEARCH OF PLASMA LENS WITH DISCHARGE INITIATION BY THE ELECTRON BEAM

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Abstract

Currently, works are actively underway to create laser accelerators with focusing of the obtained beams by plasma lenses. Our studies have shown that the density distribution in a plasma discharge initiated by an electron beam is more uniform than in a discharge with its usual formation. Moreover, the homogeneity region lasts 0.5 µs, including the maximum discharge current. These discharges are more suitable for focusing beams.

INTRODUCTION

Since the plasma lens with a large focusing force has small dimensions, it is used in the creation of new compact laser accelerators [1]. The focusing properties of the plasma lens are determined by the distribution of the discharge current density. The distribution is generally heterogeneous and varies to a considerable extent with time. The beam at different moments of the discharge pulse [2, 3] can be focused to a point, to a ring or something else. In the existent plasma lenses, the discharge process begins with a breakdown on the surface of the tube. In our case, when a high voltage pulse is applied to the discharge tube, an injected electron beam creates a plasma channel. That causes the breakdown throughout the tube cross section, but not only at its periphery. For this type of discharging, the estimated calculations in the MHD approximation were carried out [4]. They showed a smoother discharge and a relatively lower level of pinching and a lower plasma temperature.

EXPERIMENTAL FACILITY

The installation (Fig. 1) consists of the electron gun with magnetic lenses, the experimental chamber with the scintillators located in it and the chamber of Z-pinch formation [5]. The amplitude of beam current is 100 A, the electrons energy is 250 kV and the duration of the beam at the peak is 60 ns.

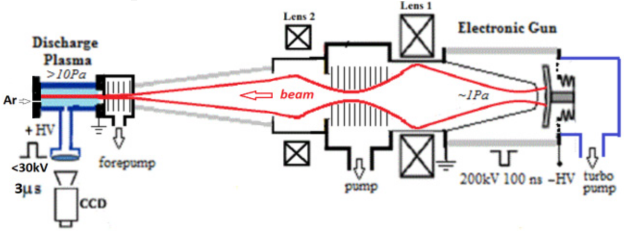

Figure 1: Installation for the research of plasma lens.

Studies are expected to be performed in a wide range of pressures, from 0.1 to 10 mbar. The problem is that the pressure in the electron gun should not exceed 0.02 mbar. The easiest way to solve it consists in installation of the decouple mylar film. Thereto a volume separation device with movable mylar tape was developed. To prevent a significant increase of the beam phase volume, the film thickness should be about 1 µm, which complicates the operation of the device and slows down the experiments. For studies in the field of low pressures, up to 0.5 mbar, it is possible to manage without the film due to the pressure gradient created by the used differential pumping system: packages of diaphragms are set near the crossover of electron beam. Vacuum pumping at the outlet and inlet of the electron gun is performed by turbomolecular pumps, and in front of the discharge chamber – by two forvacuum pumps. As a result, the ratio of pressure in the discharge tube and in the gun was reached up to 10.

Figure 2 shows a horizontal section of dynamic system of volume separation using a mylar tape with elements of plasma radiation detection. The plasma punches a hole in the tape in each the discharge pulse, but to the next pulse the tape is pulled to the next position. The discharge chamber is used in two versions:

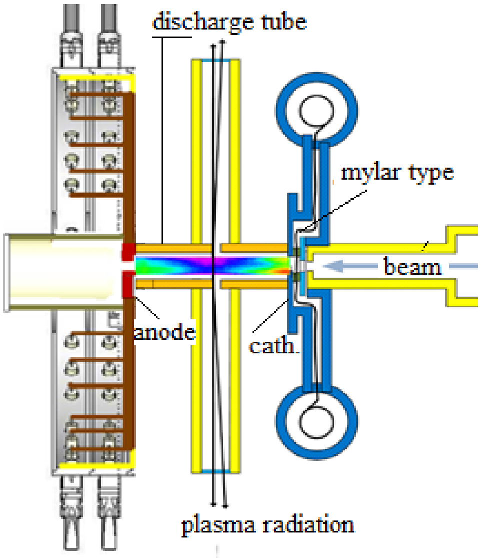

Figure 2: The horizontal slit of the discharge chamber.

- ceramic tube (Fig. 2): length is 16 cm, internal diameter is 3 cm, wall thickness is 5 mm;

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- quartz tube (Fig.3) a length of 14 cm, an internal diameter of 3.9 cm, a wall thickness of 3 mm.

To observe the pinching of the discharge in the ceramic tube, a radial 3 mm slit is made, through which the plasma radiation exits and passes through the optical channel into the recording CCD camera **B**ifo K-008. To avoid electromagnetic interference, the camera is placed in an iron box and powered by a special noise-protected power source.

Information from the camera comes to the PC via fiber optic cable.

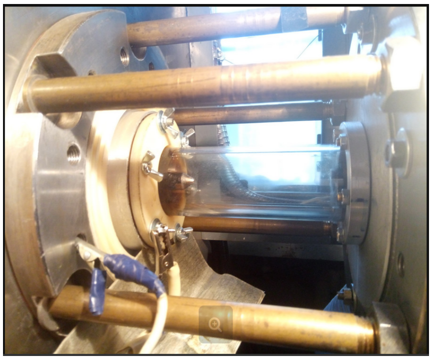
Figure 3: Quartz discharge tube.

EXPERIMENTAL RESULTS

Observations of the process of pinching of the plasma discharge in a quartz tube were carried out. The tube is filled with argon at a pressure of 0.2 Torr. The duration of the sinusoidal half-wave of the discharge was 3 μs. Beam parameters: inlet current ~ 10 A, duration ~100 ns, beam diameter ~1.5 cm. Experiments were carried out in the mode of differential pumping without separating by mylar film. Figure 4 shows the beam track luminosity before the breakdown.

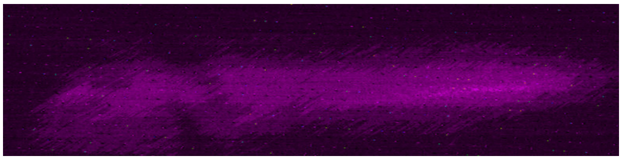
Figure 4: The luminosity of the beam track before the breakdown (frame duration – 200 ns).

Figure 5 shows the time scan of the discharge luminosity and corresponding waveforms at the supplied voltage 17 kV and the discharge current amplitude -120 kA.

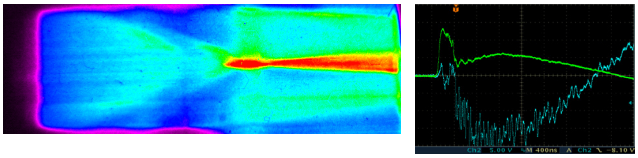
Figure 5: Plasma luminosity in the discharge tube during the first 2 μs. Current and Voltage (upper curve).

Figure 6 shows the time scan of the discharge luminosity and corresponding waveforms at the supplied voltage 17 kV without initiation of the discharge by the electron beam. On the voltage waveform at the pinching moment there is a surge in the voltage due to the increase in the inductance of the discharge.

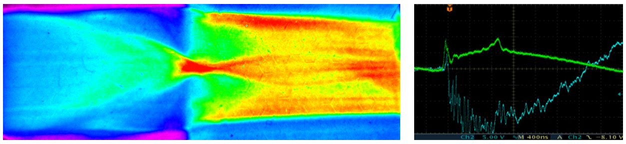
Figure 6: Plasma luminosity in the discharge tube during the first 2 μs.Current and Voltage (upper curve).

Figure 7 shows the time scan of the discharge luminosity at the supplied voltage 8 kV, the amplitude of the discharge current is 50 kA. At the beginning (within 200 – 400 ns from the discharge start) the radiation intensity is uniform in the region of the maximum value of the discharge current.

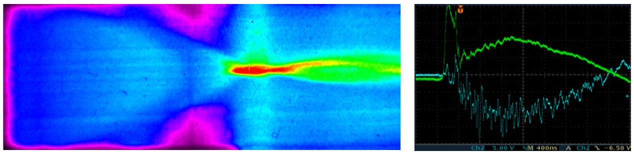
Figure 7: Plasma luminosity in the discharge tube during the first 2 μs. Current and Voltage (upper curve).

This mode is favorable for using it to focus the charged beam.

COMPARISON WITH MHD SIMULATION

The results were compared with numerical simulations in the hydrodynamic approximation using the MHD code NPINCH [3] under the following assumptions. The gas preionization by the beam occurred 200 ns before the beginning of the current. The discharge current in the considered time interval was approximated by a polyline curve close to the experimental oscillograms.

For comparison with the calculation results, mathematical processing of experimental data should be carried out. For this purpose we used the technique with the application of the Abelian transform. It was assumed that the discharge is axially symmetric and the radiation is not absorbed into the plasma.

Below (Fig. 8 and 9) the results of calculation by the MHD-code NPINCH and experimental results for radial distributions of the electron density of the discharge plasma at some moments after the beginning of the discharge are presented.

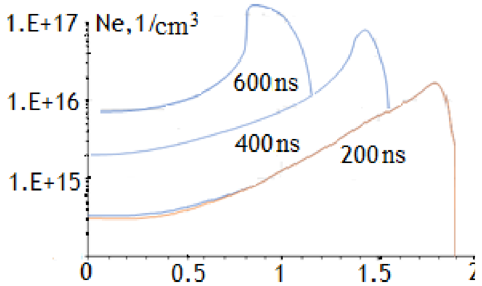

Figure 8: MHD - distribution electron density.

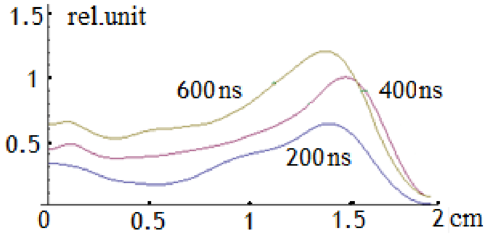

Figure 9: Experimental distribution of radiation emitters at different times after the discharge start.

As can be seen, the calculation results in the MHD approximation are well describe the traditional z-pinch, but they differ significantly from the experimental results for the case of electron beam discharge initiation. Note that MHD dependences are given in logarithmic scale. Comparison of distributions shows that the difference increases due to the difference in compression rates in the model and real discharges.

CONCLUSIONS

When a high-voltage pulse is applied to the discharge tube and simultaneously a plasma channel is created on its axis by means of a pulsed electron beam, it causes the beginning of the discharge development in the entire tube, but not only on its periphery. This leads to the smoother distribution of the current over the discharge and hence to the smaller compression ratios at the instant of maximum compression, as well as, consequently, to the lower temperatures on the discharge axis. In this case, the plasma distribution in the cross section is quite uniform during a large time interval. This distribution is more desirable for the purpose of creating a plasma lens with linear focusing forces.

Calculations using the MHD code NPINCH well describe the traditional z-pinch discharge. In the case of a discharge with electron beam initiation, this technique does not give qualitatively correct predictions for the experiments at low pressures of 0.1 – 0.5 mbar.

It should be noted that the experimental data confirm the conclusions from the preliminary MHD estimations [6] about the less energetic and at the same time more homogeneous plasma discharge initiated by the electron beam.

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