ECR BREAKDOWN OF HEAVY GASES IN OPEN MIRROR TRAP

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Present work is devoted to experimental demonstration of possibility of short pulsed (< 100 μs) multicharged ion beams creation. Two regimes of short pulsed beams generation are discussed: quasi-stationary and non-stationary in preglow regime.

Experiments with ECR discharge stimulated with gyrotron radiation @ 37.5 GHz, 100 kW were performed to reach the minimum duration of the pulse.

In quasi-stationary regime pulses with duration of 50 μs and more were obtained. "Preglow" effect was also observed and investigated in experiments. Received dependencies of the "Preglow" parameters are in good correspondence with results of numerical simulations. It was shown in experiments that generation of "Preglow" peak with duration about 20 μs is possible.

I. INTRODUCTION

Realization of the European programme for neutrino oscillations research, "Beta Beam Project" [1], requires that high-power short-pulse (10 to 100 μs) beams of multicharged ions of radioactive gases (^{6}He or ^{18}Ne) with high gas efficiency be created. A possible way to achieve formation of such beams is associated with the use of a pulsed ECR source of multi-charged ions (MCI). Application of modern classical ECR ion sources for this is not feasible, since the time of gas breakdown and the plasma density's reaching the stationary level is long (over 1 ms) as compared with the required pulse duration. Study of short pulsed ion beams creation possibility connected with investigation of ECR gas breakdown, the process of plasma density increase from zero to steady state value and plasma decay inside magnetic trap of an ion source.

In [2] possibility of gas breakdown process shortening by using of microwave radiation with higher frequency for plasma heating was demonstrated theoretically. It is connected with dependence of final breakdown stage duration on plasma life time. This stage corresponds to the process of ion charge state distribution formation when plasma density is high enough for multicharged ions generation. Plasma life time decreases with increase of its density (plasma density could be increased by using of higher frequency microwaves) in the case of classical plasma confinement [3] and reaches its minimum value determined by quasi-gasdynamic plasma outflow from the trap though magnetic plugs [4]. That is why present work is devoted to experimental demonstration of short pulsed multicharged ion beams creation possibility in ECR ion source with gyrotron plasma heating @ 37 GHz, 100 kW. Such parameters of microwave heating are much higher than in traditional ECR ion sources [5]. In the article two regimes of short pulsed beams generation are discussed: quasi-stationary and non-stationary in preglow [6] regime.

II. FORMULATION OF THE PROBLEM

In frame of short pulse creation problem first of all it is necessary to perform the analysis of gas breakdown dynamics dependences on different parameters.

A microwave breakdown of a rarefied gas in a magnetic trap under the ECR conditions may be separated conventionally into two stages [2], for which the rate of plasma density growth are determined by basically different processes. At the first stage the main process is ionization of the neutral gas by collisions with hot electrons; plasma density grows exponentially, the degree of gas ionization is less than unity, low-charge ions dominate in the distribution of ions over their charge states, and the power absorbed in the plasma is much less than the power of the microwave pumping. At the second stage the rate of density growth slows down significantly, the process of ion peeling goes further, their charge becomes higher, and the power absorbed by the plasma is equal to the power of the microwave pumping, approximately.

Electron energy distribution function (EEDF) which determines plasma life time and efficiency of gas ionization is rather different on those two stages. As it was shown in [6] that transition from breakdown to quasi-stationary stage could be attended with a unexpected transient peak of multicharged ions current. This effect was called preglow [6] and it looks very promising as a way of short pulses creation. Its amplitude and duration are depends on initial breakdown conditions which also determine discharge steady state parameters. Preglow effect was discovered experimentally in LPSC [6] and theoretically described in [6,7]. It was shown that Preglow peak with duration about of a few tens of microseconds and high average ion charge could be created only with using of microwave with high frequency (more than 30 GHz) and power.

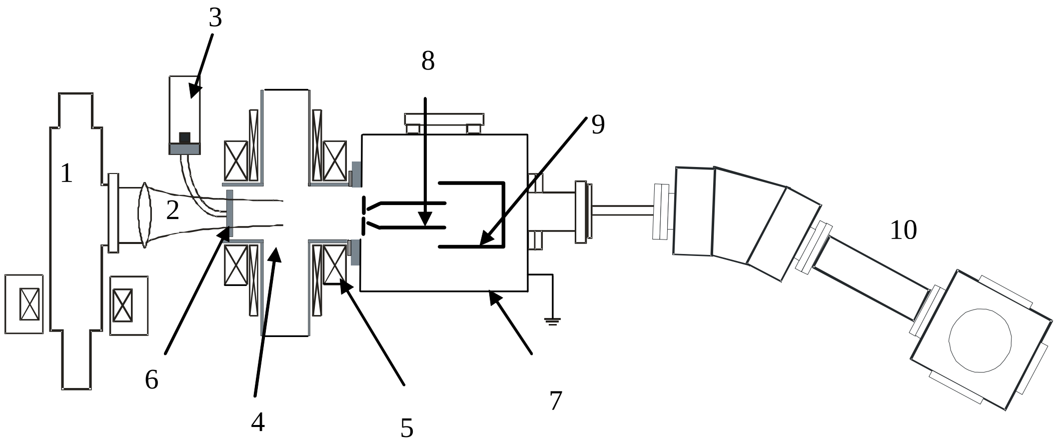

Fig.1. SMIS 37 experimental stand. 1 – gyrotron, 2 – MW beam, 3 – pulsed vacuum valve, 4 – discharge chamber, 5 – magnetic trap coils, 6 – quartz window, 7 – diagnostic chamber, 8 - extractor, 9 – Faraday cup, 10 – ion analyzer.

In present work experimental results obtained on SMIS 37 [8] stand demonstrating creation of short pulses under conditions of powerful plasma heating with gyrotron radiation @ 37 GHz are observed.

III. EXPERIMENTAL SETUP

The experimental research presented in this work was carried out on the SMIS 37 shown schematically in fig. 1. A gyrotron generating linearly polarized radiation at the frequency of 37.5 GHz, with the power up to 100 kW, and pulse duration up to 1.5 ms was used as a source of pulsed microwave radiation.

In the greatest majority of the experiments the field in the magnetic plugs of the system was 2 Tesla.

The operating gas was inlet into the trap along the axis of the magnetic system through a 20-cm long quartz tube with internal diameter of 5 mm; the tube was soldered at the center of the input quartz window.

Ion extraction and ion beam formation were achieved by means of a traditional two-electrode extracting system. A plasma electrode was placed at an arbitrary distance from the trap plug. Maximum 55 kV voltage was supplied to the extractor. Total ion current was measured by a Faraday cup mounted on the magnetic trap axis. The cup had an input window 35 mm in diameter and intercepted the entire ion beam passed through the extractor puller.

Spectral analysis of the extracted beam of positive ions was performed by means of a magnetostatic analyzer.

IV. EXPERIMENTAL RESULTS

IV.A. Quasi-stationary short pulse generation

The aim of experiments was investigation of time dynamics of the discharge and efficiency of multicharged ions generation. To realize the minimum time of gas breakdown together with high ionization rate the next experimental conditions were tuned: microwave power, neutral gas flux into the source, neutral gas pressure, magnetic field of the trap. For plasma confinement a cusp magnetic trap was used. As a result of tuning discharge evolution time about 15 μs was obtained. In fig.2 an example of total ion current oscillogram when 50 μs microwave pulse was used for plasma heating is presented.

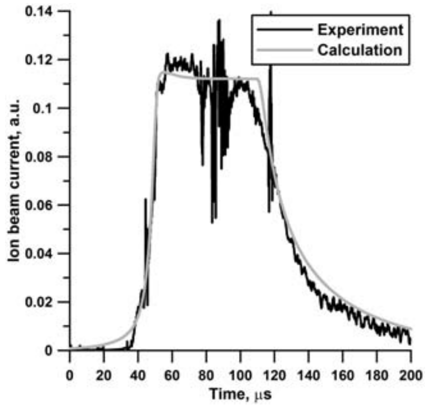

Fig.2. Total ion current. 1 – current measured with Faraday cup , 2 – numerical simulation for corresponding parameters.

As follows from fig.2 the time of current rising is about 15 μs, and it is enough for creation of the pulses with duration of 30 μs and more, that meets the challenge of the “Beta Beam project”. In those experiments the plasma flux density through the plags of the ptap was equal to 2 A/ cm^2.

IV.B. Non-stationary short pulse generation (Preglow)

As it was mentioned investigations of non-stationary generation of multicharged ions in Preglow regime in ECR sources are carried out in many laboratories. Typical oscillogram of Ar^{6+} ion current obtained on Phoenix experimental facility at LPSC [6] with plasma heating by 18 GHz radiation is presented in fig.3.

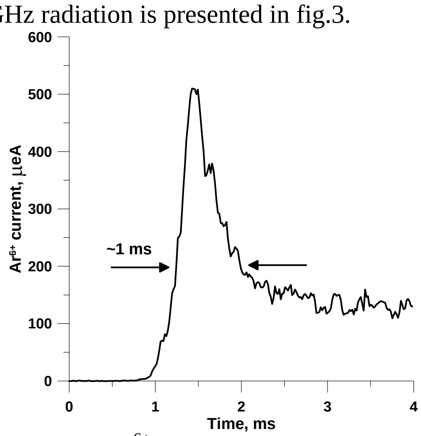

Fig.3. Typical Ar^{6+} current oscillogram on Phoenix 18 GHz facility.

It is evident that formation time of the peak in such conditions is too long for “Beta Beam project”.

In experiments on SMIS 37 the Preglow effect was also successfully observed. The Preglow peak duration in this case was about 20 μs, and that is much sorter than shown in fig.3.

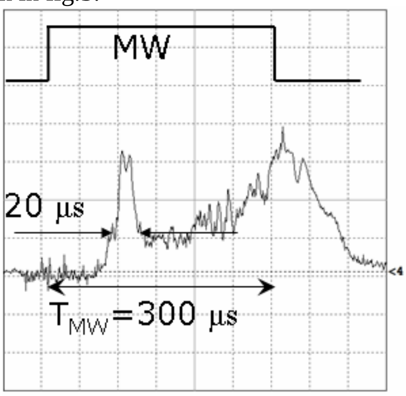

Fig.4. Total ion current.

Experimentally obtained dependences of peak parameters suit well to theoretical calculations. In present work the dependence of qualitative form of ion current pulse on initial neutral gas pressure is presented. In fig 5. a sequence of Faraday cup oscillograms obtained with increase of the pressure in discharge chamber is shown.

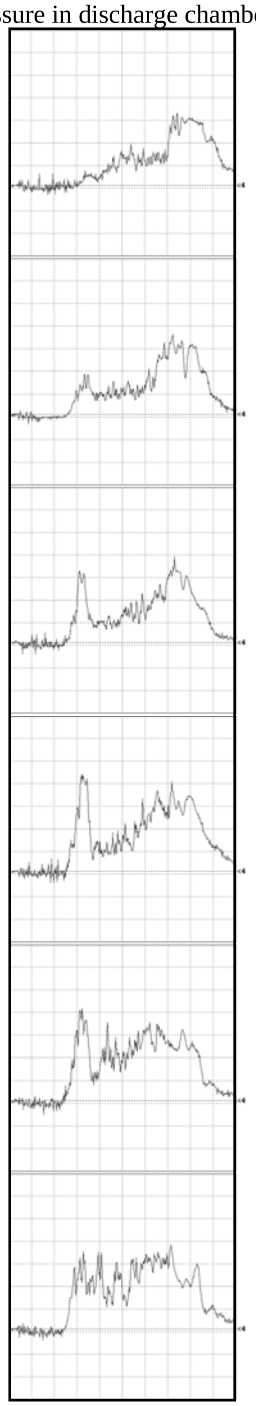

Fig.5. Oscillograms of total ion current in conditions of slight increase of gas pressure in discharge chamber.

Preglow peak could be observed in some narrow range of the pressure what was theoretically predicted in [7].

In such conditions the average ion charger in this peak could be high enough. In fig.6 corresponding ion spectrum in nitrogen is presented.

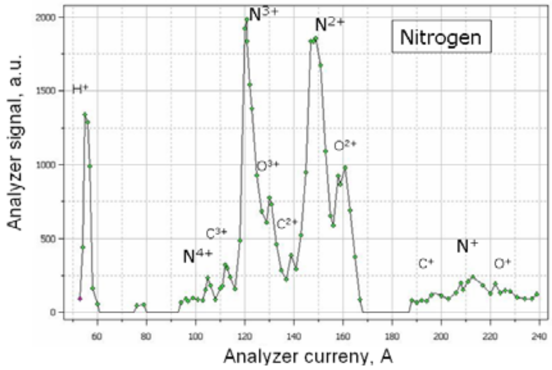

Fig.6. Ion charge state distribution. Nitrogen was used as operating gas.

V. CONCLUSIONS

Obtained results obviously demonstrate perspective of heating microwaves frequency increase for production of short pulsed multicharged ion beam.

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