MICROPULSES GENERATION IN ECR BREAKDOWN STIMULATED BY GYROTRON RADIATION AT 37,5 GHZ

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Abstract

Present work is devoted to experimental and theoretical investigation of possibility of short pulsed (< 100 μs) multicharged ion beams creation.

The possibility of quasi-stationary generation of short pulsed beams under conditions of quasi-gasdynamic plasma confinement was shown in recent experiments. Later another way of such beams creation based on “Preglow” effect was proposed. In present work it was demonstrated that in the case when duration of MW pulse is less then formation time of “Preglow” peak, realization of a regime when ion current is negligible during MW pulse and intense multicharged ions flux appears only when MW ends could be possible. Such pulses after the end of MW were called "micropulses". In present work generation of micropulses was observed in experiments with ECR discharge stimulated by gyrotron radiation @ 37,5GHz, 100 kW. In this case pulses with duration less than 30 μs were obtained. Probably the same effect was observed in GANIL where 14 GHz radiation was used and pulses with duration about 2 ms were registered [1].

In present work it was shown that intensity of such micropulse could be higher than intensity of “Preglow” peak at the same conditions but with longer MW pulse. The generation of micropulses of nitrogen and argon multicharged ions with current of a few mA and length about 30 μs after MW pulse with duration of 30-100 μs was demonstrated. The low level of impurities, high current density and rather high average charge make possible to consider such micropulse regime as perspective way for creation of a short pulsed ion source.

INTRODUCTION

Realization of the European programme for neutrino oscillations research, "Beta Beam Project" [2], requires that 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. In [3] possibility of gas breakdown process shortening by using of microwave radiation with higher frequency for plasma heating was demonstrated theoretically. 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 [4] and reaches its minimum value determined by quasi-gasdynamic plasma outflow from the trap though magnetic plugs [5]. 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 with frequency 37 GHz and power 100 kW. Such parameters of microwave heating are much higher than in traditional ECR ion sources [6]. In the article two regimes of short pulsed beams generation are discussed: quasi-stationary and non-stationary.

FORMULATION OF THE PROBLEM

To solve a problem of short pulse creation, first of all it is necessary to perform the analysis of gas breakdown dynamics dependences on different parameters.

In the very beginning of microwave breakdown of a gas in a magnetic trap under the ECR conditions 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. Electron energy distribution function (EEDF), which determines plasma life time and efficiency of gas ionization, has a form corresponding to superadiabatic regime of electron heating in a mirror trap under ECR condition. Average energy of electrons in this case is as high as hundreds kilo electron-volts [7]. Energy content of plasma grows with plasma density. Plasma confinement time is rather high. If one stop microwave pulse on this stage, ionization would continue as long as electron temperature is high. In this case appearing of ion beam after end of microwaves pulse is possible like it happen in afterglow mode.

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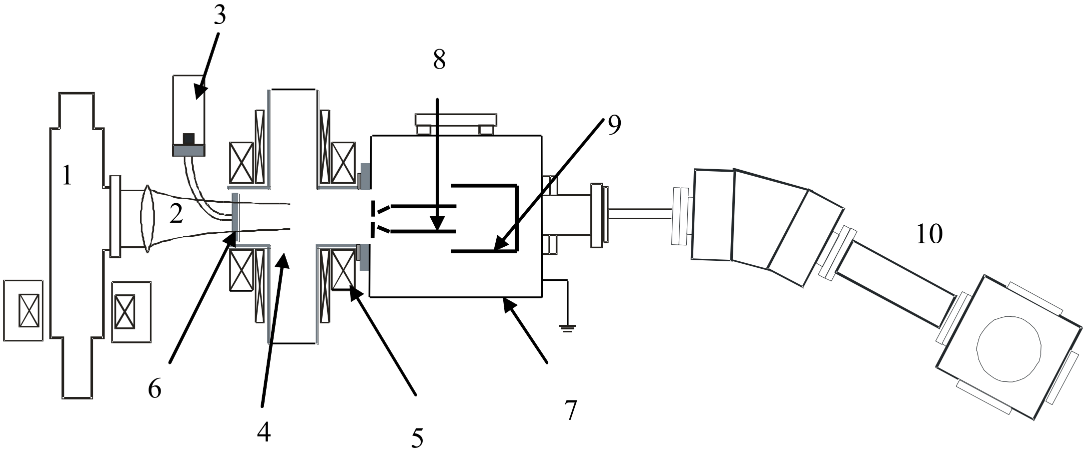

Figure 1 SMIS 37 experimental stand. 1 – gyrotron, 2 – MW beam, 3 – pulsed vacuum valve, 4 – discharge chamber, 5 – magnetic trap coils, 6 – quartz window, 7 – diagnostic chamber, 8 - extractor, 9 – Faraday cup, 10 – ion analyzer.

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 described in the present work.

EXPERIMENTAL SETUP

The experimental research presented in this work was carried out on the SMIS 37 shown schematically in Figure 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.

Mirror or cusp magnetic traps was created by 2 pulsed solenoids. 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.

EXPERIMENTAL RESULTS

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 Figure 2 an example of total ion current oscillogram when 50 μs microwave pulse was used for plasma heating is presented.

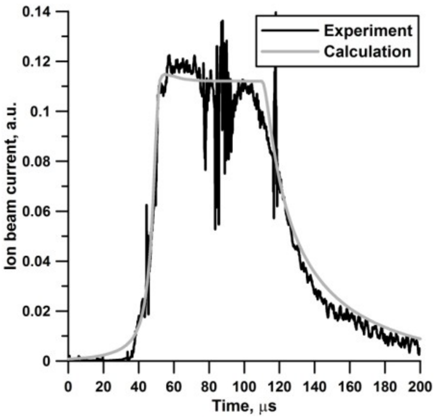

Figure 2. Total ion current. 1 – current measured with Faraday cup , 2 – numerical simulation for corresponding parameters.

As follows from Figure 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 plugs of the trap was equal to 2 A/ cm^2.

Non-stationary short pulse generation

Study of a possibility of shortening of ion beam pulse was started with study of Preglow effect. The effect was found and described in [7]. Later it was studied with higher (37 GHz) frequency of MW pumping. Three left oscilogramms in Figure 3 show this effect. Further shortening of microwave pulse leads to only one maximum on the oscilogramm (right oscilogramms in Figure 3) which appeared a certain time later of end of the microwave pulse.

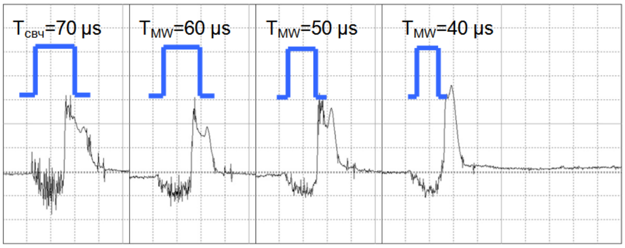

Figure 3. Ion current of Ar^{4+} versus microwave pulse duration. Negative signal on the oscilogramms is electric noise.

Such short pulse after the end of microwaves was called "micropulse". Temporal evolution of ion beam current may be described in frame of the model developed in [7]. In the beginning of the breakdown while plasma density is low electrons could accumulate a lot of energy which could course an efficient ionization after the end of MW pulse. Fast density growth and average electron energy decrease after MW pulse leads to intense peak of ion current. So nature of micropulses is close to afterglow, but with starting of afterglow peak not from steady state regime of discharge flow but from breakdown stage.

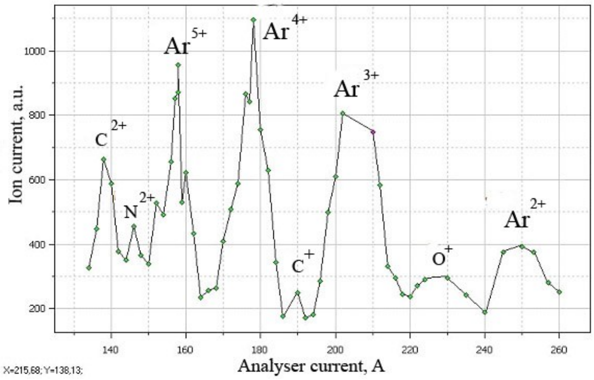

Figure 4. Ion charge state distribution for Argon.

In such conditions the average ion charger in this peak could be high enough. In Figure 4 corresponding ion spectrum in argon is presented.

CONCLUSIONS

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

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