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Experimental evidence of energetic neutrals production in an ion diode

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ABSTRACT

The paper presents several experimental proofs of the formation of energetic charge-exchange neutrals in a self-magnetically insulated ion diode with a graphite cathode. The energetic neutrals are thought to be produced as a result of charge exchange process between accelerated ions and stationary neutral molecules. The experiments have been carried out using both a diode with externally applied magnetic insulation (single-pulse mode: 100 ns, 250–300 kV) and a diode with self-magnetic insulation (double-pulse mode: 300–500 ns, 100–150 kV (negative pulse); 120 ns, 250–300 kV (positive pulse)). The motivation for looking at the neutral component of the ion beam came when we compared two independent methods to measure the energy density of the beam. A quantitative comparison of infrared measurements with signals from Faraday cups and diode voltage was made to assess the presence of neutral atoms in the ion beam. As another proof of charge-exchange effects in ion diode we present the results of statistical analysis of diode performance. It was found that the shot-to shot variation of the energy density in a set of 50–100 shots does not exceed 11%, whilst the same variation for ion current density was 20–30%; suggesting the presence of neutrals in the beam. Moreover, the pressure in the zone of ion beam energy dissipation exceeds the results stated in cited references. The difference between our experimental data and results stated by other authors we attribute to the presence of a low-energy charge-exchange neutral component in the ion beam.

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1. Introduction

Some previous studies [1] were looking into the formation of a large flux of energetic neutrals in the ion beam produced by magnetically insulated diodes with flashover anodes. The neutrals are produced though the effect of charge exchange between the ions and background neutrals in a thin gas layer onto the anode surface. The density and thickness of the neutrals layer formed above the anode are not well known. The formation time of one monolayer of molecules on the surface is $\sim$1 ms at a pressure of 0.65–6.5 mPa [2]. Based upon evidence that several monolayers of neutrals are initially present on the anode surface (adsorbed layer), the areal density is thought to be approximately 10^{16}–10^{17} cm^{-2}. The anode plasma expansion velocity is typically a few cm/μs so in a 400–500 ns pulse, the thickness increases to a few millimeters at most. This implies a neutrals density of $\sim10^{16}$ cm^{-3} or even higher [1]. Energetic neutrals are produced as a result of charge exchange process between accelerated ions that have energy of 10–50 keV and stationary neutral molecules. Therefore, the charge exchange neutrals have kinetic energy of much higher than thermal velocity of molecules of residual gas in vacuum chamber. When the ion current density is 40–80 A/cm^2 and an accelerating voltage is 250 kV, the ions density is equal to (2–3)·10^{13} cm^{-3}. This value is significantly lower than the density of neutral particles in the anode–cathode (A–C) gap. Therefore, the acceleration of the ions is accompanied by intensive interaction with the neutral gas and charge exchange. Since each ion can create many fast neutrals, the neutrals flux can be much larger than the ion flux.

Prono et al. [3] proposed charge-exchange effect to explain anomalously early impedance collapse in an ion diode experiment. This idea has also been proposed as a possible explanation for the observation of unusually rapid expansion of the anode plasma across the magnetic field in a magnetically insulated ion diode [4]. Additional confirmation that charge exchange neutrals are present in the beam is the spot formed by undeflected charge exchange neutrals in the center of Thomson spectrogram registered by the Thomson parabola spectrometer [5–7].

However, there is no experimental data on the generation of neutral beams in diodes with explosive emission cathode operating in double pulse mode. The presence of a time interval between a moment of desorption of molecules from the anode surface and a moment of ions generation increases the thickness of a layer of desorbed molecules. This leads to an increase in the number of

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charge-exchange acts for an ion. The purpose of the work is to study production of charge-exchange neutrals in an ion diode with self-magnetic insulation operating in double-pulse mode.

2. Experimental set-up and diagnostics

The experiments were carried out using the TEMP-4M ion accelerator [8]. Powerful ion beam (PIB) was generated by a self-magnetically insulated diode with a graphite potential electrode. Diode connection, diagnostic equipment arrangement and the calibration of the TEMP-4M accelerator are considered in our papers [9,10]. The waveforms of accelerating voltage, total diode current and ion current density are shown in Fig. 1.

The generator was operated in double-pulse mode: the first pulse is of negative polarity (300–500 ns, 100–150 kV), and this is followed by a second pulse of positive polarity (120 ns, 250–300 kV). The first pulse is used for formation of the explosive-emission plasma on the surface of the potential electrode (cathode). The second pulse is used for the extraction of ions from the plasma and acceleration. The ion beam was composed of carbon ions (80–85%) and protons, the ion current density was 50–70 A/cm^2, and the pulse repetition rate was 5–10 pulses per minute. To analyze the composition of the ion beam formed by our diode, a time-of-flight diagnostic, based on a magnetically insulated Faraday cup was used [11]. The shot-to shot repeatability of acceleration voltage for a set of 100–200 pulses was good with the standard deviation not exceeding 6–7% [12].

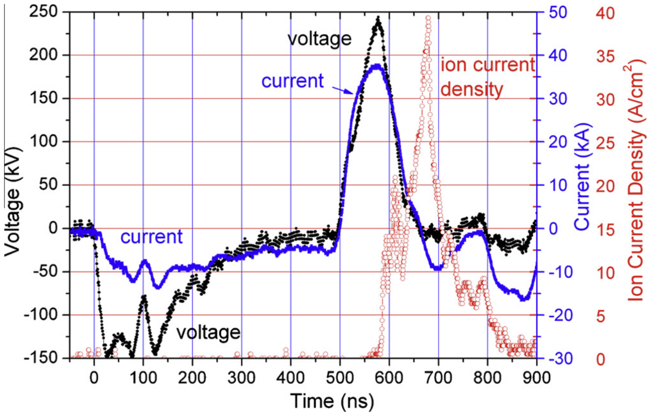

Fig. 1. Waveforms of the accelerating voltage, total diode current, and ion current density measured by a magnetically insulated Faraday cup at 10 cm downstream from the diode.

The diode current and voltage were measured by a Rogowski coil and a high-frequency voltage divider respectively. The ion current density was measured using a magnetically insulated Faraday cup ($B = 0.4$ T). For measuring the cross-sectional energy distribution of the beam we used an infrared imaging technique of targets intercepting the beam [13]. Fig. 2 shows a photograph of the strip focusing diode and the beam energy density distribution in the focus.

To increase focusing efficiency and prevent the loss neutralizing electrons from the beam during transport to the target, we used a metal shield installed on a grounded electrode of the diode [14].

3. Measurement of the ion beam energy density

The motivation for looking at the neutral component of the ion beam formed by the diode came when we compared two independent methods to measure the energy density of the beam: (1) by multiplying the measured current density with the voltage at the diode, and integrating the product over time; (2) using the infrared imaging of the target. First, we compared the results of two methods (current density + voltage, and using the infrared imaging) for the beam formed by an applied B_r magnetically insulated ion diode [15]. The experiments were carried out using the TEMP-4M accelerator configured in single pulse mode suitable for this diode. The results of the measurements are shown in Fig. 3.

The ion current density and the accelerating voltage allow one to evaluate the energy density of the ion beam by multiplying the measured current density from Faraday cup with the voltage at the diode, and integrating the product over time. During beam transport from the diode to Faraday cup the shape of ion current density waveform can change as the pulse duration of ion current density changes. The latter is determined by the velocity of ions and depends on beam composition, energy spectrum and the distance from the diode to Faraday cup. To restore the initial shape of ion current density pulse we used the following procedure. For each data point of the accelerating voltage (sample interval of 0.4 ns), we calculated the delay of arrival of ions to the Faraday cup and the plotted the original curve of ion current density. The ion beam energy density calculated for the applied B_r diode was

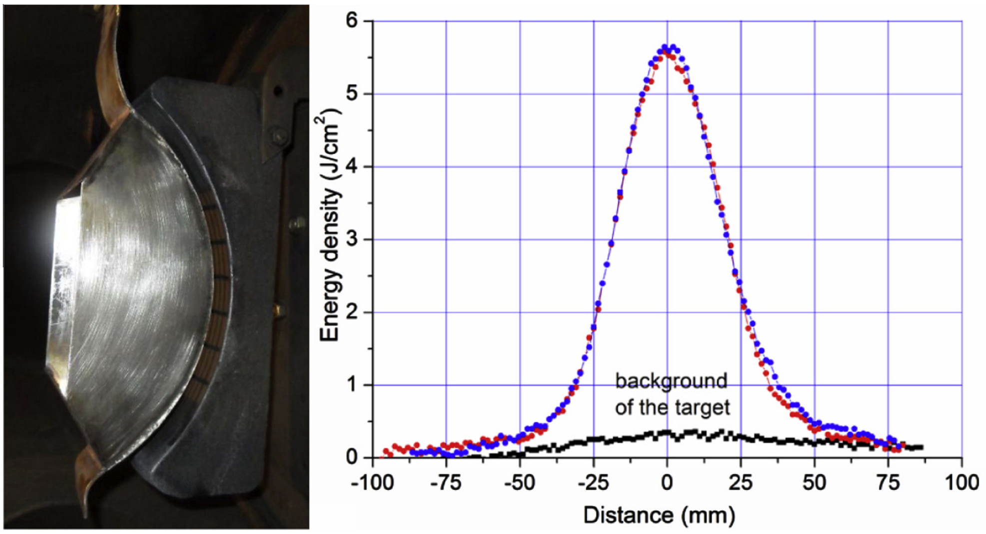

Fig. 2. Photo of the focusing diode and ion beam energy density distribution over the cross section.

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