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High-current-density gas ion ribbon beam formation

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ABSTRACT

Experimental results are presented to demonstrate the possibility of forming extended repetitively pulsed low-energy gaseous ion beams with a notably high current density. The symbiosis of plasma-immersion extraction of ions and their subsequent ballistic focusing in the semi-cylindrical geometry of the focusing system was first used to form a high-density nitrogen and argon ion ribbon beam. The gas-discharge plasma was formed using a hot-cathode-arc discharge-based modified extended source. A nitrogen and argon ion beam was steadily formed at bias potentials of an amplitude up to 1000 V and a pulse duration of 2–80 μs at a pulse frequency of 10^3-10^4 pulses/s. In the experiments, an inverse change in current amplitude of the focused ion beam was observed with respect to the initial nitrogen and argon plasma densities. The change in the current ratio formed by the nitrogen and argon ion beams in comparison with the initial plasma density is associated with the effect of the ion atomic mass on a high-voltage sheath formation near the grid electrode and the ratio of the sheath width and grid cell dimensions. An argon ion beam with a current of 0.35 A and a nitrogen ion beam with a current of 0.6 A at a focused ribbon beam length of 23 cm were obtained by installing a grid focusing system in the form of a partial cylindrical surface (radius 7.5 cm) at 35 cm from the gas-discharge plasma generator output. A decrease in distance to 20 cm ensured an increase in argon ion current to 0.8 A and nitrogen ion current to 1.3 A. The maximum ion current density at a distance that corresponded to the cylindrical grid radius for nitrogen and argon ions exceeded 0.08 A/cm^2 and 0.05 A/cm^2, respectively.

1. Introduction

Ion beams are widely used in various fields of science and technology [1–3]. One of the most common applications is associated with many advanced methods of ion and ion-plasma processing of various materials, including semiconductors, metals, alloys, and dielectrics [4]. An important practical application of ion implantation to modify the properties of metals and alloys was achieved as a result of the development of plasma-immersion ion implantation techniques [5–8]. For both beam and plasma immersion ion implantation techniques, the ion beams of gases, metals and semiconductors with ion energies from tens of keV to several MeV with a current density below several mA/cm^2 are commonly used. The prospects for developing new high-current and high-intensity ion implantation techniques at ion current densities of tens or even hundreds of mA/cm^2 with an ion energy below several keV were repeatedly discussed in various papers [9,10]. Recent publications developed a new approach to form a low-energy ion beam with a current density of the A/cm^2 scale. Recent publications also demonstrate the possibility and prospect of using repetitively pulsed highly focused ion beams of metals and gases to form deeply doped layers in high-intensity low-energy ion implantation [11,12].

Given this connection, the actual task is to create gas and metal ion ribbon beam sources with current densities up to several tens or hundreds of milliamperes per square centimetre.

This paper investigates a new approach to form extended focused repetitively pulsed nitrogen and argon ion beams with a high ion current density on the target using the gas plasma of an arc source with a hot cathode, plasma-immersion ion flow formation and ballistic focusing in an equipotential drift space.

2. Experimental installation and research method

Experimental studies were performed on a modernized industrial plant NNV-6.6-I1, which is described in more detail in [13]. The working chamber of the plant has internal dimensions of 60 × 60 × 60 cm and was pumped out by the turbomolecular pump TMN-500 at a speed of 500 l/s to a pressure of 10^{-3} Pa.

An extended gas-discharge plasma generator with hot and hollow cathodes (PINK-P) was used to form highly focused nitrogen and argon ion beams [14]. The scheme and external views of the plasma generator

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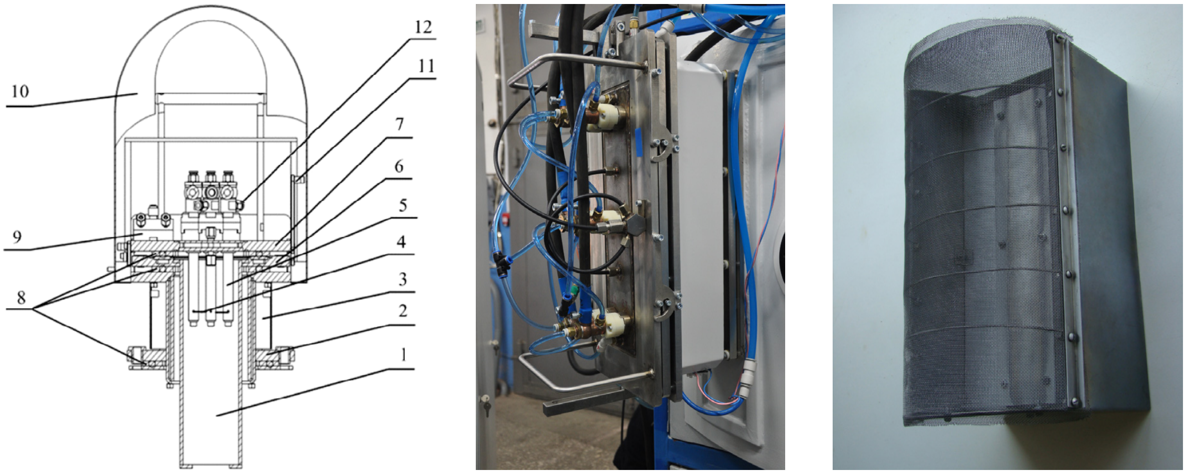

(a) (b) (c)

Fig. 1. Simplified construction (a), external view (b) of the plasma generator "PINK-P" and plasma-immersion focusing system (c): 1—hollow cathode; 2—housing; 3—magnetic coil; 4—filament cathode; 5—current leads; 6—hollow cathode flange; 7—hollow cathode cover; 8—insulator; 9—gas distributor; 10—protective cover; 11—clamps; 12—gas inlet.

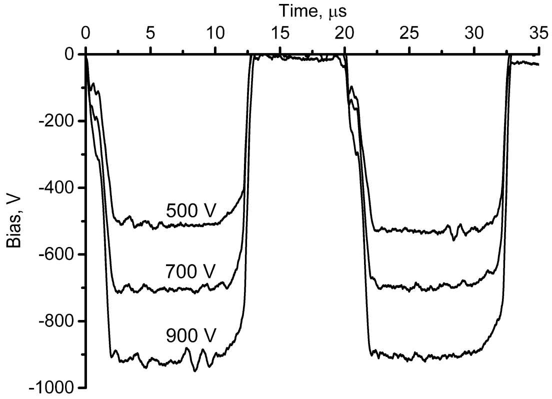

Fig. 2. Shape of the bias voltage pulses.

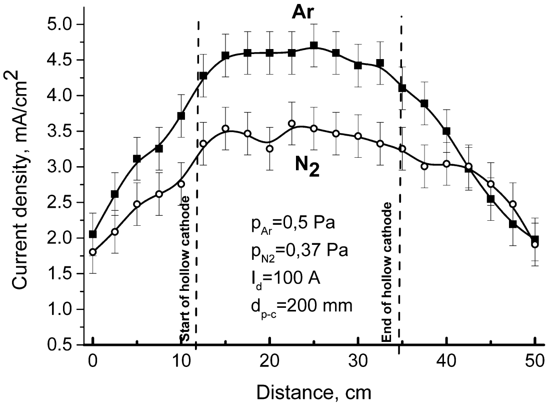

Fig. 3. Longitudinal distribution of the ion saturation current density of the plasma generator "PINK-P".

are shown in Fig. 1a and b. The external view of the plasma-immersion extraction system of ions, their acceleration and ballistic focusing are shown in Fig. 1c.

The plasma generator was mounted on the side flange of the chamber. The working gases were fed into the chamber using a 2-channel gas inlet system SNA-2 with the possibility of regulating the gas flow in the range of 2–20 mPa m^3 s^{-1}.

The high-intensity ion beam formation was studied at a fixed pressure of 0.37 Pa. As working gases, nitrogen of special purity and argon of high purity were used. The plasma generator discharge current in all studies was 100 A, and the discharge burning voltage varied in the range of 80–85 V.

The bias voltage generator provided pulses of negative polarity with an amplitude of 500–900 V at a frequency of 10–50 kHz and a pulse duty factor of 10%–85%. The ion current on the collector was measured by a Rogowski coil. An active divider was used to measure the bias voltage characteristics. Typical bias voltage oscillograms with an amplitude of 500 V, 700 V and 900 V are shown in Fig. 2.

The leading edge of the bias pulse has a small step, and its total duration is 2 μs because the bias generator was performed with semiconductor switches.

3. Study of regularities and features of the extended plasma flow formation based on the plasma generator with hot cathodes

The uniformity of the longitudinal density distribution of the ion saturation current from plasma was studied using the movable collector installed at the Wilson input. The negative bias of 300 V was applied to a collector 2 cm in diameter, and the ion saturation current from the plasma was measured.

Fig. 3 shows the results of measuring the longitudinal density distribution of the ion saturation current from the plasma at a pressure of 0.37 Pa for argon and nitrogen at 26 cm from the output of the plasma generator hollow cathode.

The data in Fig. 3 show that the non-uniformity of the plasma density distribution along the plasma generator length does not exceed 5% for argon and nitrogen. Under identical discharge burning conditions (working gas pressure: 0.37 Pa; filament current of tungsten cathodes: 70 A; discharge current: 100 A; negative bias on the collector: 300 V), the ion saturation current density from the argon plasma is typically almost 35% greater than that of plasma nitrogen. This regularity also occurs at other distances from the plasma generator.

4. Study of the regularities of ribbon high-intensity nitrogen and argon ion beam formation

The high-intensity gas ion beam formation with a high current density is based on the plasma-immersion ion flow formation from a free plasma boundary, their acceleration in a high-voltage sheath near the grid electrode and subsequent ballistic focusing of the ion beam in its transportation in the equipotential drift space [12]. The focusing grid