METHOD FOR MEASURING EXTERNAL AND INTERNAL PARAMETERS OF PLASMA WITH UNGROUNDED GAS DISCHARGE ELECTRODES

A.G. Chunadra, K.N. Sereda, I.K. Tarasov

V.N. Karazin Kharkiv National University, Kharkiv, Ukraine

This work is devoted to the method of measuring the external and internal parameters of gas-discharge plasma in conditions of non-potential "ground" using a multi-grid probe with ungrounded electrodes and a casing. The technique was developed in the plasma of a pulsed high-current high-voltage magnetron discharge with the electrodes detached from the ground. This technique makes it possible to measure ion and electron densities and plasma temperatures and potentials, as well as the ion and electron energy distribution functions, with the usual accuracy for probe measurements. The measurements were carried out by a three-electrode probe installed in the cathode sputtering zone. Selection of the investigated particles was carried out through a screen located under a floating potential.

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INTRODUCTION

In experimental studies of gas discharges, the main task is to study the external (discharge current, discharge voltage) and internal parameters of the gas discharge plasma, such as: plasma concentration, ion and electron temperatures, plasma potential and their space-time distribution. The existing traditional methods of measuring such parameters involve the use of a number of diagnostic tools and recording equipment that require good grounding. At the same time, recently gas-discharge devices working both in stationary and pulse modes, with electrodes of the system, detached from the ground, are of interest. In such cases, monitoring the discharge parameters by traditional methods is difficult, and in some cases impossible.

This work is devoted to the method of measuring the external and internal parameters of gas-discharge plasma in conditions of non-potential "ground" using a multigrid probe with ungrounded electrodes and a casing. The technique was developed in the plasma of a pulsed high-current high-voltage magnetron discharge with the electrodes detached from the ground [1, 2]. This technique makes it possible to measure ion and electron densities and plasma temperatures and potentials, as well as the ion and electron energy distribution functions, with the usual accuracy for probe measurements. The measurements were carried out by a three-electrode probe installed in the cathode sputtering zone. Selection of the investigated particles was carried out through a screen located under a floating potential. The electron and ion energy distribution functions were calculated from the measured delay curves. The standard measurement technique assumes the grounding of one of the terminals of the power supply and the first grid of the energy analyzer. In our case, because of the structural features, both the MSS and the three-electrode probe are not grounded.

1. EXPERIMENTAL EQUIPMENT

The experiments were conducted on an installation of the type NNV–6.6–I1, upgraded to use a planar MSS with a copper sputtered target of size 45×180 *mm*.

The working pressure in the chamber was set at $5 \cdot 10^{-3}$ *Torr* and ensured by a continuous uniform inlet of the working gas (argon) through the gas distribution system directly into the discharge region.

A pulsed power supply unit of capacitive type with a thyristor switch provides a single voltage pulse with a duration of 3 *ms* and an amplitude of up to 1.5 *kV* to the cathode-anode gap.

A single voltage pulse was applied between the cathode and the anode of the MSS against the background of the stationary voltage of a magnetron discharge burning with parameters $U_p = 350\ V$ and $I_p = 0.5\ A$. The limiting discharge current at a high-voltage pulse of voltage was within $I_{imp} = 6…7\ A$. The choice of such parameters of the pulse duration and voltage is due to the existence of a certain optimal relationship between the parameters of stationary and pulsed magnetron discharges [4]. The power supply of the energy analyzer, MSS and the pulse unit was carried out through an isolating transformer, which ensured reliable isolation along the power supply circuits and protection against spurious signals.

In the course of the experiments, the discharge current was measured using a current transformer (Rogowski belt), which allowed recording pulse processes in a wide range of durations.

In Fig. 1 shows a block diagram of an installation for studying discharge parameters using a multi-grid analyzer. During the measurements, the limiting diaphragm, the first grid and the body of the energy analyzer were under floating potential. The distance from the magnetron to the limiting grid was 120 *mm*. The diameter of the slit of the limiting diaphragm was 18 *mm*. The voltage ±(0...250) *V* was applied to the grids 2, 3 of the energy analyzer. The collector – ±(0...100) *V*.

A schematic diagram of the power supply of the multigrid probe for the case of the electronic component of the distribution function is shown in Fig. 2. Accordingly, for the ionic component, the terminals "+" and "–" PSE1 and PSE2 swapped their positions.

When differentiating the volt-ampere characteristic of the collector, the ion and electron distribution functions were obtained.

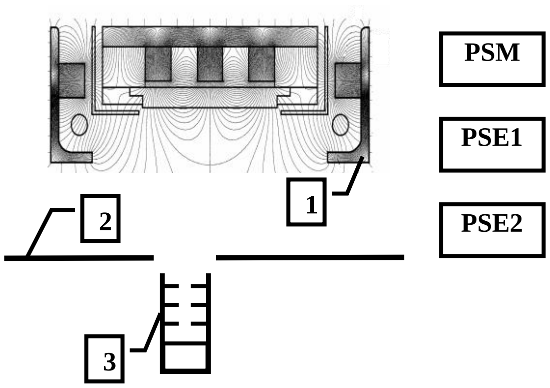

Fig. 1. Block-scheme of the installation for the study of discharge parameters using a multi-grid analyzer: 1 – magnetron sputtering system; 2 – bounding diaphragm; 3 – energy analyzer; PSM – magnetron power supply; PSE 1, 2 – energy analyzer power supplies

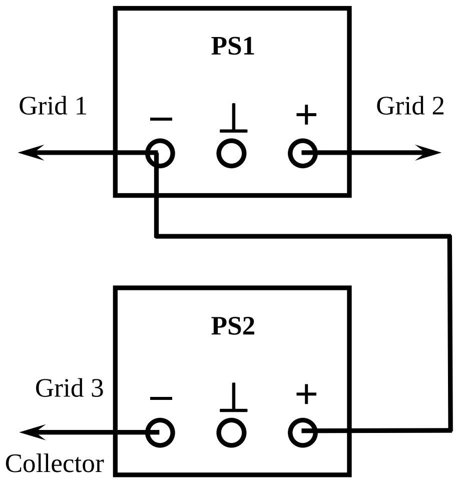

Fig. 2. Schematic diagram of the power supply of the multigrid probe for the case of the electronic component of the distribution function

2. RESULTS OF EXPERIMENTS AND DISCUSSION

In Figs. 3, 4 shows the distribution functions of electrons and ions for different values of the cutting potential applied to the grids 2 and 3 of the multigrid probe.

On the ion distribution function for all values of the blocking potential on the grid of the energy analyzer there are two clearly expressed peaks. The presence of two peaks on the distribution function indicates that in the pulsed regime, two spatially separated ionization zones arise in the MSS. Taking into account the configuration of the magnetic field lines in the MSS with a magnetically insulated anode, it can be assumed that these two ionization zones occur in the regions of the cathode and the anode transverse magnetic fields. The additional ionization zone near the anode provides increasing of the pulsed plasma density and, as a consequence, the flux of ions that bombarding and sputtering the MSS target.

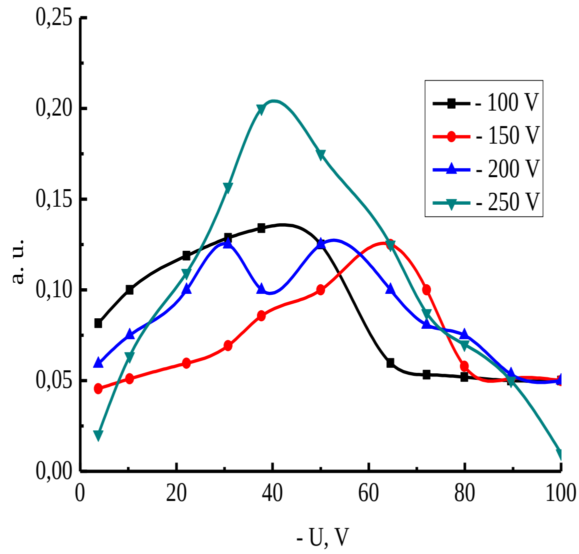

Fig. 3. Electron distribution function of MSS

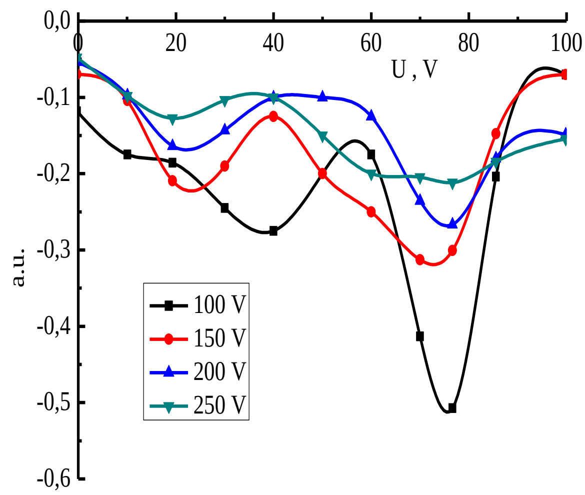

Fig. 4. Ion distribution function of MSS

CONCLUSIONS

Thus, the use of a multigrid energy analyzer made it possible to effectively measure the distribution functions of charged particles in the combined stationary-pulsed mode of operation of a MSS with a magnetically insulated anode in a non-potential ground.

The appearance of an additional ionization zone in the volume of the discharge is shown, which leads to a substantial increase in the plasma density, an increase in the ion flux to the MSS target, and ultimately to an increase in the sputtering rate of the target material and an increase in the mass transfer of the sputtered material to the surface being treated.

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СПОСОБ ИЗМЕРЕНИЯ ВНЕШНИХ И ВНУТРЕННИХ ПАРАМЕТРОВ ПЛАЗМЫ С НЕЗАЗЕМЛЕННЫМИ ЭЛЕКТРОДАМИ ГАЗОВОГО РАЗРЯДА

А.Г. Чунадра, К.Н. Середа, И.К. Тарасов

Рассмотрен метод измерения внешних и внутренних параметров газоразрядной плазмы в условиях непотенциального «заземления» с использованием многосеточного зонда с незаземленными электродами и корпусом. Методика была разработана в плазме импульсного сильноточного высоковольтного магнетронного разряда с электродами, отсоединенными от земли. Этот метод позволяет измерять плотности ионов и электронов, температуры и потенциалы плазмы, а также функции распределения энергии ионов и электронов с обычной точностью для зондовых измерений. Измерения проводились трехэлектродным зондом, установленным в зоне катодного распыления. Выбор исследуемых частиц проводился через экран, расположенный под плавающим потенциалом.

СПОСІБ ВИМІРЮВАННЯ ЗОВНІШНІХ І ВНУТРІШНІХ ПАРАМЕТРІВ ПЛАЗМИ ІЗ НЕЗАЗЕМЛЕНИМИ ЕЛЕКТРОДАМИ ГАЗОВОГО РОЗРЯДУ

А.Г. Чунадра, К.М. Середа, І.К. Тарасов

Розглянуто метод вимірювання зовнішніх і внутрішніх параметрів газорозрядної плазми в умовах непотенційного «заземлення» з використанням багатосіточного зонда з незаземленими електродами та корпусом. Методика була розроблена в плазмі імпульсного сильнострумового високовольтного магнетронного розряду з електродами, відокремленими від землі. Цей метод дозволяє виміряти щільності іонів і електронів, температури та потенціали плазми, а також функції розподілу енергії іонів і електронів із звичайною точністю для зондових вимірів. Виміри проводилися трьохелектродним зондом, встановленим у зоні катодного розпилення. Відбір досліджуваних часток проводився за допомогою екрана, розташованого під плаваючим потенціалом.