Stand for an express analysis of ion-surface interaction

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Abstract. In the paper, a simple and easy to operate stand is presented that allows irradiating the surface of solids by gas discharge plasma ions in the energies ranging from 5 to 40 keV. The results of first experiments are shown. Ion current parameters on the irradiated sample using gas discharge are presented for different gases.

1. Introduction

Investigation of plasma-surface interaction is conveniently conducted on facilities [1–3] that enable researching different processes on the surface under irradiation by plasma and its components in a wide range of irradiation parameters. “MIKMA” (Multifunctional Research Complex for Mass-Spectrometry Analysis) is one of it [4]. Such facilities as MIKMA are usually not equipped with a block that would allow irradiation of surface with plasma ions and electrons with energies of up to tens of thousands of electron volts. To remove this disadvantage, a simple in use device was developed and designed that significantly increases the energy range of ion irradiation on the MIKMA facility. The device is equipped by a relatively simple plasma ion source and a system of plasma acceleration and focusing which allows directing ions of energies ranging from 5 to 40 keV to the surface. A Wien filter installation is possible to separate accelerated ions by mass.

The device can be mounted as a console to an already existing facility or used as a separate stand. In this paper, the developed device is presented as a separate stand.

2. Main construction elements of the stand

The overview of the stand is shown in figure 1, the schematics of the primary nodes is shown in figure 2. The main elements of the stand are irradiation chamber, ion source plasma chamber, ion beam formation system, which is pulled from plasma and accelerated, ion beam focusing system, sample manipulator and others. Power source and a unit that controls the stand, registers and analyses information, are not shown here.

The plasma chamber (1) of the ion source is a cylinder 142 mm high and 79 mm in diameter. It is mounted inside a ceramic insulator (2) that provides electric isolation from the irradiation chamber (3) of the stand. To prevent overheating during discharge, the plasma chamber has double walls, between which a PMS-5 dielectric liquid circulates. A conical screen (4) that increases plasma density in anode (5) area, and a cathode screen (6) that prevents tungsten atoms sputtered from the surface of the cathode by plasma ions from entering the plasma chamber, are mounted inside the plasma chamber.

Gas pumping into the plasma chamber of the stand is done via the RRG-10 gas flow regulator that is controlled by a computer and operates automatically. Plasma in the ion source is initiated in the
pressure range of 0.07 to 1.6 Pa depending on the working gas, then a discharge occurs between the anode (5) and the tungsten heated cathode (7). The discharge power source can supply the plasma current of up to 10 A with the potential difference between the cathode and the anode of 80-100V.

The system for ion extraction from plasma and their acceleration consists of an extraction electrode (8) and an antidynatron electrode (9). The extraction electrode is formed as a conical cap with a hole of 5 mm in diameter that is mounted on a stainless steel tube connected to the frame of the stand. This allows varying the distance from the extraction electrode to the anode from 3 to 19 mm. The cap is made of molybdenum to prevent melting of its edges during the tuning of the operating regime of the accelerating system while operating with an intensive ion flux.

A positive 40 kV bias is applied to the plasma chamber relative to the stand frame, and an ion beam is extracted from a 2 mm hole in the anode. Computerized control of the power supply allows changing discharge current in wide ranges (up to 10 A), which makes it possible to vary the ion beam current without changing the extraction potential.

The ion beam focusing system contains two cylindrical electrodes (10 and 11) with 8 mm holes. The electrode 10 is positively biased relative to the frame of the stand with potential difference of up to 25 kV, the electrode 11 is electrically connected to the frame. Such focusing system allows changing the irradiation spot diameter on the sample from 5 to 20 mm.

The antidynatron electrode (9) is placed before the extraction electrode (8) to suppress the dynatron effect appearing during the operation of the ion source. A negative 10 kV bias relative to the frame of the stand was applied to it, therefore suppressing a secondary emission electron current generated in the beam from entering plasma.

The sample manipulator (13) is made of a stainless steel pipe with a copper tip (14), on which the sample in a special holder and a diaphragm (15) are mounted. Water circulates inside the inlet that cools down the tip and the irradiated sample. The fasteners are made so that a variation of the sample temperature in the range of 80 to 600 °C is possible in one irradiation regime via placing special gaskets between the sample and the tip. To measure the temperature of the sample during irradiation, the design of the tip includes a thermal couple that is attached to the sample via spot welding. In case of increase of temperature being required during irradiation, the copper tip can be replaced by a holder with a heater mounted below made of a 0.3 mm thick tungsten wire. Also angles of sample irradiation can be varied via rotating of the sample manipulator. The sample is inserted into the irradiation chamber via the lock chamber (16) using the sample manipulator. This allows changing the samples without exposing the vacuum chambers of the stand on the atmosphere.

The ion beam extracted from plasma reaches the sample. To suppress emission of secondary electrons from the sample, a diaphragm (15) is mounted on it, which is negatively biased relative to the sample with a potential of up to 1 kV. This allows proper regulation of ion/electron current on the sample and prevention of secondary electron emission into the ion beam.

Special attention is paid to keeping the pressure lower than 10⁻³ Pa in the irradiation chamber during plasma chamber discharge. This is necessary for reducing the dissipation of the ion beam on the working gas molecules on its trajectory from the anode to the irradiated sample. For that reason,
the stand has two vacuum pumping systems. The first system pumps the area of the stand attached to the plasma chamber and includes an Oerlicon TMP 50 turbomolecular pump with the pumping speed for hydrogen of 30 l/s and a WXG-2A oil-free spiral pump. The second system pumps the irradiation chamber and includes a CBVAC CFB-300Z turbomolecular pump with the pumping speed for hydrogen of 160 l/s, and a WXG-2A oil-free spiral pump. Residual gas pressure in the irradiation chamber is $2.6 \cdot 10^{-4}$ Pa. The main components of the residual gas are $H_2O = 95\%$ and $H_2 = 5\%$ ($O_2 + N_2 + CO_2 \ll 1\%$). The tube of the extraction electrode is the only channel connecting the plasma chamber and the irradiation chamber. To reduce its gas conductivity, a system of 7–9 diaphragms with 4–8 mm holes is placed inside it that allows decreasing its gas conductivity and increasing the pressure difference between the irradiation chamber and the plasma chamber. As a result, pressure in the ion source plasma chamber is $(0.8–1.6) \cdot 10^{-3}$ Pa, while gas pressure in the irradiation chamber does not exceed $(1.0–1.3) \cdot 10^{-3}$ Pa.

![Figure 2](image)

**Figure 2.** Scheme of the stand: 1 – plasma chamber; 2 – ceramic insulator; 3 – irradiation chamber; 4 – conical screen; 5 – anode; 6 – cathode screen; 7 – heated cathode; 8 – extraction electrode; 9 – antidynatron electrode; 10, 11 – focusing system electrodes; 12 – sample; 13 – sample manipulator; 14 – copper tip; 15 – sample antidynatron diaphragm; 16 – lock chamber.

A high voltage power supply feeds the ion source. It has three independent channels with varying power that are used to apply bias to the plasma chamber (potential up to 40 kV, current up to 10 mA), the ion beam focusing system (potential up to 25 kV, current up to 10 mA) and the antidynatron electrode (potential up to 10 kV, current up to 10 mA). The error in the value of potentials does not exceed 0.3% due to the existence of feedback.

3. **Test experiments results**

Experiments on measuring the dependence of extracted ion beam current density on the sample from the acceleration potential were done. Hydrogen, argon and helium were used as plasma-generating gases. Using the focusing system electrodes, the ion beam was formed so that the irradiation spot on the sample was a circle 5 mm in diameter. Figure 3 shows the dependence of hydrogen, argon and...
helium ion current densities from the accelerating potential. The current density on the sample increases with increasing the accelerating potential for all plasma-generating gases. At the accelerating potential of 20 kV, the hydrogen, argon and helium ion current densities on the sample is 5.4, 1.3 and 1.4 mA/cm², correspondingly.

**Figure 3.** Dependence of maximum extraction ion beam current density on the sample from the accelerating potential for hydrogen (a), argon (b) and helium (c) as plasma-generating gases

### 4. Conclusion
A simple and easy to operate stand that allows irradiating the surface of the samples by plasma ions with energies of up to 40 keV has been designed. This stand permits a wide variation of charged particle beam parameters: ion energy, ion beam current density and its diameter. The stand is consist of the irradiation chamber, the ion source plasma chamber, the ion beam formation and focusing system, the sample manipulator and other elements. Existence of the sample manipulator allows changing the samples without letting the atmosphere into the stand, and also gives a possibility of irradiating the samples under varying angles and varying temperatures. At the testing stage, the following parameters were obtained: at the accelerating potential of 20 kV ion current densities of hydrogen, argon and helium ions on the sample was equal 5.4, 1.4 and 1.4 mA/cm², correspondingly.

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