ANALYSIS OF ION FLUXES IN LINEAR PLASMA DEVICES

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Analysis of both ion mass-spectrum and plasma parameters is very important for plasma-surface interaction experiments to control discharge regime and ion composition. In linear plasma devices with a magnetic field, it is possible to apply a static mass-spectrometer using magnetic field of plasma device to ion separation with focusing at 180 or 360 degree.

A modified version of mass-spectrometer of magnetized plasmas (MSMP) developed in NRNU MEPhI [1] was installed at the linear plasma device PSI-2 (Juelich). MSMP is based on classical scheme of a static 180 magnetic mass-spectrometer, which uses the magnetic field of PSI-2 for mass-to-charge ion separation [2]. It contains additional equipment to measure local plasma parameters (single Langmuir probe), a local value of the magnetic field (Hall detector) and a temperature of measuring probe (thermocouple). Mass-spectrometer allows to measure plasma parameters and measure relative fluxes of plasma ions.

However, a general scheme of a static mass-spectrometer has a good mass resolution for ions of usual working gases and light admixtures (M < 10 a.m.u.), but not for ions of sputtered materials. Upgrade of MSMP, which can increase a mass resolution also in heavy mass range of plasma ions, will expand the scope of application of the instrument.

All experimental results were obtained on the linear plasma device with a stationary arc discharge (PSI-2) [2]. The plasma is produced in the discharge region containing of a heater, hollow, cylindrical LaB6-cathode and Mo-anode. Hollow plasma profile is implemented. Plasma column with a typical cross-section of 60 mm is terminated at a neutralizer plate. MSMP was mounted at a position with a homogeneous magnetic field in the target chamber. PSI-2 has a differential pumping system containing of eight turbo molecular pumps.

MSMP is a static sector instrument using a magnetic field of the plasma device to M/Z ratio ion separation with focusing at 180 degrees. Measuring probe of MSMP (cf. Fig. 1) consists of an accelerating gap between two segments (2) and two collectors for light (5) and heavy (4) ions, respectively. After passing the entrance slit ions from the plasma column periphery (1) are accelerated by the electric field applied between the inner and outer shell.

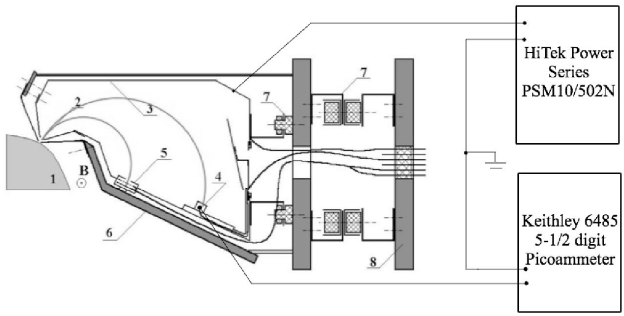

Fig. 1. Elementary scheme of MSMP: 1 - plasma column; 2 - accelerating gap; 3 - dispersive segment; 4, 5 - collectors; 6 - measuring probe; 7 - holders with ceramic insulators; 8 - flange of PSI-2.

Both an energy and gyration radius of the ion in the mass-spectrometer depend on acceleration process according to well-known expression:

$$\left(\frac{M}{Z}\right)_i = \frac{K}{U_i + U_{pl}} \qquad (1)$$

where K - constant, which depends on a geometry of a mass-spectrometer and magnetic field strength; Upl - local plasma potential; U - accelerating voltage. The subscript i denotes the value for the i-th peak in the spectrum. Mass-spectrum is obtained by varying the voltage U with recording the detector current.

Also, MSMP is equipped with a Langmuir probe to monitor plasma parameters such as electron density, temperature and potential of plasma. Particularly, it is important to monitor plasma potential, because accelerating between plasma and body of MSMP should be constant during the experiments in ideal case for a simple description of an energy distribution of plasma ions. To set correct conversion factor of an accelerating voltage to M/Z ratio a local magnetic field strength was measured by Hall detector. For monitoring temperature of MSMP, thermocouple was mounted on the top of the measuring probe to avoid overheating.

Mass-spectrum for different discharge regimes and working gases were obtained by MSMP at PSI-2. Map of the plasma parameters and ion-spectrum was created for all typical modes of argon, deuterium, helium and neon plasma. Measured spectrum showed that an ion composition of the discharge strongly depends on the plasma parameters. Particularly, it is very important to monitor an argon plasma mass-spectrum during erosion experiments because a relative flux of double ionized ions dramatically changes according a discharge power. All this data will be published later.

In context of this work, the main issue was an insufficient mass resolution of MSMP in M > 10 a.m.u. range (cf. Fig. (b)). Comparison of mass-spectra in different mass ranges is presented on Fig. 2. Theoretically, it is possible to resolve masses with difference about 1 a.m.u. in range M < 10 a.m.u. (cf. Fig. 3 and (2)) in this geometry of MSMP (cf. Fig. 2 (a)).

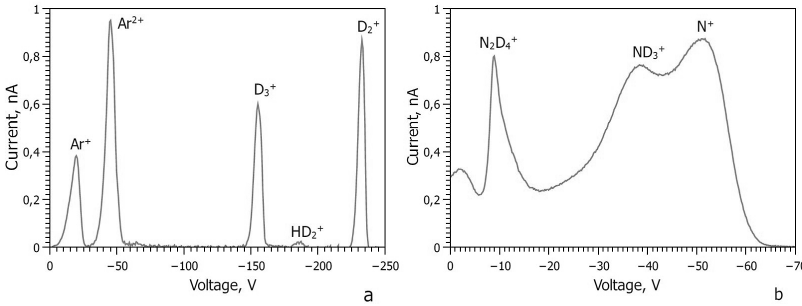

Fig. 2. Examples of a plasma mass-spectrum with different working gases: a - argon and deuterium, b - nitrogen and deuterium.

General scheme of a static mass-spectrometer have a good mass resolution for ions of usual working gases and light admixtures (M < 10 a.m.u.), but not for ions of sputtered materials. Theoretical resolution of a mass-spectrometer is shown in Fig. 1. In geometry of MSMP, it is difficult to determine two ion peaks with difference between masses 1 a.m.u. in M > 10 a.m.u. range.

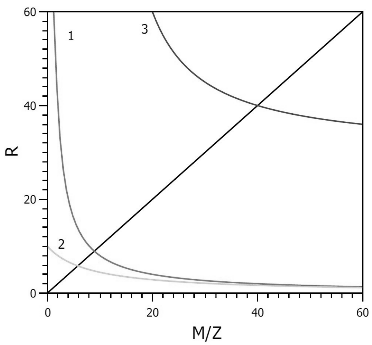

Fig. 3. Theoretical resolution of a mass-spectrometer: 1 - mass resolution limit of static MS considering an ion energy spread; 2 - considering the slit size (2 mm); 3 - mass resolution of pulsed MS (r = 8 mm, d = 0.4 mm).

To solve this issue an upgrade of MSMP containing pulsed housing-less sector with additional accelerating gap was suggested (cf. Fig. 4). The pulsed sector consists of the accelerating gap on which a voltage impulse is applied. It forms bunches of ions from an ion current obtained by the static mass-spectrometer in unresolvable mass-range. Than after magnetic focusing on 180 degrees in the static sector, plasma ions will be separated by time-of-flight in the pulsed sector of MSMP. Theoretical mass resolution of the dynamic part depends on the geometrical dimensions of a mass-spectrometer and the preset parameters of a voltage impulse. Therefore, the main advantage of such mass-spectrometer is a lack of theoretical limit of the maximum detected mass.

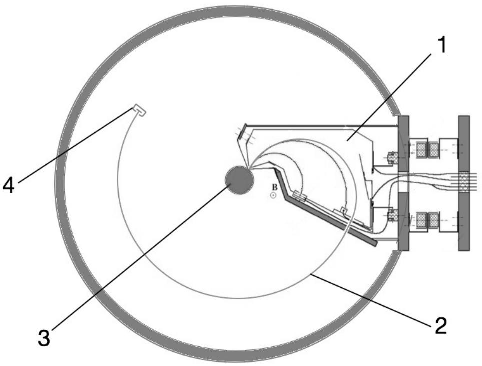

Fig. 4. Scheme of a combined MS: 1 - static MS, 2 - trajectory of plasma ions in the pulsed sector, 3 - plasma column, 4 - collector, 5 - vacuum chamber.

To detect unresolved ions, in this case, it is important to get ions in interesting area of a mass spectrum by a static mass-spectrometer, first, and then resolve all types of ions by a time-of-flight in pulsed sector of combined MSMP. In fact, it will be the combined instrument containing a static mass-spectrometer well resolving light ions and a pulsed sector for heavy ions.

1. I.V. Vizgalov, N.N. Koborov et al., Instrum. Exp. Techniques, 42 (1999) 718-721

2. O. Waldmann, G. Fussmann and W. Bohmeyer, 34th EPS Conference on Plasma Phys. Warsaw, 31F (2007) 5.108