Multifunctional material probe for impurity fluxes characterization

I. Begrambekov and A. Grunin
National Research Nuclear University MEPhI (MEPhI), Kashirskoe shosse 31,
Moscow, 115409, Russian Federation
E-mail: lbb@plasma.mephi.ru

Abstract. A new device is proposed for diagnostics of the SOL plasmas in tokamaks. The device allows to obtain a more detailed information on the impurity concentration, ionization state distribution, and particle fluxes, by combining the several techniques in a single device. The operation principle and the main parts of the proposed multifunctional probe are described.

1. Introduction
The usage of material probes in plasma and thermonuclear devices allows obtaining the information on the plasma energy, concentration, the chemical composition and the amount of impurity in the scrape-off-layer (SOL) plasmas, among other benefits. The practice of employing the probes in the tokamaks has shown that the value of the information obtained via probing increases dramatically if the probe is able to register several parameters, rather than single one, of the SOL plasma to give the complex information on the SOL plasma properties, including the ionization state distribution, chemical composition and the amount of impurity.

2. Problem setting
Currently, such probes do not exist, and its development is the goal of this work. The probe in question will enable one to implement the following measurements and researches:

- In situ measurement of the total flux of neutral and charged impurity particles;
- Research of the interaction of the SOL plasma with the samples of the first wall material and construction materials in tokamaks;
- In situ measurement of the total flux of ions;
- In situ measurement of the mass components of the ion flux;
- In situ evaluation of the energy spectra of the hydrogen isotope ions in the SOL plasma.

The working elements of the probe are located in the protecting jacket which screens the sections from the plasma particles and the heat flux. The jacket is perforated to allow the plasma particles to reach the sections where the following measurements can be made: mass-spectrometry, hydrogen ion energy analysis, in situ neutral and charged particles flux analysis, and analysis of deposited and trapped plasma particles.

The components of plasma passing through the holes in the jacket are accumulated in the plasma components deposition section either on the substrate surfaces (solid material impurities) or

---

1 To whom any correspondence should be addressed.
accumulated in the deposition layer (gas ions and atoms). After removing the substrate from the probe the deposited layer is analyzed using the SIMS, RBS, AES and other methods. Trapped plasma components are analyzed with the TDS technique. The minimum detectable amount of the trapped atoms is $5 \cdot 10^{14}$ at/cm$^2$. The sensitivity and the resolution of the device during the analysis of the trapped and deposited impurity depends on the specific method of the analysis and the respective device used.

The in situ neutral and charged particle flux analyzer collects the particles on a thin layer of a conductor with known resistance. After the particles are deposited, the value of the resistance is changed, that is then registered. The resolution of the registration of impurity flux varies in the range from one deposited layer (about $10^{15}$ atoms/cm$^2$), with the total number of deposited layers being less than a hundred on the surface of the plate, up to five layers (about $5 \cdot 10^{15}$ atoms/cm$^2$), with the total number of deposited layers lying between one hundred and five hundreds.

3. Discussion

In the mass-spectrometer (figure 1) the ions which enter the probe through the hole in the jacket are accelerated in the region between the jacket and the biased diaphragm. These ions are then mass-analyzed in the crossed $E \times B$ fields, where $B$ is the tokamak’s magnetic field and $E$ is the electric field between the plates of the probe’s electric field analyzer. Afterwards, the particles are registered on their respective collector. The entire section is biased and has the potential of the accelerating diaphragm. In figure 1, one can see the schematic of some elements of the mass-spectrometer which is now being constructed for the WEST tokamak with magnetic field of 4T.

The deviation from the initial trajectory of the ions depends on the energy and the mass-to-charge ratio ($m/Z$). The mass-spectrometer is able to register ions in a wide range of the values of the $m/Z$ parameter (between 1 and 200) and is limited by the value of potential biasing of the electric field plates. Preacceleration of the ions allows to minimize the separation of the ions with the similar values of the $m/Z$ ratio and various values of the energy. Thus, the acceleration of the ions with the energy gain of the order of 500 eV, according to calculations, will allow to detect ions in the energy range from 1 eV to 100 eV. The registration resolution is 10 for the light ions ($m/Z \approx 10$) and 3-5 for the heavier ones ($m/Z \approx 100$).

![Figure 1. The mass-spectrometer scheme.](image)
current in the circuit. The minimum detectable concentration of impurity (bounded by the conditions of measuring the ion current onto collectors) is 0.01 at.% for ions with the ratio m/Z~100 and 0.001 at.% for ions with m/Z~10. In this case, the currents in the collector circuit will be at least 0.1 μA.

**Figure 2.** The trajectories of particles with different values of the m/Z ratio: 9 (a), 56 (b) and 189 (c). 1 - jacket, 2 - E-field plates, 3 - entrance slit, 4 - ion trajectories, 5 - collectors.

The hydrogen ion energy analyzer is structurally similar to that of the section shown in figure 1, but has no accelerating electrode. The section is able to detect ions of hydrogen and deuterium in the energy range of 1÷500 eV. Energy resolution (E/ΔE) equals 10. The minimum detectable flux of ions is 1·10¹³ ion/s.

The distance between the electric field plates is taken such that the ions with the parameter m/Z> 2 does not reach the collectors. The trajectories of H⁺ ions of different energies are shown in figure 3.

**Figure 3.** The trajectories of hydrogen ions with energies 50eV (a), 150eV (b), 300eV (c). 1 - jacket, 2 - E-field plates, 3 - entrance slit, 4 - ion trajectories, 5 - collectors.

Figure 4 shows the frame on which the five sections of the measuring probe are mounted (they are shown in figure without jacket). Its main elements are the two parallel titanium plates fastened with ceramic bridges. Three sections of collecting neutral and charged impurity particles and of accumulation of deposited/implanted ions from the plasma components (with the six substrates placed here), mass spectrometry section, and the section of in-situ measuring the neutral and charged particle fluxes, are installed in-between titanium plates. The frame will be installed in a protective cylindrical jacket, with inner diameter of 35 mm. The overall dimensions of the probe are 250mm × Ø40mm.
Figure 4. The model assembly of the probe. 1 - Mass-spectrometer, 2 - E-field plates, 3 - collectors, 4 – ion and atom accumulator section, 5 - substrates, 6 - in situ neutral and charged particle flux analyzer.

References
[1] VanOost G 2004 Fusion Science and Technology 45 301-308
[2] Rubel M, Wienhold P and Hildebrandt D 2003 Vacuum 70 423-428
[3] Rubel M, Coad J, Wienhold P, Philipps V, Stamp M and Tanabe T 2004 Phys. Scr. T111 112-117