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Concerning feasibility of water microleakage diagnostics by auto-oscillating discharge

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Abstract

One of the perspective methods of water microleakages detection in thermonuclear devices is presented. Method is based on the secondary electron emission instability of Debye near-electrode layers in the contact of nonequilibrium plasma with electrode surface covered by thin dielectric film. Method is based on detection of beam-plasma discharge transition into auto-oscillation regime. It is observed when balance between oxidation and sputtering of a contact surface covered by thin dielectric film is shifted. The method has better sensitivity ($< 10^{16}$ mol/s) and response time (< 60 s) as compared with spectroscopic methods ($> 10^{16}$ mol/s and > 2000 s, respectively). In addition, it allows detecting negligible oxygen-containing admixture. In perspective, this method will allow to localize a water microleakage in vacuum chambers of thermonuclear devices and determine a water vapor flow by features of IV-curve.

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Keywords: secondary emission auto-oscillating instability; N-shape IV-curve; water microleakage.

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1. Introduction

Early diagnostics and localization of microleakage in cooling system of thermonuclear devices is an important task to ensure safety and to increase devices lifetime. Presently there is no satisfactory method, which provides instant detection and further localization of leaks in cooling system. The spectroscopic methods based on hydroxyl spectral lines detection in plasma do not provide the required responsiveness, and lower limit value of the detected water vapour flow in this method exceeds the ITER requirements (10^{16} molecules/s) by more than an order of magnitude. There are also methods using spectroscopic markers, such as small xenon admixture in water cooling systems. However, this method has a number of disadvantages associated with the markers high cost and the need for serious vacuum chamber treatment after each emergency activation event or diagnostics system test run because of the marker interaction with the wall [Voronov (2013)].

Oxidation processes due to the oxygen or oxygen-containing molecules presence in the residual gas and oxide dielectric film sputtering occur simultaneously on a non-equilibrium plasma-facing electrode surface during the discharge. Presence of such films on electrode surface leads to a significant increase in the effective secondary electron emission coefficient due to both increased secondary emission coefficient and electron tunnelling current through the film. In this case, IV-curve has N-shape with a negative differential resistance (NDR) region.

Diagnostics of oxygen-containing compounds is based on transition detection of beam-plasma discharge into auto-oscillating regime (AOR) due to a shift in the balance between electrode surface oxidation and sputtering. Beam-plasma discharge transits into auto-oscillating regime with presence of a thin (10 - 50 nm) dielectric film on electron beam collector negatively biased to IV-curve NDR area [Gutorov (2010)]. In this case, the operating point is unstable, which leads to fluctuations in electrode power supply circuit. If balance is set in a transition region between sputtering and film growth (without oscillating regime), the system becomes very sensitive to the oxygen-containing admixture. In this instance, even small oxygen admixture can shift balance toward the film growth and initiate AOR. The voltage oscillations observed in experiments have amplitude greater than the electrode biasing. Current oscillations amplitude exceeds in the electrode circuit. This mode is characterized by high-energy input and increased plasma radiation. In addition, it increases the efficiency of optical diagnostics of hydroxyl spectral lines in plasma.

2. Experimental setup

Research was carried out on the linear plasma device PR-2 (MEPhI) with axial magnetic field. Beam-plasma discharge is implemented. It is initiated by powerful electron gun with directly heated tantalum cathode. Working gas in the experiments was argon, residual gas pressure in the chamber is 10^{-3} Pa, working pressure is 2×10^{-1} Pa. Plasma parameters obtained at PR-2 are: ne is up to 10^{13} cm^{-3}, Te = 5 - 25 eV. In addition, plasma device is equipped with Langmuir probes, optical spectroscopy, static mass-spectrometer of plasma ions and quadrupole residual gas analyzer (cf. Fig. 1).