INFLUENCE OF THE REDEPOSITION PROCESSES ON LANGMUIR PROBE CHARACTERISTICS IN T-10 TOKAMAK

G.S. Kirnev, V.A. Kurnaev, V.G. Telkovsky, I.V. Vizgalov

Moscow State Engineering Physics Institute, Moscow 115409, Russia

Abstract

Essential modifications of both the Langmuir probe characteristics in T-10 tokamak and the collector current-voltage characteristics (CVC) in imitation facility PR-2 resulting in appearance of the region of CVC with negative resistance are observed. The modifications are caused by the enhanced secondary electron emission from dielectric layers generated on the probe and collector surfaces. Modelling of plasma behaviour in the vicinity of surfaces with different electron emissivity with the help of two-collector assembly in PR-2 revealed the intensification of the plasma turbulence.

1. Introduction

Electron emissivity under certain conditions can influence the formation of sheath potential drop and the pattern of non-ambipolar currents. In previous imitation experiments in linear simulator PR-2 with an electron beam-plasma discharge (BPD) [1], it was shown that plasma-surface potential drop in the sheath sets unstable provided the collector has a non-linear N-shaped current-voltage characteristic (CVC) [2]. The most pronounced instability of the sheath potential drop and the highest level of plasma potential and density fluctuations are observed for collector materials that can form dielectric layers with enhanced emissivity of secondary electrons, for example oxidised and diamond-like layers. Oxides on the surface of W, Be, Al, Mg can be formed due to the presence of small oxygen admixtures and diamond-like films on the surface of C, W - due to allotropic modifications of the redeposited graphite.

2. Experimental results

2.1. Anomalous Langmuir probe characteristics in T-10 tokamak

In T-10 tokamak experiments, we observed the modifications of Langmuir probe characteristics during radial transmission of the tungsten probe (probe area of 0.03 cm^{-2}) from the ring limiter margin (r_d = 30 cm) to the wall (r_w = 39 cm). The characteristics measured at four probe positions r_p along minor radius are shown in Fig. 1. In all figures, curves denoted by 1 were measured in ohmic regimes, 2 - in ohmic regimes with auxiliary ECR heating.

Probe characteristics measured near of LCFS (Fig. 1a, b) at $r_p < 35$ cm have conventional form and are in qualitative agreement with classical current dependence on applied plasma-probe voltage (with secondary electron-electron emission coefficient $\delta << 1$):

$$j_t(U) \approx 0.52enV_i - (enV_{Te} / 2\pi)\exp(-eU/kT_e) \ , \qquad (1)$$

where V_{Te}, V_i are the electron thermal velocity and the ion sound velocity accordingly, n is the plasma density, T_e is the electron temperature, U is the sheath potential drop.

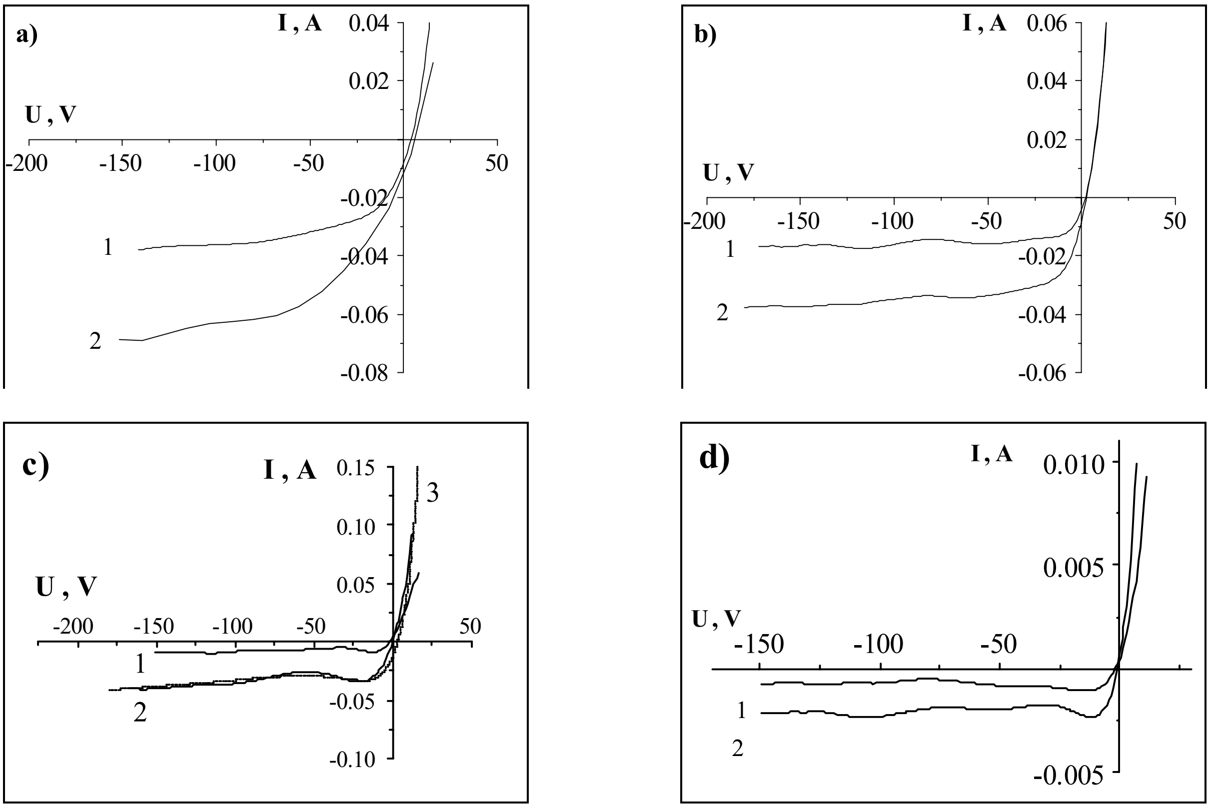

Fig. 1. Modifications of the Langmuir probe characteristics in SOL region of T-10 tokamak (ring limiter radius r_d=30 cm): a) r = 32 cm, b) r = 34 cm, c) r = 36 cm, d) r = 37 cm. (1 - ohmic regime, 2 - ohmic regime with ECRH, 3 - calculated probe characteristic (doted line)).

But probe characteristics measured (Fig. 1c, d) at $r_p > 35$ cm have pronounced N-form as it takes place in imitation experiments with BPD an can't be described by eq.1 in principal. Such behaviour of probe characteristics in T-10 is assumed to be caused by enhanced electron emission from diamond-like dielectric layers that can be formed on the probe surface for $r_p >$ 35cm. With taking into account $\delta >> 1$ with magnetic field normal to the probe surface and electron temperature T_e, the total probe current j_t can be written:

$$j_t(U) \approx 0.52enV_i - (enV_{Te}/2\pi)\exp\left(-\frac{eU}{kT_e}\right) + \frac{en}{2\pi}\sqrt{\frac{m_e}{2}}\frac{\sqrt{|eU/kT_e|}}{T_e^{3/2}}\int_{|eU|}^{\infty}\varepsilon\cdot\exp\left(-\frac{\varepsilon}{kT_e}\right)\cdot\delta(\varepsilon-|eU|)\cdot d\varepsilon, \quad (2)$$

where ε is the energy of electrons, m_e - the mass of electron.

The probe current in Eq. (2) is mainly determined by an electron temperature and an energy dependence of the electron emission coefficient δ(ε). Unfortunately, the lack of reliable information about the emission coefficients from diamond-like dielectric layers doesn't allow the electron temperature and plasma potential measurements with the help of the Langmuir probe be correct. To fit these anomalous probe characteristics, we varied δ(ε) and electron temperature T_e in Eq. (2). As an example, calculated characteristic for r = 36cm at T_e = 10eV is shown in Fig. 1c (curve 3, doted line). This characteristic is best suited to the experimental one and for the energy emission coefficient dependence δ(ε) to be monotonically increasing from threshold at electron energy $E_{th} \approx 12$eV to maximum $\delta_{max} = 8$ at energy $E_{max} \approx 450$eV.

So, the Langmuir probe characteristics measurements allow us to suggest that some plasma facing components (PFC) surfaces limiting SOL plasma flows can be covered by thin dielectric layers resulting in the change of emissivity. The presence on the PFC surface (for example, on the lateral surface of ring limiter) of zones with different electron emission properties can lead to the modification of the radial plasma potential distribution. As a first approximation let's consider the surface with two zones with distinctive emissivity. The radial electric field E_r in this case can be written as:

$$\int_{r1}^{r2} E_r dr = U_{sh}^{r1} - U_{sh}^{r2} - \Delta U_f, \quad (3)$$

where U_{sh}^{r1}, U_{sh}^{r2} are the sheath voltage drops at the surfaces with different emission coefficients, ΔU_f is dielectric film potential drop of about 10V. Radial non-ambipolar plasma current $j_r = \sigma_r E_r$ is closed through diaphragm. So, the current closing conditions depend on the lateral diaphragm surface conditions. Accordingly, the sheaths U_{sh}^{r1} and U_{sh}^{r2} depending on parallel currents described by the Equations (1) and (2) define the stability of radial current.

2.2. Simulation of the ring limiter current closing in PR-2

The appearance of currents between PFC zones with different emission coefficients δ has been modelled with the help of two-collector assembly in PR-2 facility. This assembly is axial symmetric about the plasma flow axis and includes low emissive central graphite collector and high emissive peripheral Al collector. Collectors are closed through an ammeter. When collectors are under a common floating potential, the total current to its surfaces is not zero:

the first plate operates as a source of electromotive force and the second one - as a non-linear load with the negative resistance region on CVC. So stable and unstable regimes can be observed.

In stable state the level of fluctuations is low. Fluctuation level of plasma density and potential are about 5%. But when the working point of the equivalent electric circuit of the two-collector get to the negative resistance range of Al collector CVC, the amplitude of current and potential fluctuations are found to essentially increase. Fluctuation level of plasma parameters in this case achieves 40-60%. This instability stimulates the fluctuation-induced transport and modifies the radial distribution of plasma parameters. Radial diffusion coefficient measured with an array of four Langmuir probes is about two orders of magnitude larger then Bohm coefficient. Comparative studies of the plasma parameters distributions in stable and unstable regimes have shown that there is a strong modification of the radial electric field E_r and the electron temperature T_e profiles. The electric field distributions are shown in Fig. 2 for stable and unstable regimes.

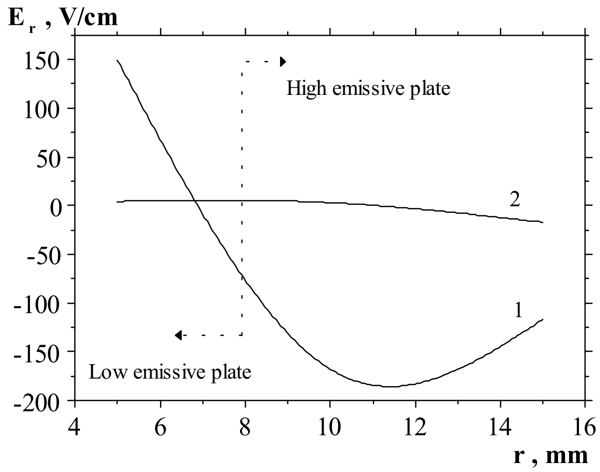

Fig. 2. Radial electric field distributions E_r:
1 - stable regime, 2 - unstable regime.

3. Conclusions

It is experimentally proved in T-10 that the layers with enhanced secondary electron emission can be formed on plasma facing components (PFC) in tokamaks due to the competition of the material scattering and redeposition. These layers strongly influence the regimes of plasma-surface interaction. These experiments combined with the ones carried out in imitation facility PR-2 have shown that the presence on the surface of PFC zones with different electron emission properties can substantially modify the plasma parameter distributions and stimulate the radial transport in the SOL.

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