RADIAL DISTRIBUTIONS OF Li^+ IONS AND Li DEPOSITION IN THE SOL OF T-11M TOKAMAK WITH Li LIMITER

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1. Introduction

Using a capillary-porous structure (CPS) impregnated with liquid lithium in modern tokamaks operating as a protective material limiter or divertor [1] and as a source of lithium for lithization [2] has shown many positive features of this material: substantial reduction of impurities in the plasma, reducing the recycling of deuterium, etc. At the same time, the accumulation of large quantities of solid lithium in a relatively cold vessel of the tokamak in the process of long-term use of lithium CPS material may create some problems. Therefore, the question of where and how much lithium is deposited during the tokamak operation with lithium sources is very important. For a stationary tokamak this question is even more important. Earlier experiments with lithium limiter on the basis of the capillary porous structure [1] on the T-11M tokamak with the recombination probe [2] measured the radial profiles of lithium ions flux in the SOL. In these experiments [3] the radial density distribution of lithium deposited on the lateral surface of the base of limiter was measured by chemical analysis. In this work, we give a comparison and analysis of the experimental flux profiles of lithium ions in the SOL of the tokamak, and the radial density distribution of lithium deposited on the lateral surface of the base limiter. The comparison of these profiles reveals significant differences. The analysis of the profiles shows that the formation of the profile of the deposited lithium is due to the balance of erosion and deposition. The erosion is mainly due to the flux of deuterium ions. Its density is approximately ten times higher than the density of the lithium flux. In this paper, we propose a model based on balance equations that explain the main features of the deposited lithium profile.

2. Experiments on T-11M

The experiments were conducted on T-11M tokamak in ohmic regime (Ip = 70kA, Bt = 1.2Tl) with deuterium as working gas with a lithium limiter of CPS material [1].

Measuring of ion flux. A lithium and a graphite limiters were installed in the opposite sections (180 degrees along the torus) symmetrically (Fig.1,2). The graphite limiter was used as a movable probe. It moved from pulse to pulse in SOL (in the lithium limiter shadow) on the surface of which there occurred recombination of lithium and deuterium ions and the subsequent sputtering and emission of neutrals in the plasma.

Fig.1. Lithium limiter with the collector plates in the T-11M.

Fig.2. Graphite limiter in the SOL of T-11M tokamak vessel.

The emission intensity of neutral lithium lines from the surface of the lithium limiter and from the graphite limiter was`measured with optical diagnostics (LiI line sensors)

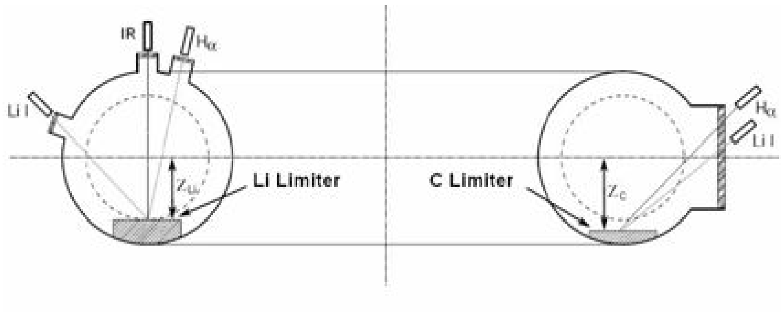

Fig.3. Li and C Limiters and optical diagnostics.

simultaneously (Fig.3). The sensors were photodetectors with preamplifiers and optical narrowband interference filters for neutral lithium line LiI (λ = 670,8 nm) and a bandwidth of about 5 nm. There was also a sensor with an interference filter with maximum transmission for the line of neutral hydrogen Hα (λ = 656,3 nm) for registering the recycling flux of deuterium from the graphite limiter.

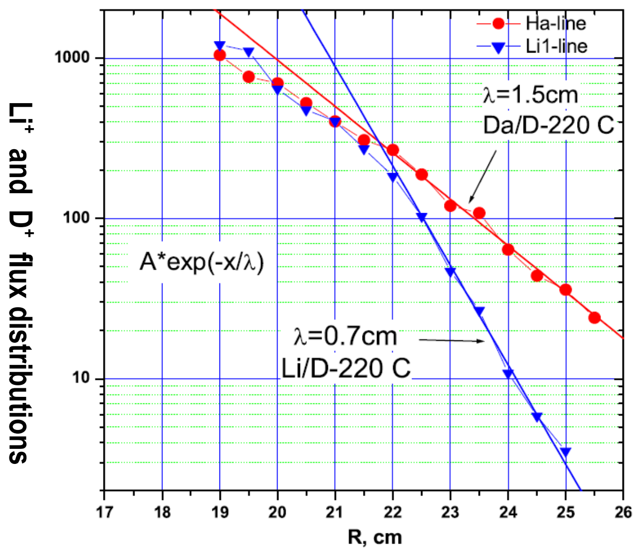

Fig.4. Radial profiles of Li^+ and D^+ ion fluxes in the SOL T-11M.

Measuring the distribution of deposited lithium. Some special tungsten plates, which are used for collection of deposited lithium were installed on the lateral surface of the base lithium limiter [3]. The location of the collector plates can be seen in the photograph (Fig.1). Those plates were taken after a large exposure (1000 shots to improve the accuracy of measurements) and chemical analysis was performed for the total amount of lithium for each collector. Results of the analysis were normalized to the square of the collector plate.

3. Results and discussions

The main results of both methods are combined and presented in Figure 5. Note that the radial profile of the deposited lithium is presented in absolute units, and flux density of lithium ions in the relative ones. In this case it is important that the forms of the curves are fundamentally different. The comparison of these curves shows that the secondary processes of the redistribution play a significant role in shaping of the profile of the lithium deposition. To explain this difference, we consider the balance equation for particles on the surface of the collector plate. Let $\mathbf{S_{Li}}$ and $\mathbf{S_D}$ – sputtering coefficients of lithium ions $\mathbf{Li^+}$, $\mathbf{D^+}$ and $\mathbf{\Gamma_{Li}}$ and $\mathbf{\Gamma_D}$ - fluxes of lithium and deuterium on the surface. Then, for the deposition rate of particles we write the balance equation:

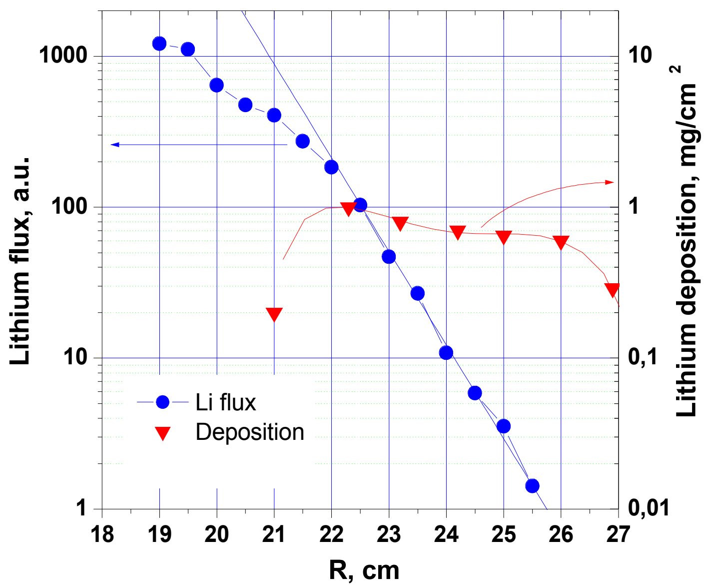

Fig.5. Profile of lithium ion flux and the distribution of the deposited lithium in the SOL T-11M.

$$\mathbf{dn/dt = \Gamma_{Li} - S_{Li}(n)\Gamma_{Li} - S_D(n)\Gamma_D}$$

$\mathbf{S_{Li}(n)}$ and $\mathbf{S_D(n)}$ **-** the density function of the deposition at low densities. If the layer growth rate of lithium: **dn/dt=0,** from the balance equation we obtain:

$$\mathbf{\Gamma_{Li}} / \mathbf{\Gamma_D} = \mathbf{S_D} / (\mathbf{1- S_{Li}}) \approx 0.01 \div 0.3$$

which is the condition of zero growth rate of the lithium layer in lithium-deuterium plasma. Thus, the flux ratio of lithium and deuterium ions must exceed the value of

$S_D/(1-S_{Li})$, which is usually close to the **S_D** for the positive growth of lithium layer (the accumulation) on the collector . It is important to note that the very magnitude of **S_D** - the sputtering yield of lithium by deuterium ions is not constant and depends mainly on two parameters: the surface temperature of the collector (and lithium, respectively) and very strongly on the deuterium ion energy [5], and hence the electron temperature plasma. In the range of 10 ч 100 eV for solid lithium **S_D** varies in the range 0.01 ч 0.3 [5]. Radial dependence of the electron temperature on the T-11M in these modes was measured with the Langmuir probe. According to the electron temperature data and using the results of Alain [5] we constructed the radial dependence of the sputtering yield of lithium with deuterium (Fig. 6, blue squares). The red dots in Figure 6 are estimated ratio of the fluxes of lithium and deuterium obtained by using code SOL-DINA. From the comparison of the curves in Figure 6. it is obvious that SOL exists in two areas: from the walls of the vessel to a radius of 23cm - the accumulation region of lithium and from the edge of the limiter up to 21cm – the region of the redistribution (erosion) of the deposited lithium, where the sputtering rate is higher than the rate of the deposition of lithium. Between them there may be an intermediate region with a slight accumulation and erosion of lithium.

4. Conclusion

The data obtained qualitatively confirm the model of the shaping of the profile and lithium redistribution by deuterium, which allows carrying out calculations of migration and circulation in the lithium tokamak reactor vessel in the future. This work was supported by Rosatom contract № 4f.45.90.11.1013.

References:

[1]. Mirnov S.V., et al, Plasma Physics and Controlled Fusion **48** (2006) 821S.

[2]. Lazarev V.B. et al, «Investigation of lithium distribution in the SOL of T-11M tokamak with lithium limiter», 35th EPS Conf on Plasma Phys, 2008, P5.004.

[3]. Mirnov S.V., V.B. Lazarev, «Li experiments at the tokamak T-11M in field of steady state PFC investigations», Conf PSI, 2010, P1-72.

[4]. Lazarev V.B. et al, «Experimental investigation of radial distributions of Li^+, H^+, D^+ in the SOL of T-11M tokamak with lithium limiter», 37th EPS Conf on Plasma Phys, 2010, P2.141.

[5] Allain J.P. et al., Journal of Nuclear Materials, 337–339 (2005) 94–98.