T-10 tokamak plasma discharge control by means of Li dust jet injection

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Introduction. The lithium dust jet injection as a possible tool for tokamak plasma discharge control is being actively investigated nowadays [1-3]. The rotary feeder lithium dust injector had been developed and installed on T-10 tokamak. The first test experiments with this injector [4] have revealed its compatibility with Ohmically and ECR heated discharge at lithium particle flows less than 5×10^{21} at/s. The deuterium recycling coefficient decreased due to lithium injection which made the T-10 plasma discharge with moderate deuterium flux from the first wall more controllable.

New lithium dust injection experiments were performed with the following goals: achievement of a reproducible injection at the lithium dust flows with rates close to maximum values initiating disruption; studying the injection influence onto the working gas recycling and wall conditioning; observation of cumulative effect of lithium injection on the plasma-wall surfaces. The corresponding results obtained are presented and discussed in this paper.

Experimental setup. The lithium dust injection technique is described in details in Ref. [4, 5]. Injection was fulfilled into Ohmically heated discharges with the following parameters: $\langle n_e\rangle=2\times10^{13}$ cm^{-3}, T_e=1.1 keV, I=200 kA, B_z=2.4 T. The metal lithium dust particles were injected into plasma with ~ 4 m/s velocities and 3-6$\times10^{21}$ at/s lithium flow rates, starting at 500 ms and lasting during the flat-top stage of the plasma current for 500 ms. Besides the standard set of diagnostics, several additional measurements were used, namely D, C, Li emission lines and continuum registration, video camera behind the LiII optical filter,. This was needed for evaluation of particle balances for three species, i.e. working gas – deuterium, major impurity – carbon, injected material – lithium.

Some difficulties of the injection technique were caused by a set of funnels that is used to supply dust flow to plasma from the exit of the dust feeder. It was observed that this set essentially changed the temporal behavior of the injection flow rate from the steady-state to the bell-shaped one.

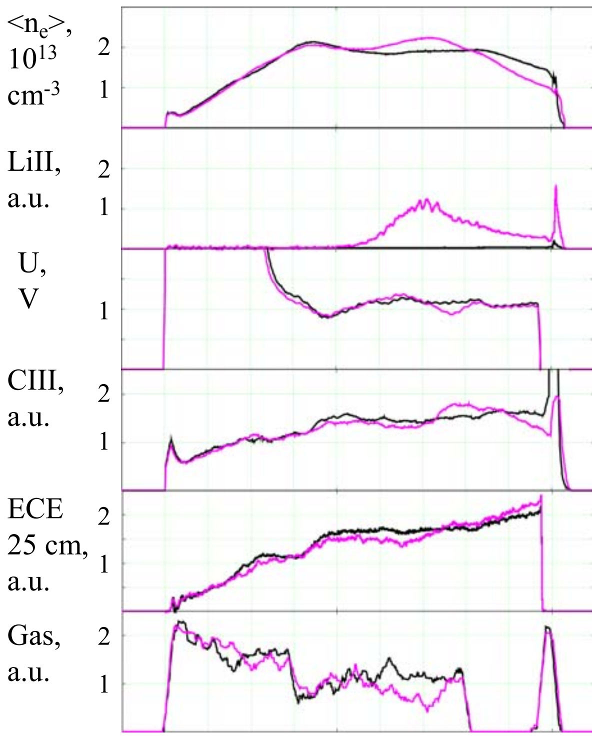

Fig.1 Li dust injection, OH. Black - #61645 without Li, magenta - #61650 with Li.

Results and discussion. The stable and reproducible injection with flows close to 5×10^{21} at/s have been obtained. The temporal evolution of main plasma parameters and the estimated dust flow rate are shown in Fig. 1. Here the line averaged electron density, LiII line intensity, loop voltage, CIII line intensity, ECE emission intensity from 25 cm of minor plasma radius, gas puff intensity are shown.

One can see from Fig.1 that no drastic disturbance of main plasma parameters including the peripheral electron temperature observed at Li flow values close to 5×10^{21} at/s. The 5×10^{21} at/s injected lithium flow threshold for development MHD event after injection estimated in the previous series [4] had been confirmed. The loop voltage and peripheral temperature signals are in opposite phase (see U increase at 600-700 ms in Fig. 1 and further decrease). This correlates with the Spitzer conductivity evolution $\sigma\sim T^{3/2}/Zeff$ in conditions of the feedback for the current stabilization at the impurity injection into the plasma discharge periphery. The exact explanations of the CIII line intensity growth at U decrease after the injection maximum (Fig. 1, 750-800 ms) had not been found. It is necessary to take into account as the decrease of the C flow from limiter due to temperature fall along with the simultaneous line excitation coefficient growth.

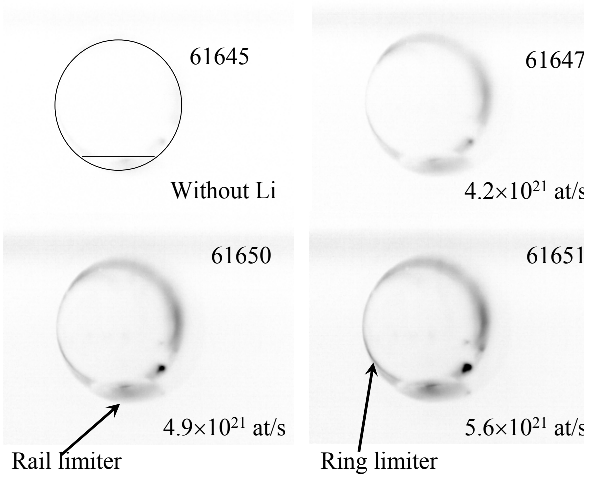

Fig.2 Video shots in LiII line. Shot time – 800 ms. Exposure duration – 20 ms.

In Fig. 2 snap shots of plasma cross section in LiII line are shown. One can see that the major lithium part deposits on limiters. It increases with a growth of Li flow into plasma and fairly correlates with the injection flow rate. There is no notable Li radiation from the plasma core and the T-10 first wall. The emission from limiters exceeds Li radiation from the plasma core in ~10 times. The discharge conditioning signs (lithium accumulation on the limiter after the series of subsequent injections and correlating CIII signal decrease) had not been detected. The possible cause is that the standard T-10 discharge ends with disruption and the lithium cover on the limiter is being ablated.

Particle balance estimation. To evaluate behaviors of three species a simple 0D balance equation approach was used:

$$\frac{dN_D}{dt} = F_D - \frac{N_D}{\tau_D^*} \ (1); \qquad \frac{dN_C}{dt} = F_C - \frac{N_C}{\tau_C^*} \ (2); \qquad \frac{dN_{Li}}{dt} = F_{Li} - \frac{N_{Li}}{\tau_{Li}^*} \ (3).$$

Here, N_D, N_C, N_{Li} are total amount, $\tau_D^* = \frac{\tau_p}{1-R_D}$, $\tau_C^* = \frac{\tau_p}{1-R_C}$, $\tau_{Li}^* = \frac{\tau_p}{1-R_{Li}}$ are effective confinement times, R_D, R_C and R_{Li} are effective recycling coefficients of deuterium, carbon and lithium correspondingly; τ_p is particle confinement time (assumed to be equal for all species), F_D is a deuterium flux, F_C is a carbon flux into plasma from the first wall and limiter, F_{Li} is a flux of injected lithium. N_e is the total amount of electrons which can be evaluated from the experimentally measured interferometric data. The particle flows were assumed to be proportional to the corresponding D_β, CIII and LiII line emissions, Z_C=6 and Z_{Li}=3 were assumed over the whole plasma volume and other impurities were not taken into account for simplicity.

The particle confinement time τ_p was assumed to be equal to energy confinement time $\tau_E \approx 30ms$ which was estimated using scaling for ohmic heated plasmas [6]. The D_2 flow from the gas puff into plasma F_D was proportional to the voltage on the gas valve V_G with the coefficient A_D ($F_D = A_D \cdot V_G$). The deuterium flow coefficient A_D was chosen to prevent an essential time variation of τ_D^* in the quasistationary phase of the reference shot #61645 without lithium injection. The carbon flux F_D and lithium flux F_{Li} were evaluated using eq-ns

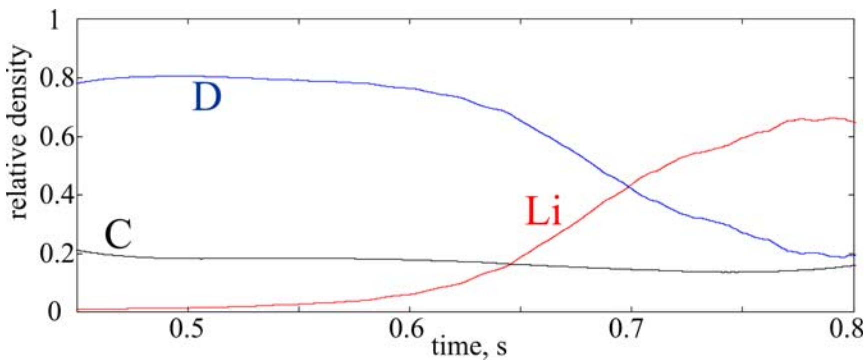

Fig. 3. The relative electron density profiles produced by different sorts of nuclei for shot #61648 (blue – deuterium, black – carbon, red – lithium).

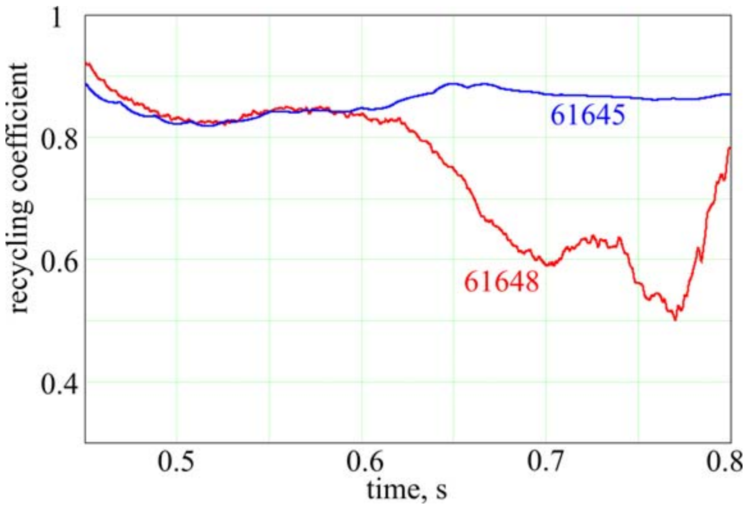

Fig. 4. The deuterium recycling coefficient evolution in the reference shot 61645 without lithium injection and shot 61648 with injection.

(1-2) and data of temporal evolution of electron density and the visible continuum signal. Using it the relative electron density profiles produced by different sorts of nuclei were calculated for shot #61648 (see Fig. 3). A decrease of deuterium density during Li injection indicates the deuterium recycling coefficient reduction.

Then, τ_D^* time evolutions for shots with and without lithium were evaluated. The results are shown in Fig. 4. Blue line presents the recycling coefficient for the reference shot, red line – for the shot with lithium injection. It is seen that it decreases from 0.85 to the essentially lower 0.6-0.5 values.

Summary. Experiments on lithium dust injection into T-10 tokamak plasma have been carried out with the Li flow rate close to 5×10^{21} atoms/s. An analysis of Li distribution in plasma core shows what Li deposits mainly on to limiters and periphery plasma region. A simple estimation of effective confinement time for deuterium might be interpreted as decreasing the deuterium recycling coefficient from the 0.85 value prior to Li injection to 0.6-0.5 ones during injection.

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