Observation of plasma processes in SOL region of T-11M tokamak with lithium limiter and target-collector by fast video registration

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Introduction

Experiments with lithium limiters (LL) based on capillary-porous systems (CPS) have been carried out on T-11M tokamak since 1998 [1, 2]. A new high-speed color camera with exposition time up to 4 μs and 300-1000 fps (frames per second) and narrowband interference filters was installed for fast video recording of plasma-surface interaction with a Lithium limiter on the base of capillary-porous system and a target-collector in T-11M tokamak vessel. This new technique gave us a possibility to observe some new phenomena near the surface of the lithium limiter especially when viewed fast transient processes and also to observe in SOL region and near the surfaces of the target-collector.

Interaction with the longitudinal limiter

The experiments were carried out in the ohmic regime on the T-11M tokamak (Ip = 70kA, Bt = 1.2T, R = 0.7m, r = 0.18m). We used hydrogen as the working gas in a tokamak chamber. A vertical lithium-type CPS limiter (VLL) was installed on the outer circumference of the torus, and a longitudinal lithium limiter (LLL) [6] was installed tangentially to a large radius in the lower part of the tokamak vessel. Both limiters were used both individually and jointly to operate in ohmic mode. VLL limiter was not available for detailed observation. We studied mainly LLL. It had the form of a cylinder with a diameter of 2.5 cm covered with a lithium-based CPS layer 1 mm thick. The operating temperature of the limiter was 200 ÷ 350 ° C. Figure 1 shows a typical LLL interaction with peripheral plasma in a stable discharge. The glow of neutral lithium has a maximum on the ion side, due to the plasma flow.

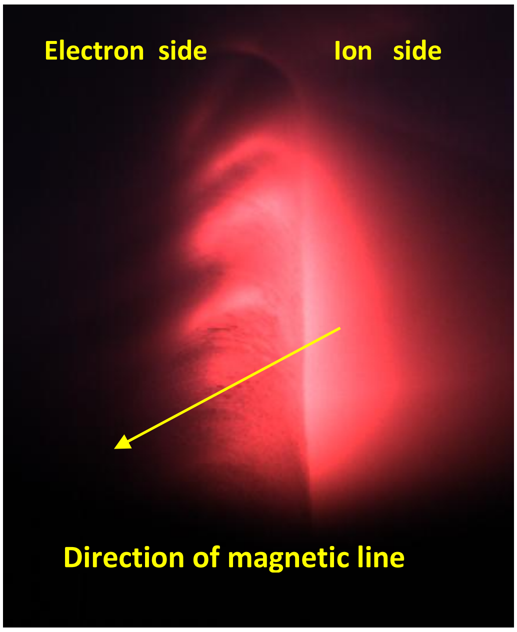

Fig.1 LLL view in stable working mode. Temperature of PLL is 262 ° C. Exposure 4μs, # 38457 frame 25, without any filter

On the surface of the limiter, a wavy fashion structure is seen. The arrow on the surface of the limiter shows the approximate direction of the magnetic field line.

Lithium CPS limiter under MHD events

The magnetic fields in T-11M tokamak vessel reach 1T and are not strictly stationary during discharge. Rapid field changes occur at the stage of rise and fall of the plasma current, as well as in the quasistationary phase of the discharge, caused by the development of MHD instability. The strongest and most dangerous perturbations of the fields arise when instability of disruption arises. The main purpose of a capillary-porous structure (CPS) in a tokamak limiter or divertor is the retention of lithium against the action of JxB forces arising during the development of such MHD instabilities. Based on this criterion, we chose the effective pore radius of the CPS structure r_{eff} on the surface of the T-11M limiter. Therefore it is interesting to observe with a fast camera the process of a fast MHD event in a tokamak with a lithium limiter. MHD instability such as ELMs and disruption instability are phenomena that do not allow you to use free-flowing liquid lithium (or another metal) in a tokamak. An example is the experiment with lithium DiMES on D-IIID [7]. The camcorder worked without filters. Fig. 2 shows one frame from the video recording of a small disruption. The average speed of the lithium droplets can be estimated by the length of the tracks and the exposure of the frame. The velocity of the drops Vd, determined from the tracks in Fig. 2, is about Vd ≈ 0.1÷1 km/s. The spots of intense interaction (on the ion side) show that the magnetic "tube" with hot plasma intersects with LLL. We believe that in this case the JxB forces do not exceed the capillary pressure. But in this case, the physics of drop generation is probably not related to JxB forces, and other physics associated with high pressure and plasma spreading rate near the surface liquid lithium layer, which causes the development of Kelvin-Helmholtz instability.

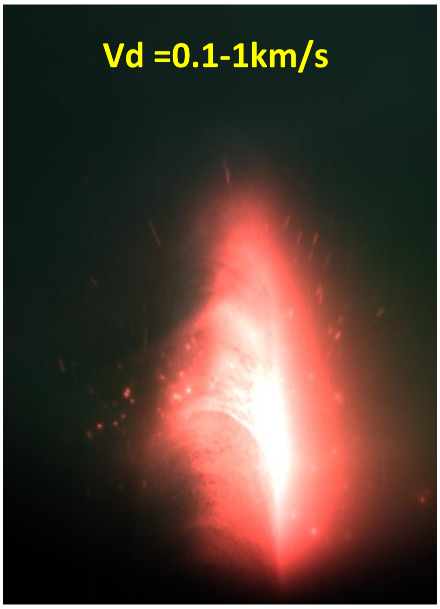

Fig.2 The effect of MHD instabilities on LLL with CPS. The temperature of LLL 262°C, exposure 4μs, discharge # 38472, frame 21, without filter

Radiation of lithium neutral atoms near the target

To register fast processes, we used a minimum exposure time of 4 μs and a video recording rate of up to 1000 frames per second was used to observe the target [5, 6] in the SOL of tokamak T-11M. A video was recorded with the use of interference filters for LiI lines (671 nm) and LiII (549 nm) and hydrogen Hα (656 nm). In these cases, when we work using interference filters for LiI (671 nm) and LiII (549 nm) and hydrogen Hα (656 nm), the exposure time should be increased to 30-300 μs, because the sensitivity of the camera is not enough. Using the video data, we determined the distribution of the emission of neutrals near the surface of the target in the poloidal and radial direction. Figure 3 shows the frame view from the video sequence (# 37338, exposure time 40μs), where you can see the glow of neutral lithium near the surface. The distribution of the brightness lines of neutral lithium LiI (671 nm) is determined by several different processes. The recombination of lithium ions takes place on the surface of the target. Neutral Li, formed after recombination on the surface of the target, is atomized and partially ionized by plasma SOL. As a result, neutral Li injected from the surface of the target is excited by electron impact in the plasma and accumulates. The injection rate of Li, measured in D-IIID experiment [7], was 2÷4 km/s. The distribution of the intensity of neutral-lithium radiation in a direction perpendicular to the surface of the cylinder (target) depends on the penetration rate and the ionization rate of neutral lithium. This distribution was obtained by scanning the video frame in the poloidal direction (Fig. 4), presented in the logarithmic scale in Fig. 3. The characteristic decay for lithium penetration obtained from these distributions is λ = 1.3 cm and depends on the plasma density.

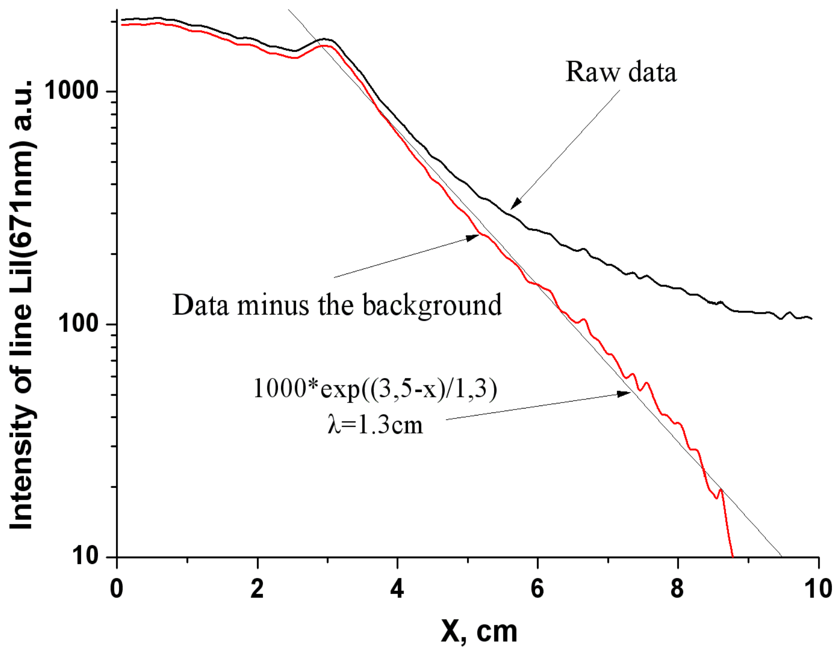

Fig.3 The distribution of LiI line (671 nm) neutrals intensity near the surface of the target in the radial direction indicated in Fig. 4

#37338, frame 77
exposure 40μs

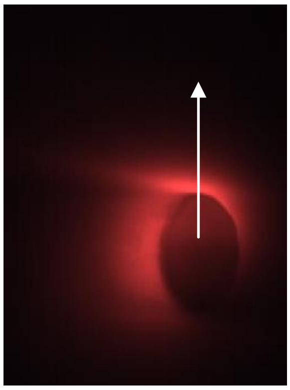

Fig. 4 The intensity of LiI line (671 nm) near the cylindrical target in the SOL of T-11M, and the scan line (arrow)

Using the obtained value of the characteristic drop λ = 1.3 cm, we can estimate the injection rate of lithium neutral from the surface: $V_{inj} = \lambda \cdot Ne \cdot \langle \sigma v \rangle \approx 2600$ m/s,

where: $\langle \sigma v \rangle \approx 10^{-13} m^{-3}/s$ - ionization rate at density $Ne = 2 \cdot 10^{+18} m^{-3}$ and temperature Te≈30eV, which roughly coincides with the results of spectroscopic measurements D-IIID [7].

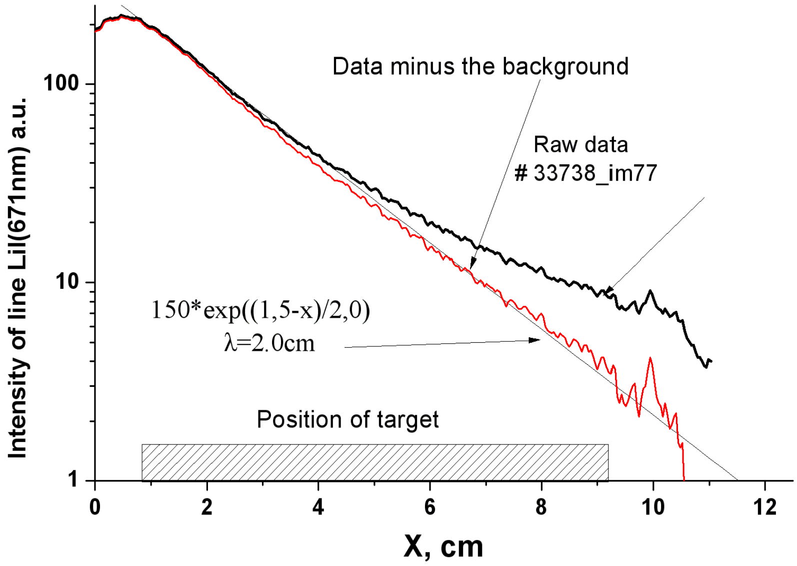

Fig.5 The distribution of LiI line (671 nm) neutrals intensity near the surface of the target in the radial direction indicated in Fig. 4a

#37338, frame 77,
exposure 40 μs

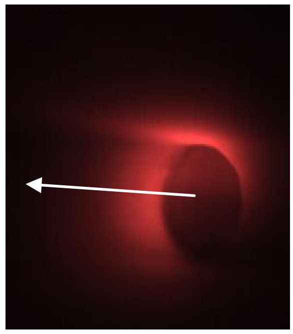

Fig. 4a The intensity of LiI line (671 nm) near the cylindrical target in the SOL of T-11M, and the scan line (arrow)

Figure 5 shows the distribution of the intensity of neutral lithium LiI (671 nm) in the radial direction along the collector target (Fig. 4a), which characterizes the radial distribution of the longitudinal flow of lithium ions in the SOL of tokamak. The magnitude of the characteristic drop for this flow is $\lambda = 2$ cm for this mode. That corresponds to the results obtained earlier on T-11M by another method [3, 4]. In both cases, when processing the data (Fig. 4, Fig. 5), a procedure was performed to subtract the background level to increase the accuracy of the exponential decay λ, assuming that the flux distributions have the form $A \cdot \exp(-x/\lambda) + C$.

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