

## Compatibility of the Lithium Capillary Limiter with Plasma in T-11M

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### 1. INTRODUCTION. Li-divertor conception.

The most critical elements of the tokamak reactor are divertor plates and plasma facing components. Berillium and carbon, as follows from JET and JT-60U experiments, are not optimal constructional materials for these elements. The next low-Z material is Lithium and the appropriate transition practically was begun in TFTR and DIII-D by injection of the Li-pellets [1]. The next step could be the divertor plates on a Li- basis. The general problem of Li-divertor is the heat transport from plasma to the wall. As the most realistic looks the scheme of the heat transportation to a wall by radiation of neutral and ionized Lithium (re-radiation). The necessary Li-level near separatrix should be carried out by income of the Lithium from divertor plate and optimum choice of its life time  $\tau$  near the plasma periphery. By virtue of a low Z Lithium is bad re-radiator. The increase of the radiation is possible, either by addition the high-Z impurity (for example Ar), or by removal Li to strong non-stationary ionized condition by worsening of its confinement near separatrix. Fig.1 shows the total Li-line intensity radiation which was calculated for different electron temperatures and non-stationary parameter  $n_e\tau$  ( $n_e$  - electron density in  $\text{cm}^{-3}$ , calculations are carried out similarly [2] in coronal approximation.). In the range of electron temperatures 30-300eV the power of non-stationary Li-radiation can exceed the stationary limit (coronal equilibrium) by 2-3 order. For ITER it would be enough to have near the separatrix the Li-radiating blanket by thickness  $\sim 10\text{mm}$ , density  $n_e=2*10^{13}\text{cm}^{-3}$  and  $n_{\text{Li}}=10^{13}\text{cm}^{-3}$ , with  $\tau=10^{-3}\text{sec}$ . This blanket re-radiates to the wall about 100MW with accompaniment of 30-100MW electron losses. It is possible, that such small  $\tau$  will be established by themselves, as a result of peripheral MHD activity (type III ELM), or as a result of special magnetic ergodization of periphery (ergodic divertor), or, at last, as a result of special limiter design. However for all radiating divertors a common element should be Li-divertor plate, as a Li-source, which is capable to keep the powerful thermal shocks, arising during ELMs or major disruption. One of the possible suggestion of the such plate was offered by V.Pistunovich e.a. [3] on a basis of the Capillary Porous Systems (CPS) with Li-filling. Elements of the similar plates have been successfully tested by electron beams and plasma guns [4]. The next step should be the plasma tests in real tokamak. What it was necessary to test?

### 2. EXPERIMENTAL TASKS AND CONDITIONS.

The compatibility of the peripheral tokamak plasma and Li- CPS was the main subject of test. Such compatibility assumes the absence of significant spontaneous Li-bursts into hot plasma during the discharge. The reason of the such bursts could be a difference of electrical potentials between plasma and wall, and, as a result of it:

- the development of unipolar arches or local surface "explosions" (Li-blooms).
- the increased erosion of the Lithium, which can be connected with the ion sputtering, - the microcapillary waves near the plasma-liquid metal boundary. Contribution of all these processes into the real Li-erosion can be investigated experimentally in conditions of

average size tokamak with boundary electron temperature on the limiter in a range of 15-30eV. The tests of CPS as limiter material was performed in tokamak T-11M.

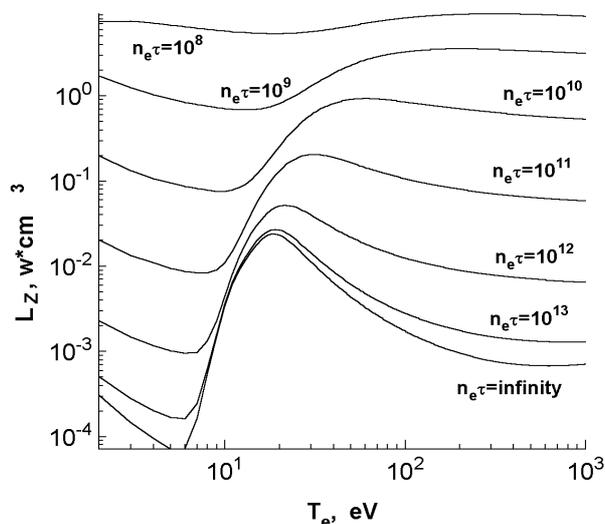


Fig.1. Intensity of the Lithium line radiation calculated for different electron temperatures and non-stationary parameter -  $n_e\tau$  (on one Li atom and one electron).

In these experiments plasma current was  $I_p \leq 100$  kA, duration of the discharge  $\tau \leq 0.1$  sec, toroidal magnetic field  $B=1$  T, major radius  $R=0.7$  m, minor radius  $a=0.19-0.23$  m, average electron density  $\langle n_e \rangle \sim 1.5-2 \cdot 10^{13} \text{ cm}^{-3}$ , and electron temperature  $T_e(0) \sim 0.5-0.8$  keV.

The experiment on T-11M was carried out as follows: the horizontal rail limiter covered with CPS was moved into the plasma. Design has Li-impregnated multilayer Molybdenum grids from wires (thickness  $d=0,1$  mm and cell size  $0,15$  mm) [4]. In the cross section separated by  $90^\circ$  in toroidal direction was installed geometrically equivalent graphite limiter. To control the plasma-limiter interaction the optical monochromator and set of photo diodes were installed in both cross sections. These instruments allow to register the H, Li, He-line radiation, and total light- $I_\Sigma$  in visible and quartz spectra. Also were measured the central chord average density  $\langle n_e \rangle$ , Soft X-Ray (SXR) and spatial radiating losses of plasma -  $I_{\text{rad}}$  in vacuum ultraviolet (by AUXV-photo diodes [5]), During experiment, we gradually (from discharge to discharge) replace the C-limiter and put into the plasma Li-limiter (from  $r=24$  to  $19$  cm). Simultaneously we measure above mentioned parameters near the surface of the both limiters and  $n_e$ . The typical energy deposition on the limiter surface -  $P \sim 0.3-1 \text{ kW/cm}^2$  - was measured in similar conditions [6]. It was expected, that during the discharge the temperature of the Li-limiter surface is increased to  $100-150^\circ\text{C}$ , i.e. it will not exceed the melting temperature of the Lithium ( $186^\circ\text{C}$ ). To guarantee the liquid Lithium surface, the Li-limiter was preliminary heated approximately up to  $300-400^\circ\text{C}$  ( thermocouple measurements).

### 3. EXPERIMENTAL RESULTS AND CONCLUSIONS.

The first qualitative comparison of the Helium plasmas in conditions of C- and Li-limiters has shown, that solid ("cold") Li as limiter material is practically equivalent to graphite covered by Boron. The transition of the Lithium into liquid ("hot") condition has found out some new features. Fig.2 shows the temporary behavior of total light intensity close Li-limiter in three hydrogen discharges with different initial Li-limiter temperature. The spectral line analysis has shown, that total light intensity close Li-limiter is almost proportional to LiI and LiII radiation and can be the indicator of Li-emission. We shall notice, that in "cold" condition the light is almost constant during the discharge. That is approximately the same as in the case of C-

limiter. It means that the impurity fluxes are similar in both cases.

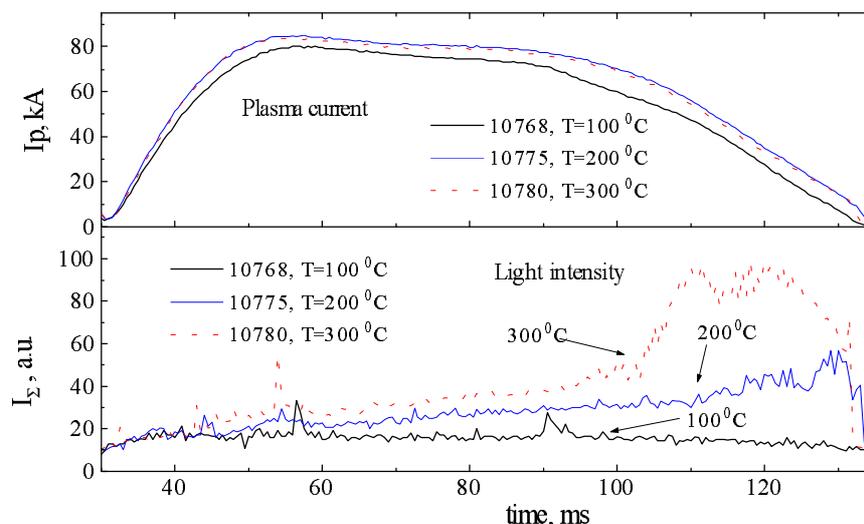


Fig. 2. Light intensity near the limiter during same shots for different initial lithium temperature 100-300 °C.

We shall note also, that in all cases the total light intensity have smooth character without any strong spikes of the emission. It shows that there is no unipolar arches. However, in the case of "hot" limiter (Fig.2) there is burst of integrated light intensity at the end of the discharge. The analysis has shown, that this burst is not accompanied with some significant emission of the Lithium into plasma and there was absent the total radiation losses. Probably, this phenomenon is connected with local re-radiation of a plasma thermal flow of a MARFE type in peripheral low electron temperature regions. That is a subject of future investigation. Fig.3 shows the discharges with two Hydrogen puffing pulses for cases with "cold", "hot" and again "cooled" Li-limiter. It is possible to see, that the added hydrogen rather quickly leaves the discharge with the time close to life times of charged particles (12-17 msec). The H-recycling is low. H-behavior does not depend directly on limiter temperature and prehistory. It allows to make a conclusion, that Lithium works as a strong Hydrogen sorbent, but absorption is not by limiter. Most probably, it is connected with Lithium sputtered on the wall. This conclusion proves the fact, that effective H-absorption take place a long time in discharges with C-limiter after replacement of the Li- one. The different behavior of  $n_e(t)$  in "cold" and "hot" cases is obvious result of the Lithium emission. It was found, that during gradual heating of the limiter this emission has jump growing. Also it has jump falls during limiter cooling. Such behavior of the Lithium emission, apparently, reflects the transition through melting point of Lithium. Also it might be connected with the growth of the sputtering coefficient (in 3-5 times [7]). But it is also possible, that the jump falls of the Li-thermal conductivity as result of the temperature transition through melting point, increases the surface temperature and has as a consequence the increase of Lithium thermal emission. Experiments with Helium, where the sputtering should be higher than in Hydrogen, has shown approximately the same total light intensity that proves this conception. We believe, the anomalous Li-erosion was absent in our experiments. The visible Li-emission corresponded to thermal emission under  $T_{LM}=500^{\circ}C$ .

Experiments with Helium have found out however some feature, which could be used in the future. Helium, as expected, has no absorption by "cold" Lithium. In this case the added Helium pulse injection was not required for discharge organization (as it was applied in hydrogen discharges). However at transition to liquid phase it was found, that in a discharges

with fixed gas puffing the gradual (from a pulse to a pulse) decrease of  $n_e(t)$  occurs. Let's notice, that there is the same tendency as at the beginning phase in Hydrogen (Fig.3) and at the ramp down phase of the second gas puffing. That is possible if to take into account, that the liquid Lithium, having low coefficient of secondary electron emission, can obstruct the electron returning into the plasma, i.e. to promote increase of its positive charge and, accordingly, reduction of life time of peripheral ions. This mechanism could be useful for creation of the radiating blanket.

In summary it is necessary to emphasize that the major technical advantage of the Lithium limiter is self restoration after heating. In experiment with "cold" limiter, when Lithium replenishment was absent, sometimes it was possible to observe appearance of the Molybdenum grids). The warming up to Lithium melting allowed completely to avoid these defects, restoring homogeneous structure of a surface. It is important quality of the reactor divertor plate. After more than 1000 pulses, the analysis of Molybdenum grids have shown complete absence of any traces of destruction.

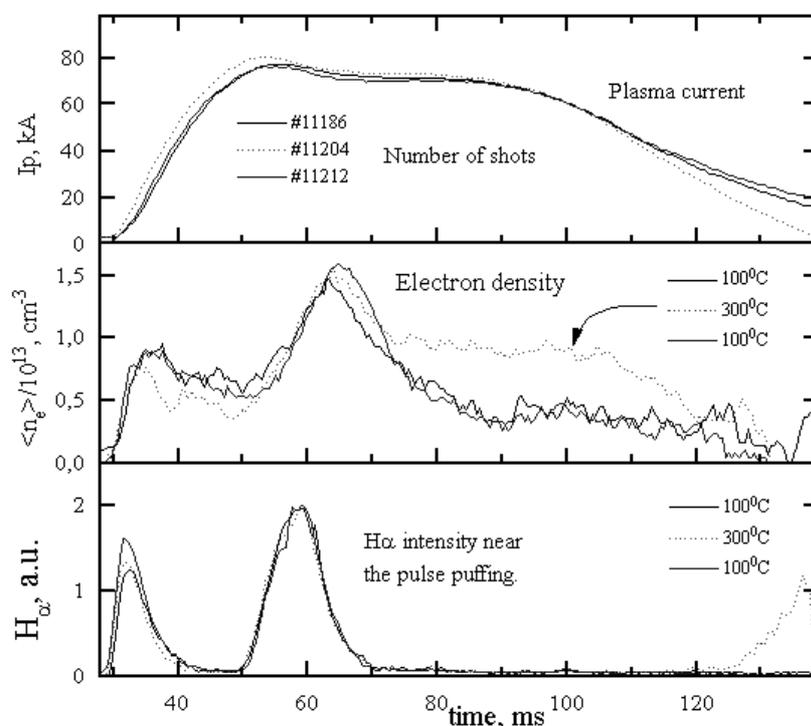


Fig. 3. Behavior of plasma electron density in different conditions: before heating of Lithium limiter (#11186), under heating about  $T=300^{\circ}\text{C}$  (#11204), and after the cooling (#11212).  $\text{H}_2$  pulse puffing.

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