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Development of lithium vapor injector for boundary control

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ABSTRACT

A lithium (Li) vapor injector for boundary control has been developed. A diverter covered with lithium is expected to reduce particle recycling. Recycling reduction is considered to be one of the triggers for the L–H transition. In this paper, the method of lithium dispersion is investigated under the assumption that the experiment is carried out in the Large Helical Device in National Institute for fusion Science, Japan (LHD). A performance test is performed on a prototype of the vapor injector. The amount of injected lithium was approximately 1% of the value expected from the vapor pressure data, due to the generation of lithium oxide. It is also found that nozzle temperature is quite important to suppress the Li dispersion.

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1. Introduction

The transition to the improved confinement mode (H-mode) is one of the most important issues for self-burning plasmas in fusion test devices. It is believed that reducing the density of the edge plasma is a trigger for the L–H transition, according to reports on the relationship between the edge density and the confinement [1]. It is thought that pumping neutral particles out at the diverter may control recycling at the first wall or diverter. To physically pump out the neutral particles, a closed diverter will be installed in the Large Helical Device (LHD) [2]. The diverter room with a baffle plate causes the neutral pressure near the diverter to rise, and they are removed by the cryopumps. A chemical tool has also been proposed for reducing particle recycling. If the wall or diverter is unsaturated, then recycling would be small. To realize an unsaturated diverter, we suggest covering the diverter with Li. The Li can co-deposit as Li-Hydride (LiH), meaning that the Li absorbs the recycling hydrogen. Li conditioning has already been attempted in NSTX [4–6] and TJ-II [7]. Because coating was performed before discharge, the effect of coating may be limited. It is possible that an unsaturated diverter could be realized if sufficient Li vapor is continuously injected into the diverter [3]. There exist some methods to inject Li into the plasma. Lithium Pellet Injection (LPI) has been used in tokamaks such as the Tokamak Fusion Test Reactor (TFTR), the National Spherical Torus Experiment (NSTX), ALCATOR C-MOD-ification (C-Mod), Doublet III-D (DIII-D) and Tokamak de Varennes (TdeV). Laser ablation is another predominant technique for injecting a great deal of vapor [8].

In this study, a Li-injector that can inject Li vapor during discharge and is suitable for steady-state discharge was developed for the Large Helical Device (LHD). It is expected that the coated diverter will efficiently catch recycling particles and lead to density control in the long-time discharge plasma.

2. The Li dispersion idea

We should put Li only on the diverter to protect the measurement devices, vacuum window, etc. To coat the entire helical diverter of the LHD with Li, all we need to do is to inject Li vapor into the surrounding plasma, which is located in chaotic, open magnetic field lines. Fig. 1 is an image seen from the LHD outer side port. The purple is the twisted toroidal plasma in the LHD. We injected the thermal Li beam within the white circle, which is 40 cm in diameter. The Li beam should be collimated as much as possible to suppress particle loss.

Li in the plasma ionizes easily, as the ionization cross-section is $6 \times 10^{-8}\ \mathrm{cm^{-3}\ s^{-1}}$ at 10 eV. The penetration length is a few centimeters below the surrounding plasma conditions. Because the LHD has thick surrounding plasma, almost all of the charged Li particles are transported to the diverter along the open field lines. There is also a diverter leg on the way to the surrounding plasma. However, at least 50% of the lithium vapor can pass through the leg plasma.

We can estimate where the ionized Li particles will go by calculating the open field line traces. Fig. 2 shows the result of this calculation. The starting points of the traces are located in the area

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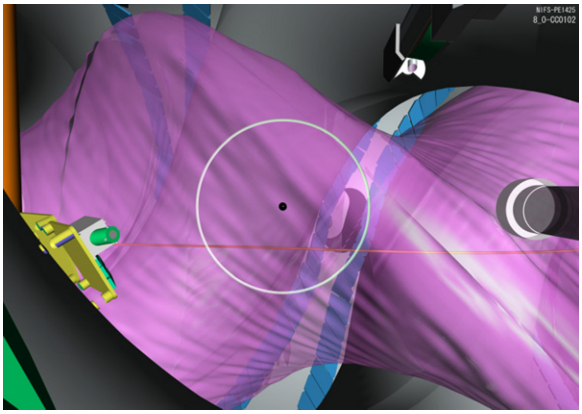

Fig. 1. Image of LHD plasma.

indicated by the white circle in Fig. 1. The LHD has ten toroidal sections, corresponding to the horizontal axis. The vertical axis is the poloidal angle. So this graph indicates a map of the diverter location. We can also see this plot in the entire diverter. This figure shows that Li particles injected at one source will be widely dispersed within the toroidal section.

We have estimated the amount of Li dispersion necessary for boundary control in an LHD-size device. We assumed that the hydrogen flux is on the order of 10^{18} atom/s/cm^2. Particle recycling should be controlled to 90% for boundary control. Consequently, a Li flux on the order of 10^{17} molecules/s/cm^2 is required to pump the hydrogen. Because the helical diverter area is 10^4 cm^2, on the order of 10^{21} Li atoms/s should be injected into the main discharge plasma. If we can continue to flow Li into the main discharge plasma, we would obtain an unsaturated wall, and long-time discharge in the H-mode, driven by reduced recycling, may be achieved.

3. Prototype of vapor injector

We made a prototype of the Li vapor injector to check for mechanical issues and to verify the principle of operation. The nozzle size is important, as a large amount of Li vapor must be injected. Because the vapor pressure increases logarithmically with the temperature (see Fig. 4), the injector should be heated to at least 650 °C. The flux is 10^{20} Li-atoms/s/cm^2 at 650 °C, so a nozzle size of 10 cm^2 is required. In this study, a 50 mmΦ nozzle (19 cm^2) was selected.

The picture and the draft of the prototype are shown in Fig. 3. The container is made of stainless steel. A stick heater (250 V–1000 W) is

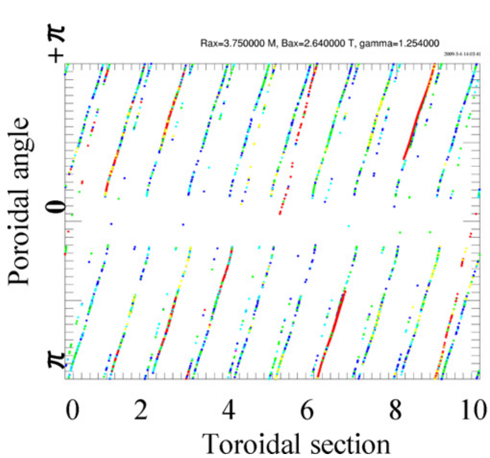

Fig. 2. The calculated open field line traces.

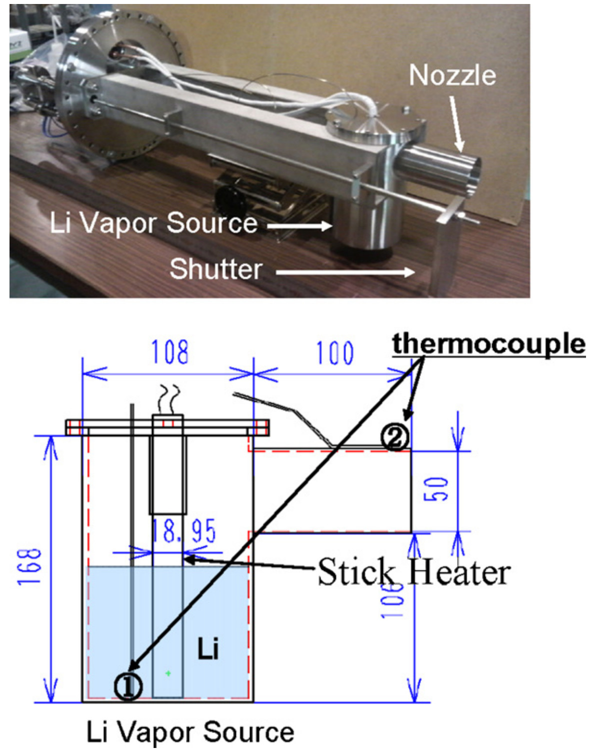

Fig. 3. Picture and draft of the prototype.

used. Two thermocouples are included to monitor the temperature. One is directly attached to the solid or liquid lithium (thermocouple 1 in Fig. 3), and the other thermocouple measures the temperature at the end of the nozzle (thermocouple 2 in Fig. 3). The sharpness of the Li beam depends on the temperature of the nozzle. If the temperature is higher than the melting point of Li (hot nozzle), then the beam is wide, because Li particles can re-evaporate at the nozzle wall. If the temperature is lower than the melting point (cold nozzle), then the beam is sharp.

4. Experimental result and discussions

We carried out the experiment in the cylindrical vacuum chamber LIGHT-1 (Lithium Injection Gettering of Hydrogen and its Transport exps.) [9]. The chamber is 1 m in diameter and 1 m in length. The prototype is set at the end of the chamber, and quartz crystal film thickness monitor that measure the real-time deposition rate are installed 50 cm from the end of the nozzle to measure the Li beam profile.

A 200 g Li ingot was heated gently in the injector. After keeping the melting point (180.5 °C), we measure the Li vapor flux radial profile at 550 °C. The nozzle edge temperature is 380 °C. It correspond to the hot nozzle. The results are shown in Fig. 4. The point $r = 0$ corresponds to the center of the nozzle. Fig. 4(a) shows a comparison of the experimental deposition rate and the rate predicted by the Monte-Carlo code (dashed and solid line) [10]. In the simulation, lithium atoms pass through the nozzle, reflecting in arbitrary directions from the wall of the nozzle in the case of the hot nozzle. A Cold nozzle catches the particle. Li–Li collisions are not taken into account. By measuring the number of atoms in the target plasma, we can estimate the beam flux and its profile. In Fig. 4(a), the dashed and solid lines are normalized by the data at $r = 2$ cm to clearly compare the beam profile. The result agrees with the hot nozzle simulation. The lower graph shows the reconstructed flux. The experimental plots are calculated from the deposition rate. The simulation line is calculated from the measured vapor pressure. We

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