Improvement of the STOR-M tokamak plasma discharges by lithium coating of the inner wall

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Introduction

In a tokamak, increased fuel recycling may lead to loss of control of the plasma density and high-Z impurity release from the first wall to tokamak discharges will increased radiation loss. These two adverse effects can be reduced by coating of the tokamak wall. Boronization, siliconization and lithium coating of the tokamak first wall have been used to reduce the fuel recycling and the high-Z impurities release from the tokamak wall [1]. Lithium (Li) is one of the most chemically active metallic elements with a low charge number and low melting temperature. Lithium can be employed as an active getter for low-mass impurities inside the tokamak chamber such as oxygen, carbon and water. It has been reported previously that Li coating of the inner tokamak wall reduces low-Z impurities (oxygen and carbon) in the tokamak plasma [2–6]. Improvements of plasma parameters, such as the increase of plasma current and energy confinement time, have been experimentally observed after utilization of Li as the plasma facing components (PFC) [3,6,7]. Furthermore, coating of the inner wall of a tokamak with Li reduces the hydrogen recycling from the tokamak wall [2,7,8] and thus reduces the plasma density. To compensate for the reduction of the plasma density, additional fueling using different techniques such as supersonic gas puffing, molecular cluster injection and neutral beam injection (NBI) are necessary [9-10]. The STOR-M tokamak (R/a = 0.46/0.12 cm, B_t = 0.65 T, I_p = 22 kA) is a small research tokamak located at the University of Saskatchewan. It is equipped with a tangential compact torus injector which is used for fueling purposes and the plasma toroidal flow control [11]. The tokamak chamber is made of stainless-steel (304L alloy) [12]. In recent collaboration with General Fusion (GF) Inc. Li evaporators developed by GF have been installed on the STOR-M tokamak. The experimental setup and results are described in the following sections.

Experimental Setup

General Fusion has developed a modular lithium plasma vacuum deposition (PVD) system which can safely and conveniently deposit lithium coatings on relatively large vacuum vessels in situ. The PVD system, illustrated in Figure 1, consists of a 2 grams Li rod placed inside a basket which is covered by a mesh to prevent Li from splashing during the evaporation and boiling process. A closed end stainless steel (SS) pipe is inserted into the basket and a heater cartridge integrated by a thermocouple is inserted into the pipe to heat the Li rod. The inside of the SS pipe is isolated from the vacuum. The heater, which is controlled by a PID controller, can heat up the Li rod to 600 ºC which is higher than the melting point of Li (180 ºC). The whole system is installed on a long feedthrough. To coat inside the chamber, the evaporator is inserted into the center of the chamber while the chamber is pumped to high vacuum. The coating process typically lasts for 10 minutes at 500 ºC. After finishing the coating process, the evaporator is pulled out from the center of the chamber and placed away from the plasma during discharges. The whole coating process is performed under high vacuum. The STOR-M tokamak is equipped with a residual gas analyzer (RGA) which can monitor contamination in the chamber with molecular mass up to 100 amu. A spectrometer attached to a high resolution ICCD camera is used to record line emissions of plasma impurities. The spectrometer is a 0.3-meter triple grating monochromator (Spectrapro 300i) with a 0.1 nm resolution. An 8-channel fiber optic cable is connected to the spectrometer to collect line emissions of impurities from the tokamak plasma at 8 different radial locations. Three bright ion species (C_{III}, O_V and C_{VI}) have been chosen to study plasma impurities due to their bright line emissions.

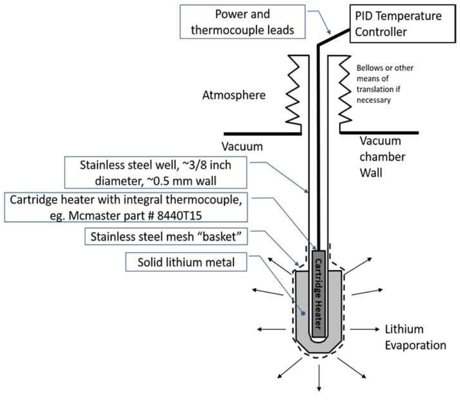

Figure 1. Lithium evaporator schematic.

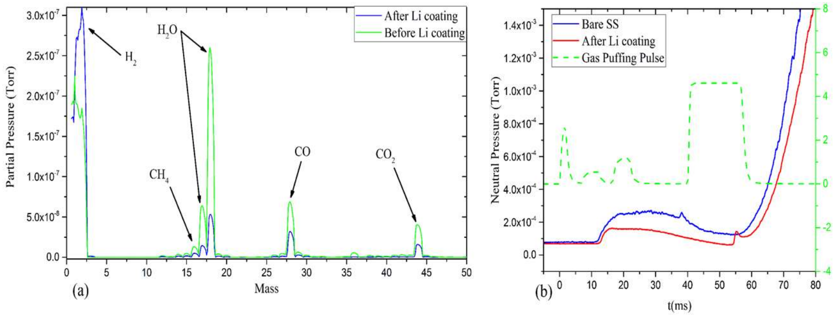

Figure 2. (a) The partial pressure measured by RGA before (green line) and after (blue line) Li coating. (b)The neutral pressure measurement during the plasma discharges with (red line) and without (blue line) Li coating. The green dashed-line is the gas puffing control voltage signal.

Experimental Results

Before carrying out Li coating in the STOR-M tokamak, the main gaseous molecules measured by the RGA are H_2, CO, H_2O and CO_2, as shown in Figure 2(a). These gasses are considered as impurity gasses (except for H_2). After Li coating, the impurity gasses are reduced significantly. This reduction is due to the absorption of impurity gasses by the Li layer. The partial pressure of H_2 is increased after Li coating. This increase comes from the absorption of water by Li.

Figure 2(b) shows the total neutral gas pressure measured by the ionization vacuum gauge before and after Li coating during the STOR-M discharges. The nominal background filling pressure (H_2) is typically 1×10^{-4} Torr. The STOR-M discharge contains 4 gas puffing pulses with different lengths and amplitudes to puff gas into the tokamak through two piezoelectric gas valves in order to control the plasma density during the plasma discharges. The neutral pressure measurements during the plasma discharge can be considered as the combination of gas puffing and the wall recycling during the plasma discharge. During the plasma discharges, three gas puffing pulses are applied to keep the plasma density constant, while the fourth gas puffing is used to terminate the plasma discharges. Despite the same background pressure and gas puffing, the maximum neutral pressure after the Li coating is lower than that for the case without Li coating. This difference in an indication of the reduced recycling of gas due to Li coating.

The plasma discharge parameters, before (black line) and after (red line) Li coating, are shown in Figure 3(a) under otherwise similar discharge conditions. Before Li coating, the plasma discharge is about 30 ms long and reaches a peak current value of 19 kA immediately after the plasma ramp-up. After Li coating, the plasma discharge duration is increased to 35 ms with a peak current of about 23 kA at the end of the plasma flat-top. The plasma loop voltage is reduced from 3 V to 2 V after Li coating during the plasma flat-top. The reduction of the plasma loop voltage and the increase in the plasma current suggest the reduction of the plasma resistivity or higher Spitzer temperature of the electrons. The line-averaged electron density for the case with Li coating is reduced to half compared with the case without Li coating. After Li coating, the maximum value for the plasma density is about $n_e = 5.2 \times 10^{12}$ cm^{-3} which decays at a fast rate during the plasma flat-top. The hard x-ray (HXR) trace shows a significant increase in the HXR radiation after Li coating. The HXR radiation starts to increase simultaneously with the plasma current when the plasma density drops to $n_e = 3.8 \times 10^{12}$ cm^{-3} ($t = 17.5$ ms). The increase in both plasma current and HXR intensity may also be attributed to the enhanced run-away supra thermal electrons in the low density plasma discharges. Supra thermal electrons contribute to plasma current and enhance the generation of HXR emission when they collide with the chamber wall.

The Li coating also plays a significant role in the reduction of impurity contents of plasma during the discharges. As shown in Figure 3(b), the radiation intensity of $\mathrm{C_{III}}$, $\mathrm{O_{V}}$ and $\mathrm{C_{VI}}$ measured by the ICCD camera are significantly reduced after Li coating, suggesting that the amounts of impurity ions are decreased after Li coating. It should be pointed out that the spectrometry measurements before Li coating show that $\mathrm{C_{III}}$ ions mostly are located at $r = 7$ cm from the plasma center. Therefore, the reduction of $\mathrm{C_{III}}$ impurity ions after Li coating is more pronounce at the plasma periphery. The reduction of the radiation intensity of $\mathrm{O_{V}}$ ions (i.e. reduction of oxygen impurity ions) is more noticeable at $r = 3$ cm due to the high concentration of $\mathrm{O_{V}}$ ions at this radial location. Therefore, Li coating prevents wall material from being sputtered off the surface by the plasma.

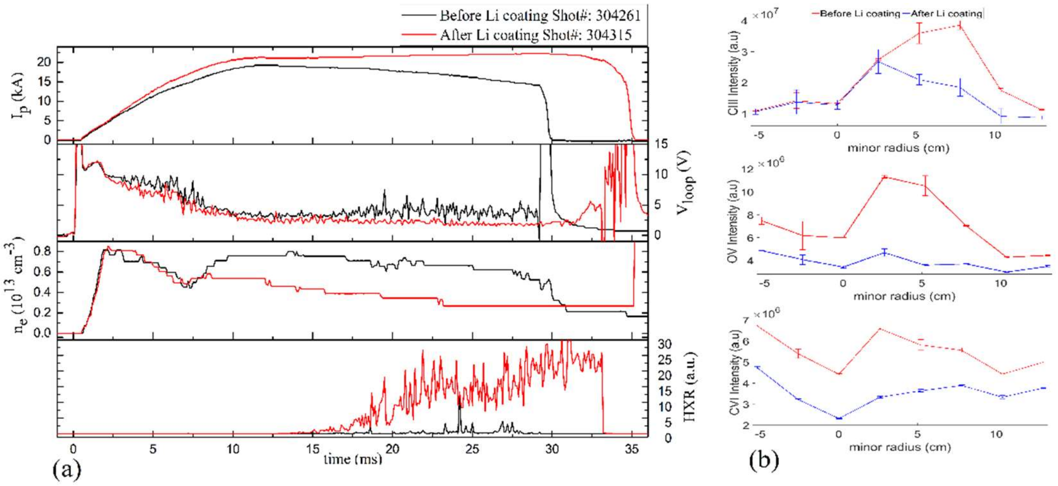

Figure 2~~3~~. STOR-M plasma discharge parameters before (black line) and after (red line) Li coating (a). The intensity profiles of $\mathrm{C_{III}}$, $\mathrm{O_{V}}$ and $\mathrm{C_{VI}}$ before (red line) and after (blue line) Li coating (b).

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