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The wall conditioning experiment by Li–Si coating in the HL-1M tokamak

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Abstract

The mixture coating of lithium and silicon, which is called 'Li–Si coating' for short, is formed on the plasma facing wall of HL-1M by means of direct current glow discharge with the mixture of lithium vapor and monosilane and helium. In HL-1M after Li–Si coating, the most favorable vacuum condition is obtained and, the impurities and recycling are restrained forcefully in plasma discharges. By once Li–Si coating, about two hundred quality shots are performed in HL-1M. The experimental results show that the Li–Si coating is of advantages of Li coating and siliconization but weakens their defects.

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Keywords: Li–Si coating; Restrain; Impurity; Recycling; Lithium coating; Siliconization

1. Introduction

The wall conditioning of tokamaks plays an important role in controlling impurities and hydrogen recycling during plasma discharges. The required wall condition is harsh with the progress in plasma experiments. Therefore, the wall conditioning technology must be innovated and developed continuously. After boronization applied generally, siliconization [1,2] and lithium coating [3,4] have been developed and, shown better effects than boronization in some aspects, for example, stronger restraint for carbon, oxygen impurities and hydrogen recycling. Inadequately, the silicon impurity sputtered from the siliconized wall should result in a higher radiation power loss, and the lithium coating should deteriorate rapidly in plasma discharges. Therefore it is necessary to develop a more excellent wall conditioning technology.

Not only boronization has applied, but also siliconization and lithium coating have been developed in HL-1M since 1995 [5]. The most radical effects of boronization in HL-1M have been proved to be three to six times reduction of the total plasma radiated power and a decrease of the loop voltage by 60%. Metal impurities in plasmas, e.g. Fe, Ni, Cr and so on, almost disappeared. Carbon and oxygen impurities decreased by 60–90%. Energy confinement time rose by 30–40% [6]. Unfavorably, hydrogen recycling lowered only a little and, presented rapid increment with an increase of shot number and plasma density. Low Z plasma impurities (C, O) with siliconization were further reduced over boronization. Especially, the hydrogen recycling in plasma discharges under the siliconized wall was very low. Therefore plasma discharges were highly stable and reproducible, and the plasma density controlling became easier. By means of this wall conditioning technology, plasma duration up to 4 s was achieved and a large progress was made in a series of extremely difficult experiments, for example, multi-shot pellet injection, supersonic molecule beam injection, lower hybrid current drive, high power auxiliary heating and so on [7]. At present, in situ siliconization has been a necessary wall conditioning technology in HL-1M. Regrettably, silicon sputtered from the siliconized wall is a medium Z impurity. After lithium coating the lowest level of impurities, the total plasma radiated power and hydrogen

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recycling was obtained, but the effect could only keep in a few shots.

Li–Si coating has been tested in HL-1M since 1999. This work is funded in part by the National Science Foundation of China under contract no. 19885003.

2. Wall processing with Li–Si coating

HL-1M is a circular cross-section tokamak with $R = 1.02$ m, $a = 0.26$ m, $B_t = 3$ T, $I_p \leqslant 350$ kA and two full poloidal graphite limiters located at a distance of 180° from each other toroidally. Its vacuum chamber is made of AISI304L stainless steel and GH39 bellows. The coverage of graphite parts on the plasma facing surface (PFS) is about 6%.

Li–Si coating on the PFS of HL-1M is performed by means of a direct current glow discharge with a mixture of lithium (Li) vapor and monosilane (SiH_4) and helium (He). The discharge pressure ($P_{He} + P_{Li} + P_{SiH4}$) is about 10^{-1} Pa and the discharge current is about 1.0 A with anode voltage of 400–500 V. The process takes 30–40 min and the few tens nm thick film containing Li and Si is formed on the PFS. Helium glow conditioning is used to reduce hydrogen recycling after Li–Si coating.

Li vapor is produced by an oven heated to 400–600 °C. The purity of the lithium is 99.9%. About 2 g lithium is put in the oven under argon gas flow to prevent the lithium surface from oxidation. The oven assembly is mounted on the long shaft that can be moved radially inwards and outwards. Ordinarily the oven is behind the limiters. During coating it is moved into the central part of the vacuum chamber.

After Li–Si coating, the various plasma discharge experiments are conducted to survey the effect of the coating.

3. Experimental results and discussion

In the vacuum chamber of HL-1M, main components of the residual gas mass spectrum are H_2, CH_4, H_2O and CO. Except H_2, the others is ordinarily called as impurity gases. After Li–Si coating, the impurity gases are obviously reduced. Tables 1 and 2 show the typical mass spectrum intensities of the impurity gases for different wall conditions during and after He glow discharge cleaning, in the tables 'pre-' and 'post-' represent 'pre-processing' and 'post-processing' respectively.

It is found that siliconization is better than Li coating in controlling carbon, but Li coating is better than siliconization in controlling oxygen, and Li–Si coating is of the characteristics of both siliconization and Li coating. Therefore the total reduction of impurity gases is the biggest after Li–Si coating. Moreover, under He ions induce, the impurity gases desorbed from the wall is the smallest after Li–Si coating, as seen in Table 1, which proves again that Li–Si coating has a stronger bond ability for carbon and oxygen. The above phenomena show that the more favorable vacuum condition for plasma discharges can be obtained by means of Li–Si coating.

In plasma discharges with Li–Si coating, the line radiation intensities of metal impurities except lithium are very small so that the signals are not found by the vacuum ultraviolet spectrometer, which is similar to

Table 1
Typical mass spectrum intensities of impurity gases during GDC for different wall conditions

Gas	Siliconization			Li coating			Li–Si coating		
	Intensity (mV)		Reduction (%)	Intensity (mV)		Reduction (%)	Intensity (mV)		Reduction (%)
	Pre-	Post-		Pre-	Post-		Pre-	Post-	
CH_4	40	13	68	39	18	53	43	7	84
H_2O	374	176	53	250	75	70	175	78	55
CO	161	66	59	350	128	63	343	13	96

Table 2
Typical mass spectrum intensities of impurity gases after GDC for different wall conditions

Gas	Siliconization			Li coating			Li–Si coating		
	Intensity (mV)		Reduction (%)	Intensity (mV)		Reduction (%)	Intensity (mV)		Reduction (%)
	Pre-	Post-		Pre-	Post-		Pre-	Post-	
CH_4	6.3	3.2	49	7	5	29	8	4.5	44
H_2O	120	95	21	130	48	63	113	53	53
CO	35	14	60	39	12	69	32	11	66

siliconization. The measurement proves that the main impurities in the plasmas are carbon and oxygen. The impurity radiation lines found by the vacuum ultraviolet spectrometer have CII, CIII, CIV and OII, OVI, OVII. Among them the intensity signals of CII, CIII and OVI are bigger due to the sensitivity of the spectrometer, therefore CIII and OVI are chosen as mainly monitored lines. Under similar discharge parameters, CIII and OVI line intensities may reflect the increase or decrease of carbon and oxygen impurities in whole plasma region though they only represent the radiation of carbon and oxygen at the plasma edge. CIII and OVI line radiation intensities with Li–Si coating are generally 50% and 30% less than those with siliconization respectively, especially the increment of CIII intensity with the plasma density increase is only a little with Li–Si coating, but is sharply with siliconzation, as illustrated in Fig. 1. This characteristic of Li–Si coating is important for the plasma discharge experiments in high density. Generally, with Li–Si coating the loop voltage decreases by 30–50% and total radiation power decreases about 25% over siliconization (see Fig. 2). The conditions prove that the

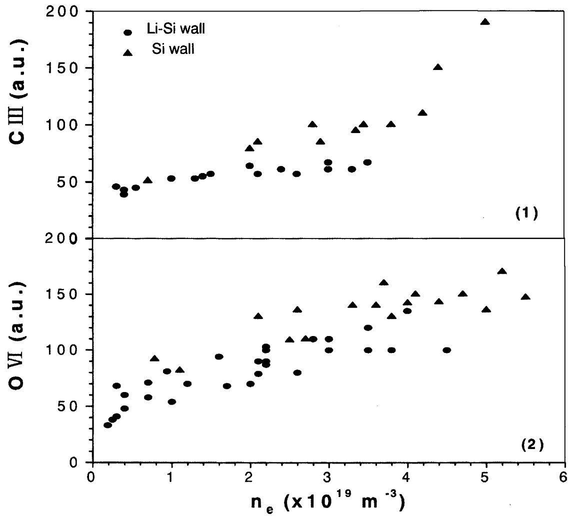

Fig. 1. CIII (1) and OVI (2) line radiation intensities as a function of the line averaged electron densities for different wall conditions under similar discharge parameters, $B_t = 2$ T and $I_p = 110$–125 kA.

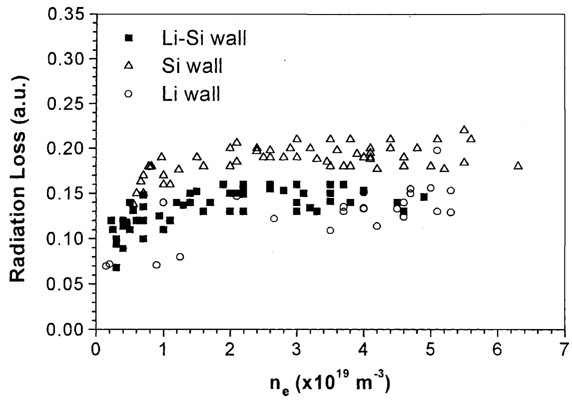

Fig. 2. Core radiated power losses as a function of the line averaged electron densities for different wall conditions under similar discharge parameters.

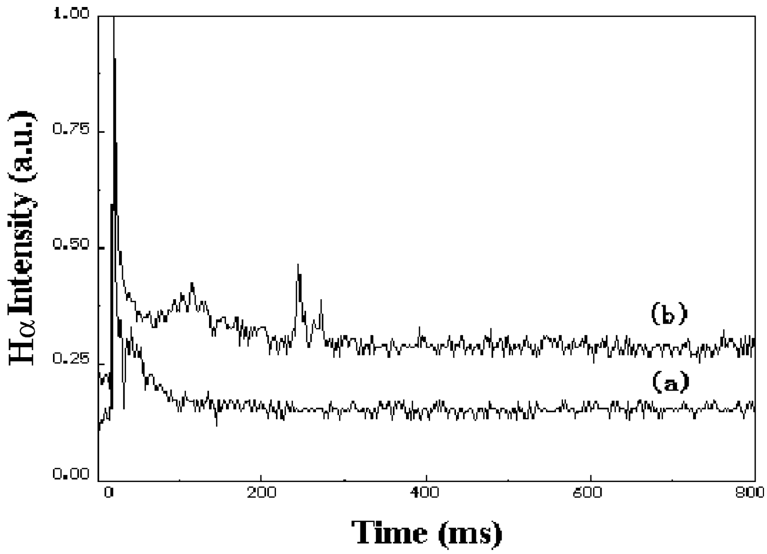

Fig. 3. Time resolution of the mean H_α intensity in typical shots with Li–Si coating (a) and siliconization (b) under the same discharge parameters.

plasma impurities can be restrained more forcefully by means of Li–Si coating.

Li–Si coating results in highly stable and reproducible plasma discharges as siliconization. Moreover the plasma density is controlled easily and has reached $5.5 \times 10^{19}\ m^{-3}$ with hydrogen gas filling. During the plasma discharges with the same parameters, H_α is monitored by means of a visible spectrometer, and it is found that the Li–Si coating makes a 50% reduction in H_α line intensity by contrast with siliconization. Fig. 3 illustrates the variation of the mean H_α intensity with discharge time in typical shots with Li–Si coating and siliconization Under the same plasma parameters, a large reduction in H_α intensity implies that the neutral hydrogen particles in plasmas decrease largely. These characteristics show that the hydrogen recycling is restrained more forcefully with Li–Si coating.

About two hundred quality plasma discharges are performed with once Li–Si coating in HL-1M, which is similar to siliconization. Therefore Li–Si coating is of a strong capacity against plasma etching as silicon coating.

A fresh Li coating is similar to Li–Si coating in controlling plasma impurity and hydrogen recycling, but it does deteriorate in a few shots.

4. Conclusions

Li–Si coating concentrates advantages of siliconization and Li coating but weakens their defects. After Li–Si coating in HL-1M, the most favorable vacuum condition is obtained and, the impurities and hydrogen recycling are restrained forcefully in plasma discharges. The effects of Li–Si coating can be kept in hundreds of shots, which is similar to siliconization but incomparably superior to Li coating. The experimental results show that the Li–Si coating is the most excellent wall conditioning technology in the HL-1M experiments.

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