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Wall condition and density control in the HL-2A tokamak

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1. Introduction

It is important for present tokamaks to achieve a good confinement and high performance plasmas by means of controls on the vacuum condition, the usage of low Z materials, control on the recycling of neutral particles and suppressions on the yield of impurities e.g. Boronization was performed on TEXTOR[1] and sequentially reduced the impurities, and broke the density limit. H-mode or VH-mode discharges were obtained on JT-60U[2] and JET[3] after boronization. Even better plasma performance in VH discharges were achieved on JET by beryllium getter. Boronization and siliconization have been conducted with $C_2B_2H_{12}$ and SiH_4 respectively on HL-1M[4] and HT-7[5], the plasma parameters have been increased. In order to conduct the experiments of confinement improvement, higher heating power and plasma refueling, we cover some of the first wall of HL-2A with graphite materials and carbon fiber tiles. Hence the studies on the in-situ coating application and development, and the interactions between the coated film and plasma are needed to effectively control the impurity, improve plasma confinement and achieve high performance plasma.

2. Glow discharge cleaning(GDC) system

GDC is selected for the conditioning and in-situ treatment of the first wall on HL-2A. The system is shown in fig.1. Four stainless steel anodes are installed into the limiter shadow region in the vacuum chamber. Combining the anode, working gas, and the vessel of the vacuum chamber, the GDC power supply system sets up an electrical circuit. Two anodes share one the power supply system, whose output voltage and current are 0-1200V and 0-8A, respectively. The uniform glow plasma can be achieved when some of the gate valves in the main pumping system are shut, by the adjustments on the amount of the feeding gas and output parameters of the power supply systems. The whole system can be used for different wall conditionings(H_2, He) and different in-situ coatings(siliconization, boronization) according to the requirements of physical experiments.

3.Experiments of wall siliconization and density control

3.1 Process of siliconization

After the helium glow discharge cleaning, we obtains stable dc glow discharge with to gradually shut off helium and inject gas mixture containing 0.9He+0.1SiH_4. This can provides stable dc glow discharge plasma contained the alkane of silicon. The operation parameters are helium pressure: 8.8×10^{-2}, anode electric voltage: 650 volt, electric current: 2.4A. The electric current density on the first walls is 5.3 uA cm^{-2}. The main abruption reaction of the molecule of silicon-alkane is [6]:

$$SiH_4 + e \rightarrow SiH_2 + e + H_2 \quad (1)$$

$$SiH_4 + H \rightarrow SiH_3 + H_2 \quad (2)$$

When the density of the alkane of silicon is low, the formative SiH_2 and SiH_3 within the glow discharge plasma propagate to the frist wall, which is then absorbed by wall surface. Figure 2 illustrates the photograph of silicon film by electron scan microscope. After siliconization, a dense layer (20um) of the non-crystal silicon has been formed on the surface of stainless steel collections probe, the main components of the residue gases in vacuum vessel are CO and H_2, and the peak value of the H_2O reduces from 49.5% to 24.5%.

3. 2 The effects of siliconization and density control on plasma discharges

After wall siliconization in the HL-2A tokamak, the ionization levels of light and heavy impurities are measured with Optic multichannel Analyzer (OMA3), Figure 3 demonstrates the signal strength of the ionization levels of the impurities, where the signal strength of C radiation decreases by 64% and the signal strength of O drop by 80%, the amount of impurity reduces and the wall condition stabilizes. Consequently, this significantly improves the repetition of tokamak discharges and the density control of plasma during discharges. A higher electron density at plasma current Ip=250kA (No.3039) has been obtained. In particular, when plasma current rise up to plateau (about 200ms), we direct puff the work gas(H_2)to edge of plasma. This leads to a significant increase in average electron density and radiation intensity of Hα at edge, which demonstrates the typical procedure of edge fuelling. The average electron density of plasma reaches $4.2\times10^{19}m^{-3}$ at 750ms. The achievable density limit in the contemporary large tokamak depends on both q and current density of plasma[7]. For the tokamak with near rotundity cross section such as HL-2A, we obtain:

$$ne = 1\times10^{17}\left(kA^{-1}\cdot m^{-1}\right)\frac{I_p}{\pi a^2} \quad (3)$$

where Ip is plasma current, a is mini radius of plasma.

The average electron density in discharge No.3039 exceeds the upper bound defined by Greenwald.

During the experiments in 2005, we enhance the settings the vacuum vessel in HL-2A. We add 30% of the carbon fiber protection tiles on the first wall, and effectively shield the splash of heavy metal impurity. This significantly improves the repetition of tokamak discharges and effective density control during tokamak discharges.After a fine tuning of gas puff parameter of twain pulse gas puff systems, we provide stable discharges with higher electron density in HL-2Atokamak with limiter configuration, and further expand the stable operation region. Figure 4 illustrates changes of plasma behaviors about current, plasma shift, carbon, Hα, Density and Signal pulse gas puff in 5 continuous discharge (No.3912-3916). The experimental parameters are Bt=2.3 T, Ip=350 KA, Q_{95} = 2.8, the average electron density is 3.1-5.6×$10^{19}$$m^{-3}$.

4. Conclusion and Discussion

We utilize the glow wall conditioning system (He-GWC) in the HL-2A tokamak to performe siliconization of first wall based on chemical steam phase aggradations. This effectively reduces the light and heavy impurities strength during discharges, and improves the repetition of discharges and density control of plasma during discharge. In the experiments with plasma current I_p=250kA, the peak average electron density reaches up to 4.2×10^{19}.m^{-3}, exceeding the upper limit defined by Greenwald, In the experiments with current I_p=350kA, the peak density reaches up to5.6×10^{19}.m^{-3}, which significantly extends the stable operation region. Our future work includes optimizing the processing of wall, researching on the wall condition under higher parameter, high power heating and current drive. We are also working on exploit the impact of different processing on recycling to provide favorable wall condition for future HL-2A experiments.

References

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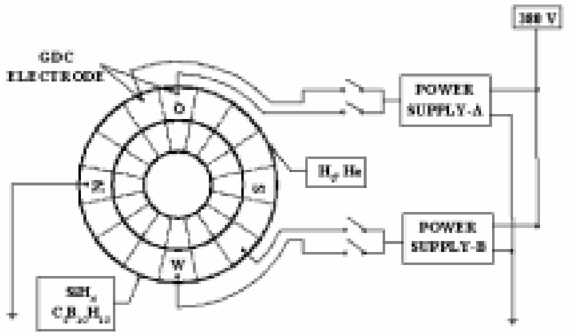
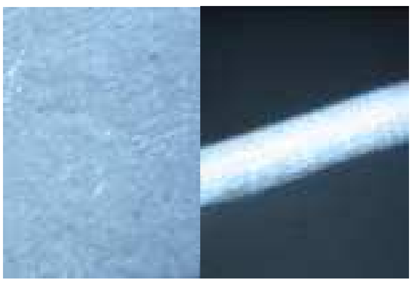


Fig.1. Glow discharge cleaning (GDC) system in HL-2A



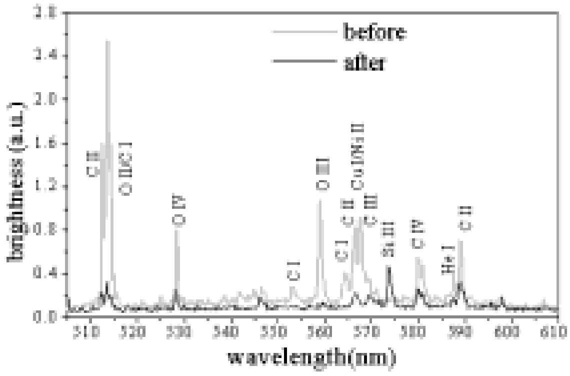


Figure 2 illustrates the photograph of silicon film by electron scan microscope.
Left: The layer surfaces facial look
Right: a cross section of layer

Figure 3 demonstrates variety of the signal strength of the ionization levels of impurities before and after wal siliconization

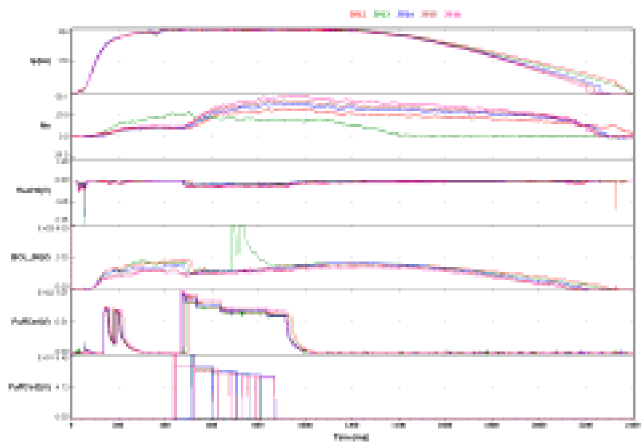


Figure 4 illustrates changes of plasma behaviors about current, plasma shift, carbon, Hα, density and signal pulse gas puff in 5 continuous discharge (No.3912-3916).