LASER BLOW-OFF EXPERIMENT AND STUDY OF IMPURITY TRANSPORT ON HL-IM TOKAMAK*

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Abstract : the Laser Blow-off technique has been used to HL-IM tokamak. Small quantities of metal impurities ,Al, Fe, Li etc., have been injected into the plasma. Their characteristics of the transports and the confinements were studied during the Ohmic, L-mode, Bias limiter and LHCD discharges. The diffusion coefficients, D (r), inward convection velocities ,V (r), and confinement times τ_{imp} were obtained.

1. Introduction

The Laser Blow-off technique is the right transient perturbation method[1]. It has been used to several tokamaks[1,2,3].The injected time and the amount of the impurity can be controlled exactly and it is the minimum perturbation for the plasma. The data analysis is based on the measured curve of the line emission of injected impurity and the numerical simulation of the line brightness using an impurity transport code. We carried out the experiments of injecting various metals, Ni, Fe,Cr, Al , Li etc. on HL-1M device. We studied the transport and confinement characteristics of Al impurity. The results show that the diffusion coefficients and convection velocities are much small in the r/a~0.3 inside region of plasma with values for D~ 0.01-0.1m^2/s, V~0-0.1m/s.They are closed to neoclassical calculation. But in the r/a $>$ 0.4 outside region D and V reach great values for D~0.5 - 1.3m^2/s ,V~0.4 -2.6m/s. They are greater than the neoclassical prediction. In the this region the transport is anomalous. The confinement times are given by the characteristic decay times of the spectral line emission brightness of injected impurities.

2. Experimental conditions and diagnostics

The experiment arrangement is shown in figure 1. HL-1M is a circular cross section tokamak, its main parameters are : major radius R=1.02m, minor radius a=0.26m, toroidal field B_T~2-2.8 T, plasma current I_p~100-320 kA, n_e~2-8x10^{19}/m^3, T_e~0.6-1.2 keV. The source is a single pulse ruby laser with output energy 1-3J, pulse duration 20-30ns.The laser beam is focused on the surface of target film by a lens. It can produce a spot of diameter 1-3 mm on the target film, the metal element in the spot is evaporated to produce a burst of metal atoms, it contains a few 10^{18}atoms with energy of the order of a few eV . They move towards the plasma, but only a fraction of them can reach to center of plasma. The amount of injected impurity is kept sufficiently low to avoid perturbing parameters of plasma apart from radiation. This corresponds to concentration of 0.01-0.05% of the electron density[1,3]. These atoms reach to the plasma boundary and are ionized, These ions spread out rapidly along the toroidal field lines . At the same time, due to collision or turbulence, the ions move slowly radially inwards.

The penetration progression of the impurities into plasma is observed using four soft x-ray cameras(total 68 channels),the smallest spatial and temporal resolutions are 2cm and 10μs respectively. The intensities of line emission from injected impurity are measured with the VUV spectrometer and visible multichannel optical fiber sensors. The electron density and temperature are also measured by HCN laser interferometer ,laser Thomson scattered system and ECE system. The general energy radiation loss is given using multichannel bolometers.

3. Experimental results

The metals ,Al, Fe, Li etc. were injected successfully into HL-1M device during OH,L-mode, Bias limiter and LHCD discharges. The transport, confinement and penetration of the injected impurity were observed and studied .

Figure 1 shows the central channel soft X-ray signal , the central chord electron line average density n_e , the central chord VUV emission signal, the central channel bolometer signal and plasma current I_p when Al was injected in 2691 shot. We can see that there are additive pulse signals on the soft X-ray, VUV and bolometer signals around the time of Al injection. But n_e and I_p are not varied obviously. It means that the perturbations of plasma parameter were avoided.

Figure 2 shows the central chord X-ray emission signal around time of Al injection with the background emission subtracted during L-mode discharge in 2696 shot. It represents the contribution of soft X-ray emission from injected Al alone. As the impurity ions propagate inwards, they enter region of higher electron density and temperature, and the intensity of soft X-ray signal grows. When the intensity of X-ray reaches its maximum, the impurity concentration is also near its maximum in the center of plasma, and then the signal of x-ray starts to decay, as the impurity ions continuously escape due to the transport. During the rising phase of soft X-ray, We observed that the sawtooth was inverted for two times. It implies an inward flow of the impurity ions into the central region at the time of each sawtooth crash.

During the decay phase of the signal of soft X-ray, it is inversely progression , the impurity ions flow outwardly from central region at the time of each sawtooth crash[3].

Figure 3 gives the radial spatial distributions of the diffusion coefficients D(r) and inward convection velocities V(r) in the cases of Ohmic, L-mode, Bias limiter and LHCD discharges. These distributions are obtained by the numerical simulation using an impurity transport code(selecting 2-4 spectral lines of the different ionized state to carry out simulating and fitting with the experiment data for each discharge state), assuming that the ion flux of injected impurity is in a form:

$$\Gamma_{imp} = -D\,\partial n_{imp}/\partial r - n_{imp}V \qquad (1)$$

where Γ_{imp} is the flux , D is diffusion coefficient , n_{imp} is the density, V is convection velocity of injected impurity.

We can see that from figure 4, the diffusion coefficients and convection velocities are much small close to neoclassical calculation in the r/a =0.3 inside region of plasma with values for D~0.01-0.1 m^2/s, V~0-0.1m/s. It means that in this region of HL-1M the transport is normal. But in the outside region, r/a $\geqslant$ 0.4, of plasma the transports of impurity are much faster than neoclassical prediction with values for D~1.0 m^2/s, V~0.05-1.9m/s, τ_{imp}=16.6ms in OH plasma, D~1.3 m^2/s, V~0.08-2.6m/s, τ_{imp}=17ms in L-mode, D~0.8 m^2/s, V~0.05-1.4m/s, τ_{imp}=24ms in bias limiter discharge, D~0.5 m^2/s, V~0.05-0.85 m/s, τ_{imp}=33ms in LHCD. So the transports are anomalous in all above states. there is barrier at 22-25 cm of HL-1M plasma, because there is the pulse electric field in this region from bias limiter. We also found that in LHCD discharge the confinement time is longer than that in the cases of OH, L-mode and Bias limiter. The confinement characteristic is improved in the case of LHCD.

Figure 4 shows the distribution of Al XI(55.0nm) line brightness at the central chord in the OH,L-mode and LHCD, their characteristic decay times of line brightness are a measure of the confinement time of injected impurity.Above confinement times are given from figure 4.

References

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[3] D. Pasini Plasma physics and controlled fusion , Vol. 34, No. 5 pp.677 ,1992.

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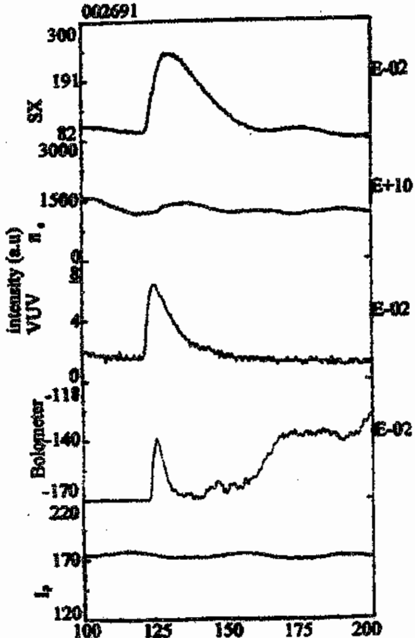

Fig. 1 Central chord soft x-ray signal, n_e, VUV signal, Bolometer signal and Ip diagrams in the case of injected Al.

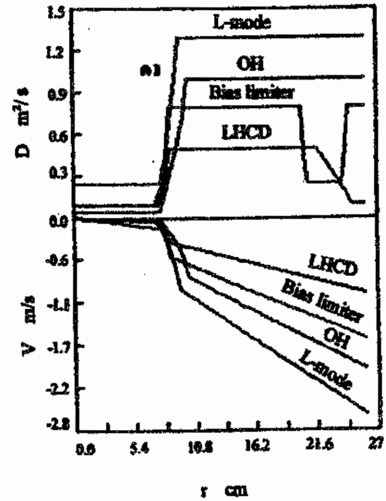

Fig.3 The radial spatial distributions of the diffusion coefficients D(r) and inward convection velocities V(r) in the cases of Ohmic, L-mode, Bias limiter and LHCD discharges.

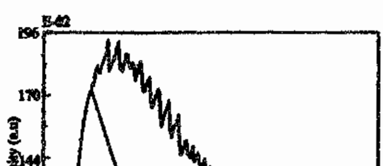

Fig.2 The central chord X-ray emission signal around time of Al injection with the background emission subtracted during L-mode

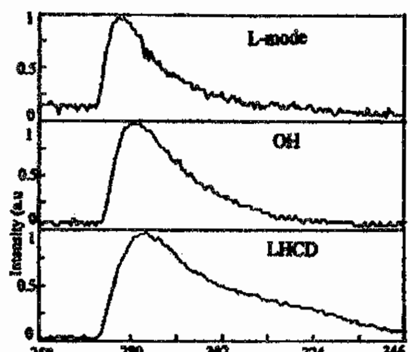

Fig.4 VUV spectral emission AL XI(55.0nm) diagrams.