H_α Line Shape in Front of the Limiter in HT-6M Tokamak

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Abstract

In this paper H_α line shape in front of the limiter in HT-6M tokamak is analyzed by multi-Gaussian fitting. The energy distribution of neutral hydrogen atoms reveals that H_α radiation is contributed by Frank-Condon (FC) atoms, atoms reflected at the limiter surface and charge exchange. Dissociation of hydrogen molecules and reflection of particles at the limiter surface are dominante in edge recycling. To lower particle reflection at the limiter surface is an important issue for controlling edge recycling. The measured profiles of neutral hydrogen atom density are reproduced by particle continue equation and a simplified one-dimension Monte-Carlo simulation code.

1. Introduction

For a better understanding of recycling and neutral particle transport it is of general interest to know the velocity distribution of neutral particles being recycled at a limiter. The velocity distribution can be derived from the measured line shape of H_α, D_α for Doppler dominated broadening. Also, H_α line emission is used as an indicator for global particle confinement. However, it becomes much more difficult to separate recycled particles from different mechanisms. Clarification of contents in H_α radiation is an important issue to understand mechanisms of edge recycling and to get reliable measurement of particle confinement time. In HT-6M tokamak H_α spectral line shape is obtained from observation of particle recycling at main stainless steel limiter. The line of sight is oriented through the plasma center, such that photos from particles moving towards the plasma center are Doppler shifted to shorter wavelength and wavelength shift due to plasma rotation is avoided.

2. Analyzing of H_α line shape

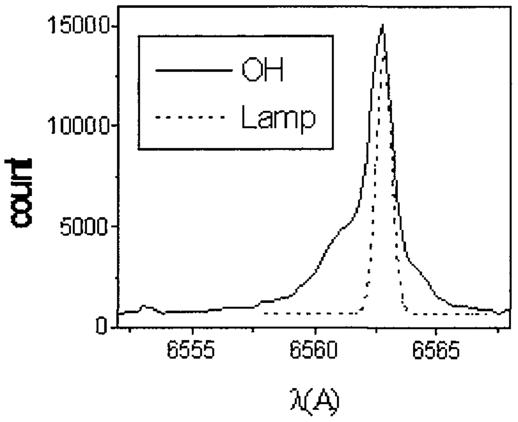

Fig.1 H_α line shape for ohmic discharge (solid line)

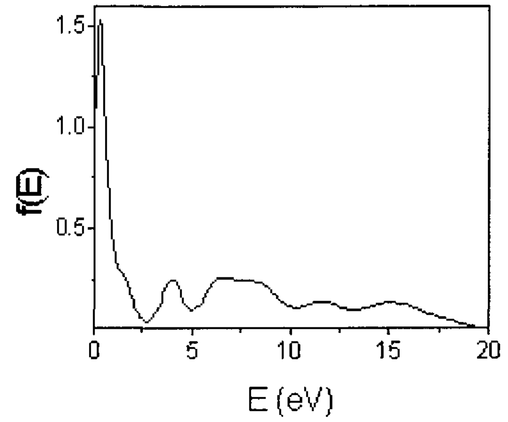

Fig.2 Energy distribution of neutral H

HT-6M is an air-core tokamak operated in circular configuration with R=65cm, a=20cm, B_T=1T, I_P=55~65kA, $T_e(a)$=8~12eV, $n_e(a)=1\sim2\times10^{12}/cm^3$. H_α emission is spectroscopically resolved by grating spectrometer and interference filters and detected by an ICCD and photomultipliers[1]. H_α line shape for typical ohmic discharge and a lamp as comparison are displayed in fig.1. Obviously, spectral line shape differs strongly from Gaussian profile. Most atoms have an inward radial velocity component. The line in blue side has a broad part from atoms having energies up to 150eV derived from wavelength shift. To get energy distribution of particles, the spectral line shape in blue side is differentiated to wavelength shift. The result up to 20eV is shown in fig.2. Slow atoms (Frank-Condon, 0-5eV) are produced mainly by molecule dissociation or ionized molecule dissociation. It is clear to see that H_2 dissociation by electron impact into H(1s)+H(2s) channel with averaged fragment energy of 0.3eV[2] is the dominated molecular process to form FC (slow) atoms for typical HT-6M ohmic discharge with T_e(a)~10eV. Fast atoms produced by charge exchange can reach such high energies up to 150eV. However, amount of such fast atoms is not sufficient to account for atom population in energy between 5-20eV. We conclude a significant contribution of fast atoms originating from the limiter surface exists in addition to the molecule released from the limiter and charge exchanged atoms. These atoms stem from ions neutralized and reflected at the limiter surface.

We consider excitation of (a) FC atoms, (b). atoms produced by charge exchange and (c) reflected atoms. Atoms produced by charge exchange can be in excited state or in the ground state, which can be excited by electron impact, emitting photos. The two types of photos should have same energy distribution depending on ion energy distribution of background plasma. It has Gaussian profile for thermal plasma. Photos emitted from reflection atoms have also Gaussian profile if energies of particles do not significantly vary in neutralization at the limiter surface. Therefor, H_α line shape can be simplified by three Gaussian profiles. In order to avoid uncertainty of multi-parametric non-linear fitting, emission of atoms produced by charge exchange is deduced by fitting the H_α line shape in the far wing[1]. The result is shown in fig.1. This part is of about 21% of total emission. The FWHM is 6.5Å corresponding ion temperature of 170eV in good agreement with measurements by NPA and Doppler broadening of CV (2271Å) emission line.

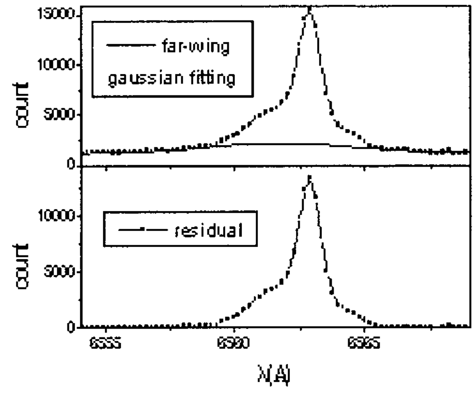

Fig.3 Far-wing Gaussian fitting and residual

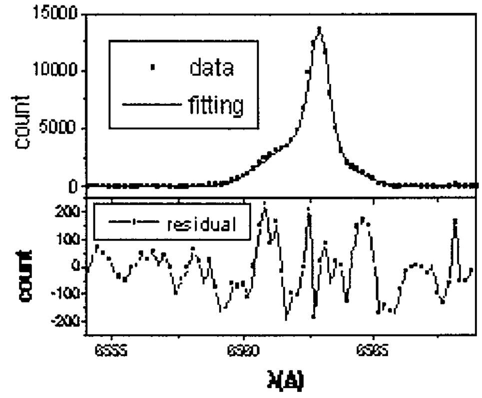

Fig.4 Double Gaussian fitting of residual of fig.3

The residual H_α line shape shown in fig.3 is fitted by double Gaussian profiles. The residual after double Gaussian fitting is stochastic and only in level of detector thermal noise representing a good fitting. The first Gaussian profile has FWHM of 1.8Å (13eV) which is close to T_e(a) in front of the limiter. It stems from reflected atoms at the limiter surface and contributes about 47% of whole H_α emission. The value of the corresponding particle reflection coefficient is R_N=0.6 by considering the fact that charge exchange does not change atom population. The fraction of reflected particles varies between 57%-62% in HT-6M ohmic discharges, comparable to those expected for a clean metal (Ni) surface (R_N=0.55)[3]. Wavelength shift of this Gaussian profile is -0.7Å, corresponding a bulk velocity of 3.2×10^4m/s. The second Gaussian profile with narrow FWHM of 1.1Å is from FC atoms contributes 32% of whole H_α emission, corresponding to 40% of recycled particles. Wavelength shift of 0.15Å corresponds to a bulk velocity of 7×10^3m/s. These results are confirmed in isotopic exchange experiments[4].

3. Simulation

Results obtained above are valuable for edge model calculations in order to get information about penetration depth, fuelling efficiency and local recycling. Neutral hydrogen atoms undergo the ionization by electron impact and charge exchange with ions. However, charge exchange does not cause neutral particle loss. For typical HT-6M edge conditions with 60% reflected particles and 40% molecule released at the limiter surface, which dissociate into atoms, continue equations of particles reproduce spatial profile of neutral particles. Results are shown in fig.5. A multi-channel IF-photomultipliers monitoring and Abel-inversion experimentally measure the profile of neutral hydrogen particle density. The simulated result is lower than measured data because contribution of charge exchange to H_α emission is not subtracted in calculation.

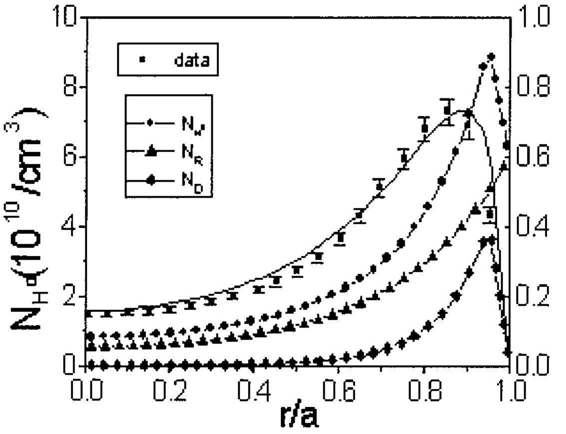

Fig. 5 N_H^0 and simulation by continue equation.

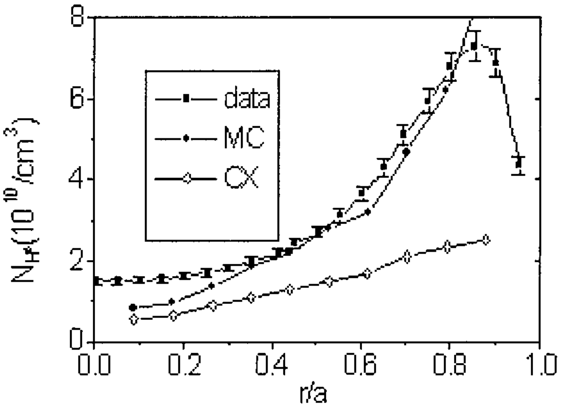

Fig.6 Monte-Carlo simulation

Also, the simulation based on a simplified 1D Monte-Carlo[5] gives neutral particle profiles in good agreement with measurements in region of 0-0.7a. Fig.6 gives simulated results and measured data. Discrepancy near the edge is caused due to uncertain charge exchange cross-section in lower ion impact energy. Molecular dissociation is replaced directly by FC atoms with bulk energy of 0.3eV in the simulation. Contribution of charge exchange to H_α emission is included in derivation of spatial profile of neutral particle.

4. Conclusion

In conclusion, recycled particles at the limiter surface are 40% molecules dissociating into FC atoms and 60% reflected particles. To lower particle reflection at the limiter surface is an important issue to control edge recycling in HT-6M tokamak. Ion temperature inferred from the far wing of H_α line shape is in good agreement with those measured by NPA and spectroscopy. Charge exchange contributes to H_α emission of about 21% meaning a significant correction of particle confinement time measured by H_α emission. Spatial profile of neutral particles can be reproduced both by continue equation of particle and Monte-Carlo simulation based on the values obtained from analysis of H_α line shape

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Current Relaxation and its Roles in Improved Confinement

Abstract

Effective **Low** Hybrid wave Current Driving (LHCD) and improved confinement in higher electron density have been attained in HT-6M tokamak by combining with Low Hybrid wave Heating (LHH). Experiments and code simulation show that off-axis plasma current is driven and sustained by LHW in higher electron density and relax at the time scale of resistive diffusion. Sustaining of improved confinement is strongly governed by current density profile and its relaxation. Relevant issues are also discussed.

1. Introduction

Plasma current density profile is well known to be one of key factors to sustain advanced tokamak discharges. LHCD is a powerful tool to sustain discharge, control current density profile and improve global confinement. In HT-6M tokamak, a mode of an off-axis LHCD with help of second LHW heating was found to be very effective to control current density profile. The discharges can be sustained by LHW in quasi-steady state in improved confinement. Detailed description of LHW experiments in HT-6M tokamak is presented by Li et.al [1]. In this paper we will concentrate on features of current density relaxation and relevant issues.

2. Experiments and discussion

HT-6M is an air core tokamak operated in circular limiter configuration with R=65cm, a=20cm, B_t~1T and I_P~60kA. Frequency of both LHCD and LHH is 2.45GHz. The plasma current is increased from 60kA to 70-90kA by LHCD and LHH depending on characteristics of target plasma and power and $N_{\parallel}$ of LHW. Effective current driving and heating were indicated by dropped loop-voltage, increased plasma current and improved (particle) confinement as shown in fig.1. LHCD wave is applied at 18ms and LHH wave at 20ms and terminated at 46ms and 50 ms. In addition to common features of improved confinement, the MHD and fluctuation in ion saturated current of Langmuir probe are suppressed substantially after the onset of H_α dropping. SX radiation behaves complicated such as giant, double, triplet sawteeth shown as one example in fig.2. Bursts occur in H_α emission looking like ELM. But they are not fully correlated with fluctuations in SX radiation and Mirrov coils as shown in expanded part (right) of Fig.2. Termination of the improved confinement depends on

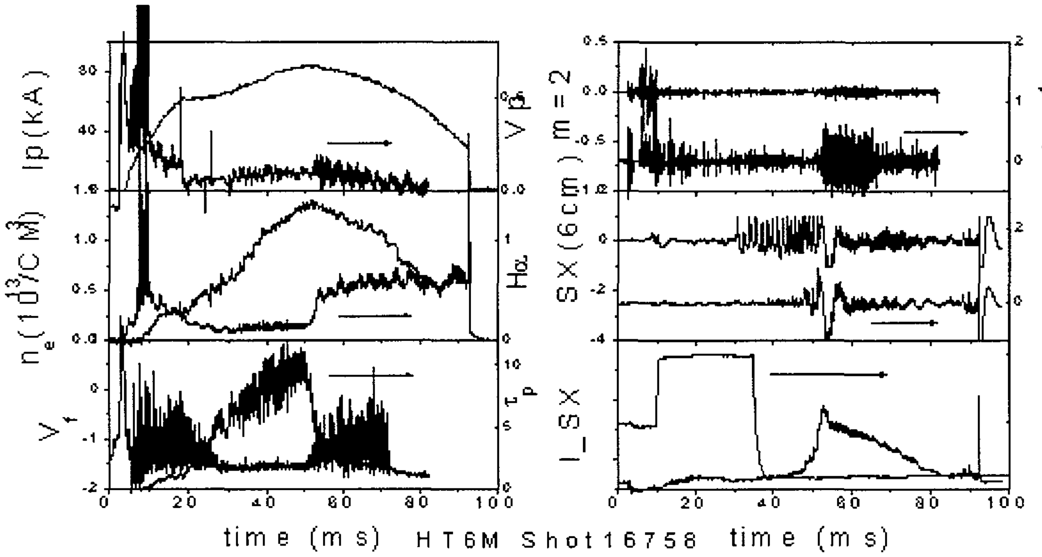


Fig.1 Typical waveforms of discharge with combined LHCD and LHH applied at 18ms and 20 ms.

development of MHD. Fig.3 shows that confinement is deteriorated as double sawtooth transits to single one and fluctuation is increased after H_α changes. These facts suggest that the current density profile change MHD behaviors and may influence the fluctuations and the confinement.

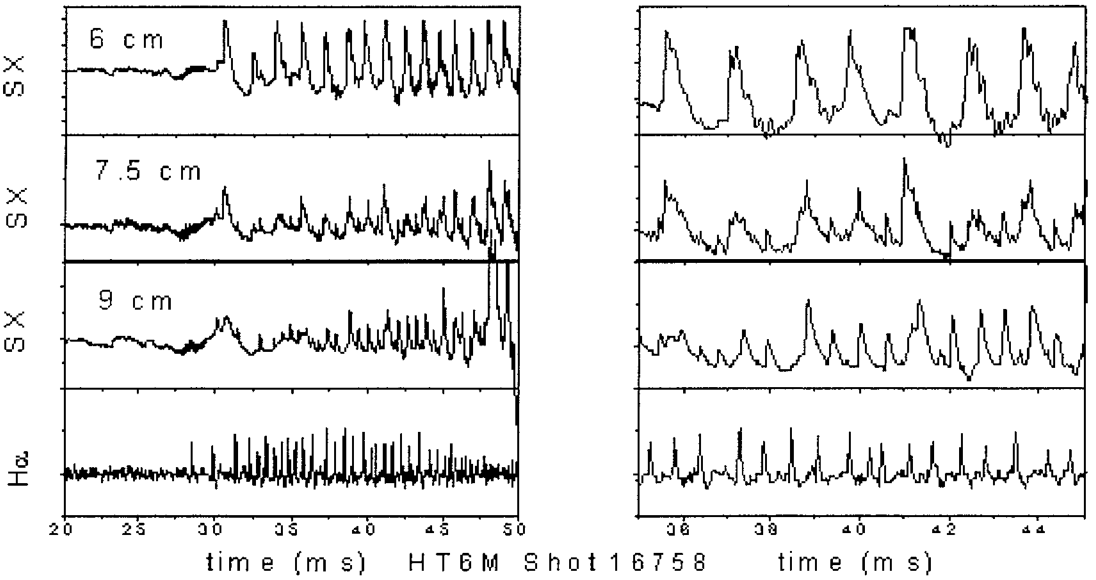
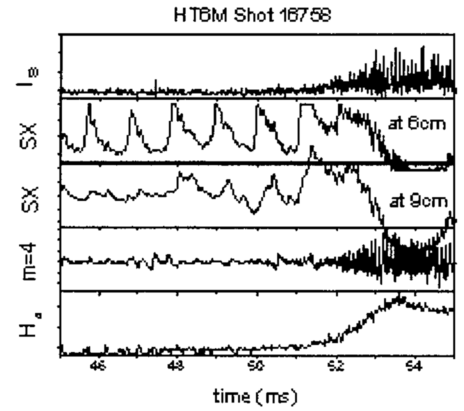


Fig.2 SX signals show double sawteeth at position of r/a=0.5. Bursts occur in H_α emission but not fully correlated with SX fluctuations.



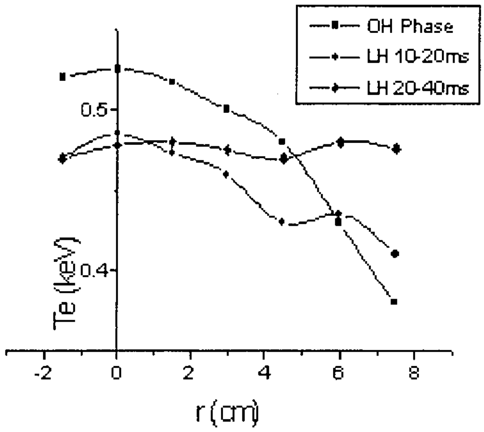


Fig.3 Deterioration of the confinement by MHD. Fig.4 T_e profiles before and during LHW

Code calculation shows LHW can produce off-axis current driving in high electron density. Most power of LHW deposits in radial region of 0.3a-0.6a by code calculation [1]. Electron temperature profiles are measured by soft x-ray pulse-height analyzer with integration time of 20ms shot by shot in reproducible discharges as shown in fig.4. Electron temperatures around half radius of a plasma increase substantially after LHWs are applied, which confirms the simulation. HX PHA toroidal scanning show off-axis energy deposition of LHCD waves. Global current density profile can be significantly modified with typical off-axis current increment of 20kA by LHCD with power of 50kW and $N_\parallel$=2.4 and LHW of 50kW. Formation of reversed shear in half radius of plasma and large gradient out half radius of plasma can be expected. Proper magnetic shear will stabilize MHD, suppresses the fluctuations and improves confinement as in ERS discharges[2] and EOH discharges[3].

At beginning phase of off-axis current driven by LHCD, there exist double or triplet q=1 rational surface. As diffusion of off-axis current, multi-tearing modes cause double or triplet sawteeth in SX radiation [4] depending on position and fraction of current produced by LHW. The radius of double and triplet sawteeth occurring around r=9cm (0.45a) is in region of power deposition of LHW predicted by code simulation. Normally, anomalous behaviors in SX radiation occur at 10-15ms after decreasing of the H_α radiation. The time is in order of time scale of current resistive diffusing over 0.2a with $T_e \approx 400$eV at ~0.45a, where double or triplet sawteeth were observed. Diffusion of current density driven by LHW with target ohmic current together can connect double or triplet q=1 rational surface, which cause double or triplet magnetic reconnection processes[5]. Bigger single-sawteeth occur within the mixing region and deteriorate confinement as clearly shown in fig.3. Sustain of improved confinement is obviously relevant to LH heating producing higher averaged electron temperature and increasing current diffusing time.

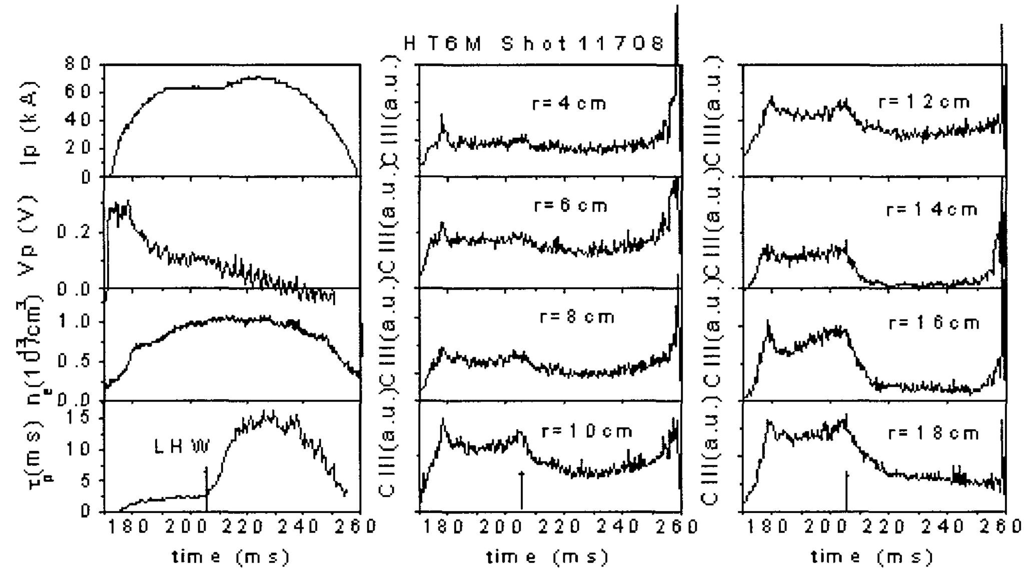


Fig. 5. Variation of CIII radiation at different chords after LHWs applied at 210 ms.

Impurity monitoring and code simulation shows that particle diffusive coefficients decrease dramatically and transport barrier forms around 0.7a in confinement improved phase of a discharge. After LHWs are applied, the variation of impurity radiation from different chords is strongest in region of 0.6a-0.8a, where current density is expected to have largest gradient. Typical observation is shown in Fig.5 for CIII radiation at 4647 |. This fact implies a correlation of the confinement improvement and current density profile. Temporal difference of variation of impurity radiation between chords of 0.7a and 0.9a is about 4ms. This time is again in order of resistive diffusion time for typical edge conditions in HT-6M. It is another clear evidence that current relaxation influence the confinement improvement.

3. Conclusion

Current density profile produced by off-axis LHCD and LHH and its relaxation and roles in confinement improvement are analyzed. The off-axis current relaxes in time scale of resistive diffusion. It governs developing of MHD, improved confinement and relevant behaviors.

Reference

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