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Analysis of $H\alpha(D\alpha)$ Line Shape

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Abstract. The particles energy distribution is derived directly from the $H\alpha(D\alpha)$ line shape, which is measured by two sets of OMA. The dissociative excitation of molecular is dominating when the local electron temperature is >10 eV. The $D\alpha$ line shape is also simulated by the Monte–Carlo method, the molecular dissociation contributes to 57% neutral atoms and 53% emission intensity in front of the limiter, and 85% neutral atoms and 82% emission intensity in front of the wall. The processes of atoms and molecules influence on the energy balance is discussed in SOL, the power loss from molecular dissociation is 6×10^4 kW at SOL.

Key words. Plasma: energy profile: processes of atoms and molecules: simulation of $D\alpha$ line shape.

1. Energy distribution of particles and processes of atoms and molecules at edge

The $H\alpha(D\alpha)$ line shape measured by OMA is determined by the convolution of several facts: the instrument function, the geometry of observation, the geometry of resource, the effect of atoms and molecule processes. The instrument function can be eliminated by deconvolution, the excited atoms in $n = 3$ state decay by photon emission on a microsecond timescale, the exposure time of OMA detector is about 5–8 ms, and hence the atoms emission is spatially isotropic. The $H\alpha(D\alpha)$ line intensity at wavelength $\Delta\lambda$ from the centre can be written as

$$I(\Delta\lambda) \propto \int n_0 n_e \langle\sigma v\rangle \int_{E(\Delta\lambda)}^{\infty} f(E) E^{-1/2}\, \mathrm{d}E\, \mathrm{d}V, \tag{1}$$

where n_0 is the local atoms density, n_e is the electron density, $\langle\sigma v\rangle$ is the excitation rate coefficient for $H\alpha(D\alpha)$ emission and $E = mc^2(\Delta\lambda)^2/2\lambda^2$, the spatial integral is the measuring region. For temperature >10 eV, photon number emitted per ionization is approximately constant (Abdo *et al.* 2010), and equation (1) can be simplified as

$$I(\Delta\lambda) \propto \Gamma_0 \int_{E(\Delta\lambda)}^{\infty} f(E) E^{-1/2}\, \mathrm{d}E, \tag{2}$$

where Γ_0 is the particle influx. Equation (2) can also be inverted to (Ackermann *et al.* 2011):

$$f(E(\Delta\lambda)) \propto \mathrm{d}I(\Delta)/\mathrm{d}\lambda. \tag{3}$$

Hence, the energy distribution is proportional to the gradient of the $H_\alpha(D_\alpha)$ line shape. The result of particle energy distribution in several kinds of experimental conditions is shown in Fig. 1.

There are two clear peaks in the energy distribution of atoms in front of the wall, quite strong one is at 0.3 eV, which is produced by molecular dissociation excitation. The reaction is (Fan *et al.* 2011)

$$e^- + H_2 \to e^- + H(1s) + H^*(2s). \tag{4}$$

The neutral atoms produced in this reaction have energies 0 to 1.4 eV, peaking at 0.3 eV. The average energy loss of the electron in collision is about 15.3 eV. Another peak is at 3 eV, which are produced by molecular dissociation (Fan *et al*. 2011):

$$e^- + H_2 \to e^- + H(1s) + H(1s). \tag{5}$$

The neutral atoms produced in this reaction have energies from 2 to 6.5 eV, peaking at 3 eV, and the average energy loss in the collision is about 10.5 eV. The higher the peak at 3 eV, the lower is the local temperature. The energy profile of particle in front of the limiter also depends on the experimental condition or local electron temperature. In addition to the peaks at 0.3 and 3 eV, two peaks at 2.5 and 4.5 eV can also be observed when the local temperature is >20 eV, both of them being produced by molecular dissociation excitation (Fan *et al.* 2011):

$$e^- + H_2 \to e^- + H(1s) + H^*\ (n = 3), \tag{6}$$

$$e^- + H_2 \to e^- + H^*(2p) + H^*(2s). \tag{7}$$

The neutral atoms produced in two reactions have an average energy of 2.5 and 4.8 eV, the average energy loss of the electron in two collisions are about 21.5 and

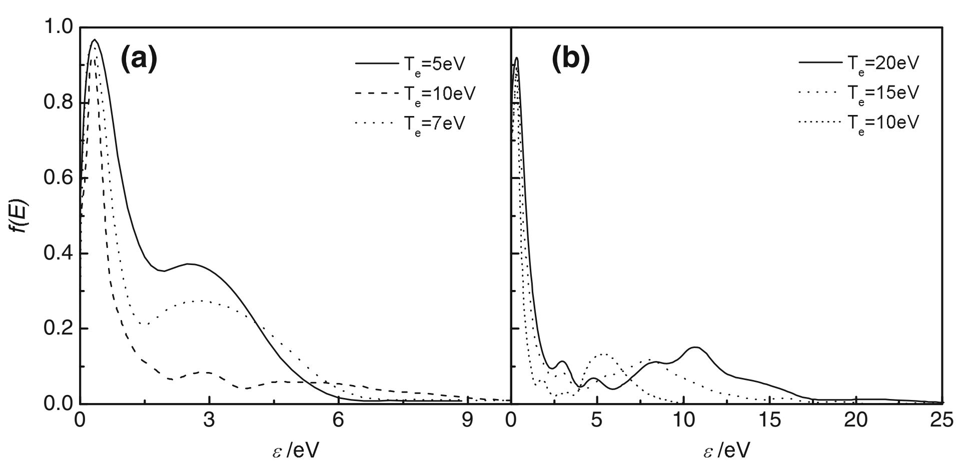

Figure 1. Particle energy distributions in front of the limiter (**a**) and the wall (**b**).

34.6 eV, respectively. A wide distribution of energy from 5 to 20 eV in the blue wing can always be detected.

2. Result of line shape simulation

The D_α line shape is simulated by calculation based on the Monte–Carlo method (Nolan *et al.* 2012), the background plasma parameters during the simulation are calculated by one-dimensional code (Padovani 1992), in which the fluid equation along the field line in each flux tube are solved with the boundary conditions given by the Langmuir probe. The ion temperature in front of the limiter or the wall is assumed to be equal to the electron temperature. And the ion density is also assumed to be equal to the electron density at the edge. The molecules in simulation are simplified and considered by several dominating processes that are discussed above. The charge-exchange and the reflection particle are considered in the simulation. The Zeeman split is about 0.04 nm, the Doppler D_α line is wider than 0.1 nm; the Zeeman effect can be neglected. The H_α line in front of the wall can be entirely separated from the D_α line shape and the ratio of the H_α line intensity to D_α line intensity is about 5% in front of the limiter. Therefore, the Zeeman effect and the effect of the H_α line are not included in the simulation. The result of the simulation is shown in Fig. 2.

The simulated D_α line shape agrees with the measured data except the distribution at red wing due to the effect of the H_α line. The simulation D_α line shape in front of the wall (Fig. 2a) shows that central wavelength shift is 0.015 nm to the blue wing, which means the velocity flowing into the plasma is about $3.0^{*}10^3$ ms^{-1}, and large emission components deriving from dissociative excitation and dissociated atoms contribute 82% emission intensity and almost the same proportion of neutral atoms. The emission profile from the dissociative excitation atoms is symmetrical in these processes, the excited atoms decay by photon emission almost instantaneously, on a microsecond timescale, without interaction with the plasma and the wall. The emission profile from the dissociated atoms is asymmetrical; the profile is shifted to

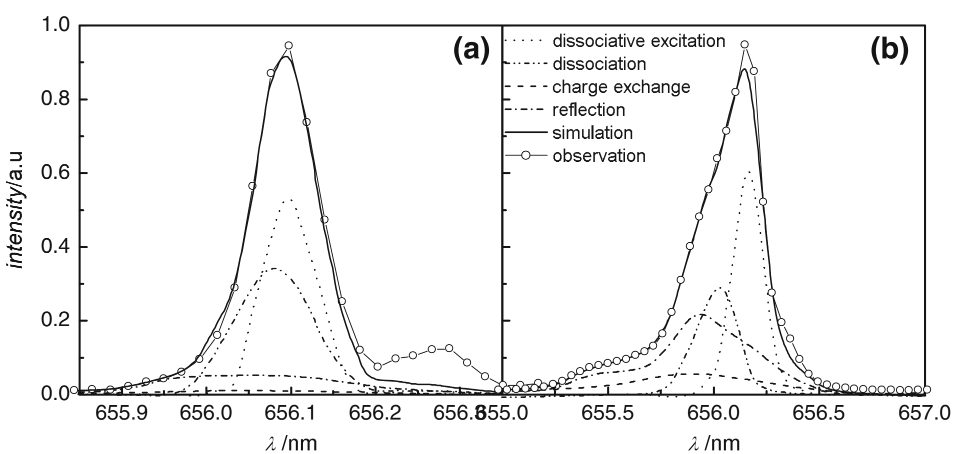

Figure 2. Comparison of D_α distribution of observation with the simulation in front of the limiter (**a**) and the wall (**b**).

the blue wing and is stronger. This is due to the direction of observation, the atoms moving to the spectrometer will flow into the core of the plasma, where the density grows higher, and hence the emission from atoms excited by the collision with electron is stronger. The emission from reflected and charge-exchanged atoms is quite weak, they contribute 3% neutral atoms and 13% emission intensity, respectively. The simulation D_α line shape in front of the limiter includes larger emission components deriving from dissociative excitation and dissociated atom, they contribute 53% emission intensity and about 57% neutral atoms. Their emission profile is similar to the profile in front of the wall, but the emission from the dissociated atoms is weaker, and this is due to the temperature in front of the limiter which is higher. The emission from reflected and charge-exchanged atoms contribute 34 and 13% emission intensities, respectively. The rate of particle reflection in the surface of limiter (R_{N}) is about 0.47.

3. Summary and conclusions

The particles energy distribution shows that the main molecular processes in the SOL are molecular dissociation excitation, especially, when the local electron is >10 eV, and the reflection rate of average energy (R_{E}) in the limiter is about 0.2. The result of the D_α line shape simulation shows that the molecular dissociation contribute 57% neutral atoms and 53% emission intensity in front of the limiter, 85% neutral atoms and 82% emission intensity in front of the wall. 47% reflection rate of the particles and 20% reflection rate of the energy will reduce the heat flux in the surface of the limiter and the power loss from molecular dissociation is about 6×10^4 kW. Both of them play an important role in maintaining the balance of energy in SOL and in controlling impurity.

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