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Polarization spectroscopy for the study of plasma anisotropy in LHD

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We have succeeded to detect polarization of the hydrogen Lyman-α line in the Large Helical Device (LHD). It is the first observation of a polarized atomic emission line in magnetically confined fusion plasma devices. With the help of an atomic model simulation, anisotropy in the electron velocity distribution function (EVDF) in terms of $T_\parallel/T_\perp$, where $T_\parallel$ and $T_\perp$ represent the electron temperature, T_e, in the parallel and perpendicular directions to the magnetic field, respectively, is evaluated. The results show a strong dependence on T_e measured by Thomson scattering rather than n_e.

Anisotropy in EVDF is thought to play a key role for characterizing the plasma confinement state both in the core and edge regions of the fusion plasma. However, no established measurement method regarding the anisotropy in EVDF to date. The polarization spectroscopy is a promising technique for this purpose. Excited states of atoms or ions in fusion plasma are dominantly created by electron collisions. When EVDF is anisotropic, excited states may have an inhomogeneous population distribution among the magnetic sublevels in that state [1], and emission lines from such a state could be polarized.

We have modified a VUV spectrometer for the polarization measurement. First, in the spectrometer, a mirror is placed in front of the detector at the Brewster's angle so that the vertical component of linearly polarized light is exclusively measured. In addition to that, the angle of the detected polarized light in the plasma can be changed by a half-wave plate placed at the entrance slit. By rotating the half-wave plate continuously during a steady-state discharge, we obtain linearly polarized lights at different angles as a time series.

When the light is polarized, the intensity signal shows a sinusoidal modulation synchronized with the half-wave plate rotation. The amplitude of that intensity modulation relative to the total intensity is here defined as the polarization degree.

The polarization degree observed is in the order of several percent and generally decays with increasing $\bar{n}_e$. It is also found that the characteristic direction of the polarization matches the magnetic field direction at the emission location which suggests that the anisotropy is created between in the parallel and perpendicular directions to the magnetic field. For a quantitative analysis of the measurement results, we have developed an atomic model which simulates the polarization formation of the Lyman-α line [3]. The model is based on an equation of motion of the density matrix composed of fundamental atomic data for the electron impact excitation, radiative deexcitation, polarization creation, and polarization destruction processes. Here, we assume EVDFs having different temperatures in the parallel and perpendicular to the magnetic field. Under a quasi-steady-state approximation, the equation of motion of the density matrix is numerically solved and the polarization resolved line intensities are calculated.

With the help of this simulation model, the values $T_\parallel/T_\perp$ are determined so as to give the measured polarization degrees. It is noted that in this analysis, the line emission location is fixed at $r_{\mathrm{eff}} = 0.67$ m, where r_{eff} is the effective minor radius, as derived in a previous study [4]. The local parameters of $T_\perp$ and n_e are taken from the results of the Thomson scattering measurement. The derived $T_\parallel/T_\perp$ values are found to be always lower than unity, i.e., $T_\parallel$ is lower than $T_\perp$. The Lyman-α line is emitted in the region where the magnetic field is not completely closed. Because in such regions passing electrons are immediately guided to the divertor plates while the trapped electrons would stay for a longer time in the plasma, the obtained result of $T_\perp > T_\parallel$ is understandable. Figure 1 shows that $T_\parallel/T_\perp$ has a strong dependence on $T_\perp$ rather than n_e. This result suggests that the electron

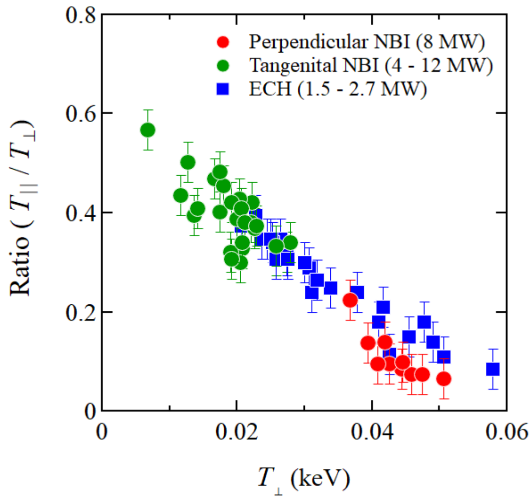

Figure 1. Ratio of $T_\parallel$ and $T_\perp$ derived from the measured polarization degrees with the help of model calculations.

temperature governs the relaxation of anisotropic EVDF rather than the electron density.

References

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