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Application of an RF plasma source for divertor plasma study and its recent results

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In magnetically confined fusion reactors, detached divertor regime is a strong candidate to protect divertor plates from large heat loads. Although detached plasma study has been enthusiastically conducted in toroidal and linear machines, some aspects of divertor plasma physics still remain as unclear i.e., influence of the energetic ions on detached plasma and mechanism of a detached plasma formation. To investigate these subjects, a device which is capable of producing a recombining/detached plasma and of superimposing energetic ions, is necessary. In addition, development of non-Maxwellian distribution plasma diagnosing technique is also required because divertor plasma could deviate from the Maxwellian distribution whereas usually plasma diagnostic methods postulate single Maxwellian one. However, conventional divertor plasma simulators have difficulties to satisfy aforementioned requirements. Then, we have been developing a linear plasma machine with a radio-frequency (RF) plasma source, DT-ALPHA [1]. The DT-ALPHA device has no electrode so that ion beam components, which simulate ELM-like burst, can penetrate into the device.

In an RF plasma device, keeping compatibility among stable RF discharge and enhancement of volumetric recombination is troublesome matter. We resolved this problem by controlling spatial distribution of neutral particles [2], and then we superimposed helium ion beam onto helium recombining plasma [3]. To keep ion collision cross section constant, energy of ions was maintained at 13 keV. Changing ion beam flux, we collected several optical emissions emitted by volumetric recombination. It was found that optical emission decreased when ion beam existed and amount of decrease in emission intensity seemed to proportional to ion beam flux. This result indicates that reaction rate of helium volumetric recombination degraded due to energetic ion collision. Similar result was reported from an experiment conducted with detached plasma and energetic electrons [4]. In the Ref. 4, experimental results were interpreted as increase of electron temperature. However, in our case, similar interpretation is difficult because no clear change was seen in T_e between with and without beam injection cases. One possible interpretation is charge-exchange momentum transfer because excited neutral atoms can move outside the observation volume before it emits optical emission once momentum of energetic ion is transferred.

To evaluate reaction rate of several atomic/molecular processes, T_e and n_e should be determined. For low electron temperature plasma, those can be easily obtained using emissions from Rydberg atoms (Boltzmann plot method). However, our numerical calculation indicated that the Boltzmann plot method drastically underestimates those values when electrons deviate from single Maxwellian distribution [5]. To confirm this calculation, we measured optical emission from helium recombining plasma which forms bi-Maxwellian distribution [6]. It was found that electron temperature and density evaluated using the Boltzmann plot (T_e^B and n_e^B) were drastically smaller than that evaluated from slope of continuum emission (T_e^C and n_e^C). To clarify the influence of the electron energy distribution, we calculated electron temperature and electron density using a collisional-radiative model taking hot electron components into consideration. Calculated values well matched experimentally obtained T_e^B and n_e^B. This implies that special care is required when a divertor plasma is optically diagnosed. Otherwise, one would considerably misunderstand reaction rate of atomic/molecular processes. As well as electron temperature, evaluation of ion temperature is also important because ions are expected to have an important role for detached divertor formation. However, detached divertor plasma study including ion measurement hasn't been conducted enthusiastically. Recently, we started ion temperature measurement experiment using an ion sensitive probe (ISP) technique. Although an ISP seems to be available when it is used inside plasma, it would result in overestimated T_i when it is placed outside a finite boundary plasma [7].

This talk highlights these recent progresses of divertor plasma research conducted in the DT-ALPHA device.

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