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Diagnostics to Investigate Thermal Equilibrium/Disequilibrium Features ~ in Fusion Edge And Laboratory Discharge Low-temperature Plasmas ~

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Divertor/edge plasma in magnetically confined fusion-orientated device plays important roles since it determines boundary conditions of the atomic and molecular processes that can be a source or sink of the particle and heat fluxes. Parameters of these partially ionized plasmas are also close to the technical plasmas produced by an arc or radio-frequency discharge so that common technical issues and modeling can be recognized.

In particular, producing recombining plasma is a key issue in mitigating the heat load onto the plasma facing components through the neutralization of the plasma before reaching the divertor plate. This phenomenon is widely known as "divertor detachment". Although the reaction rates strongly depends on the electron temperature, determining the appropriate values from the spectroscopy or from the particle measurements includes many difficulties, such as anomalous probe characteristics, absence of light emission.

In order to examine the applicability of varieties of plasma diagnostics to divertor-relevant plasmas, we have conducted the experiments on the linear divertor/edge plasma simulator MAP-II (material and plasma)[1]. It consists of a dual-chamber with an arc discharge LaB_6 source (< 45A), and has a longitudinal magnetic field of 20 mT. Typical examples of the measured parameters are listed in Table 1.

We have developed the laser Thomson scattering (LTS) system using a frequency-doubled Nd:YAG laser aiming at the low-electron-temperature (far below 1 eV) detached recombining plasmas [2], which enabled the measurement of n_e and T_e from the attached to detached regime including the transition regime without optical emission.

Measuring the ion and/or neutral temperatures in low-temperature plasmas based on the *passive* optical emission spectroscopy is also a challenging issue. In this regime, low-principal quantum number (n) states exhibit only the Doppler broadening, while the high-n states *can* exhibit both the Doppler and Stark broadenings if the electron density is relatively high. However, the question is *which temperature the measured temperature reflects*. In order to clarify this, he has proposed measuring the line profile of several atomic helium spectra (He I), in which the contribution balance of Gaussian (Doppler) and Lorentzian (Stark) is different [3]. Applying this method to recombining plasma, he found that the temperature of the electrons, ions and atoms became close to each other (~ 700 K), suggesting the achievement of the *thermal equilibrium* around the gas temperature.

In the ionizing plasmas, on the other hand, the temperature of the excited states of the atomic helium was reveled to be dependent on the states. This *disequilibrium* feature became more apparent as the electron density n_e increases [4].

Throughout applying these diagnostics to partially ionized plasmas, radiation-trapping process sometimes needs to be considered. We have demonstrated that a near-infrared neutral helium line is useful to monitor this phenomenon[5].

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Table 1. List of typical parameters in MAP-II and their diagnostics updated from [1].

Source chamber	Parameter range	Diagnostics
n_e	0.9- 30 x10 ^{18} m^{-3}	Thomson Scattering
T_e	0.06 - 10 eV	Thomson Scat., He I
T_i	0.8 - 1 eV	He II (n = 3-4)
T_0	~ 0.06 eV	Doppler-Stark
Target chamber	Parameter range	Diagnostics
n_e	10 ^{17}- 2x10 ^{18} m^{-3}	probes
T_e	0.5 - 15 eV	probes
T_e	0.05 eV(He-EIR)	He I
T_i	0.4 - 0.7 eV	He II (n = 3-4)
$M_{//}$	~ 0.1 - 0.3	Mach probes [6]
V_i	~ 1.5 km/s	He II (n=3-4)
[H^-]	10 ^{14}- 10 ^{16} m^{-3}	LPD
T_{H-}, V_{H-}	~ 0.6 eV, ~ 1 km/s	LPDV [7]
T_{rot}	400 - 600K	Fulcher-band spectroscopy
T_{vib}	2000 - 10000 K	Fulcher-band spectroscopy
dissociation	0.8- 5 %	Fulcher-Balmer ratio [8]