§3. Robustness of Steady-state Discharge for Impurity Contamination in Radio-frequency Sustained Helium Plasmas

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Long-pulse discharges sustained by radio-frequency heating for ion cyclotron heating (ICH) and electron cyclotron heating (ECH) in hydrogen plasma, helium plasma and hydrogen minority regime in helium plasma, have been investigated in LHD, and sudden impurity contamination was one of critical issues to terminate plasma duration. As increasing plasma temperature by increasing radio-frequency heating power by development of ICH and ECH devices, sophisticated real-time gas-fueling and integrated controls for plasma operations, impurity penetration region was pushed to plasma edge region close to last closed flux surface (LCFS) and/or to the more outer region, and then long-pulse plasmas were robust to be sudden impurity contamination for the small flakes. In FIY 2013, long-pulse plasma was terminated by the continuous impurity contaminations of carbon flakes. Evaluation of robustness for impurity contamination with temperature > keV and density > 10^{19} m^{-3} is more important issues to keep the plasma duration.

Tracer encapsulated solid pellet (TESPEL) is one of powerful tools to identify the robustness for sudden impurity contamination, and we can confirm the robustness for injecting the accurate number for particles in TESPEL in various kinds of materials (carbon, iron and tungsten). Figure 1 shows the typical discharge waveform with radio-frequency heating power of 3.5 MW, electron density of $1.2\text{x}10^{19}$ m^{-3} and center electron temperature of 3 keV, and electron density and radiation power were rapidly increased just after TESPEL injection with tungsten particles of $1\text{x}10^{17}$. Injected TESPEL was ablated at plasma edge in short time (< 0.01 sec), and strong radiation was occurred with different rising and recovering time-scales for density and temperatures. We fond drop of electron temperature was much larger than drop of ion temperature, and density recovery time seems to be longer than particle confinement time.

Figure 2 shows the density increment in various numbers of particles and various injection materials, and tungsten injection clearly increased rather than increments of injection with the other materials. Injected electron was evaluated from previous experiment results, which implied that tungsten could not be fully ionized, and ionization number was defined to 27. When iron injection predicted electron particles was larger than $4\text{x}10^{19}$ atom, plasma was terminated. In tungsten, injection threshold of electron density to sustain plasma was $1.2\text{x}10^{19}$ atom. As increasing the ionization number and atomic number, plasma could not be sustained by the TESPEL injection, and it suggests that high-Z material injection is easily raising electron density rather than low-Z material injection.

Acknowledgements

The authors would like to thanks to LHD experiment group and collaborators in Universities by the useful discussion and kindly help. This works was supported by the LHD project (ULRR703, ULRR022, ULRR806, KNWR001).

1) Saito, K., et al., NIFS Annual Report (2014).

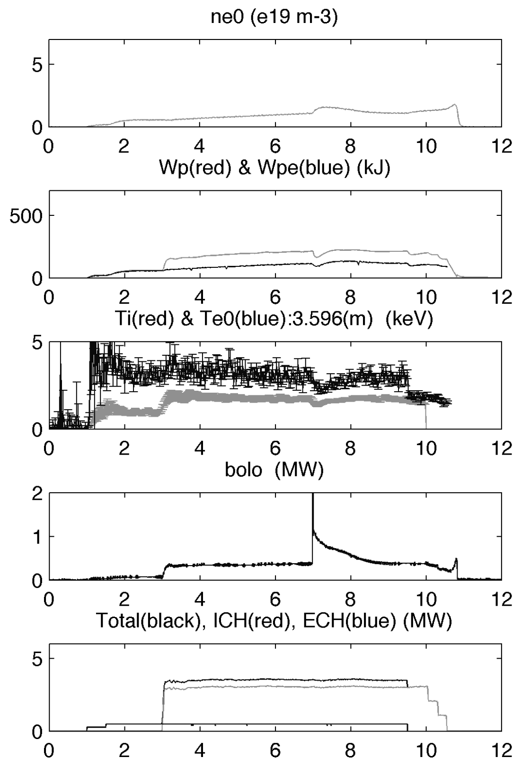

Fig. 1. Achievement of long-pulse discharges sustained by ICH and ECH in LHD. (#129472)

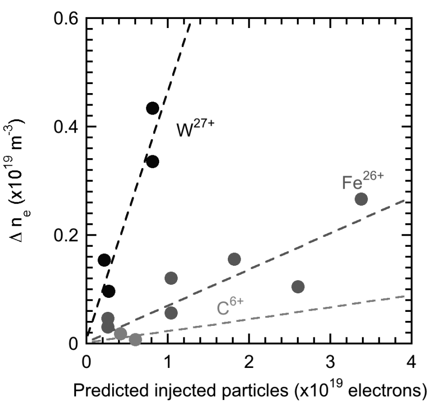

Fig. 2. Density rising in W, Fe and C injections.