For a future upgrade of the LHD and consequent physics and engineering toward a fusion reactor, research and development related to the LHD torus and heating systems have been performed mainly under the NIFS collaboration programs.

Development of heating system is inevitable for fusion relevant devices, such as ITER and DEMO, as well as the LHD experiments. Plasma heating and control by the high-energy Neutral Beam (NB) injection are most prospective to realize the burning fusion plasmas. The LHD is equipped with five NB Injectors (NBI) as main heating devices. The NBIs consist of three negative-ion based NBI and two positive-ion based NBIs. The total maximum injection powers of 14MW and 11MW were achieved during the 18th campaign for negative-ion based NBI and positive-ion based NBI, respectively. The high power operation of NBI contributed to the extension of LHD plasma parameters, such as the achievement of 4.1% β-value at 1-T operation and the simultaneous achievement of high ion temperature of 6keV and high electron temperature of 7keV.

The negative-ion related physics research has been carried out together with the technology developments. In the vicinity of a Plasma Grid (PG) of NIFS Research and development Negative-Ion Source (NIFS-RNIS), very unique plasmas, so called *ionic plasmas* which mainly consist from negative- and positive- ions of Hydrogens, are observed. The behavior of the negative-ions near the PG is widely investigated by various diagnostics. For the negative-ion density measurement, the Cavity Ring-Down (CRD) system was used. By changing the vertical position of the sight lines of the CRD system around a beam extraction hole in the grid, the distribution of the negative ions around the hole was measured in detail. As a result, we have found that the reduction of H^- density at the beam extraction timing is larger at the center of the beam extraction hole and the smaller at the peripheral region of the hole. The CRD method is very reliable H^- density measurement, but is line integrated measurement along its sight line. To overcome this defect, the local measurement of H^- density were tried by applying the Laser aided Photo Detached electron currents (LPD) measurement. The LPD measurement was performed along the CRD sight line. The measured H^- density profile shows concentration of H^- ions at the central region and a steep density gradient was formed at the intermediate region between the core and the edge. In the vicinity of the PG in a cesium seeded negative ions, the mutual charge exchange process between H^-- ion and H^+-ion can be considered as a dominant process of H_α emission reaction. Thus, H^--ion distribution can be estimated from the H_α imaging measurement. The H^- density reduction distributions at the beam extraction timing were compared between an arc-filament type negative-ion source at NIFS and RF-type negative-ion source at IPP-Garching. It was found that the decrement of H^--ion density distribution formed some structure above beam extraction holes in the arc-filament type source, while the decrement distribution shows flat distribution in the RF-type source. Fine spectrum measurement of H_α line might provide us the temperature of H^--ion or Hydrogen neutral atom. The Doppler broadening of the line spectra indicates the temperature of n=3 Hydrogen neutral atom is about 0.6eV. Another approach of measuring H_α line was also tried by using laser absorption method. Temperature of Hydrogen neutral atom of n=2 state were evaluated to be 2000-4000K, which correspond to 0.17-0.34 eV. The evaluated temperatures show weak dependence of arc power and agree with H_α-line emission spectroscopy within an order. The behaviors of Cesium atom and Cs^+ ion in NIFS-RNIS are also of our interest in the Cs seeded negative-ion source because the Cs seeding play an essential role in H^--ion production. We found it difficult to measure the line emission from Cs^+-ion, i.e., Cs II lines. It was also found that the mutual charge exchange process between Cs^+-ion and H^--ion must be taken into an account in the interpretation of the line emission from Cs neutral atoms. As was mentioned, the decrement of H^--ion densities were observed at the timing of beam extraction in the vicinity of the PG. The behavior of electrons at this timing is also of our great interest. The Surface Wave Probe (SWP) method, which was not influenced by the magnetic field existing near the PG region of NIFS-RNIS, was applied as a measurement of electron density. It was found that the electron density was increased at the beam-on timing. It was also found that the increase of electron density is smaller at the center of the beam extraction hole, while the electron density increase is larger at the peripheral of the extraction hole. These tendencies are opposite to the H^--ion behavior, and can be understood if the conservation of charge neutrality is considered.

Integrated modeling study of optimization for negative-ion production, extraction, and acceleration has been performed for the ionic plasmas. To investigate the formation mechanism of ionic plasma layers near the PG in NIFS-RNIS, a 3D3V PIC (Three Dimensional in real space and Three dimensional in Velocity space Particle-In-Cell) model is under development. The electron diffusion process across the filter magnetic field is taken into an account by $\tau_{//}/\tau_{\perp}$ model, where $\tau_{//}$ is the electron loss time along the magnetic field line and $\tau_{\perp}$ is the electron diffusion time across the field line. It was found the thickness of the ionic layer can be altered by the variation of $\tau_{//}/\tau_{\perp}$ value.

A role of electron suppression magnet to the electron behavior in the vicinity of a PG is investigated by using a small negative-ion source, where the electron suppression is installed at the Extraction Grid (EG) to suppress the co-extracted electron current with the negative-ion beam. By comparing the electron density near the PG with the suppression magnet to that without the magnet, it was confirmed the suppression magnet is effective in reducing electron density near the PG in the ion source plasma. A modeling of 2D3V PIC (Two Dimensional in real space and Three dimensional in Velocity space Particle-In-Cell)

It is essential to study on the mechanism of lowering the work function of metal surface by cesium adsorption in the negative-ion source development. The variation of work function for adsorbed alkali metals (Li, Na, K, Rb and Cs) on W(110) at different coverages was analyzed. It was found that the minimum work function occurs at the optimum coverage of 0.22ML for Cs, Rb and K, and 0.33ML for Na and Li. It was also found that Cs gives the lowest work function of 1.42eV. The surface dipole induced by the alkali metal coverage seems to attribute to the minimization of work function.

The effect of plasma grid configuration was also investigated by changing the aperture shape of the beam extraction hole. Two types of aperture shapes, 'straight' and 'tapered', with several opening angles of the extraction hole were tested to evaluate the optimum shape for negative-ion extraction. It was found that the tapered aperture with the opening angle of 60-degree is the optimum. The perveance dependence of the beam width shows same tendency, which indicates the meniscus formation was similar to each other.

Developments for new types of Negative-Ion Sources (NIS) were also conducted. One is the development of cesium-free negative-ion source based on a catalytic ionization method. An aluminum PG is used as a catalyst and the negative-ion produced at the PG is guided by a electric potential produced by a Controle Grid (CG). The mass species of the charged particles extracted from the Ion Source (IS) is analyzed by using a mass spectrometer based on a magnet. An extraction of H^--ion current comparable to the H^+–ion current was observed by the catalytic IS. The other approach of the development is the use of Helicon-Wave Plasma (HWP) as a NIS. To understand the property of HWP and to examine its application to NIS, the Small Helicon Device (SHD) was developed. A production of very small diameter plasma of 2cm with the electron densities between 10^{17} and 10^{19} m^{-3} were successfully demonstrated by SHD.

Electron Cyclotron Resonance Heating (ECRH) is widely used in the LHD experiments. Development of CW high-power transmission line is a critical issue for future reactor design. During the 18th campaign of the LHD experiments, simultaneous operation of the three 77GHz and the two 154GHz 1MW-gyrotrons, the total injected power into LHD exceeded 5.4MW. A new real time power and polarization monitor was installed on the LHD-ECRH transmission line to evaluate the input power and polarization of the injected micro waves, accurately. The monitored polarization agreed well with the polarization evaluated from the setting of the polarizer which was installed at the entrance of the transmission line. A new technique to evaluate the microwave profiles in the transmission line was also developed. An array of Peltier-modules were installed at the corner of transmission line, so called the miterbend. The heat load profile by the microwave at the miterbend was evaluated by the signals from the Peltier-modules. The evaluated beam profile agreed well with the conventional beam profile measurement by using thermal sensitive paper. A new grooves for the ECRH polarizer was developed for steady state operation. The new grooves are optimized to minimize the transmission loss at the polarizer. In the Fiscal Year (FY) of 2014, the fabrication and the installation was finished. The evaluation of the transmission loss will be done during FY2015.

A development for millimeter wave component for the Collective Thomson Scattering (CTS) diagnostic was also conducted. In FY2014, the CTS receiver system of using the 154GHz microwave injection system were installed and tested. The system was used as an ECE system as a trial during 18th campaign and operated successfully.

A basic study on the Bloch Wave Cavity (BWC) was conducted for the future use of power source for Tera-Hertz waves. A G-band corrugation on the concaved surface of cylindrical waveguide was used as a BWC and tested as a 170GHz wave source. The radiation pattern observed by experiments is broad. This indicates that the cavity might be a multimode system.

Recently, micro-, millimeter-, and Tera-Herz-waves oscillator and related components have been progressively developed. To promote the information exchange on the related research field, a workshop was held. Main topics of the workshop were the development of high power sources of micro- and Tera-Hertz waves, i.e., gyrotrons for ITER and JT-60SA, and their components. About 24 members participated the workshop.

For the Ion Cyclotron Range of Frequency (ICRF) heating, its maximum heating power reached 4.5MW for 100ms operation and 3.9MW for 30s. ICRF heating can be an important heating tool for core-ions in large size plasmas. To enhance the ICRF heating technology including Lower Hybrid Wave (LHW) heating and current drive, a work shop for “the development and applications of ICRF heating devices” was held. 8 topics were presented and discussed by 30 participants.

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