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Optimum Generation of High Heat Flux Toroidal Plasmas by RF Ohmic Discharge

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Abstract

We have developed a new toroidal divertor plasma simulator, NAGDIS-T (NAGoya DIvertor plasma Simulator with Toroidal magnetic configuration). Plasma is generated by RF Joule discharge. In order to obtain high density plasmas relevant to divertor plasmas in fusion devices, we investigate the optimum condition of RF Joule discharge by varying gas pressure and driving frequency. The experimental result shows that the optimum condition strongly depends on these parameters.

1. Introduction

Linear divertor plasma simulators (L-DPS), like NAGDIS-II [1], have contributed to understanding the various physics in edge plasmas of fusion devices, since they have good accessibility for comprehensive diagnostics and flexible control of plasma parameters. However, L-DPS, which has a simple magnetic configuration, can not simulate some important factors appeared in edge plasmas of tokamaks related to the magnetic configuration, such as curvature and grad B effects and long connection length of magnetic field lines. For example, recent observation in tokamak edge plasmas indicated non-diffusive blobby plasma transports across the magnetic field [2,3], which is thought to be driven by a charge separation due to the grad B effect in the scrape-off layer (SOL) region with open magnetic field. It is difficult to study these phenomena in L-DPS. To overcome these insufficient capabilities, we have developed a new toroidal divertor plasma simulator, NAGDIS-T (NAGoya DIvertor plasma Simulator with Troidal magnetic configuration) to investigate the SOL/Divertor plasma physics.

In the NAGDIS-T, the plasma can be generated by DC and RF Joule discharge. In order to obtain high density plasma relevant to edge plasma, we need to optimize experimental parameters for discharge such as neutral gas pressure, RF driving frequency, transformer turn-ratio, plasma volume, etc. In this article, we focus on the RF Joule discharge in the NAGDIS-T. The experimental results show that the optimum condition for RF Joule discharge strongly depends on both the driving frequency and the neutral gas pressure.

2. Toroidal Divertor Plasma Simulator

NAGDIS-T consists of twelve toroidal magnetic field coils and four vertical field coils as shown in Fig. 1. The typical machine parameters are listed in Table I.

2.1 *Toroidal Magnetic Configuration*

These magnetic coils produce a helix configuration, in which the magnetic line of force starting from the upper surface of the vacuum chamber with a rectangular cross section is rotating toroidally and gradually going down to reach the lower surface. The incident angle of the magnetic line of force to the target plates and the connection length of magnetic line of force can be controlled by changing the ratio of vertical magnetic field strength to the toroidal one. This magnetic configuration in the NAGDIS-T can make it possible to simulate such as particle transport in long and curved magnetic line of force, and plasma-surface interaction with strongly inclined magnetic line of force to the divertor plate, and so on.

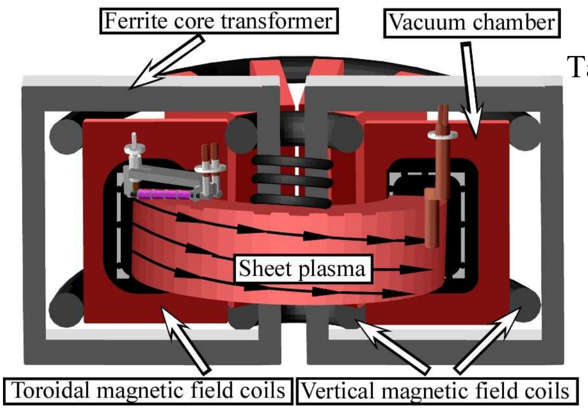


Table I. Typical parameter of the NAGDIS-T.

Major Radius	34cm
Cross Section	28x18cm^2
Toroidal Magnetic Field	0.1T
Vertical Magnetic Field	10G
Connection Length	20m
Incident Angle of B field line	0.6°

Fig. 1. Schematic diagram of the toroidal divertor plasma simulator, NAGDIS-T.

2.2 *RF Joule Heating System*

Figure 2 shows the circuit diagram of RF Joule heating system. The RF Joule power is introduced to plasma through a transformer made of ferrite core in order to reduce hysteresis loss at high frequency range. The turn ration of the primary to secondary winding is set 7 to 1 at the present. Primary circuit has a capacitor C to achieve electrical series resonance condition. The resonance frequency can be varied by changing the capacitance. RF power supply of SIT (Static Induction Transistor) inverter has a maximum power of 9 kW with 30 A and 300 V.

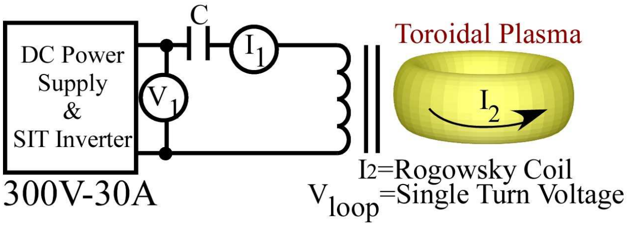


Fig. 2. The circuit diagram of RF Joule heating system. Capacitor C in the primary side is adjusted for matching the electrical resonance condition.

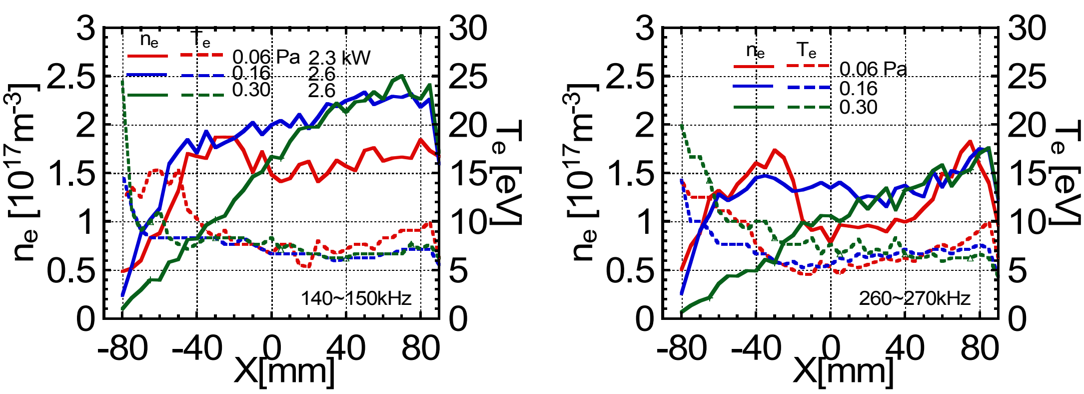
3. Experimental Results

We have investigated the optimized experimental parameters for RF Joule discharge to get high electron densities n_e above 10^{18} m^{-3} in hydrogen plasma. The toroidal magnetic field is 1 kG at the center with the vertical field of 1G. Electron density and temperature were measured with Langmuir probe movable in the radial direction. Experiments have been conducted when the hydrogen gas pressure was varied from 0.06 Pa to 0.3 Pa and the driving frequency was varied from 150 kHz to 270 kHz. The electron temperature T_e ranged from 5 through 20 eV, has similar profile among various gas pressures and frequencies: high in the high field side.

3.1 *Horizontal Profiles without Limiter*

Figure 3 shows the horizontal profiles of electron density n_e as a parameter of neutral gas pressure. X represents horizontal position at the equatorial plane, where $X = 0$ mm is center of the vacuum vessel, and the positive X means low field side. Input RF power was set to 2.6 kW in this experiment except for the data at 0.06 Pa in Fig. 3(a). The driving RF frequency is 150 kHz and 270 kHz in Fig. 3 (a) and (b), respectively. Comparison between Fig. 3(a) and (b) indicates that a lower driving frequency tend to give a higher plasma density.

At a higher driving frequency of 270 kHz in Fig. 3(b), the horizontal profile of n_e at 0.06 Pa becomes hollow, which is due to an RF skin effect. The RF skin effect prevents a penetration of RF power into the central region of plasma, resulting in a relatively high percentage of the RF power being deposited in the plasma edge, especially at high field side when RF electric field is stronger than in low field side. On the other hand, other horizontal profiles of n_e shows higher electron density at low field side.



(a) 150 kHz (b) 270 kHz

Fig. 3. Horizontal profiles of electron density with different gas pressures and driving frequencies. X is horizontal position at the equator of the vacuum vessel.

3.2 *Horizontal Profile with Limiter*

In order to increase injected RF power density, we inserted a limiter made of molybdenum into the vacuum vessel. The limiter covers cross section from X=-60 mm to 90 mm with the height of 28 mm.

Figure 4 shows the horizontal profile of electron density n_e and the electron temperature T_e with limiter at the driving frequency of 150 kHz and at the power of 4.1 kW. The maximum electron density n_e reaches 1×10^{18} m^{-3} at the edge of limiter, $X\sim$ -60 mm. T_e becomes higher in the shade of the limiter due to less electron collision.

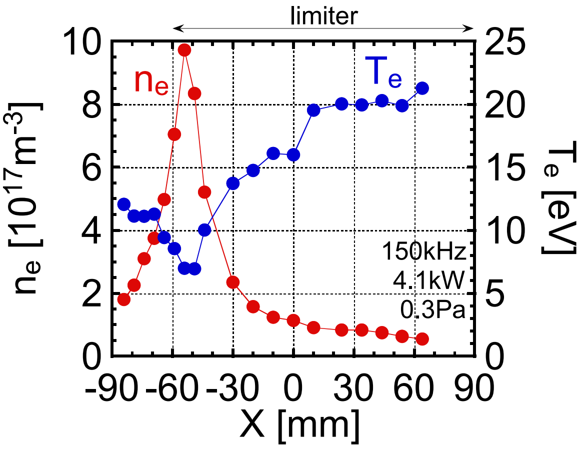


Fig. 4. Horizontal profiles of n_e and T_e when the discharge volume is reduced at the gas pressure of 0.3 Pa and the driving frequency of 150 kHz.

4. Summary

We have operated the RF Joule heating system of NAGDIS-T in order to find optimum conditions to generate high density hydrogen plasma. In the present system, the electron density n_e is increasing with the decrease of driving frequency at the gas pressure of about 10^{-2} Pa. The high power RF source of 30kW with a sophisticated control of frequency, waveform etc. will start to work in near future so that we may have a much higher plasma density relevant to the boundary plasma in fusion devices.

Acknowledgement

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