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Development of Target Plasma for Proof of Principle of Energetic Ion Injection
高エネルギーイオン注入法の原理検証に向けたターゲットプラズマ開発

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We developed a target plasma for a compact ion injector using hydrogen storage material. The plasma will be produced by electron cyclotron resonance heating in a cylindrical vacuum vessel (length: 2 m, diameter: 0.2 m). Two groups of magnetic coils are located around the vessel. One is for a plasma production region ($B \lesssim 0.1$ T), and the other is for a measurement region ($B = 0.3$ T). A circuit for pulse operation of the latter was designed, and the induced electromotive force on the former was calculated. Now we are constructing these components for the first plasma experiment. The vacuum chamber for the production region is successfully pumped down. Sufficiently low pressure for plasma production has been obtained.

1. Introduction

In the study of magnetically confined fusion plasmas, it is important to understand transport property of fusion products in plasma. The property is investigated using energetic ions derived from neutral beam injection instead of fusion products [1]. However, the birth point of the energetic ions is restricted because of the fixed beam line and the ionization, the latter of which depends on the target plasma. To advance understanding of the property, a more flexible method for supplying energetic ions is required; in particular, one that is applicable to smaller devices and lower density target plasmas.

We are developing a compact ion injector, which consists of hydrogen storage material containing hydrogen molecules. It is expected to accelerate hydrogen ions by using the electron sheath potential between the plasma and the surface of positively biased electrode. Using the injector inside the last closed flux surface, more flexible experiments are expected. It has been observed that emission of hydrogen atom line increase according to increase of bias voltage of the electrode in a small standard heliac device at Tohoku University (TU-Heliac) [2]. Proof of the principle, however, requires more sophisticated diagnostics with a simple target plasma. So target plasma, which is more suitable to prove of principle of the method, is developed.

2. Requirements of target plasma

It is preferable that the target plasma is produced in a linear device, because of easier measurement and analysis. Parameters of the plasma should be generally consistent with typical values of small torus devices in which the injector is assumed to use in the future (magnetic field strength: ~0.3 T, temperature: ~10 eV, density: ~10^{18} m^{-3}). Duration time of the plasma over 10 ms (discharge time of TU-Heliac) is required, because the time is enough for investigation of plasma response to the biased electrode. Characteristic length of the plasma should allows Larmor motion of the energetic ions assumed in this research (H^+, ~1 keV in ~0.3 T); larger radius than maximum of Larmor radius (~1.5 × 10^{-2} m), and larger length than maximum of axial length in a Larmor motion period (~0.1 m).

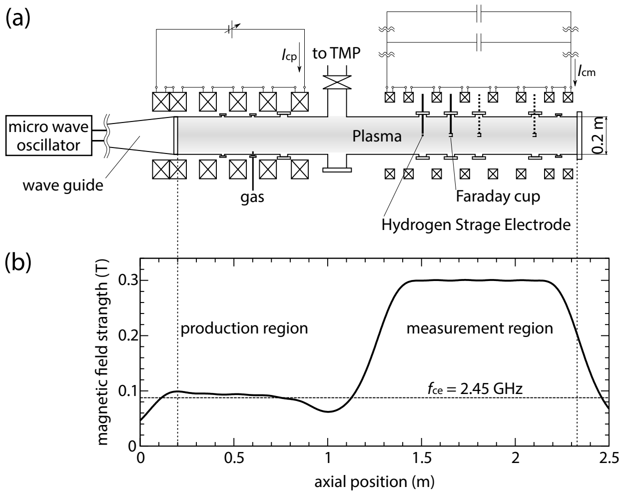

Fig.1. (a) A schematic diagram of a device in which target plasma is produced. (b) Axial profile of magnetic field strength.

3. Device in which target plasma is produced

3.1 *Outline of device*

A device, in which the target plasma will be produced, was designed as shown schematically in Fig. 1(a). The plasma will be produced by the electron cyclotron resonance (ECR) heating, using a microwave of frequency 2.45 GHz and injection power ~6 kW, in the cylindrical vacuum vessel (length: 2 m, diameter: 0.2 m). Fourteen magnetic coils located around the vessel have two groups: one consists of six magnetic coils, produces a magnetic beach configuration for ECR heating in a production region [3], and the other consists of eight coils, produces uniform configuration of 0.3 T (typical value of toroidal magnetic field strength in a small torus device) in a measurement region, as shown in Fig. 1(b). Each groups of coil is connected to its power supply. In the measurement region, the hydrogen storage electrode and tools of measurement of energetic ion, for example Faraday cup, are inserted.

3.2 *Circuit for pulse operation of magnetic coils, and coupling between two magnetic coil systems*

On the magnetic coil system for the plasma production region, coil current I_{cp} is ~100 A, which is small enough to realize steady operation. On the other hand, on for the measurement region, larger current I_{cm} over 1000 A is required. To realize steady operation with the current is difficult and expensive, so we designed a circuit consists of two capacitances for pulse operation of magnetic coils as shown in Fig. 3(a). The elements in the circuit had been used in TU-Heliac. Time evolution of I_{cm} was calculated by a circuit simulator as shown in upper of Fig. 3(b). Duration time over 10 ms is obtained.

The two magnetic coil systems are coupling, so pulse operation of the system for the measurement region induces electromotive force on the coils of the other system V_{cp}. Figure 3(a) shows schematic diagram of coupling between the two systems. Values of inductance L_{cp}, L_{cm}, and M_{pm} are calculated as sum of magnetic flux through each coil per current that produces the magnetic flux. Calculated time evolution of V_{cp} is shown in lower of Fig. 3(b). Maximum of absolute value of V_{cp} becomes ~40 V: the same order to power supply voltage of the system (~50 V).

3.3 *Current state of development*

The components for the first plasma experiments: micro wave oscillator, wave guides, magnetic coils for production region, a turbo molecular pump (TMP), and vacuum vessel for production region, are constructed. Vacuum pumping using TMP has been done, and the pressure reached sufficiently low background pressure for plasma production (~6 $\times 10^{-5}$ Pa without working gas).

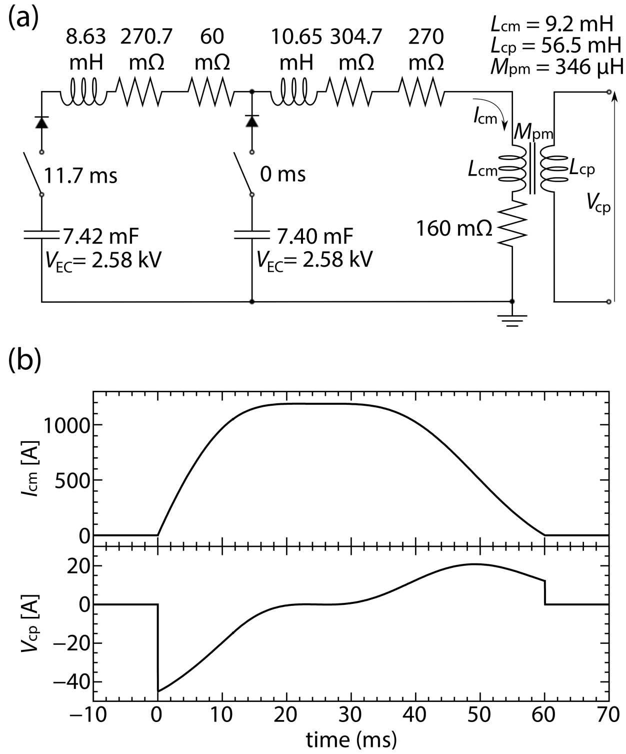

Fig.3. (a) A circuit for pulse operation of magnetic coils for the measurement region and schematically diagram of coupling of magnetic coils. (b) Time evolution of I_{cm} and V_{cp}.

4. Summary

We designed a linear plasma device to meet the requirements of target plasma for a compact ion injector using hydrogen storage electrode. A circuit for pulse operation of the magnetic coils for the measurement region was designed, and induced electromotive force on the coils for production region was calculated. Now we constructed components for the first plasma experiments using the production region and have obtained sufficiently low pressure for plasma production.

Acknowledgments

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