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NBI Plasma Startup using Non-resonant Microwave Injection in Heliotron J
ヘリオトロンJにおける非共鳴マイクロ波入射アシストによるNBIプラズマ着火

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This paper describes development of a plasma startup method with neutral beam injection by assistance of 5kW 2.45GHz microwaves in Heliotron J. The plasma startup has succeeded in the magnetic field strength more than 0.63T, where a fundamental or higher-harmonic layer for the microwave has not existed in the confinement region. The microwave power scan experiments show the higher microwave power is desirable for the reliable density build-up at lower magnetic field strength.

1. Introduction

Electron cyclotron heating (ECH) with either fundamental O-mode or second harmonic X-mode is a conventional scheme for plasma production commonly utilized in many heliotron devices [1]. While this scheme is advantageous for reliable startup and sustaining high electron temperature plasmas, it requires electron cyclotron resonance layer in the confinement region, giving rise to the limitation of operational magnetic field regime satisfying the electron cyclotron (EC) or its higher harmonic resonance.

Plasma startup only by neutral beam injection (NBI) has been demonstrated in LHD and W7-AS [2,3]. An issue for plasma production only by NBI is how the electron temperature is increased to a high enough value to ionize the background neutral gas. Since the electrons are heated only through the Coulomb collisions with the injected beam ions in the early phase of the NBI startup plasmas, the confinement time of the beam ions should be longer than the production time for the amount of the hot electrons.

In this paper, we present experimental results on startup of NBI plasmas by assistance of 2.45GHz 5kW microwaves in Heliotron J [4]. We experimentally demonstrate that the plasma was built-up less than 20ms after the turning-on of NBI, and that the operational magnetic field was widely extended down to B=0.63T.

2. Experimental results and discussions

Experiments were carried out in the standard configuration at the magnetic field strength B on the plasma axis from 0.59T to 1.0T. Figure 1 shows a typical time evolution of plasma parameters in the NBI plasma startup discharge at B=0.83T. The 2.45 GHz microwaves (5kW) were launched 0.6 s before turning-on of neutral beams. Neither fundamental nor higher harmonic EC resonance for 2.45GHz microwaves exists in the vacuum chamber during the microwave launching. A plasma with electron density ($\bar{n}_e$) less than $1\times10^{17}m^{-3}$, ECE intensity and CIII line emission were observed in the ramp-up phase of a poloidal (AV) coil current. The third-harmonic resonance layer for the ECE of 75.5GHz frequency is located at r/a = 0.3 in the configuration. It should be noted that the ECE intensity is not proportional to the local electron temperature because the plasma is optically thin due to quite low density, but it can be regarded as a measure of the intensity of “hot” electrons. After that, increase in the density of the seed plasma was observed from t=-120ms. In the case that the microwave was not launched, on the other hand, increase in the seed plasma density was not observed and high density plasmas could not be built after the NBI injection.

The co- and counter- NBIs were injected at the port through power of 1MW in total. $\bar{n}_e$ increased

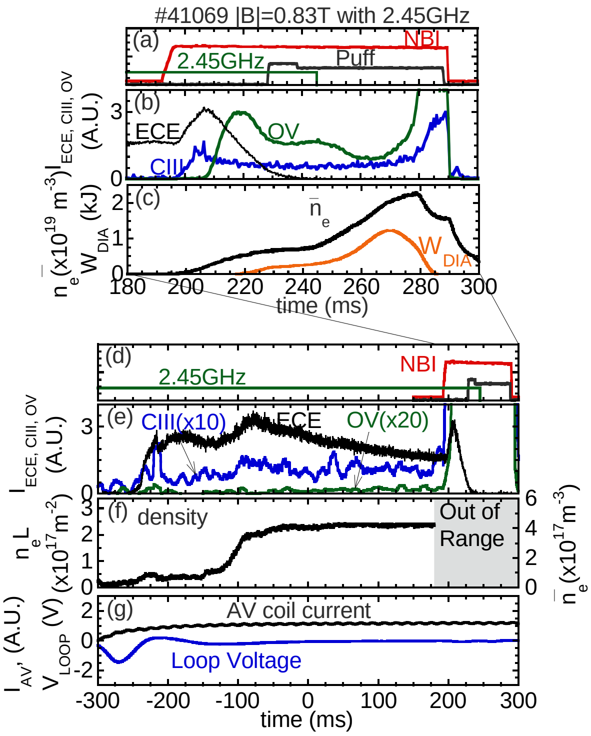

Fig. 1. Time evolution of plasma parameters obtained in NBI startup plasmas (standard config.).

just after the start of the neutral beam injection, and plasmas with the electron density of $\bar{n}_e$ ~0.2 $\times 10^{19}$m^{-3} appeared 10ms after the beam injection. At the same time, the intensity of OV line emission increased, which indicates a large number of electrons whose energy exceeds the ionization potential (113eV) were produced in the early phase of the beam injection. After that, an additional gas puff increased $\bar{n}_e$ to over 1×10^{19}m^{-3}.

Figure 2 shows the time evolution of the ECE intensity and $\bar{n}_e$ obtained by changing the microwave power. Just before the timing of the NB injection (t=210ms), the ECE intensity and $\bar{n}_e$ increases as increasing the microwave power. A clear threshold of the ECE intensity and $\bar{n}_e$ is found to build up the density.

Figure 3 shows the microwave-power threshold for the NB density build-up as a function of the magnetic field strength for the standard configuration case. At the higher magnetic field strength more than 1.1T, the plasma was built with the lower (~2kW) microwave power. The lowest power for the density build-up increases with decreasing the magnetic field strength. This result indicates a higher microwave power is required to enlarge the operational space. We are installing and testing a new 20kW-2.45GHz magnetron system.

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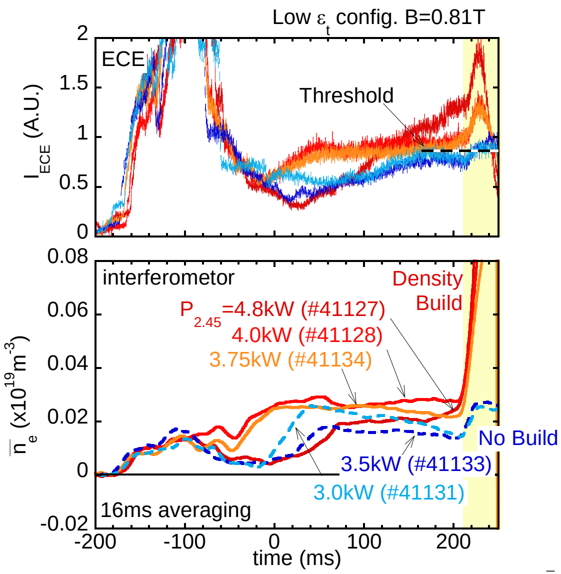

Fig.2. Time evolution of ECE intensity and $\bar{n}_e$ obtained in a low toroidicity (ε_t) configuration by changing microwave power.

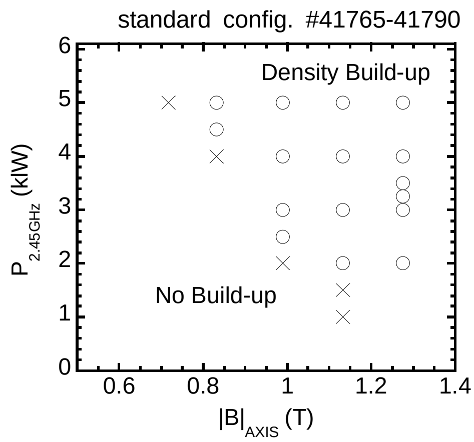

Fig. 3. Relation of density build-up by NBI between microwave power and magnetic field strength.