## §2. Production of NBI Plasmas by Assistance of 2.45GHz Microwaves

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In Stellarator/Heliotron (S/H) systems, plasmas can be produced by external heating power without loop voltage. Electron cyclotron resonant heating such as fundamental O-mode or second harmonic X-mode are conventionally used. While this method is advantageous for high electron temperature plasmas, electron cyclotron resonance layers should be located in the confinement region, which limits operational magnetic field. In LHD, plasmas have been successfully produced only by a neutral beam injection (NBI). The key point for plasma production by NBI is that electron temperature is high enough for background neutral gas to be ionized. Since electrons in NBI start-up plasmas are heated through Coulomb collision with injected beam ions, large vacuum volume or high magnetic field is required for long distance so that the beam and neutral particles collide much.

In the medium-sized device, Heliotron J, it was not possible to produce plasmas by NBI only. Recently we have successfully demonstrated plasma production by NBI with assistance of 2.45 GHz 5 kW microwaves [1]. Two tangential (counter- and co-) beamlines of the hydrogen NBI system have been used in Heliotron J (BL1 and BL2, respectively). Each beamline has two bucket-type ion sources, a maximum beam power of 0.7 MW, and an acceleration voltage of 30 keV. Microwaves of 2.45 GHz frequency and 20 kW power were generated by a magnetron. The electric field of the injected waves close to the O-mode is oriented in the horizontal direction.

A low-density plasma was initiated when 2.45 GHz microwaves were turned on. When 2.45 GHz microwaves were not applied, the line-averaged electron density did not increase during beam injection within the resolution limit. Figure 1 shows a tangential view of plasma generated by the 2.45GHz microwaves, measured with a CCD camera. The plasma is generated along the magnetic axis, and does not expand to the last closed flux surface. Since the line-averaged density measured with a microwave interferometer is the order of $10^{17}$ m$^{-2}$, the electron density at magnetic axis may be higher than $1\times10^{17}$ m$^{-3}$. Electrons generated by the 2.45 GHz microwaves should be confined in the good confinement region for plasma production. As shown in Fig. 2, intense electron cyclotron emission signals have been observed during 2.45 GHz microwave injection, possibly by third harmonic ECE and/or synchrotron radiation due to high-energy electrons. Neither the fundamental and higher-harmonic electron cyclotron resonances for 2.45 GHz microwaves exist in the vacuum chamber during microwave launching. Production mechanism of high-energy electrons is under investigation.

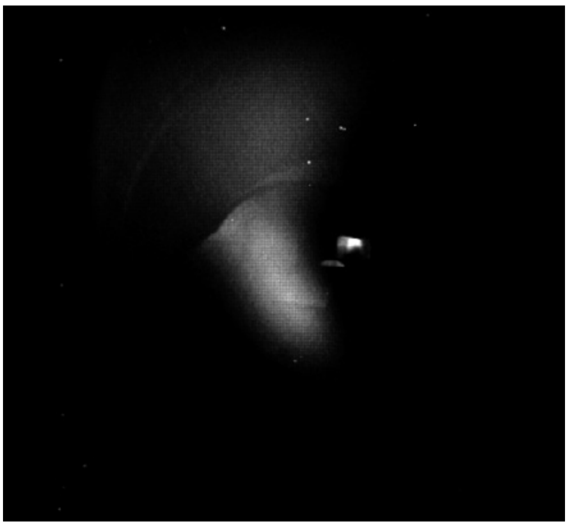

Fig. 1 Tangential view of a plasma produced by 2.45GHz microwaves measured with a CCD camera. The magnetic field is set as B=0.83 T.

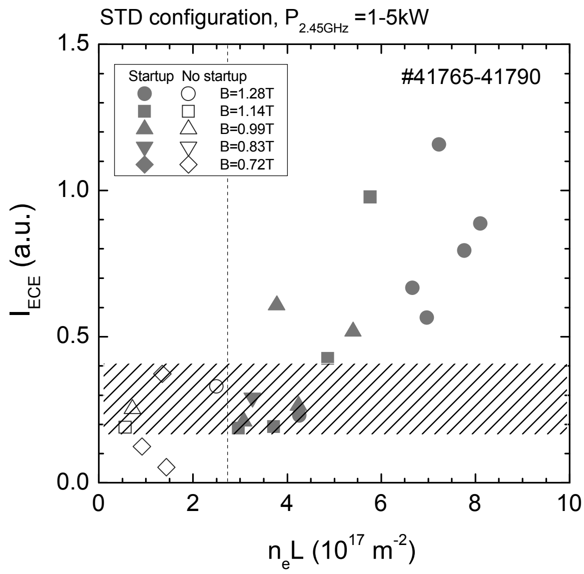


Fig. 2 Relation between line-averaged electron density and ECE radiometer signal intensity.

There are necessary conditions for successful NBI plasma start-up: the number of neutral particles (gas pressure), electron heating (microwave power) and the number of high-energy ions (NB power). The magnetic field scanning experiment shows that higher microwave power is required at lower magnetic field strength. The confinement of high-energy ions and/or high-energy electrons is degraded under low magnetic field condition, requiring higher microwave power.

We have studied operation capability of a 2.45GHz magnetron system under high magnetic field circumstance in LHD. We expect that application of 2.45GHz microwaves can extend the operational magnetic field regime and reduce the injection beam power for plasma production.

[1] S. Kobayashi, et al., Nucl. Fusion **51** (2011) 062002