§57. The Observation of Lower Frequency Waves during High-harmonic Fast Wave Heating in the LHD

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High-harmonic fast wave (HHFW) heating has been investigated in high beta regime, and the accessibility and electron absorption has been inspected in torus plasma like spherical tokamak. In electron heating experiments using HHFW in NSTX, the temperature of the hot ion component is observed using charge exchange and recombination spectroscopy [1]. The excited wave frequency is typically 10 times larger than the ion cyclotron range of frequencies (ICRF), and ion cyclotron damping is negligible in the experimental region. When the ion temperature at the plasma edge is directly increased, an ion Bernstein wave (IBW) is detected using Langmuir probe. Due to a non-linear wave coupling process in parametric decay instability (PDI), three-wave coupling, the launched HHFW is transformed into an ion cyclotron quasi-mode (ICQM) of slow wave, and an IBW of electrostatic wave.

An HHFW electron heating experiment was attempted in the Large Helical Device (LHD) with the normalized beta of 1 % (magnetic filed B of 1.5 T at major radius R of 3.6 m), and central electron heating was clearly achieved when additional electron cyclotron heating was injected at the core region of plasma [2]. In some parts of the experiment with a low electron heating efficiency an extended ion tail was observed, and ion heating was carried out in HHFW electron heating experiment. Second ion cyclotron resonances of hydrogen exists at near $r/a \sim 0.6$, and second hydrogen cyclotron damping is a strong candidate to be the ion heating mechanism, rather than non-linear wave-particle interaction like parametric decay instabilities (PDI) [3]. It is important to clarify the parasitic ion heating mechanism in HHFW electron heating experiments, and a high-sensitivity wave measurement system using a new designed detector to measure these waves was installed in the LHD.

Figure 1 shows electromagnetic waves using the real-time spectrum analyzer measurement during HHFW heating, and the frequency of 38.47 MHz is the pumped wave frequency using HHFW heating antenna excitation with the injected power of $P_{HHFW} \sim 1$ MW. Line averaged electron density ne0 of 3.2×10^{19} m^{-3} at $R = 3.67$ m, electron temperature of $T_e = 2$ keV at $R = 3.6$ m and the minority ratio of hydrogen is approximately 20 % using spectroscopy measurement in helium discharge. In the lower frequency range from DC to 10 MHz, clearly frequency peaks are observed, and the frequency peak at 7.5 MHz is an ordinary strong peak. These lower frequency peaks do not change for electron density from 1.7×10^{19} m^{-3} to 1.1×10^{19} m^{-3}, and the appearance of these lower frequency waves is not related to high energy particle distribution because there is little difference between lower frequency waves and only pumped wave discharges in the high energy particle distribution measured by SiFNA. In the power modulation experiments, these lower frequency waves vanish at the same time after HHFW injection is stopped. This shows that these lower frequency waves are not some kind of high energy particle driven Alfven wave or ion cyclotron emission (ICE) [4]. This shows that these lower frequency excitation, some non-linear wave-particle interaction like PDI is required. Assuming that the daughter waves of these lower frequency waves are IBW, the daughter wave caused by PDI can not be detected by this detector because IBW is an electrostatic wave. Even if ICQM as lower-sideband daughter waves are excited around a frequency of 30 MHz, it is difficult for it to propagate to this detector because there are cyclotron resonance and an L cut-off layer around the detector with high magnetic filed. Solving the ion cyclotron wave (ICW) dispersion relation in experimental parameters, lower frequency waves (< 10 MHz) are excited around magnetic field B of 1 T at plasma edge, which is consistent with the observed lower frequencies.

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2) H. Kasahara, T. Oosako, Y. Takase, et al., Journal of Korean Phys. **12**, S192 (2006)
3) M. Porkolab, Phys. Fluids **20**, 2058 (1977)
4) K. G. McClements, C. Hunt, R. O. Dendy, et al., Phys. Rev. Lett. **82**, 2099 (1999)

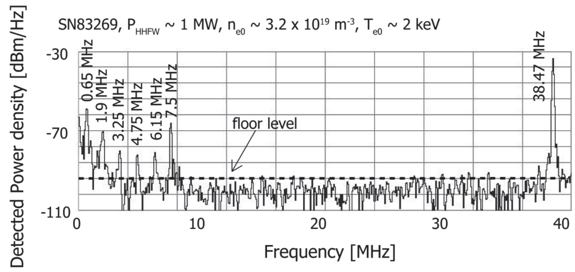

Fig. 1. Lower frequency waves are observed during HHFW heating, and the pumped wave frequency is 38.47 MHz. The difference observed power density level between the pumped wave and the detected lower frequency waves are approximately 40 dBm/Hz ,

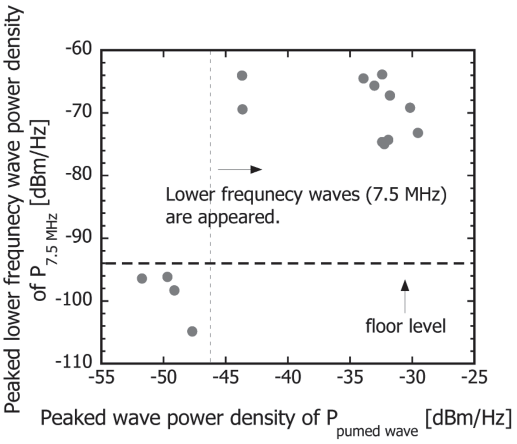

Fig. 2. A clear power density threshold of the lower frequency wave (7.5 MHz) appearance is observed for the case of the pumped wave (38.47 MHz), and the threshold power density level is approximately -46dBm/Hz.