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Observation of Electromagnetic Fluctuation and Density Decay of Magnetospheric Plasma in RT-1
RT-1における磁気圏型プラズマの電磁揺動と密度崩壊の観測

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In the RT-1 device, a magnetospheric configuration generated by a levitated dipole field magnet, high beta plasma is created by using electron cyclotron resonance heating (ECH). When the population of energetic electrons (~30keV) is very large at low neutral gas pressure operation, a high frequency electromagnetic fluctuation is observed. The fluctuation rotates in the electron curvature drift direction and has no clear phase difference along magnetic field lines. The fluctuation can cause rapid loss of plasma especially in a decay phase after the ECH power is turned off. Sufficient gas fueling suppressed the fluctuation, realizing stable high beta confinement.

1. Introduction

The Ring Trap 1 (RT-1) device [1-2] is a magnetospheric dipole field configuration constructed for the studies of high-beta plasma suitable for burning advanced fuels [1-4]. The dipole confinement concept [3] was motivated by a natural example of high-beta plasma observed in the Jovian magnetosphere. Although plasma is trapped in bad curvature regions, it was pointed out that dipole plasma can be stable against MHD interchange and balooning instabilities due to the effects of plasma compressibility [3] and magnetic separatrix [5]. In the first series of experiments in RT-1, plasma is generated by using electron cyclotron resonance heating (ECH). High-beta hot-electron plasma has been successfully realized in RT-1 [6] through the optimization of formation conditions including the feedback-controlled levitation of the dipole field magnet [7].

In the presence of intense energetic charged particles in plasmas, emergence of several kinds of fluctuations and instabilities are widely observed.

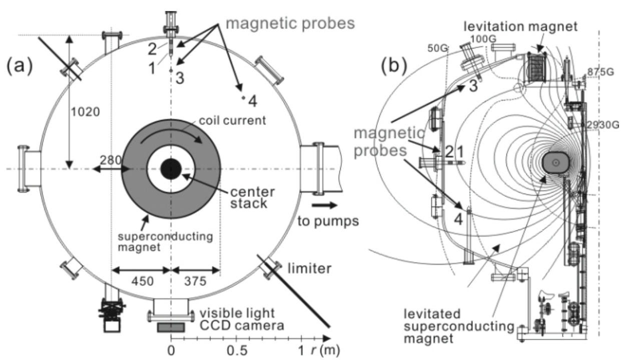

Fig.1. (a) Top view and (b) projection on the poloidal cross section of the RT-1 experiment.

Existence of multiple temperature components and velocity space anisotropy in the plasma can be energy sources for the onset of instabilities. Understanding of the fluctuation properties is very important for the realization of stable confinement of high-beta plasma in the magnetospheric configuration. In this study, we report the observation of high-frequency electromagnetic fluctuation in RT-1 emerges when the population of energetic electrons is very large. Spatial structures and conditions for the excitation of the fluctuation were experimentally studied.

2. RT-1 and Experimental Setup

Figure 1 schematically shows the vacuum chamber, magnetic surfaces, and diagnostics of RT-1. External magnetic field is generated by a combination of the dipole field magnet and a levitation magnet located at the top of the chamber. Toroidal field coils are not installed at present and plasma is confined in a pure poloidal field configuration. Hydrogen plasma was generated by ECH with 2.45GHz microwave. Measurements with Si(Li) and CdTe x-ray detectors, and edge Langmuir probes show that electrons in the plasma have multiple temperature components. Plasma pressure in the present experiments is mainly due to hot electrons of ~30keV. Due to its small cross section of collisions with other particles, the hot electrons have long confinement time.

For the measurements of electromagnetic fluctuations, magnetic pickup coils (B dot probes) are installed at an equator port (1 and 2), an upper port (3), and a bottom port (4) of RT-1 as shown in the figure. Pickup coils 1, 2, and 3 are located on the same poloidal cross section. Fluctuation signals were measured by a 500MHz broad-band oscilloscope. The signals of magnetic probes were converted into frequency spectra with a conventional fast Fourier transform (FFT) method. Diamagnetic signals and plasma pressure were measured by magnetic loops and Hall sensors. A 75GHz interferometer was installed for the measurements of electron line density.

3. Observation of Electromagnetic Fluctuation

After the stop of microwave injection, the electron density was observed to decrease with different time constants. The initial rapid decrease is due to the loss of cold electrons, and the second slow decay is due to the effects of long-lived hot electrons. By decreasing neutral gas pressure, very intense hot electrons are generated by ECH. In such cases, the plasma is sometimes unstable and the excitation of MHz range magnetic fluctuation was detected in the hot electron plasma. In the slow decay phase, burst of electromagnetic fluctuation is observed. Temporal evolution of plasma in the decay phase is shown in Fig.2. Just after turning off the microwave injection at t=0s (Fig.2a), the plasma started to decay quietly. Large magnetic fluctuation was not observed at this point. At t=2.6ms, burst of electromagnetic fluctuation (Fig.2d) and rapid loss of line density (Fig.2b) were simultaneously observed. In Fig.2c, diamagnetic signal shows that plasma pressure decayed slowly after the onset of fluctuation, suggesting that some amount of hot electrons were trapped in this period outside the chord of the interferometer.

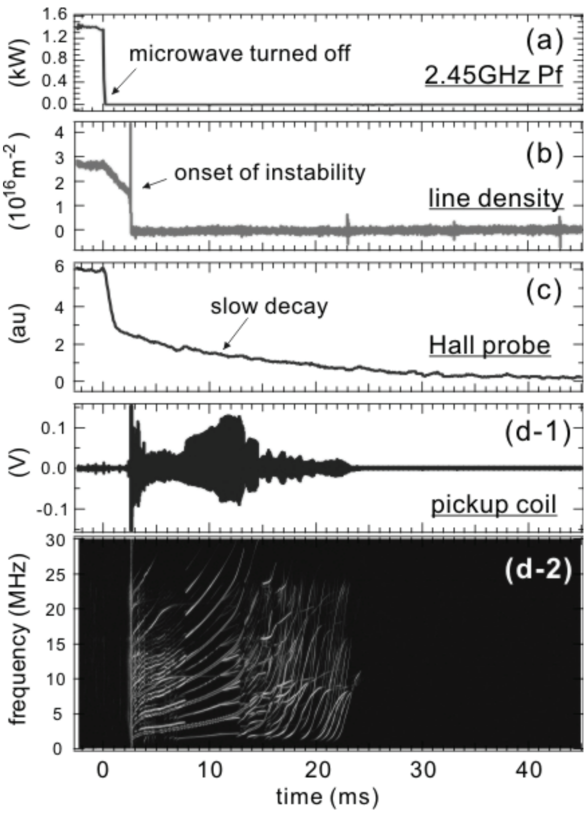

Fig.1. Onset of fluctuation and plasma decay. (a) Input power of microwave power, (b) line density, (c) diamagnetic signal, (d-1) magnetic fluctuation measured by the pickup coil, and (d-2) its power spectrum.

The fluctuation had complicated frequency sweep behaviors, and the spectrum had several peaks as shown in the figure. Temporal variation of the fluctuation frequency, or chirping, with df/dt~10MHz/ms was repeatedly observed in the following phase. Emergence of the high-frequency fluctuation was observed only when the neutral gas pressure was low (~2mPa) and the plasma had a large amount of hot electrons. This observation suggests that the effects of hot electrons are possible reasons for the onset of instability. Electrostatic fluctuation in the similar frequency range was reported in other experiments [8].

The spatial mode structures of the fluctuation in toroidal, vertical, and radial directions were measured by using two magnetic probes located at different positions. The fluctuation phase had weak radial and vertical dependences when measured at edge region, suggesting that fluctuating plasma current was located apart from the pickup coils. In contrast, clear phase differences were observed in the coil signals observed at different toroidal positions. The propagation direction of the fluctuation agrees with the electron diamagnetic motion, also suggesting that the hot electrons are energy source for the onset of fluctuation. By using typical parameters of field strength B=0.03T, hot electron temperature T_e=30keV, electron density after the initial plasma decay $n_e \sim 10^{15}m^{-3}$, and assumed spatial scale length of the plasma structure $\Lambda = n/n' \sim 0.1$m, electron diamagnetic drift velocity is calculated to be $v_D = k_B T_e / eB\Lambda \sim 10^7$m/s, which is comparable to the observed toroidal propagation velocity of the electromagnetic fluctuation.

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