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Potential Formation And Confinement In High Density Plasma On The Tandem Mirror GAMMA 10

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Abstract

GAMMA 10 experiments have advanced in high density experiments after the last EPS Conference where we reported high density plasma production by using an ion cyclotron range of frequency (ICRF) heating at a high harmonic frequency. Recently a high density plasma was obtained with much improved reproducibility than before. The high density plasma was attained by adjusting the spacing of the conducting plates installed in the anchor transition regions. Dependencies of particle confinement time and plasma confining potential on plasma density were obtained for the first time in the high density region.

Introduction

GAMMA 10 experiments have been directed to realization of a high density plasma with potential confinement and also to study dependencies of the confining potential and confinement time on the plasma density. These problems are important for understanding the physics of potential formation in tandem mirrors and also for the development of a tandem mirror reactor. We reported a high density plasma production by using an ion cyclotron range of frequency (ICRF) heating at a high harmonic frequency in the last EPS Conference [1]. However, the diamagnetic signal of the high density plasma could not be sustained when electron cyclotron resonance heating (ECRH) was applied for the confining potential formation due to some instabilities. Although the instabilities are not explained yet, the high density plasma production is much improved by adjusting the spacing of the conducting plates installed in the anchor transition regions [2]. It is considered that the conducting plates will be more effective for suppression of the instabilities by installing them close to the plasma. A high density plasma was produced without degradation of the diamagnetic signal with ECRH. Then, experimental studies of the dependencies of the confining potential and the confinement time on the density progressed up to the density of 4×10^{18} m^{-3}.

The GAMMA 10 tandem mirror and high density plasma production

GAMMA 10 tandem mirror consists of an axisymmetric central cell, two anchor cells with minimum-B configuration located at both ends of the central cell, and axisymmetric plug/barrier cells located outside the anchor cells. Plasma guns located at both ends produce the initial plasma and the plasma is sustained by ICRF heating in the central cell (RF2: 6.3 MHz, RF3: 36-76 MHz) and anchor cell (RF1: 9.9 MHz) with hydrogen gas puffing in the central cell, where RF2 heats ions mainly in the central cell with the fundamental resonance and RF1 and RF3 are for plasma production. After the Yokohama IAEA Conference [2], it was observed that a density higher than 2.5×10^{18} m^{-3} was difficult to be achieved with and without potential confinement due to a density clamping mechanism. Although this mechanism has not been made clear yet, a higher density plasma was obtained by application of a high harmonic ICRF power (RF3) [1]. In addition to RF3, a neutral beam injection (NBI) in the central cell was started last year for plasma heating and production. A plasma confining potential is produced in the plug/barrier cells by a fundamental ECRH at the plug region (Plug ECRH) and second higher harmonic ECRH at the barrier region (Barrier ECRH).

High density plasma confinement

The high density plasma was obtained through optimization of the heating scenario with respect to ECRH, ICRF heating and NBI. Another important factor was adjustment of the spacing of the conducting plates installed in the anchor transition regions. We reinstalled the conducting plates close to the plasma along magnetic field lines, which contributed to reduce the instabilities. Figure 1 shows waveforms of a plasma density in the central cell (a) and diamagnetic signal (b). The FWHM of the density profile was 0.19 m and the plasma density indicates that on the axis n(0). We reported this data last year, where the diamagnetic signal decreased with application of ECRH. The decrease of the diamagnetic signal was larger at a higher density. The cause of the decrease is not well explained yet, but is considered to be due to some instabilities caused by plasma wall interactions because the decrease tends to be smaller with progress of wall conditioning. However, we could not obtain a data without

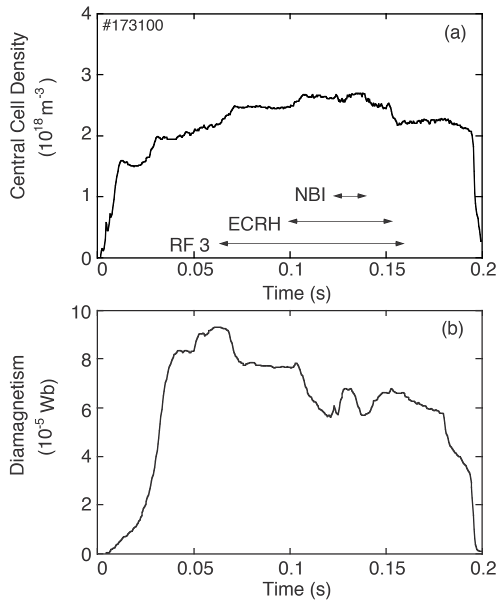

Figure 1 Waveforms of a plasma density in the central cell (a) and diamagnetic signal (b) [1].

degradation of the diamagnetic signal before the reinstallation of the conducting plates even after long wall conditioning. Figure 2 shows recently obtained waveforms of the density in the central cell (a), diamagnetic signal (b), and end loss current (c), where the diamagnetic signal slightly increased with a density higher than that in Fig. 1. An end loss energy analyzer is used in a bias-scanning mode for the measurement of Fig.2(c) and the envelope of the signal traces the end-loss ion-current. The line density increased 20% by application of RF3 power at 100 kW. In experiments without RF3, the density saturated at about 2.5×10^{18} m^{-3} even if the RF1 power for plasma production was increased more than 100 kW. So the high harmonic ICRF power is effective for higher density plasma production. The decrease in diamagnetic signal with application of RF3 is not explained yet but it is considered to be due to plasma wall interactions. The line density increased further due to the potential confinement by application of ECRH. The ion temperature in the central cell was anisotropic with different perpendicular temperature of 3 keV and parallel temperature of 0.3 keV to the magnetic field. The electron temperature was 0.08 keV. The axial ion confinement time $\tau_{//}$ is determined as $\tau_{//}=eN/I_{loss}$, where e is the unit charge, N is the total number of ions in a flux tube and I_{loss} is the end loss current from the flux tube as shown in Fig. 2(c). At a time just before ECRH turned on, that is without confining potential, the axial ion confinement time was 0.005 sec and the radial confinement time was estimated to be longer than 0.03 sec. Those confinement times of the plasma sustained only by ICRF heating correspond to the mirror confinement time in the GAMMA 10 magnetic field.

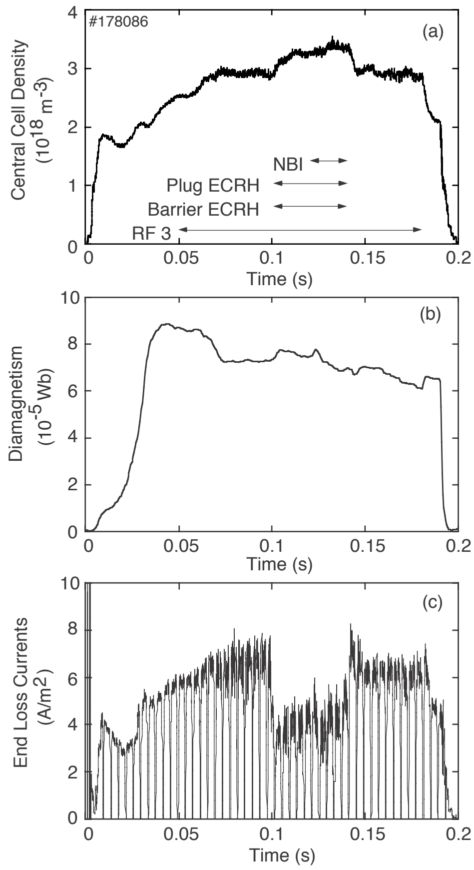

Figure 2 Waveforms of central cell density (a), diamagnetism (b) and end loss current (c).

In Fig. 3 the axial ion confinement time and confining potential are plotted with respect to the plasma density. Both of them have a tendency to decrease with the density but the decrease is not so strong as an inverse proportionality. Recently, a theoretical model was developed for the potential formation mechanism [3]. In this model, however, the potential depends only on the axial density profile but not on the absolute value. Therefore, we are to study the dependence of potential on density experimentally. The magnitude of the confining potential depends strongly on the anisotropy of the plug electron distribution function. The electron velocity anisotropy is considered to be relaxed when the plasma density increases. Then the decrease of the confining potential with the plasma density is expected. We need more experiments in order to obtain an empirical scaling between them.

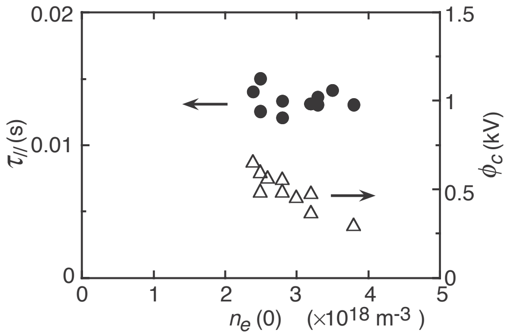

Figure 3 Axial confinement time $\tau_{//}$ (●) and plasma confining potential ϕ_c (△) as a function of plasma density. Plug ECRH power: 140-150 kW

Summary

A high density plasma was obtained without degradation of the diamagnetic signal with application of ECRH. Dependencies of the confinement time and confining potential on the plasma density were obtained for the first time in the high density region. More detailed experiments in wider density region will be necessary for determining a scaling relation for the dependencies.

[1] K. Yatsu, T. D. Akhmetov, T. Cho, et al., 28th EPS Conference on Contr. Fusion and Plasma Phys., Funchal, 18-22 June 2001, ECA Vol.25A (2001) 1549-1552.
[2] K. Yatsu, L. G. Bruskin, T. Cho, et al., Nucl. Fusion 39, No.11Y (1999) 1707.
[3] I. Katanuma, Y. Tatematsu, K. Ishii, et al., J. Plasma and Fusion Research, 77 (2001) 1085.