J. Plasma Fusion Res. SERIES, Vol. 5 (2002) 428–432

Behavior of the Edge Plasma near the Anchor Conducting Plates and Their Effect on the Plasma Confinement in the GAMMA 10 Tandem Mirror

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(Received: 11 December 2001 / Accepted: 5 July 2002)

Abstract

This paper describes the behavior of the edge plasmas near conducting plates installed for improving the plasma performance of GAMMA 10. The conducting plates are fixed closely to the plasma surface where the cross section of the plasma is flatly elongated in the anchor transition region. In this region a significant asymmetry of the edge plasma was observed in both probe currents and floating potentials. The direction of the shift in the ion-saturation current corresponds to the gradient B drift for ions. It is also found that the deposition areas observed on the conducting plates, which show a rotational symmetry to the magnetic axis, are expanding with the progress of plasma experiments. Most probable mechanism explaining the above-observed results is discussed based on the results of the magnetic field and ion orbit calculations. Effects on the plasma parameters of the conducting plates are studied and it is found that the floating condition of the plates leads to the increase of the plasma performance during potential formation.

Keywords:

GAMMA 10, tandem mirror, edge plasma, Langmuir probe, gradient-B drift, ion orbit calculation

1. Introduction

Improvement of plasma confinement by using electrostatic potential is a key element for tandem mirror devices. In the GAMMA 10 tandem mirror, extensive studies have been made and the improvement of confinement due to the potential formation has been proved [1-3]. However, the existence of radial loss in axially confined plasmas was also revealed. As a suspicious region where the radial loss occurs, we have pointed out anchor transition region which has a non-axisymmetric structure of magnetic field and has flatly elongated plasma cross section. This region also contains strong gradient-B structure where the magnetic filed line of the minimum-B region is connected with the axisymmetric field line of the central and plug/barrier regions. In the region containing such a complicated magnetic configuration, discrepancy between the equi-potential surface and flux surface of plasma may cause a large amount of distortion of the electric field, which leads to the radial transport of the plasma.

In 1998 four sets of conducting plates were installed in the anchor transition regions to improve the performance of plasma confinement further. The conducting plates are installed close to the plasma surface in both inner and outer transition regions in each anchor-cell. Several series of experiments on the basic

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characteristics of the conducting plates in plasma discharges were performed [3-5]. The effect of the plates on the plasma parameters during potential formation also have been investigated by using Langmuir probes and calorimeters installed in the outer transition region of the east anchor-cell [4-6]. Furthermore, the anchor conducting plates were modified in their shapes and sizes for investigating the effect of the plates in the summer of 2001. In this paper the behavior of the edge plasma near the anchor conducting plates are reported and the effect of the plates on the plasma confinement is discussed.

2. Experimental Apparatus

2.1 The GAMMA 10 device

GAMMA 10 consists of an axisymmetric central-mirror cell, anchor-cells with minimum-B magnetic fields, and plug/barrier cells with axisymmetric mirrors. Figure 1(a) shows the schematic view of the GAMMA 10 tandem mirror. The length of the central-cell is 6 m and both ends of the central-cell are connected to the anchor-cells through the mirror throat regions. Injecting the gun plasma from both ends produces initial plasma, and then main plasma is built up with ICRF waves together with gas puffing in the central-cell. One of the ICRF waves (RF1) is used for MHD stabilization of the whole plasma at the anchor-cell. Another wave (RF2) is used for heating the central-cell ions by ion cyclotron damping near the mid plane of the central-cell. The plug potential produced with ECH by using gyrotrons installed in each plug/barrier region confines escaping particles along the magnetic field line.

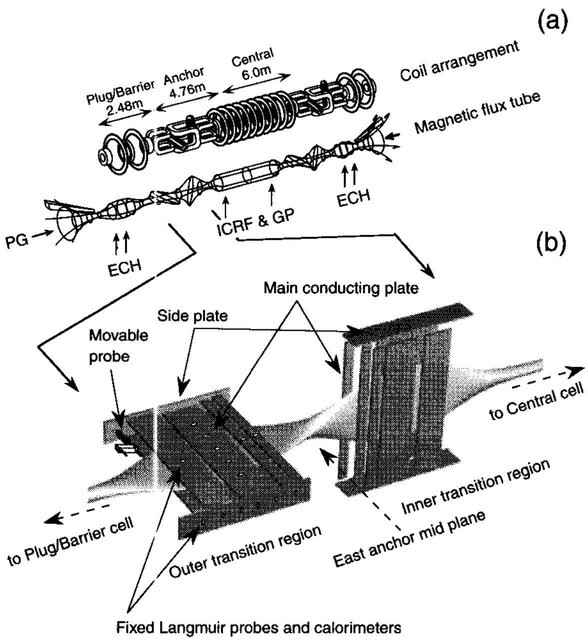

Fig. 1 Schematic illustration of the GAMMA 10 tandem mirror device: (a) coil arrangement and shape of the magnetic flux tube, (b) the conducting plates and diagnostic system at the east anchor-cell.

2.2 Anchor conducting plates and diagnostic system

The schematic view of the conducting plates at the east anchor-cell installed in 1998 (AP1) is illustrated together with the magnetic flux tube in Fig. 1(b). The main conducting plates, which are placed along the longer axis of the elliptic plasma cross section, are separated to 4 pieces in an axial direction. At both ends of the longer axis, side plates are installed facing each other. The potential of each plate is changed in floating and grounded conditions individually, and also can be biased by using external power supplies. On the side plates of the east outer-transition region, arrays of calorimeters and Langmuir probes are installed in order to investigate the behavior of the edge plasmas. In the course of experiments using the anchor conducting plates, the space between each facing plate was expanded in the spring of 1999 (AP2) and recently the structure was considerably modified and reinstalled in the summer of 2001 (AP3). In the present conducting plates, the distance between the plates is set to be narrower and is carefully adjusted along the magnetic field line in this region.

3. Experimental Results

Figure 2 shows the spatial profile of ion saturation current measured with the movable Langmuir probe at the east outer-transition region in a standard hot-ion mode plasma used in the present experiment. A clear asymmetry in x (vertical) direction is observed in the

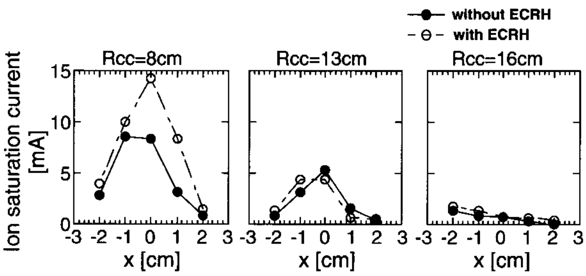

Fig. 2 Spatial profile of the ion saturation current in the vertical direction at the outer-transition region of the east anchor-cell.

periphery region (Rcc ≥ 13 cm) and it has a tendency to be enhanced with the distance from the plasma axis. In this figure Rcc represents the effective radius of the probe position which is mapped on the central-cell mid plane along the magnetic field line. It is found that the above feature is independent of the potential formation produced by the plug ECH.

Figure 3 shows the floating potentials of the newest conducting plates (AP3) measured under a similar experimental condition as shown in Fig. 2. The illustration in Fig. 3 shows that AP3 is separated in the azimuthal direction of the plasma cross section. Spatial profile of floating potentials in y (horizontal) direction measured with arrays of fixed Langmuir probes installed on the conducting plates facing each other at the same region are shown in Fig. 3. It is found that positive potentials are measured in all the plates and generally higher potentials are observed in the plates of inner transition region that is connected to the central cell. The floating potentials on the top plate array in the outer transition region increase with the positive y (horizontal) direction and those on the bottom plate array present an opposite dependence to the top plate case. This dependence agrees with the profile of floating potential in y-direction measured with an array of Langmuir probes installed on the same plates. These experimental results support that the asymmetry of the edge plasma measured in the outer-transition region is ascribed to the effect of ion drift motion due to the strong gradient-B structure in this region.

Figure 4 shows the photographs of the main plates on the side of facing the plasma, which were taken after being used in the experimental period of 3 years (1998 – 2001, 19000 plasma shots). There are some deposited areas of impurity observed on the plate and their locations correspond to the opposite place to the ion drift side. This phenomenon shows a clear structure containing a rotational symmetry in 180 degrees around the magnetic axis. The left photograph of each region in Fig. 4 gives the result obtained after the first one-year operation (1998–1999) and the right one corresponds to

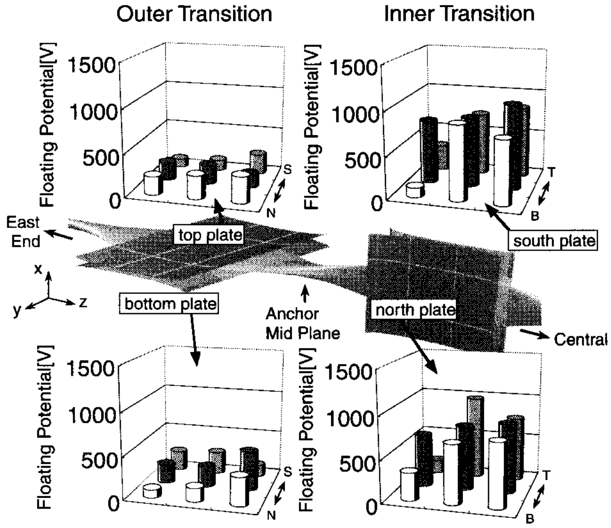

Fig. 3 Spatial profile of the floating potential on the conducting plates at the outer-transition region of the east anchor-cell.

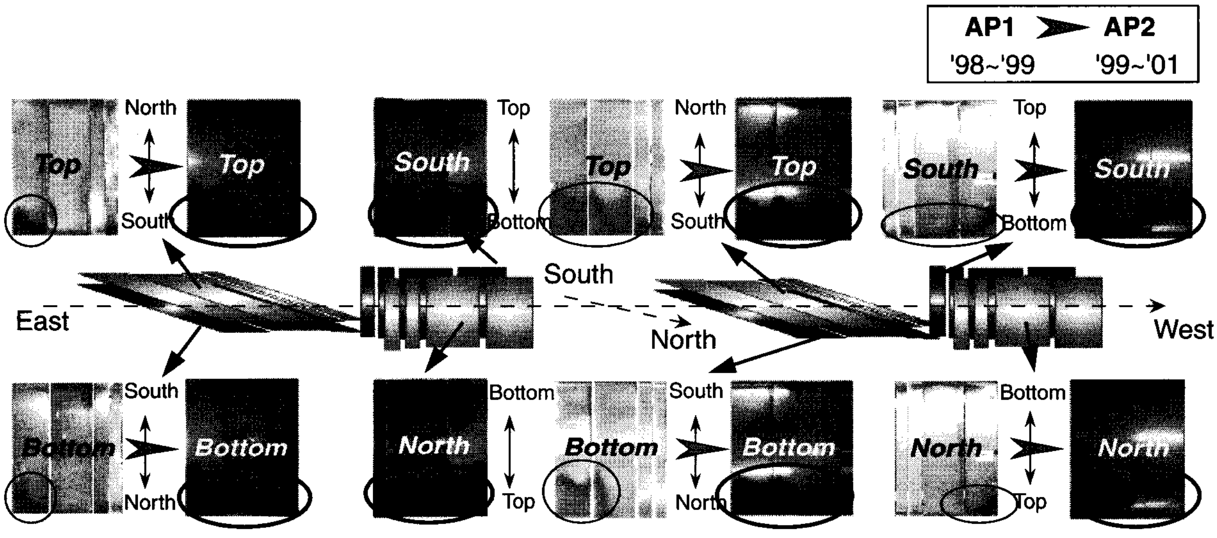

Fig. 4 Photographs of the anchor conducting plates used in 3 years. The circles show the area of typical deposited area by impurity material. All the plates are shown in inner surface (facing the plasma).

that after 3-years operation (1998–2001). A significant expansion of the deposited area is recognized in every region due to the latter 2-years operation. These observations are explained by such mechanism that plasma ions hitting on the plate sputter impurities from the plate due to the drift effect and the sputtered impurities are redeposited on the opposite plate.

4. Discussion

4.1 Ion orbit calculations

To investigate the mechanism of the asymmetry in measured data, a numerical calculation for tracking the passing-ion orbit has been carried out considering the effect of gradient-B drift in the anchor transition region. The edge region at the anchor-cell mid plane is selected as a launching position of test particles and the tracking of the orbit is started toward both inner (central-cell) and outer (plug/barrier cell) directions. The initial value of test particles is given by assuming the conservation of magnetic moment and energy of ions coming from the central-cell. The obtained results are shown in Fig. 5. Symbols in the figure represent the locations of guiding center of passing ions launched at the initial positions in Rcc = 20 cm, 26 cm and 30 cm, respectively. In the inner transition region (Fig. 5(a)), a shift of the orbit in the direction of gradient-B (upward in the north side and downward in the south side) is observed and the passing ions have a considerable possibility of collision with the conducting plates. A similar observation is confirmed at the outer transition region (Fig. 5(b)). From the above calculation, observed asymmetry in the probe measurements and impurity deposit areas on the plates is mainly ascribed to the gradient-B drift of ions originated from the anchor-cell mid plane.

4.2 Effect on the plasma parameters

Figure 6 shows an example indicating improvement of plasma confinement by adjusting the electrical connection in the conducting plates. The time behavior of plasma line-density and diamagnetism in the central-cell are compared between the case in the floating mode (Fig. 6(a)) and that in the grounded mode (Fig. 6(b)). In the floating mode, a remarkable increase in both the line-density and the diamagnetism is observed accompanied by the ECH pulse for potential formation. In the case of the grounded mode, on the other hand, the density increase is small and a slight decrease of diamagnetism is observed during the plug ECH. This shows that the floating mode is advantageous for improving plasma confinement by potential formation. A typical time variation of plasma parameters measured under the condition that the space between the plates is

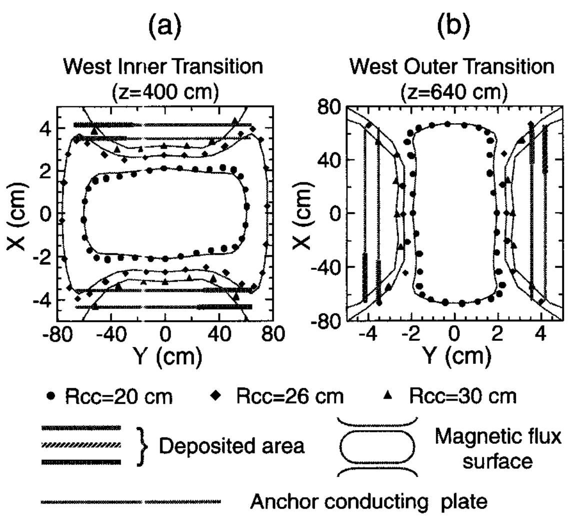

Fig. 5 Results of the orbit calculations. Filled symbols represent the guiding-center trace of ions. Cross section of magnetic flux surface is plotted corresponding to the launching positions of test particles (Rcc=20 cm, 26 cm and 30 cm). Locations of the anchor conducting plates and impurity-deposited areas are also indicated.

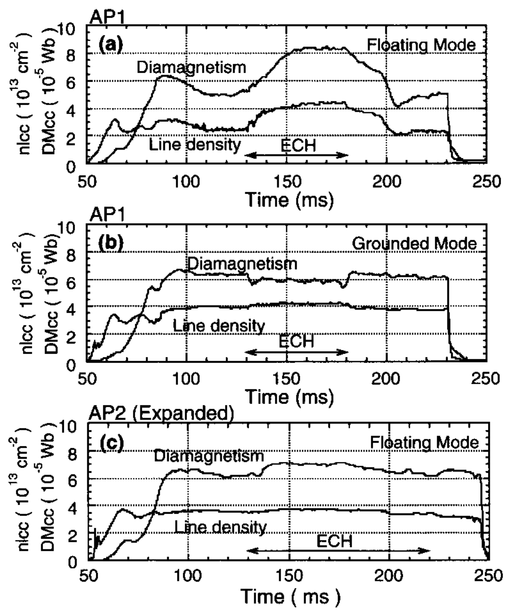

Fig. 6 Time behavior of plasma line-density and diamagnetism measured at the central-cell. (a) in the floating mode of the anchor conducting plates, (b) in the grounded mode, (c) in the expanded conducting plates.

expanded by 20% is shown in Fig. 6(c). As shown in the figure, it is found that the increase of line density as well as diamagnetism during potential formation become less even in the floating mode and their behavior is similar to the case with the grounded mode. These results clearly indicate that installation of the conducting plates near the plasma surface in a suitable distance has a certain effect on improving the radial loss during potential confinement. These observations can be explained qualitatively by the following interpretation: The floating condition of narrower conducting plates prevent drift ions from escaping to the radial direction in the transition region due to the positive sheath potential produced in front of each main conducting plate. In the case of expanded plate, however, the suppression effect on radial loss may be reduced since the location of repelled ions becomes close to the vacuum chamber

5. Summary

Edge plasmas in the anchor outer-transition region were investigated by using Langmuir probe array and a movable probe. A significant asymmetry in the ion saturation current and the floating potential are recognized, which corresponds to the direction of gradient-B drift for ions. Impurity deposited areas observed on the conducting plates showed the same asymmetry and the structure of rotational symmetry in 180 degrees. The results of orbit calculation taking the effect of gradient-B drift into consideration indicated that the drift effect is a dominant factor to cause the asymmetry of ions observed at the outer transition region. Further investigation is needed to clarify the influence of this drift on the radial loss of core plasma based on the more detailed experimental results. The effect of the conducting plates on the plasma performance is investigated and it is confirmed that the floating mode is advantageous for improving plasma confinement by potential formation. However, it is recognized that expansion of the space between the plates facing each other reduces the above effect.

Acknowledgement

The authors would like to acknowledge the members of the GAMMA 10 group, University of Tsukuba for their collaboration in the experiments.

References

[1] K. Yatsu, *et al.*, *Proc. 17th IAEA Fusion Energy Conference*, Yokohama, 1998, IAEA-CN-69/EX4/6.

[2] K. Yatsu, *et al.*, Trans. of Fusion Technol. **35**, No. 1T, 52 (1999).

[3] Y. Nakashima, *et al.*, J. Plasma Fusion Res. **75**, No. 10, 1211 (1999).

[4] K. Md. Islam, *et al.*, J. Phys. Soc. Jpn. **69** No. 8, 2493 (2000).

[5] Y. Nakashima, *et al.*, Trans. Fusion Technol. **39,** No. 1T, 139 (2001).

[6] Y. Nakashima, *et al.*, J. Nucl. Mater. **290-293**, 683 (2001).