Study of Plasma Stability and Confinement Using a Novel Matrix-Type Semiconductor X-Ray Detector

Ryutaro MINAMI

A dissertation submitted to the Doctoral Program
in Physics, the University of Tsukuba
in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Science

January 2003

Abstract

In nuclear-fusion-oriented experiments, plasma X-ray diagnostics is widely employed to obtain plasma-electron spatial distributions, plasma-electron temperatures and velocity-distribution functions for the purpose of fusion-oriented investigations on plasma-electron confinement, electron heating as well as plasma-energy transport. Over these a few tens of years, semiconductor detectors have commonly been utilized for plasma X-ray diagnostics in most of plasma confinement devices as standard detectors.

X-ray detection systems using semiconductor detector arrays have been developed as position sensitive X-ray imaging systems for the purpose of analyzing temporally and spatially varying plasma behaviour. However, it is still difficult to determine electron temperatures T_e ranging below 100 eV by the use of conventional semiconductor X-ray detectors because of the X-ray absorption due to the existence of a dead layer covering over the detector surface. Furthermore, the conventional "X-ray absorption method" requires many plasma discharges with good plasma reproducibility because of the necessity of shot-to-shot changes of X-ray absorption filters. Thus, it is also difficult to study the scalings of T_e with various plasma parameters by the use of the conventional X-ray systems, for instance, an important scaling of T_e with central-cell electron confining potentials ϕ_b.

In this thesis, the following investigations are carried out.

(1) For the purpose of the measurements of temporally and spatially resolved electron temperatures during a single plasma discharge alone, a novel matrix-type X-ray semiconductor detector array is developed and installed in the GAMMA 10 tandem mirror. The detector has seven "matrix columns" for the measurements of plasma X-ray profiles along with six "matrix rows" for the simultaneous analyses of six different X-

ray-energy ranges by the fabrication of six different thicknesses of SiO_2 semiconductor surface layers from 1 nm to 495 nm as ultra-thin and unbreakable "X-ray absorption filters". Such a matrix idea enables us to analyze X-ray tomography data in the T_e region down to a few tens eV and investigate various magnetohydrodynamic (MHD) activities during a single plasma discharge alone.

(2) Observations of internal core plasma structural behaviour during the MHD destabilization of the central cell plasmas are carried out by the use of the newly developed semiconductor X-ray detector arrays installed in both central cell and anchor regions of the GAMMA 10 tandem mirror. In the present report, it is found from the developed X-ray diagnostics that the bulk plasmas rotate without a change in its shape and structure with an $\boldsymbol{E}\times\boldsymbol{B}$ velocity during the destabilization. The onset of the off-axis rotation is identified to be closely related to a scaling of the MHD stability boundary (i.e. the anchor beta requirements for stabilizing central cell hot ion plasmas). These data confirm pressure driven interchange instability in tandem mirror plasmas, and reveal the rigid rotational bulk plasma structure as the first demonstrated interior plasma property during the destabilization.

(3) Applications including investigations of electron energy confinement during a period with central-cell electron cyclotron heatings are made with the newly developed semiconductor X-ray detector arrays. In order to find out generalized physics interpretations covering over the experimental results, theoretical analyses are carried out by the use of a widely applicable energy-balance equation. The important scaling of T_e with central-cell electron confining potentials ϕ_b is well interpreted in terms of the generalized Pastukhov's theory of plasma potential confinement.

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