§10. Study on Electron Distribution Function and Spatial Structure of Weakly Relativistic Electrons in Microwave and Mirror Devices

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This project is aimed at analyzing weakly relativistic electrons in a range of a few keV to around 100 keV, distributing in a form of beam, plateau, or other shape in the momentum space. The beam is important for a high-power microwave source. At Niigata University, the pulsed microwave device based on slow-wave interaction with a weak relativistic electron beam is studied as one of the candidates for a compact high-power microwave source. Energy distribution and spatial structure of electron beam need to be analyzed for efficient operation and for realization of compact high-power microwave source. For the GAMMA10 tandem mirror at University of Tsukuba, it is necessary to clarify distribution and structure of such electrons in both momentum and real spaces to study the confinement mechanism of high temperature plasma. The purposes of this research include development and examination of system for measurements and analyses of electron energy distributions, their spatial structure and their time development. The relativistic and weakly relativistic electron distribution functions can be analyzed for non-thermal as well as thermal distributions, based on the numerical code for the x-ray energy analysis developed under the collaboration between Niigata Univ. and Plasma Research Center, University of Tsukuba. Under the collaboration, the physics related to the electron distributions have been studied. The important publications in the 2007 fiscal year are listed at the last of this report.

Experiments on beam-like electron are performed by an equipment of Niigata University.[1-3] Generations and propagations of weakly relativistic electron beam are studied. We have been proposing a new type of cold cathode. This cold cathode is able to operate in a weakly relativistic energy region with a high current density of some 100 A/cm^2. The cathode consists of metal only, and may be favorable for real applications. It is necessary to investigate the generation mechanism of weakly electron beam and the control of the spatial structure using the new cold cathode. By using the annular electron beam generated, a weakly relativistic oversized microwave device is examined. Replacing a mesh anode by a Bragg reflector, a stabilized operation and an increase in the output power are demonstrated. Since the mesh interrupts the beam, the beam quality might deteriorate. For a large current beam like our experiment, the Bragg reflector seems to be advantageous for high-power operations.

In the case of the microwave device, the physics related to the electron distributions can be examined based on a rather simple model and system. Generally, there are three kinds of models of beam instability analysis. Those are based on cylindrical solid beam, infinitesimally thin annular beam and annular beam with finite thickness. Actual electron beams in high-power experiments have a finite-thick annular shape. We develop a numerical code for an annular beam having a finite thickness.[4] For the other beam models, we have already developed numerical codes. In other words, the analyses with three beam models become available. Our models are valid for any beam velocity less than the light velocity and deal with the essence of boundary problem for “moving plasmas”. Three-dimensional beam perturbations and boundary conditions on the beam surface are considered self-consistently.

For the mirror device, phenomena involved become much more complicated than the beam case in the microwave devices.[5-7] To understand the physics common to a high-potential mode and a hot-ion mode in the operation of GAMMA10 tandem mirror, generalization of scaling laws for the formation of plasma confining potentials are investigated. The consolidated potential-formation scaling has been proposed on the basis of the consistency with finding of wider validity of Cohen’s strong electron cyclotron heating (ECH) theory. In order to investigate distribution functions and their spatial structure, x-ray diagnostics such as x-ray energy spectrum analyses, x-ray absorption methods and x-ray tomographic reconstructions using various types of x-ray detectors are performed. A plateau-shaped electron distribution function is observed in the plug region when an electron-confining potential is formed in the hot-ion as well as high-potential operation mode of GAMMA10. This implies that there exists a common physics to both modes.

In conclusions, weakly relativistic electrons from a few keV to around 100 keV are investigated in microwave and mirror devices. Electron distributions in the momentum and real spaces are closely related to the device performances and are very important in view of understanding the underlying physics.

1) Ogura, K., *et. al.*: IEEJ Trans. FM. **127** (2007) 681.

2) Ogura, K., *et. al.*: Plasma Fusion Res. **2** (2007) S1041.

3) Takamura, Y., *et. al.*: *17th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion* (Toki, Japan, October 2007) P1-074.

4) Tamura, S., *et. al.*: *17th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion* (Toki, Japan, October 2007) P1-011.

5) Hirata, M., *et. al.*: Plasma Fusion Res. **2** (2007) S1077.

6) Cho, T., *et. al.*: *11th IAEA Technical Meeting on H-mode Physics and Transport Barriers* (Tsukuba, Japan, August 2007) P3-02.

7) T. Cho *et. al.*: *49th Annual Meeting of the Division of Plasma Physics of the American Physical Society* (Orlando, USA, November 2007) Invited Talk GI2.