§7. Comprehensive Study of Relationship between Electron Distributions and Performances of Microwave and Mirror Devices.

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This project is aimed at studying the electron distributions in both energy (or momentum) space and real space. In order to examine electron distribution functions, the x-ray diagnostics systems are used. The numerical code for the x-ray energy analysis has been developed under the collaborations between Niigata Univ. and Plasma Research Center, University of Tsukuba. The relativistic and weakly relativistic electron distribution functions can be analyzed for non-thermal as well as thermal distributions. And the physics related to the electron distributions are studied. Important results of the project published in fiscal 2006 are listed in the references.

In the case of the microwave device, the physics related to the electron distributions can be examined based on a very simplified model and system. We have been developing a new version of self-consistent theory.[1-3] It contains the essence of boundary problem for "moving plasmas". Three-dimensional beam motions and boundary conditions on the beam surface are considered self-consistently. For an electron beam propagating along the direction of an axial magnetic field, there exist four beam modes: slow and fast space charge modes and slow and fast cyclotron modes. Cherenkov instability occurs at the intersection of slow space charge mode, whereas slow cyclotron instability occurs at the intersection of slow cyclotron mode. The latter is attributed to the anomalous Doppler shifted cyclotron frequency. Although the slow cyclotron instability is due to the transverse perturbation of beam, it is essentially different from the fast cyclotron instability due to the normal Doppler effect, which requires an initial perpendicular beam velocity. A new version of self-consistent field theory considering three-dimensional beam perturbation has been developed based on a solid beam. The effect of the transverse beam perturbation appears as a surface charge at a fixed beam surface.[3] However, in the case of a thin annular beam, the boundary (annular surface) is modulated due to the transverse perturbation. The treatment of the beam boundary is essentially different from the solid beam. No self-consistent field theory considering the modulated boundary has been presented, to the authors' knowledge. We propose a new linear self-consistent field theory considering the modulated beam surface.[1] And the slow cyclotron instability driven by a thin annular electron beam is shown theoretically.

The interactions between annular beams and electromagnetic waves are investigated in oversized backward wave oscillator (BWO) driven by a weakly relativistic electron beam less than 100 kV. The term "oversized" means that the diameter D of SWS is larger than free-space wavelength λ of output electromagnetic wave by several times or more. The electromagnetic waves are localized near the SWS wall, so-called surface waves.[2] In ref. 3, we extend the self-consistent field analysis to the oversized cases. In experimental studies, operating frequencies are relatively high, K and Q bands.[4] Cold cathodes are used to obtain a beam with high current density. It is very difficult to generate a uniformly distributed annular beam by the cold cathode, especially in the weakly relativistic region. In this work, the uniformity of the beam has been improved by using a novel disk cathode. The novel type cathode is successfully applied to the high-power oversized BWO in the weakly relativistic region.[4]

For the mirror device, phenomena become very complicated. Generalized scaling laws for the formation of plasma confining potentials are investigated to find the physics essentials common to a high-potential mode and a hot-ion mode of the GAMMA10 tandem mirror. The potential-formation scaling is consolidated and generalized on the basis of the consistency with finding of wider validity of Cohen's strong electron cyclotron heating (ECH) theory. Electron-velocity distribution functions are investigated, since they are directly related to the mechanism of electrostatic potential formation.[5] 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 required for obtaining various shapes of electron-velocity distribution functions as well as their spatial profiles. A plateau-shaped electron distribution function is observed in the plug region when a plug electron-confining potential is formed in the hot-ion as well as high-potential mode of GAMMA10, as predicted the strong ECH theory.[5] This means the existence of the common underlying physics for the potential formation in both modes in GAMM10.

In conclusions, the comprehensive study of relationship between electron distributions and device performances has been performed, examining various electron distribution functions and their spatial profiles with the help of the x-ray diagnostic systems.

References

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