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

Ogura, K., Saito, H., Miyazawa, Y. (Niigata Univ.),
Hirata, M., Cho, T., Kohagura, J., Numakura, T., Fukai, T., Yokoyama, N., Tokioka, S., Tomii, Y., Miyake, Y. (Plasma Research Center, University of Tsukuba)

We study oversized backward wave oscillator (BWO) driven by a weakly relativistic electron beam less than 100 kV and are operating in relatively high frequency region, above 10 GHz.[1] 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. Note that high-power operations beyond 10 GHz are difficult for the conventional non-oversized slow-wave devices. It is important to study the relationship between the BWO performance and beam distributions.[2]

The output powers of oversized BWO increase by increasing the beam voltage, i.e. by shifting the beam interacting point to the point of $k_z z_0=\pi$. The quality factor Pf^2 of oversized BWOs is about 2×10^4 [kW·GHz^2] in the range of 40-50 kV. This factor increases to about 6×10^4 [kW·GHz^2], by increasing the beam voltage above 70-80 kV. The power levels are about 100 kW or less. The output powers are not improved above 6×10^4 [kW·GHz^2], only by increasing beam voltage. To realize the higher output power, we need to change the beam configuration.[2] By improving beam diode, the beam is distributed uniformly in a thin annular shape and propagates close to the waveguide wall. With the improved beam, the powers increase to about 500 kW (K-band BWO) and 200 kW (Q-Band BWO), with 90-100 kV beam voltage. The quality factor Pf^2 is improved up to about 3.5×10^5 [kW·GHz^2], by controlling the beam configuration.

In tandem-mirror devices, the second-harmonic electron cyclotron heating (ECH) in the barrier region is utilized for the formation of a thermal-barrier potential, which reduces the electron heat flow between the central cell and the plug region. The fundamental ECH is employed for the formation of an ion-confining potential in the plug region. Scaling laws of potential formation and associated effects along with their physical interpretations are consolidated on the basis of experimental verification using the GAMMA10 tandem mirror. A proposal of extended consolidation and generalization of the two major theories—(i) Cohen's strong ECH theory for the formation physics of plasma confining potentials and (ii) the generalized Pastukhov theory for the effectiveness of the produced potentials on plasma confinement is made through the use of the energy balance equation.

It is important to investigate electron-velocity distribution functions in these thermally isolated regions (the plug, the central-cell, and the barrier regions), since these electron distribution functions are directly affected by electrostatic potentials in the kilovolt range. Several types of 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 have been employed for obtaining various shapes of electron-velocity distribution functions as well as their spatial profiles.[3,4]

The progress in the confining potential leads to the remarkable effects of radially produced shear of electric fields on the suppression of intermittent vortex-like turbulent fluctuations. Such a shear effect is visually highlighted by x-ray tomography diagnostics. Spatially and temporally intermittent vortex-like fluctuated structures are observed as two-dimensionally reconstructed visual structures in kiloelectronvolt order ion-cyclotron heated plasmas having a weak shear. Such intermittent turbulent vortices disappear during the application of plug ECH. The potential rise due to ECH produces a stronger shear and improves the plasma confinement.[5] The scaling data fit well to our proposed consolidated theory of the strong ECH theory with Pastukhov's theory on energy confinement.

In this work, the electron distributions in both energy (or momentum) space and real space are examined. For the x-ray spectrum analyses, the relativistic Born approximation corrected by the Elwert factor is used for the values of the x-ray cross section. The numerical code for the x-ray analysis has been developed under this collaboration between Niigata Univ. and Plasma Research Center, University of Tsukuba. And the physics related to the electron distributions are examined. For the mirror device, phenomena are very complicated. In the case of the microwave device, the essential physics related to the electron distributions can be examined based on a very simplified model and system. For example, we propose a new version of self-consistent theory properly considering three dimensional beam motions and boundary conditions on the beam surface.[2] It contains the essence of boundary problem for "moving plasmas". Therefore, the comprehensive study of relationship between electron distributions and device performances is important to develop diagnostic methods of the various electron distribution functions and their spatial profiles.

References

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