§9. 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 studying weakly relativistic electrons distributing in a form of beam, plateau, or other shape in the energy or momentum space. For the GAMMA10 tandem mirror at University of Tsukuba, it is necessary to clarify distribution and structure of 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 the electron energy distributions as well as their spatial and time development. At Niigata University, the pulsed microwave device based on slow-wave interaction with a weak relativistic electron beam is studied.[1,2]

For microwave sources, it is essential to use reliable cathodes producing a high current electron beam with uniformly distributed cross sectional shape. Most high-power microwave sources in the relativistic region have used simple tubular explosive cold cathodes to obtain annular beams. However, it is very hard to realize a uniformly distributed electron beam. With the help of dielectrics, the uniformity of beam has been improved. For example, the cathode surface is coated with a mixture of fine graphite powder and epoxy.

To test the cold cathodes, we use experimental setup shown in Fig. 1. The high voltage source is a 10-stage, 1 kJ Marx generator. Electron beam diode consists of a hollow anode and a cold cathode. In our experiments, output voltage raging from about 30 kV up to 100 kV of the pulse-forming line is applied to the cathode. Magnetic field B_0 for beam propagation is provided by using ten solenoid coils. The maximum B_0 is about 0.9 T. Spatial distributions of beam along the transport section is examined by the beam burn patterns in thermally sensitive paper on beam collector.

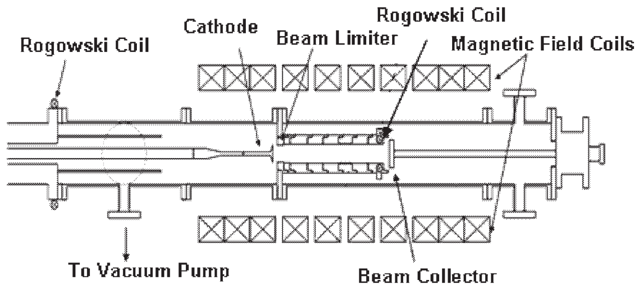

Fig.1 Schematic diagram of the experimental setup.

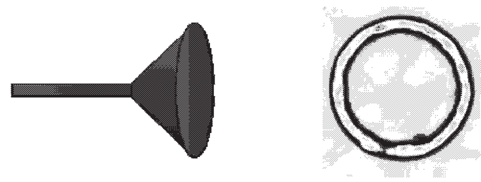

Fig. 2 Solid conical disk cathode (left) and beam burn pattern (right).

For generations of weakly relativistic beams, we propose a new type of cold cathode shown in Fig.2.[2,3] This cold cathode consists of metal only and has a solid conical disk shape. A beam burn pattern in Fig. 2 is obtained by 1-shot without any coating on the emitting area. Beam voltage and current are respectively about 90 kV and 400 A. Tubular cathodes are very common in high-power slow-wave devices. However, beam filamentation is unavoidable since the electron emission centers are formed at cracks and/or protrusions. To improve the uniformity, the velvet on the emitting area is required. On the other hand, our proposed cold cathode consists of metal only. It is able to operate in the weakly relativistic energy region with a high current density of some 100 A/cm^2. The beam generated by the disk cold cathode has the more uniform distribution and the higher current density compared with the tubular cathode with the velvet. For the uniform emission, some surface roughness of 1 μm order is required on the emission surface. Metals such as aluminum, copper and stainless steel are tested as the cathode material. Up to now, the copper cathode seems to be most suitable for the operations in the weakly relativistic region.

Energy distributions of pulsed beam are investigated by an X-ray absorption method. The energy spread due to the beam self-potential is confirmed at the beam current close to the space charge limiting current. A plateau-like distribution is formed. It is demonstrated that the energy spread can be suppressed by the charge neutralization by plasma.

In the microwave devices, the physics related to the electron distributions can be examined based on a rather simple model and system. We have developed numerical codes based on cylindrical solid beam, infinitesimally thin annular beam and annular beam with finite thickness.[1,4] Three-dimensional beam perturbations and boundary conditions on the beam surface are considered self-consistently. And we analyze the slow-wave device operations including slow cyclotron interaction as well as the Cherenkov interaction by comparing the experimental and numerical results.

1) S. Tamura *et. al.*, Plasma Fusion Res. 3 (2008) S1020.
2) Y. Takamura *et. al.*, Plasma Fusion Res. 3 (2008) S1078.
3) H. Oe *et. al.*, *International Conference on Plasma Physics 2008* (September, 2008, Fukuoka, Japan) EPP.P1-233.
4) K. Otubo *et. al.*, *18th International Toki Conference on Plasma Physics and Controlled Nuclear Fusion* (December, 2008, Toki, Japan) P2-57.