§5. Study of Interaction between Plasma and EM Wave in Prospect of Application of Millimeter & Sub-millimeter Waves

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In FIR FU, gyrotrons as electromagnetic wave sources with wavelength from millimeter to sub millimeter have been developed and their applications have been advanced. On the other hand, electron cyclotron heating (ECH) techniques with high power gyrotron systems are used for the transport control and diagnostics as one of the main subjects in PRC, University of Tsukuba. Spatial transport in plasmas is strongly connected to global structures of plasma parameters. This is essentially true for fusion, non-neutral and gyrotron plasmas magnetized and confined in conductor walls.

With wide and integrated scope of various plasmas, we have taken a first step of linear analysis of global structure of drift waves. Many works have been reported for decades on drift waves, and formations of global structures in nonlinear stages have been examined numerically. However, only a few works have been reported in connection to linear analyses of global structures [1- 3]. Actually most of extensive linear analyses have been limited to slab models or fluid dynamics in cylindrical configurations. We constructed a Vlasov–based equation in a cylindrical geometry with the guiding-center approximation including arbitrary radial distributions of density and anisotropic temperature for multi-species. We have expected that extending the linear analyses of global wave structure in interaction with plasma particles will contribute a lot to further the activities in EM wave applications.

Further examinations of global structure of eigen-function of unstable drift waves, however, remains in a narrow radial band region as reported in 2011 annual report. Under a wide variation of plasma parameters as observed in the GAMMA10 plasma, the localized unstable drift waves satisfying the boundary conditions shift radially as the frequency varies in an unstable range. If these analyses are applicable to the actual plasma, we could observe a finite width of frequency spectra composed of radially dependent, therefore randomly-phased multi-component eigen-functions. However, as reported later, the unstable waves observed in the GAMMA10 appear to be in a frequency band narrower than expected as based on the linear analysis.

These considerations may lead to several paths. One is possibility of mathematically wrong treatment of the inhomogeneous plasma analyses. Other possibilities include the spatially shifted but progressively overlapped drift waves may interact nonlinearly, for example via modulations of plasma particles orbiting through neighboring wave packets, to generate coherent oscillations covering a wide radial range. This "non-linear" interaction is different from nominal nonlinear coupling between waves and provides a new task to explore a new non-liner field of plasma wave interactions.

In GAMMA 10, a micro-wave reflectometer system has been newly installed to evaluate the behavior of the EM waves in the core region. In the temporal evolution of the frequency spectra of magnetic probe signal in the peripheral region and micro-wave reflectometer signal in the core region, the same frequency peaks are observed in both signals of magnetic fluctuation and density fluctuation. There is strong coherency between both signals. About the wave-particle interactions, high-energy ions are detected at the location outside the limiter radius in the central cell. Fluctuations, of which frequencies are the same as those of drift-type fluctuations, are clearly observed in the signal of central-cell high energy ion detector (ccHED). To clarify the radial transport of high-energy ions caused by fluctuations at their turning points, the pitch angle dependence of the interaction between fluctuations and high-energy ions is analyzed. The phase differences between density fluctuations detected by an electro-static probe and fluctuations in high-energy ion signal have been measured as a function of the turning point of high-energy ions. The pitch angle dependence of the phase difference is clearly observed.

About the gyrotron system, an interesting physics on the interaction between an electron beam and an RF field structure in a cylindrical cavity appears as mode competition. This phenomenon becomes important with increases in power and frequency. In FIR FU, a high power and high frequency gyrotron is under development [4]. Its power is of the order of 100 kW and the frequency is around 0.4 THz. It oscillates at second harmonic electron cyclotron resonance. Many types of mode competition are observed in this gyrotron. In some case, a second harmonic mode assists oscillation of a fundamental harmonic mode. In other case, mode competition between second harmonic modes takes place. Moreover, simultaneous oscillation of a fundamental harmonic mode and second harmonic modes often happens. Different RF modes interact nonlinearly through deformation of the electron distribution in phase space caused by the RF fields.

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