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Instability of the Trivelpiece Mode in a Beam-Plasma System

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Spatial growth of an electrostatic wave is observed in a beam-plasma system, and can be explained consistently as an instability of the Trivelpiece mode.

In a cylindrical plasma column, it has been shown theoretically that an electrostatic wave propagates as a guided wave confined in a plasma boundary (Trivelpiece mode)[1]. Experimental investigations on the propagation measurement and spatial damping of the wave have been done in a thermal equilibrium plasma[2]. In this letter, we report that the wave which is excited by an external signal applied from a coaxial antenna is observed to grow in a beam-plasma system and the growth rate of the wave is explained consistently as the result of mode coupling between the Trivelpiece mode and a space charge wave of beam.

The plasma is produced in the TP-D type device[3] which has a discharge region and a diffused region. Both regions are connected by an orifice (200mm in length and 7.5mm in diameter). The pressures of the former and the latter are maintained at about 1.5×10^{-2} and 5.0×10^{-4} Torr, respectively, by using the method of differential pumping. The plasma is jetted through the orifice from a hole (8mm in diameter) in the center of the anode and flows along the line of magnetic force into the diffused region. It is supported on the axis of the glass tube (720mm in length and 95mm in diameter) by the uniform magnetic field whose intensity is 180 G (the electron cyclotron frequency $\omega_c/2\pi$ is 504 MHz). The plasma density n_p at the center of the tube is changed from 1.3×10^9 to 1.0×10^{10} cm^{-3} by varing the discharge current I_d, and its profile in the axial direction is uniform within about 5%. The electron beam is generated by an electron gun and injected into the plasma from the opposite side of the discharge region. In the diffused region, the electron beam (2mm in diameter) penetrates on the center axis of the plasma (10mm in diameter).

Here, the electron beam is so weak that the spontaneous excitation of the wave is not observed and only when the external signal is applied, the wave is excited

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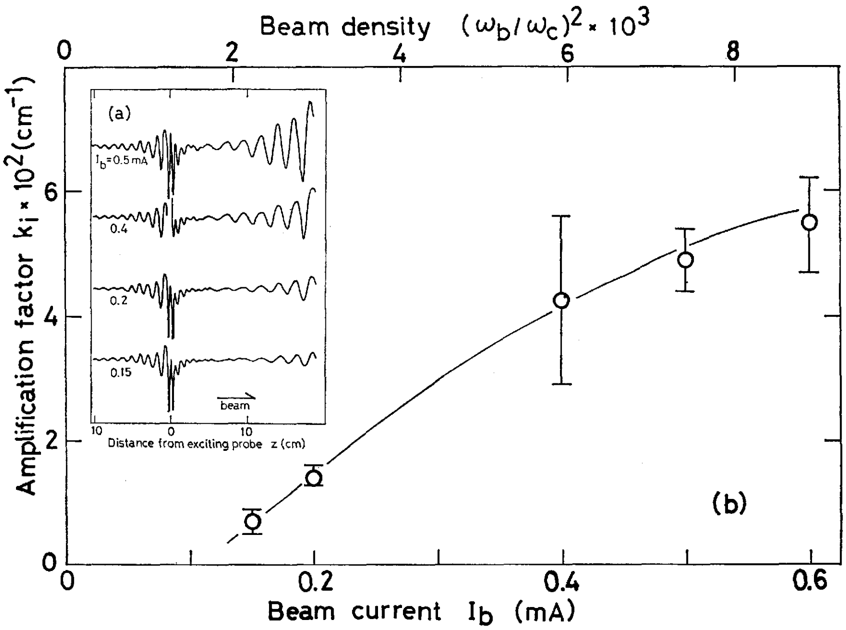

Fig. 1 (a) The propagating wave patterns with beam current I_b as a parameter. $\omega/2\pi=360$ MHz. $\omega^2_p/\omega^2_c=1.0$. $V_b=200V$.

(b) The amplification factor $k_{\parallel i}$ as a function of I_b.

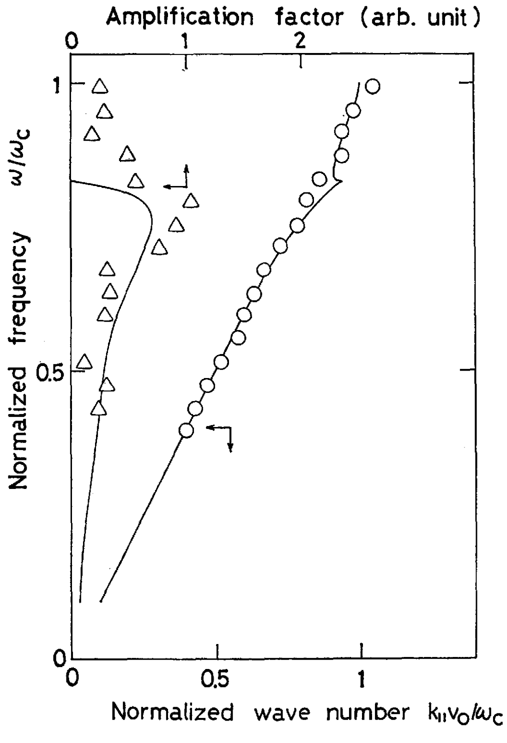

Fig. 2 Both real and imaginary parts of $k_{\parallel}$ as functions of frequency. $\omega^2_p/\omega^2_c=1.9$. Solid lines show the real and imaginary parts of $k_{\parallel}$ calculated from eq. (1) using the experimental condition.

and grows with the aid of the electron beam. Using an interferometer system, the patterns of the propagating waves are drawn on an XY recorder as the function of axial distance z and radial distance r from the exciting antenna.

In Fig. 1 (a), the patterns of the propagating waves along the axial direction are shown with the beam current I_b as a parameter. The amplification factor $k_{\parallel i}$, *i. e.*, the imaginary part of the parallel component of wave vector $\boldsymbol{k}$, is estimated and shown in Fig. 1 (b). It is seen that $k_{\parallel i}$ increases with the beam current increased.

Under constant parameters of plasma and beam, the measurement of the growing wave patterns are done with the frequency f of interferometer system as parameter. Both real and imaginary parts of $k_{\parallel}$ estimated from the observed patterns are plotted in Fig. 2 as functions of the frequency. The phase velocity component $v_{p\parallel}$ of the growing wave is nearly equal to the beam velocity v_b. Therefore, the growth is considered as a result which comes from the coupling between the space charge wave of beam and the Trivelpiece mode.

Solid lines in Fig. 2 show the real and imaginary parts of $k_{\parallel}$ calculated from the dispersion relation[4] containing the coupling between the Trivelpiece mode and the beam wave,

$$k_{\perp}^2 = -k_{\parallel}^2 \frac{K_{\parallel}}{K_{\perp}} \qquad \cdots\cdots\cdots(1)$$

where $K_{\parallel}$ and $K_{\perp}$ are components of the dielectric tensor of a beam-plasma system and $k_{\perp}$ is the perpendicular component of wave vector. The value of $k_{\perp}$ is determined to be about 3 cm^{-1} from the measurement of the wave pattern propagating across the magnetic field. Since the theoretical curves agree with the experimental results, we may conclude that the growth of wave results from the coupling between the Trivelpiece mode and the space charge wave of beam.

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