Observation of Transition from a Reactive-Medium Instability to an Inverse Landau Damping in a Beam-Plasma System

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The wave excited by a coaxial probe in a beam-plasma system usually propagates as two waves which are independent of each other, i.e., a damped Trivelpiece mode of plasma and growing space charge wave of beam (refered to a reactive-medium instability). While, when the beam velocity is equal to or slightly larger than the phase velocity of plasma wave, the inverse Landau damping of the wave is observed, instead of the reactive-medium instability of beam wave.

The spatial growth of wave in a beam-plasma system has been investigated by many authors with a great interest. Two mechanisms of growing wave can be considered; One is the reactive medium instability of beam wave (two stream instability) and the other the inverse Landau damping of plasma wave. The former appears in the case where the modulation of beam applied spontaneously or artificially grows along the streaming of beam in a reactive plasma. Most instabilities which has been reported until now are considered to result from this mechanism. On the other hand, the latter can occur, only when the phase velocity of plasma wave coincides with the beam velocity and the modulation of beam is suppressed at lower level than that of plasma wave. Because the condition of the latter is more severe than that of the former, a growing wave refered to the latter is scarcely observed. In this letter, we report that the test wave excited by coaxial probe is usually grown due to

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the reactive medium instability, while the transition to the inverse Landau
damping is observed under the severe condition for the plasma wave.

The plasma is produced by the dc discharge in the TP-D type device 2) and
diffused along the line of magnetic force into the chamber (9.5 cm in diameter
and 65 cm in length), its parameters being as follows. The density \( n_p = \frac{3.5 \times 5.3 \times 10^9}{cm^3} \), the electron temperature \( T_e = 7.0 \ eV \), the magnetic field \( B = 180 \ \text{gauss} \) (homogeneity<3%) corresponding to the electron cyclotron frequency
\( f_c = \frac{\omega_c}{2\pi} = 504 \ \text{MHz} \), the plasma diameter \( D = 30 \ \text{mm} \) and the pressure of the
neutrals (Ar) \( p = 7.4 \times 10^{-4} \ \text{torr} \) (the collision frequency of electron with neutrals
\( \nu_e = 4 \ \text{MHz} \) is much smaller than \( f_c \)). The electron beam is generated by an
electron gun placed at the opposite side of the discharge region and injected
into the diffused plasma, so that the electron beam-plasma system is formed and
the density \( n_b \) and velocity \( V_b \) (or energy \( V_b^2 \)) of the beam are controlled inde-
dependently of the plasma parameters. This device has been used in the experi-
ment which was reported recently. 3)

The test wave is excited by the coaxial probe situated in the center of a
beam-plasma system (\( r = 0 \) and \( z = 0 \)) and detected by the other antenna movable
axially. By using the interferometer system, the propagating wave patterns
along the field (along the axial direction \( z \)) are observed. They are shown
in Fig. 1 (a), with the exciting wave frequency \( f \) as a parameter. It is
seen in the figure that the slowly damping plasma wave (Trivelipelce mode)
propagates near the exciting probe, while the wave growing along the streaming
of beam does in the region far from the probe. The wave number \( k || \) for both
waves are calculated by using these wave patterns and plotted as functions of
wave frequency \( f \) in Fig. 1 (b), which shows the dispersion relation curves of
the waves. As the latter wave satisfies the condition \( \omega = 2\pi f = k || V_b \), the
growth is referred to the reactive-medium instability of the space charge wave
of beam. 4) The dispersion relation curves intersect at the frequency \( f = 280 \ \text{MHz} \), where the beam velocity is equal to or slightly larger than the phase
velocity of plasma wave. The wave pattern corresponding to this case is
shown in the second trace of Fig. 1 (a). It is seen that the plasma wave
propagates growing along the streaming of beam in the distance of a few wave-
lengths. The growth is referred to the inverse Landau damping of plasma wave.
However, the mismatching between beam and phase velocities occurs and the plasma
wave damps rapidly. In the region more far from the probe, the amplitude
oscillation is observed.

The radial correlation of the wave is measured and the propagating wave
surface is determined, which is shown in Fig. 2. Fig. 2 (a) shows the feature
of waves in the case where the beam velocity is larger than the phase velocity
of plasma wave. It is seen obviously that the wave excited near the probe (plasma wave) is quite different from that far from the probe (beam wave). Fig. 2 (b) shows the case where the beam velocity is nearly equal to the phase velocity of plasma wave. The single wave does propagate along the streaming of beam in whole region.

In conclusion, the probe excites both plasma and beam waves in a beam-plasma system, the former being a slowly damping wave near the probe and the latter appearing in the region far from the probe as growing wave referred to the reactive-medium instability. Especially, only when the beam velocity is nearly equal to phase velocity of plasma wave \(v_b = \omega / k \|\), the plasma wave grows as the result of the inverse Landau damping.

References

Figure Captions
Fig. 1 (a) Propagating wave patterns along the streaming of beam with the exciting frequency \(f\) as a parameter. Beam voltage \(V_b = 120\) V.
Normalized plasma density \((f / f_p)^2 = 0.5\) and normalized beam density \((f / f_b)^2 = 2 \times 10^{-3}\), where \(f_p\) and \(f_b\) are the plasma frequencies of plasma and beam. \(f_c = 504\) MHz.
(b) The dispersion relation of excited waves.
Fig. 2 Propagating wave surfaces. (a) the case of mismatching between beam and plasma wave and (b) the case of matching between beam and plasma wave.
Fig. 1 (a)

Distance from the excitor \( z \) (cm)

Fig. 1 (b)

Wave number \( k_m \) (cm\(^{-1}\))

- \( \circ \) Growing wave
- \( \triangle \) Damping wave

Fig. 2

Radial distance \( r \) (cm)

Distance from the excitor \( z \) (cm)

- \( \omega_p/\omega_c \)^2 = 0.77
- \( \omega_b/\omega_c \)^2 = 1 \times 10^{-3}
- \( V_b = 100 \text{ V} \)  \( \omega/2\pi = 280 \text{ MHz} \)

- \( \omega_p/\omega_c \)^2 = 13
- \( \omega_b/\omega_c \)^2 = 3 \times 10^{-3}
- \( V_b = 100 \text{ V} \)  \( f = 360 \text{ MHz} \)