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Reflection of Oblique Electron Thermal Modes in an Inhomogeneous Plasma

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RESEARCH REPORT

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Further commuication about this report is to be sent to the Research Information Center, Institute of Plasma Physics, Nagoya University, Nagoya, Japan.

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Abstract

In an inhomogeneous magnetoplasma, reflection of an oblique electron thermal mode radiated from a local source is investigated experimentally and theoretically near the electron plasma frequency layer. The experimental observation of reflection in the lower plasma density region than the f_p-layer is found to be in qualitative accord with the theoretical reflection, which is obtained from a kinetic theory in an inhomogeneous magnetoplasma. The reflection of the thermal mode is also compared with that of an electromagnetic mode at the f_p-layer.

Much attention has been paid to RF-heating of plasmas to achieve controlled thermonuclear energy. Lower hybrid heating of plasmas is considered as one of the effective method of the heating and has been investigated in an energetic way [1-3]. The lower hybrid wave is directly related to so-called resonance cone fields, which are also studied extensively[4-7]. In this letter, the oblique electron thermal mode associated with resonance cone fields in an inhomogeneous magnetoplasma is investigated experimentally and theoretically near the electron plasma frequency and below the electron cyclotron frequency. Especially, reflections of the oblique thermal mode are studied.

Trajectories of wave energy in an inhomogeneous plasma can be obtained by the usual ray theory. Those ray trajectories can be described by following formula :

$$\frac{d\vec{k}}{dt} = - \frac{\partial D}{\partial \vec{r}} \Big/ \frac{\partial D}{\partial \omega} \quad , \qquad (1)$$

$$\frac{d\vec{r}}{dt} = \frac{\partial D}{\partial \vec{k}} \Big/ \frac{\partial D}{\partial \omega} \quad , \qquad (2)$$

where D, $\vec{k}$ and ω are the dielectric constant, the wave number and the frequency, respectively. Wave fronts radiated from a local source in an inhomogeneous plasma are also obtained by

$$\frac{d\Phi}{dt} = \vec{k}\,\frac{\partial D}{\partial \vec{k}} \Big/ \frac{\partial D}{\partial \omega} \quad , \qquad (3)$$

in which ϕ indicates the phase factor. By using these formulae, one can obtain the results of Fig.1, which are typical ray trajectories and wave fronts of an electromagneic mode radiated from a local source below the electron cyclotron frequency in an inhomogenous magnetoplasma. This result is obtained numerically in a kinetic electromagnetic theory with a use of kinetic full dispersion relation for D. Ray pathes have different trajectories according to the initial wave number conditions given at the source point. Refraction and reflection of the RF-fields are shown clearly in the figure. This reflection of the RF-fields at the electron plasma frequency layer is the same effect as the reflection of the cone fields which will be discussed in Fig.2 and 3.

Figure 2 shows theoretical wave fronts of the oblique electron thermal mode (the electrostatic mode) radiated from a point source in an inhomogeneous magnetoplasma, the density profile of which is indicated by dotted lines. Those results are obtained numerically with use of formulae of Eqs.1-3. Ray trajectories of resonance cone fields are also indicated. As for the oblique electron thermal mode, the equivalent phase lines are indicated by solid and dotted lines, and the ray trajectories are not shown in the figure. Distance between nearby two wave fronts indicates the half wavelength of the oblique electron thermal mode. This oblique electron mode corresponds to the thermal structure associated with the resonance cone field which is investigated in a uniform plasma[4-7]. Refractive effects of the oblique electron thermal mode in an inhomogeneous plasma are shown clearly in the lower density region. The reflection of the oblique electron thermal mode is found to occur near the electron plasma frequency layer in Fig.2. The electron thermal mode is reflected in the lower density region than the electron plasma frequency layer. This shift of the reflection point from the f_p-layer can be understood due to the existence of the finite parallel wave number $k_{\parallel}$ which is given at the source point. With the larger parallel wave number, the reflection point shifts to the lower density region. This behavior of reflection of the electron mode has clear difference from that of the electromagnetic mode of Fig.1. This reflection of the oblique electron mode is confirmed in the following experiments.

The experiments have been carried out in a magnetized plasma which was produced by a radiofrequency discharge. An argon plasma was formed in a 60 cm in diameter and 120 cm in length in ESTEC. The neutral gas pressure was nearly 3×10^{-4} Torr. The uniform magnetic field was applied with a strength of $B_0 \simeq 70$ gauss. The typical electron temperature and density are T_e=2-3eV and $N_0=10^8-10^9 cm^{-3}$. The transmitter and the detector of the localized RF-field were electric probes with an exposed surface 3mm long and 1mm in diameter. Figure 3 indicates experimentally observed wave fronts of the oblique electron thermal mode radiated from a local probe in an inhomogeneous magnetized plasma. Those are indicated by open circles. This mode is confirmed as the oblique electron thermal mode. Ray trajectories of resonance cone fields are also indicated by closed circles. The cone fields are confirmed to be reflected at the f_p-layer and its some fields go out. From the reflection of the cone fields, one can know easily the f_p-layer of the inhomogeneous plasma. Experimental results of Fig.3 show the reflection of the oblique electron thermal mode. The reflection-point is also shown to occur in the lower density than the f_p-layer, which was measured with a Langmuir probe and from the above reflection-point of the cone field. Around the reflection area, incident and reflected electron thermal modes are phase-mixed, and the experimental data are not clear in comparison with the theoretical phase lines of Fig.2. However, many experimental data in this series indicate that the reflection of the electron thermal mode appear in the lower density region than the f_p-layer. The experimental observations are in qualitative accord with that of theoretical results of Fig.2. Refractive effect is not shown clearly in the figure 3 because of the relatively sharp plasma density profile. In an experiment of more moderate density profie, the refractive effect of the electron thermal mode was observed, which was similar to the numerical result of Fig.2.

In conclusion, a reflection of an oblique electron thermal mode in an inhomogeneous magnetoplasma is observed in the lower density region than the electron plasma frequency layer. This observation of reflection is confirmed with the theoretical results, and is found to be different from that of an electromagnetic mode.

References

1. J.J. Schuss, S.Fairfax, B. Kusse, R.R. Parker, M. Porkolab, D. Gwinn, I. Hutchinson, E.S. Marmor, D. Overskei, D. Pappas, L.S. Scaturro and S. Wolfe, Phys. Rev. Lett. 43, 274 (1979)
2. T. Imai, T. Nagashima, T. Yamamoto, K. Uehara, S. Konoshima, H. Takeuchi, H. Yoshida and N. Fujisawa, Phys. Rev. Lett. 43, 586 (1979)
3. C.M. Surko, R.E. Slusher, J.J Schuss, R.R. Parker, I. Hutchinson, D. Overskei and L.S. Scaturro, Phys. Rev. Lett. 43, 1016 (1979)
4. R. K. Fisher and R.W. Gould, Phys. Fluids 14, 857 (1971)
5. H.H. Kuehl, Phys. Fluid 16, 1311 (1973)
6. K.H. Burrell, Phys. Fluids 18, 1716 (1975)
7 T. Ohnuma, IEEE Trans. on Plasma Sci. PS-6, 464 (1978)

Figure Captions

Fig.1 Theoretical ray trajectories and wave fronts of an electromagnetic mode radiated from a local source ($k_{\parallel}\rho_e \simeq (3.0\sim7.5)\times10^{-2}$, $k_{\perp}\rho_e \simeq (\sim1\sim17)\times10^{-2}$) in an inhomogeneous magnetoplasma. The electron plasma frequency and the electron cyclotron frequency are expressed as f_p and f_c, respectively. The curve of N_0 is the density profile and the position of $f=f_p$ is the electron plasma frequency layer. T_e=20eV.

Fig.2 Theoretical wave fronts of an oblique electron thermal mode and ray trajectory of resonance cone fields radiated radiated from a point source ($k_{\parallel}\rho_e \simeq (0.9\sim18)\times10^{-2}$, $k_{\perp}\rho_e \simeq (0.5\sim15)\times10^{-2}$) in an inhomogeneous magnetoplasma. T_e=2eV. The value of f_p is evaluated from the maximum plasma desity of the inhomogeneous plasma.

Fig.3 Experimental wave fronts of oblique electron thermal mode (00) and trajectories of resonance cone fields radiated from a monopole-type exciter in an inhomogeneous magnetoplasma.

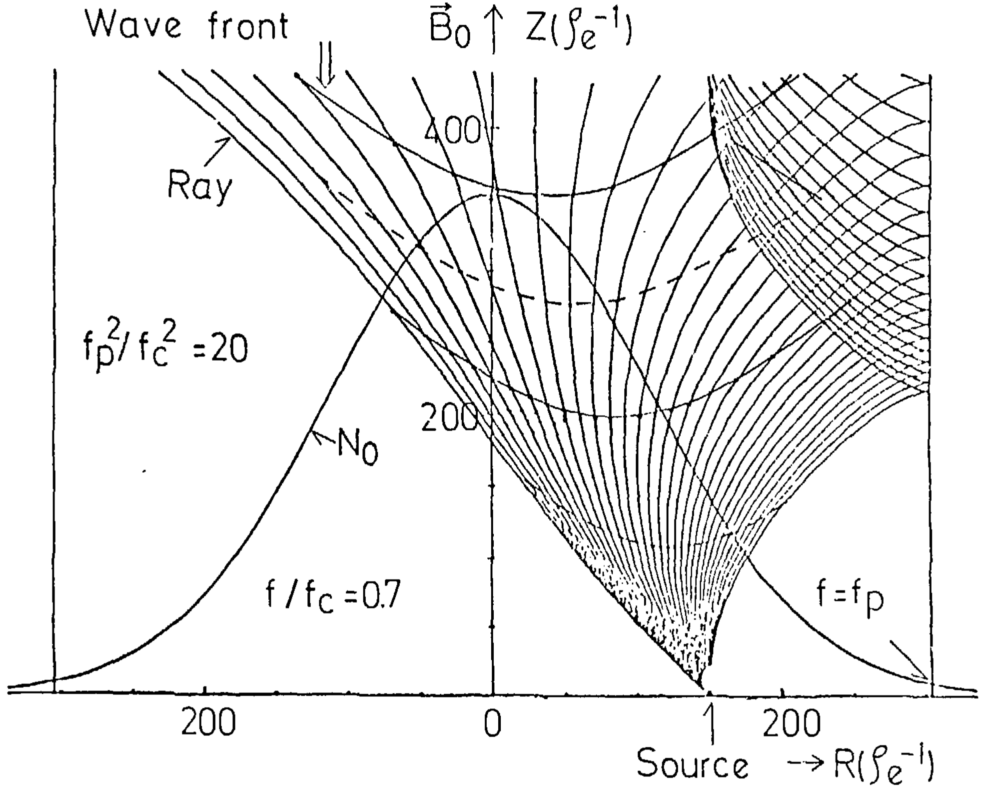
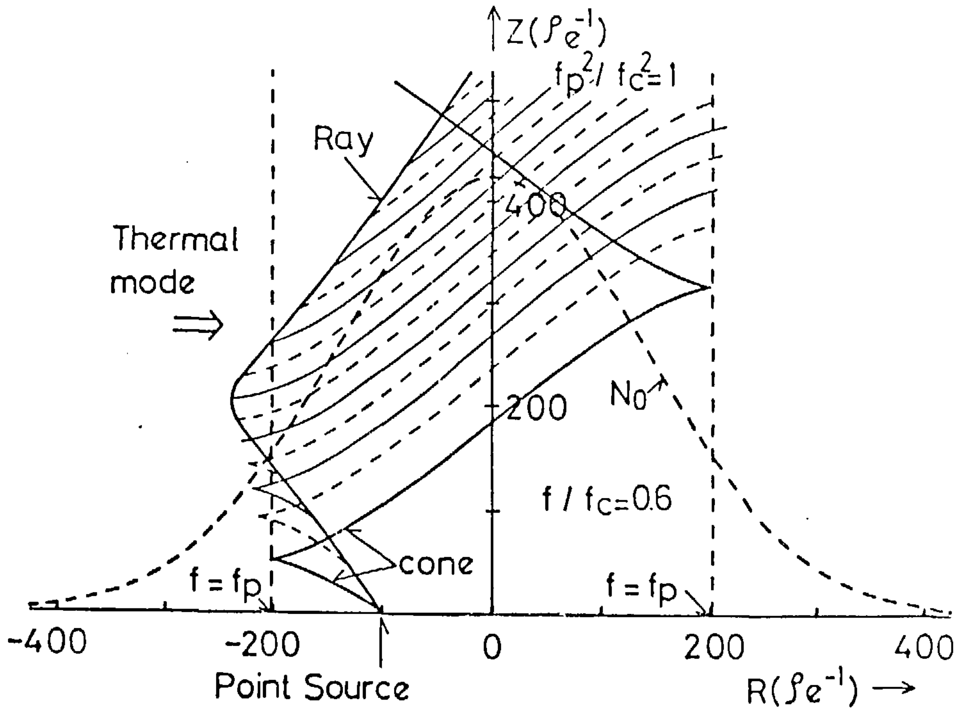
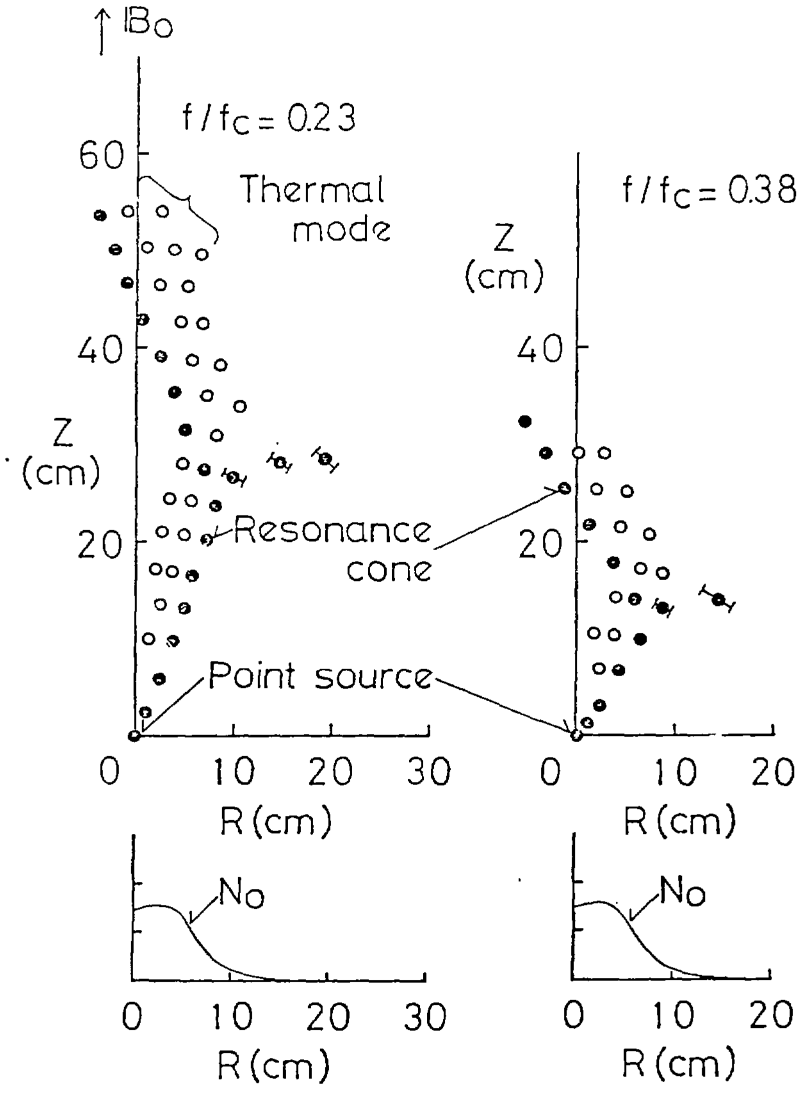

Wave front
$\vec{B}_0 \uparrow Z(\rho_e^{-1})$
400
Ray
$f_p^2/f_c^2 = 20$
200
N_0
$f/f_c = 0.7$
$f = f_p$
200
0
200
Source
$\rightarrow R(\rho_e^{-1})$

Fig. 1



Z(ρe⁻¹)
fp²/ fc²=1
Ray
Thermal
mode
400
200
N0
f / fc=0.6
cone
f = fp
f = fp
-400
-200
0
200
400
Point Source
R(ρe⁻¹)

Fig. 2



Bo
f / fc = 0.23
60
Thermal
mode
40
Z
(cm)
20
Resonance
cone
Point source
0
10
20
30
R (cm)
No
f / fc = 0.38
Z
(cm)
40
20
0
10
20
R (cm)
No

Fig. 3