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MEASUREMENT OF ION ACOUSTIC TEST WAVES IN A MAGNETIZED PLASMA BY MEANS OF A 30 GHz LECHER WIRE INTERFEROMETER OF HIGH SPATIAL RESOLUTION

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ABSTRACT

A 30 GHz Lecher wire interferometer of high sensitivity and spatial resolution is used for the detection of ion acoustic test waves. Coherent density fluctuations of .1% for electron densities of 10^{10} cm^{-3} can be detected by means of a Lock-in technique. The spatial resolution of 3 - 3 mm is given by spacing of the Lecher wires, which is large compared to the Debye-length.

In a former experiment we determined the parameters of the current driven ion acoustic instability in a plasma from a measurement of the propagation characteristics of ion acoustic test waves {1}. The usual method of wave measurement, which involves the use of biased Langmuir probes as receivers to collect ion or electron saturation current, was not applicable in this case, since the current drawn by the probe severely disturbed the plasma and led to a filamentation of the plasma column. This effect is even more important in the presence of a magnetic field, as the electrons are guided by the field lines. The problem was solved by the use of a 30 GHz microwave interferometer, which offers the advantage of a direct non-disturbing measurement of the density fluctuations induced by the ion acoustic test waves. The microwave beam was transmitted through the plasma by means of horn antennas, which were polarized to detect the fluctuations of the index of refraction for the ordinary electromagnetic mode. Coherent density fluctuations of the order of .1% (corresponding to a phase shift of about $2x10^{-5}$ rad. for an electron density of 10^{10} cm^{-3}) could be measured by applying a Lock-in technique.

The use of this interferometer is, however, restricted to a certain range of wavelengths $1 \text{ cm} \leq \lambda \leq \frac{2C_s}{\nu_{ic}}$ (C_s is the ion sound velocity and ν_{ic} is an effective collision frequency accounting for ion-ion and ion-neutral collisions). The lower limit is given by the resolution of the interferometer, which is determined by the microwave-wavelength and by the dimensions of the horn antennas. The upper limit corresponds to the e-folding length of collisional damping, which is the dominant damping mechanism for low frequency waves for the case of an elevated electron to ion temperature ratio.

In order to improve the spatial resolution for the observation of high frequency ion acoustic test waves, we have modified the interferometer by the use of Lecher wires in the way proposed by Bacon et al. {2,3}.

The spatial resolution of this system is given by the distance between the wires, since the electric field of the microwave is concentrated in the plane of the Lecher lines. Moreover, the phase shift, and thus the sensitivity, can be increased by decreasing the separation of the wires.

A schematic of the experimental set-up is shown in Fig. 1. A weakly ionized argon plasma of densities of 10^{10} cm^{-3} is produced by a rf discharge for neutral gas pressures of 10^{-4} - 10^{-3} mmHg and confined by a homogeneous magnetic field of 350 gauss {4}. The electron temperature and the electron to ion temperature ratio (derived from the propagation characteristics of ion acoustic waves) are 2.2 eV and 15, respectively. The Lecher lines have a spacing of 1.5 mm, which is large compared to the Debye-length (λ_D = .1 mm). (However, we observe that the distance of the wires increases by a factor of two in the presence of the plasma due to thermal expansion. A variation of the wire separation will be prevented by a new mechanical construction.) The Lecher lines consist of a coated Constantan wire of .1 mm diameter, which has been chosen for the sake of an impedance matching of the Lecher lines to the rectangular 8 mm wave guide. The connection between the Lecher lines and the wave guide was constructed following the design of Bacon et al. {3}. Because of the smallness of the coated wires, a filamentation or a disturbance of the plasma by a dc current to the Lecher system does not occur.

The electric field of the microwave propagating along the Lecher system is aligned with the external magnetic field, in order to detect the fluctuations of the index of refraction for the ordinary electro-magnetic mode. Sum and difference of the electric fields of the transmitted beam and a reference beam are obtained by means of a MAGIC TEE and measured by square law crystal detectors. The difference of the detector signals is proportional to the cosine of the phase shift induced by the plasma.

The interferometer is adjusted for maximum sensitivity to small density fluctuations by a 90 degree phase shift between the two beams. The test waves were excited by applying an ac signal of about 500 mV amplitude to a movable coarse thin wire grid, which was kept on dc floating potential in order to minimize the perturbation of the plasma. A high sensitivity coherent mode detection was achieved using a Lock-in technique.

The sensitivity of the Lecher line interferometer is comparable to the one of the interferometer using horn antennas, however, the spatial resolution is considerably increased. Fig. 2 shows typical wave patterns obtained for frequencies of 100, 200 and 500 kHz corresponding to wavelength of 23, 11.5 and 4.4 mm, respectively. Measurements at frequencies above 220 kHz are performed using a technique of heterodyning. The attenuation of the wave amplitude is due to Landau and collisional damping. The magnitude of the two effects can be determined from the plot of the experimental values of the damping constant against the wave number, Fig. 3. The Landau damping is given by the slope of the line in Fig.3. *) The collosional damping ($K_i^{coll} = \frac{\nu_{ic}}{2C_s}$) is given by the ordinate of the intersection point for wave number zero. The value of 90 kHz for the collision frequency derived from Fig. 3 is in good agreement with the estimates for the ion-neutral and ion-ion collision frequencies {6}. The measurements show that the Lecher wire interferometer is well suited as an unperturbative diagnostic tool of high sensitivity and spatial resolution for the study of ion acoustic test waves.

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*) The part of the spatial damping constant, which is determined by collective effects, is proportional to the real wavenumber ($K_i = \frac{\omega i}{\omega r} K_r$, $\frac{\omega i}{\omega r}$ is given by the solution for the least damped mode of the initial value problem) for the case of an elevated electron to ion temperature ratio {5}.

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FIGURE CAPTIONS

Figure 1 : WS - rf wave structure; P - movable grid probe; K - Klystron (30-35 GHz, 100 mWatts); F - Frequency meter; C - Directional Coupler; A_1, A_2 - Variable (0 - 30 dB) Attenuators; $\emptyset_s$ - Variable (0 - 30 degree) phase shifter; T - MAGIC TEE; D - Crystal Detector; D-A - Differential Amplifier; L-I - Lock-in Amplifier.

Figure 2 : Wave patterns (a), (b), (c) obtained for frequencies of 100 kHz, 200 kHz and 500 kHz, respectively.

Figure 3 : Experimental values of the damping constant (K_i) as a function of the real wave number (K_r) for frequencies in the range from 50 kHz to 500 kHz. The value of the damping constant has been determined from a least square fit of the amplitude variation to an exponential. The value of the linear regression factor was typically about .99.

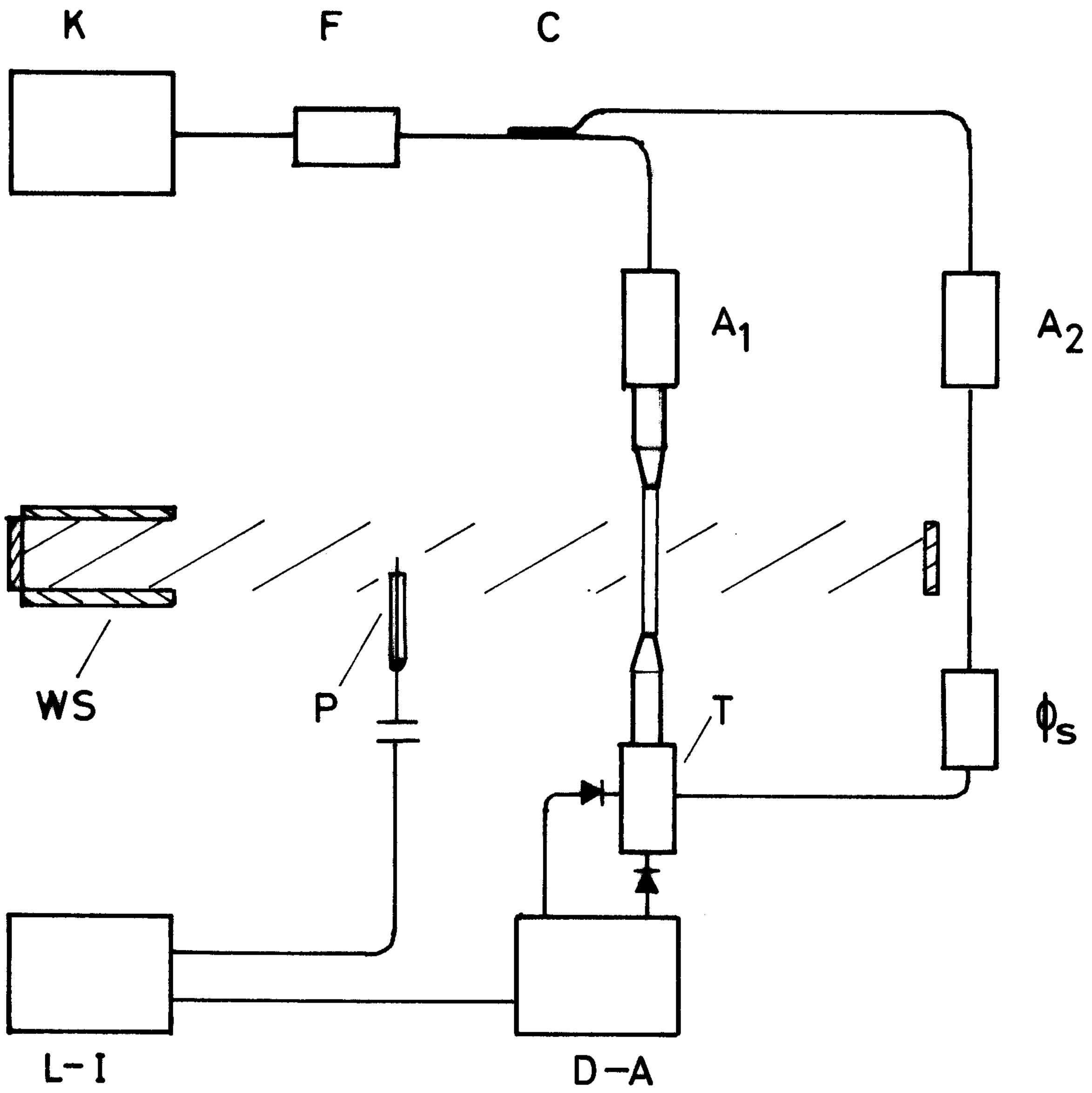

Fig. 1

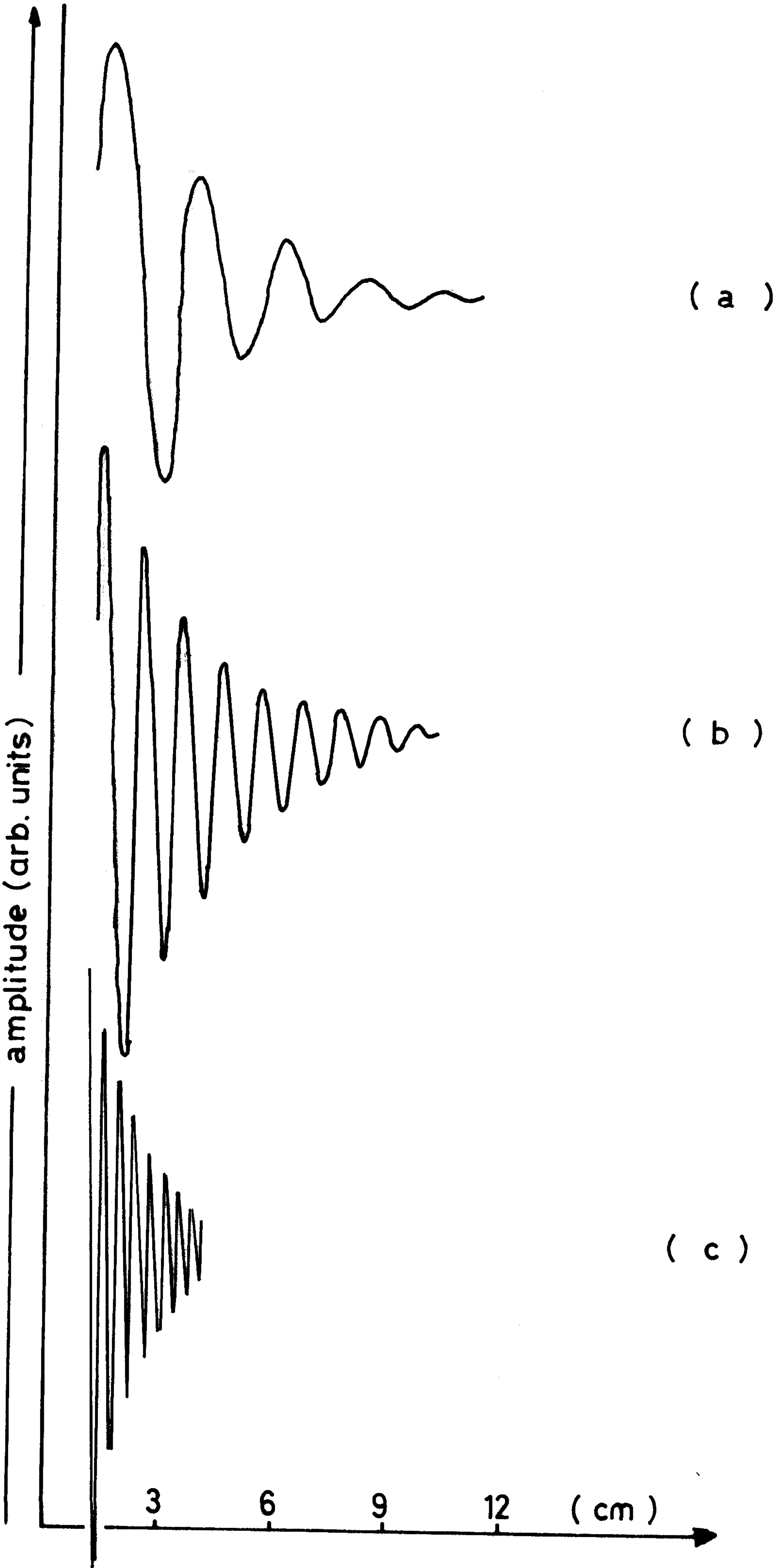

Fig. 2

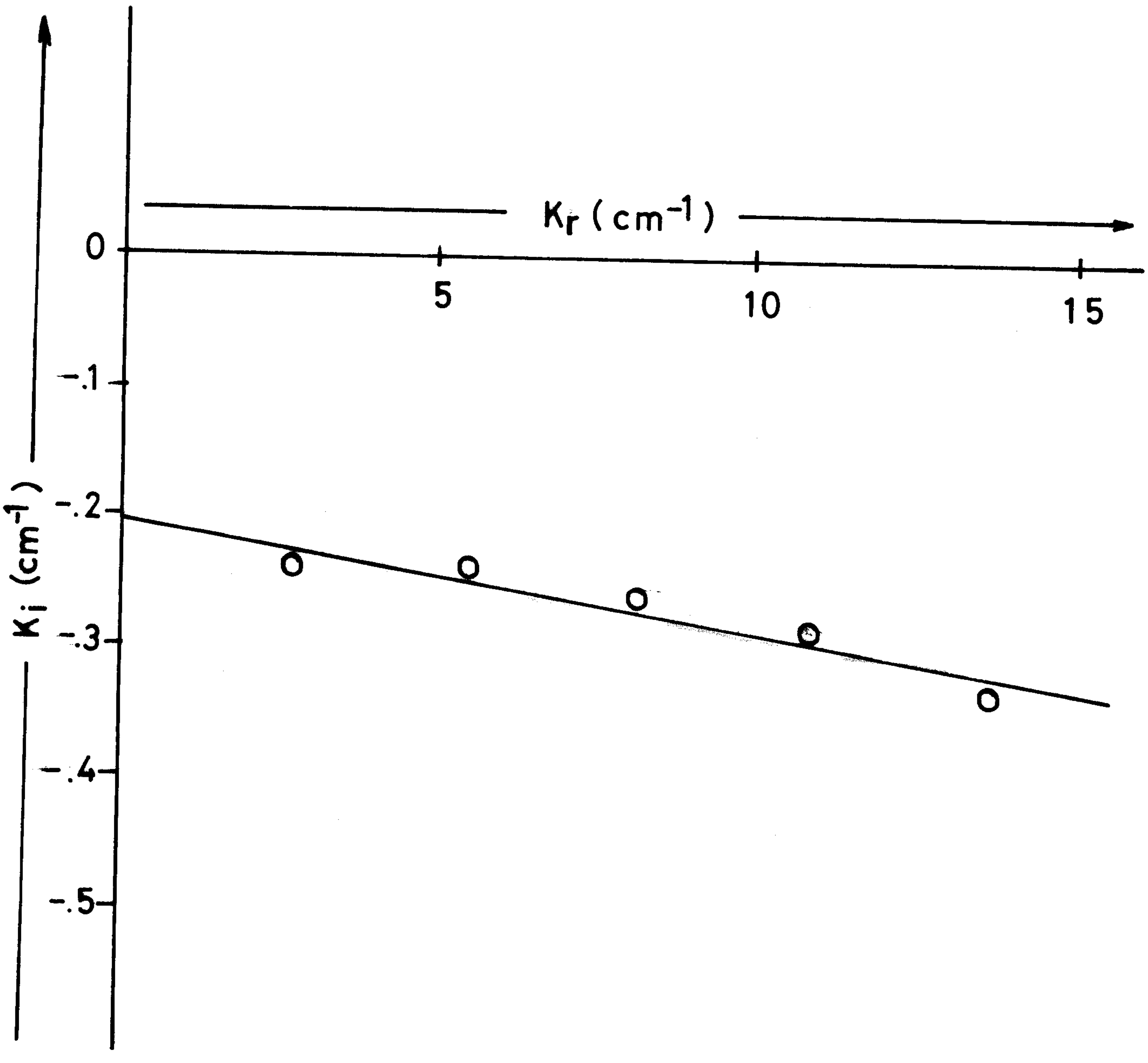

Fig. 3