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COLLECTIVE SCATTERING OF CO_2-LASER LIGHT BY THE HIGHLY IONIZED ARGON PLASMA OF A HOLLOW CATHODE ARC DISCHARGE

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Introduction: Collective scattering of CO_2-laser radiation is an important diagnostic for the study of turbulence in plasmas. This diagnostic has obtained a lot of interest during the past few years. Most of the studies so far refer to: a) detection of externally excited single frequency waves, b) scattering in high density plasmas (electron density $n_e \gtrsim 10^{21}\ m^{-3}$), or c) experiments with high power (pulsed or c.w.) CO_2-lasers [1,2,3,4]. We present as far as we know for the first time collective scattering measurements of spontaneously excited turbulence in a medium density plasma with a low power c.w. 2 W CO_2-laser.

Collective scattering refers to plasma scattering of electromagnetic radiation for which the so-called scattering parameter $\alpha=(k\lambda_D)^{-1}>1$. Here $k=|\underline{k}|=|\underline{k}_s-\underline{k}_i|$, where $\underline{k}_s$ and $\underline{k}_i$ are the wavenumbers of scattered and incident radiation respectively; λ_D is the Debye length. It is possible to obtain information about the electron density fluctuations for various wavenumbers $\underline{k}$ and angular frequencies ω. Here $\omega=\omega_s-\omega_i$, where ω_s and ω_i are the angular frequencies of the scattered and incident radiation respectively. The scattered power P_s is proportional to $n_e S(\underline{k}_s-\underline{k}_i,\omega_s-\omega_i)$, where $S(\underline{k},\omega)$ is the spectral density function, which represents the electron density fluctuations [5]. Mostly optical homodyne or heterodyne detection is used. The (k,ω)-window can be varied by changing the scattering angle θ, which is proportional to k for small θ, and by changing the angular frequency ω_f of a variable bandpass filter after the optical mixer. For homodyne detection one gets $\omega_f=|\omega|$, so that the spectrum after the optical mixing is a direct measure of the fluctuation spectrum of the plasma.

Experimental equipment: The low power c.w. CO_2-laser is focussed in the plasma to a spot with a diameter of 2 mm (see figure 1). The plasma is created in a stationary, current driven (10-300 A), low pressure (10^{-3} torr) hollow cathode arc discharge. The plasma is cylindrical (radius 10 mm, length 0-2.5 m), magnetically confined (0-0.5 T) and highly ionized. Typical values of the plasma parameters are: electron density 10^{19}-$10^{20}\ m^{-3}$, electron temperature 3-4 eV, ion temperature 1-2 eV, neutral density 10^{18}-$10^{19}\ m^{-3}$, ion plasma frequency 200 MHz and Debye length 1.5 µm. A fraction of the incident laser beam is used as local oscillator (10 mW). The radiation scattered with angle θ is the signal beam, which is chopped for phase sensitive detection. Both beams are combined via a beam splitter and focussed on a liquid helium cooled Ge:Cu detector (1 mm^2, current 1 mA). The detector is coupled via a source follower (600 Ω-50 Ω) and a high pass frequency filter (1 MHz) to broad-band low noise amplifiers (0-500

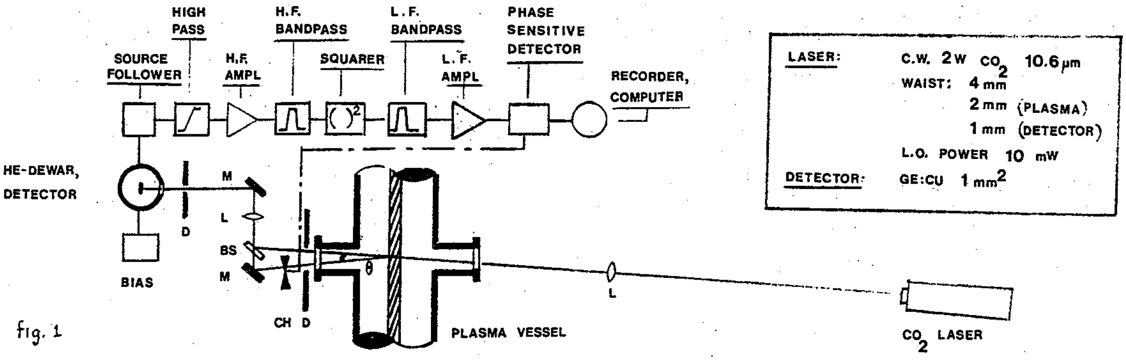

fig. 1

MHz, gain 40 dB). Home-made band pass filters (center frequency ν_f 1-50 MHz, bandwidth 0.1-0.3 of ν_f, 24 dB/octave) are used for spectral analysis. We can vary the scattering angle θ from 1° to 7° ($0.02<k\lambda_D<0.1$). We emphasised optimization of the signal to noise ratio and determination of the absolute sensitivity of the diagnostic as a whole. Both are crucial points. In optical mixing experiments it is the ambition to keep the shot noise of the local oscillator dominant with respect to other noise sources. We realized this by the use of an impedance transformer and ultra low noise active components; In this way also the local oscillator power is kept at a low level. The absolute sensitivity was determined by performing coherent and incoherent measurements with a black body and scattering from high level acoustic waves in 1 atm. argon. We are able to detect a scattered signal close to the quantum limit.

Experimental results: We used two scattering geometries: $\underline{k}//\underline{B}$ and $\underline{k}\perp\underline{B}$. We found that for all plasma conditions considered the fluctuation level with $\underline{k}//\underline{B}$ was close to thermal. As in this case the signals are very small we merely measured the total contents of the spectra. However, preliminary measurements indicate a maximum at the frequency-equivalent of the ion acoustic velocity. For $\underline{k}\perp\underline{B}$ we found fluctuation levels which could reach 3 orders of magnitude above thermal. In fig. 2 we show for a specific plasma condition $S(\underline{k},\omega)$ for $\theta=2°$ for various radial positions in the plasma. In fig. 3 we show $S(\underline{k},\omega)$ as functions of $k_\perp$ and ω for a specific plasma condition for the center of the plasma. The dispersion indicates the presence of ion acoustic-like waves.

Discussion: One of the most evident result is the strong anisotropy in $\underline{k}$-space, which indicates also the large selectivity in $\underline{k}$-space of the collective scattering method. For $\underline{k}//\underline{B}$ the level is close to thermal; for $\underline{k}\perp\underline{B}$ the level is highly non-thermal. This was contrary to our expectations for a plasma with the electron drift below but close to the critical drift for excitation of longitudinal ion acoustic waves. Perpendicularly propagating disturbances are prefered, moving with ion acoustic phase velocities, with an accumulation at long wavelengths. The frequency domain we studied so far is far above the ion cyclotron frequencies. We note, that the measurements with low frequency optical probing indicate also a strong anisotropy in $\underline{k}$-space and mainly perpendicularly propagating waves.

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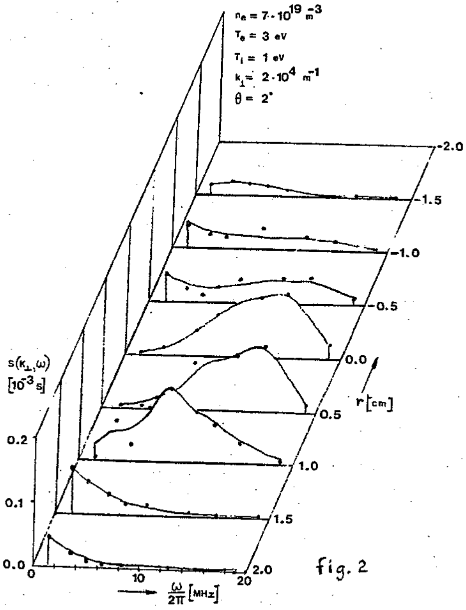

fig. 2

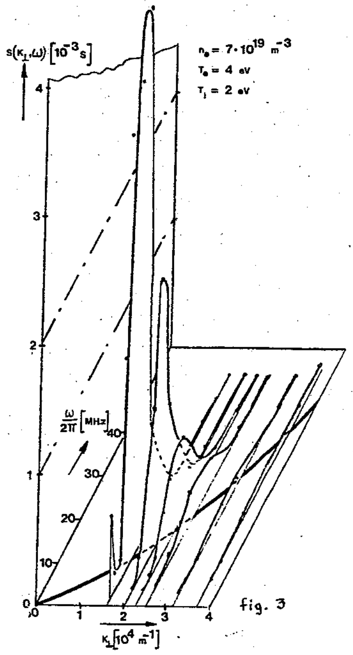

fig. 3