§25. Stimulated Electron-Acoustic-Wave Scattering in a Laser Plasma

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The propagation of a laser light through an underdense plasma is an active research topic. In order to explain high reflectivities observed in experiments, we investigate excitation and growth of electron-acoustic waves. From our simulation data stimulated electron-acoustic-wave scattering (SEAS) is identified as a resonant three-wave parametric interaction [1] involving the laser pump (ω_0, k_0), the backscattered lightwave (ω_s, k_s) and the trapped electron-acoustic wave (EAW) (ω_a, k_a). In the linear instability stage, resonant conditions $\omega_0 = \omega_s + \omega_a$ and $k_0 = -k_s + k_a$ are well satisfied, while electromagnetic waves (pump and Stokes wave) satisfy standard dispersion equation $\omega_{0,s}^2 = \omega_p^2 + c^2 k_{0,s}^2$. The backscattered wave is always found to be driven near critical, i.e. $\omega_s \approx \omega_p$ which implies $k_s \approx 0$ and $V_s \approx 0$ (ω_p is the plasma frequency and $V_s = c^2 k_s / \omega_s$ is the light group velocity). The above decay scheme is observed for a wide range of laser intensities, plasma densities and temperatures. It is known that the high temperatures can significantly change the growth rates and sometimes suppress parametric instabilities. However, according to [2], efficient excitation of trapped EAW ($\omega_a < \omega_p$), is expected in the range $v_{ph}/v_t = 1-2$ (v_{ph} and $v_t = (T/m)^{1/2}$ are the phase and electron thermal velocities). Thus, for SEAS excitation at the threshold, high thermal velocities which closely match the EAW phase velocity are important.

In Fig. 1 EM and ES spectra of fully developed SEAS are shown. The density and the plasma length are $n = 0.9n_{cr}$ ($n_{cr} = n(\omega_0/\omega_p)^2$) and $L = 50c/\omega_0$, respectively, the temperature is $T = 500\text{eV}$ and the laser strength is $\beta = (eE_0)/(mc\omega_0) = 0.4$ (E_0 is the amplitude of the electric field). The backscattered EM wave grows at the electron plasma frequency $\omega_p \approx 0.85\omega_0$, while corresponding EAW is at $\omega_0 - \omega_p \approx 0.15\omega_0$. Note that apart from ES noise around a natural plasma mode ($\omega_p \approx 0.85\omega_0$), ponderomotively driven non-resonant modes are also present at 2-nd, $\omega = 2\omega_0$ and $k = 2k_0$, as well as at zero-harmonic.

The temperature effect can be clearly seen near the threshold intensity for SEAS ($\beta \sim 0.3$). Since the longitudinal thermal velocity of electrons can easily increase due to e.g. the Raman instability, the temperature in transverse direction was set to 500eV, with a longitudinal temperature taken as a control parameter. Just above the threshold, high electron temperature may be essential for an instability growth. This is

illustrated by Fig. 2 in which reflectivities are shown for $\beta = 0.3$, $n = 0.4n_{cr}$, $L = 40c/\omega_0$ at several temperatures, $v_t/c = 0.19, 0.20, 0.28$ and 0.30 . There is an optimum temperature for perfect matching with an excited EAW which results in a maximum SEAS reflectivity. For $v_t/c = 0.2$ observed reflectivity is very high - nearly 140% of the incident laser light. One calculates $v_{ph}/v_t \approx 2.64, 2.50, 1.84$ and 1.72 for $v_t/c = 0.19, 0.20, 0.28$ and 0.30 , respectively. For temperatures $\leq v_t/c = 0.18$ and $\beta = 0.3$ the instability was not observed during time period of $t\omega_0 = 5000$.

Fig. 1. Spectrum of electromagnetic (a) and electrostatic (b) waves in the plasma layer for time interval $t\omega_0 = 1000 - 1864$.

Fig. 2 Reflectivity in time from the plasma layer for different initial electron thermal velocities v_t/c .

References

- 1) K. Mima and K. Nishikawa, in *Basic Plasma Physics II*, edited by A. A. Galeev and R. N. Sudan, (North-Holland, Amsterdam 1984), p. 451.
- 2) H. A. Rose and D. A. Russell, *Phys. Plasmas* **8**, 4784 (2001).