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On the two-plasmon decay instability in laser plasma interaction

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Overview

The presence of the strong electromagnetic wave of the laser in the corona of a laser-fusion target provides a source of free energy which can be tapped by a number of plasma instabilities. One example of these is the two-Plasmon decay (TPD) instability in which the pump electromagnetic wave (the laser light) decays into two plasma waves.

TPD instability was identified as a source of **hot electrons**, which could induce preheat of the fuel and inhibit strong compression and hot-spot creation. In this process an in-coming laser photon ω_0 decomposes into two plasmons (ω_1 ,ω_2) in the vicinity of the quarter-critical density $n = n_{cr}/4$, with $n_{cr} = 10^{21}/\lambda_0^2\ cm^{-3}$ and λ_0 the laser wavelength in microns. The plasmon frequency is determined by the dispersion relation for electron plasma waves, $\omega_{1,2} = \omega_p\left(1+3k_p^2\lambda_D^2\right)$, and by the matching conditions for $2\omega_p$ instability, $\omega_0 = \omega_1 + \omega_2$ and $\vec{k}_0 = \vec{k}_1 + \vec{k}_2$. Here, $\omega_p = \left(4\pi n e^2/m_e\right)^{1/2}$ is the electron plasma frequency, $\vec{k}_{1,2}$ the plasmaon wave vector, $\vec{k}_0$ the laser wave number at the quarter critical density, $\lambda_D = v_e/\omega_p$ the Debye length, and $v_e = \left(T_e/m_e\right)^{1/2}$ the thermal velocity [1].

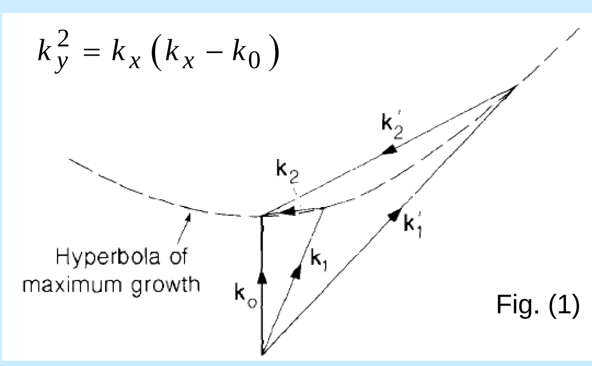
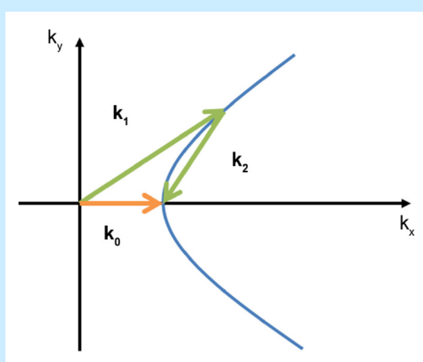


Fig. (1)



In a **homogeneous plasma,** the wave vectors of the plasmons have the maximum of TPD growth rate lying in the plane of incidence on the *hyperbola* (Fig.1). Each point of the hyper-bola corresponds to a particular density deter-mined by the frequency-matching conditions. TPD and SRS cannot operate in a homogene-ous plasma whose density exceeds the quarter critical density (Fig.2).

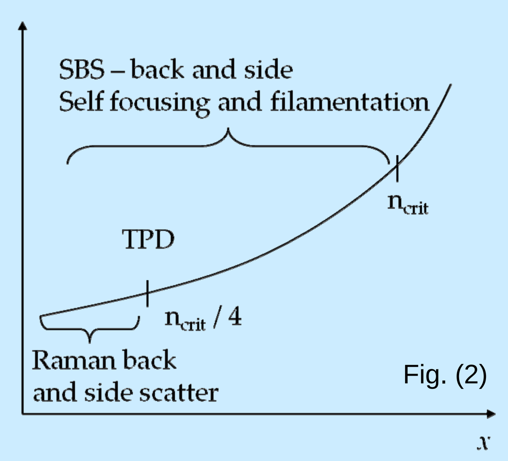


Fig. (2)

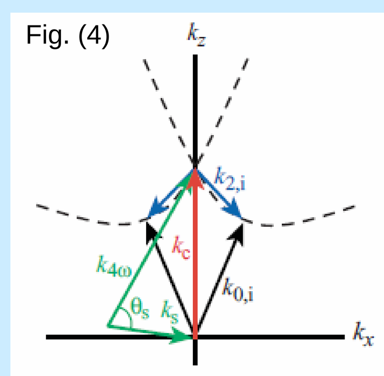
The theory of the absolute $2\omega_p$ instability in an **inhomogeneous plasma** was first treated by Lee and Kaw, who restricted their calculation to the case of plasma waves whose wave vector greatly exceeded that of the pump. During TPD process, a plasma wave with mixes with the (reflected) laser wave to a new transversal electromagnetic wave with $\omega_p = 0.5\omega_0$ maximizes with the (reflected) laser wave to a new transversal electromagnetic wave with $\omega = 3\omega_0/2$. The momentum conservation is the reason why $\omega = 3\omega_0/2$ was always created by TPD plasma waves . So, the TPD instability has also a potential of $3\omega_0/2$ radiation of laser in in the long laser pulse experiments.

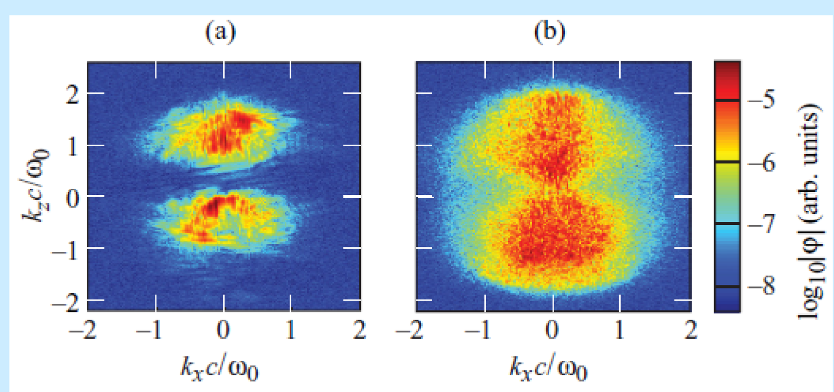
Nonlinear stage of TPD instability

Two-dimensional particle-in-cell simulations for conditions relevant for the shock-ignition (SI) scheme of inertial confinement fusion show that in a hot, large-scale plasma, TPD develops in concomitance with stimulated Raman scattering (SRS). It is active only during the first picosecond of interaction, and then it is rapidly satu-rated due to plasma cavitation. TPD-excited plasma waves extend to small wave-lengths, above the standard Landau cutoff.

Hot electrons are generated mainly in the nonlinear stage. For the current direct-drive experimental parameters, the linear stage of TPD only lasts about 1-2 *ps*, however, the duration of the peak laser intensity in the experiments is on the order of *ns*. This means that laser absorption and hot electron generation are determined mostly by the nonlinear properties of TPD. The nonlinear stage involves physics, i. e., ion dynamics, secondary decays, laser absorption, and electron acceleration, that is not included in the linear theory. The plasma waves generated in the linear and nonlinear stages have different phase velocities. The phase velocities of the forward-propagating plasmons, from TPD are 0.5c. Energetic electron ($50keV$) generation occur in the nonlinear stage. Fig.(3) shows the time-averaged electro-static field spectrum at a time when nonlinear saturation has been attained. The in-stability is driven by two plane EM waves (black arrows) that are incident at an angle 23° of with respect to the direction of the density gradient (x direction). The red cir-cle indicates the location of the Landau cutoff at $k\lambda_D = 0.25$.[2].

Fig. (4)





Thomson-scattering geometry can also be used to probe EPW wave vectors near the region of maximum common-wave growth [3]. In an experimental configuration on the OMEGA laser system, a broad spectrum of TPD-driven EPWs was observed, indicative of nonlinear effects associated with TPD saturation [Fig.4]. The new modes generated in the nonlinear stage are correlated to the ion density fluctuations driven by the ponderomotive force of the plasma waves. The linear stage ends when the plasma waves first generated near the $n_c/4$ surface start to drive ion density fluc-tuations and propagate toward the low-density region. Plasma parameters taken in this simulation are, $T_e = 2keV$, $T_i = 1keV$, $I = 6\times10^{14}\ W/cm^2$, $\lambda_s = 413nm$, $L = 190\mu m$.

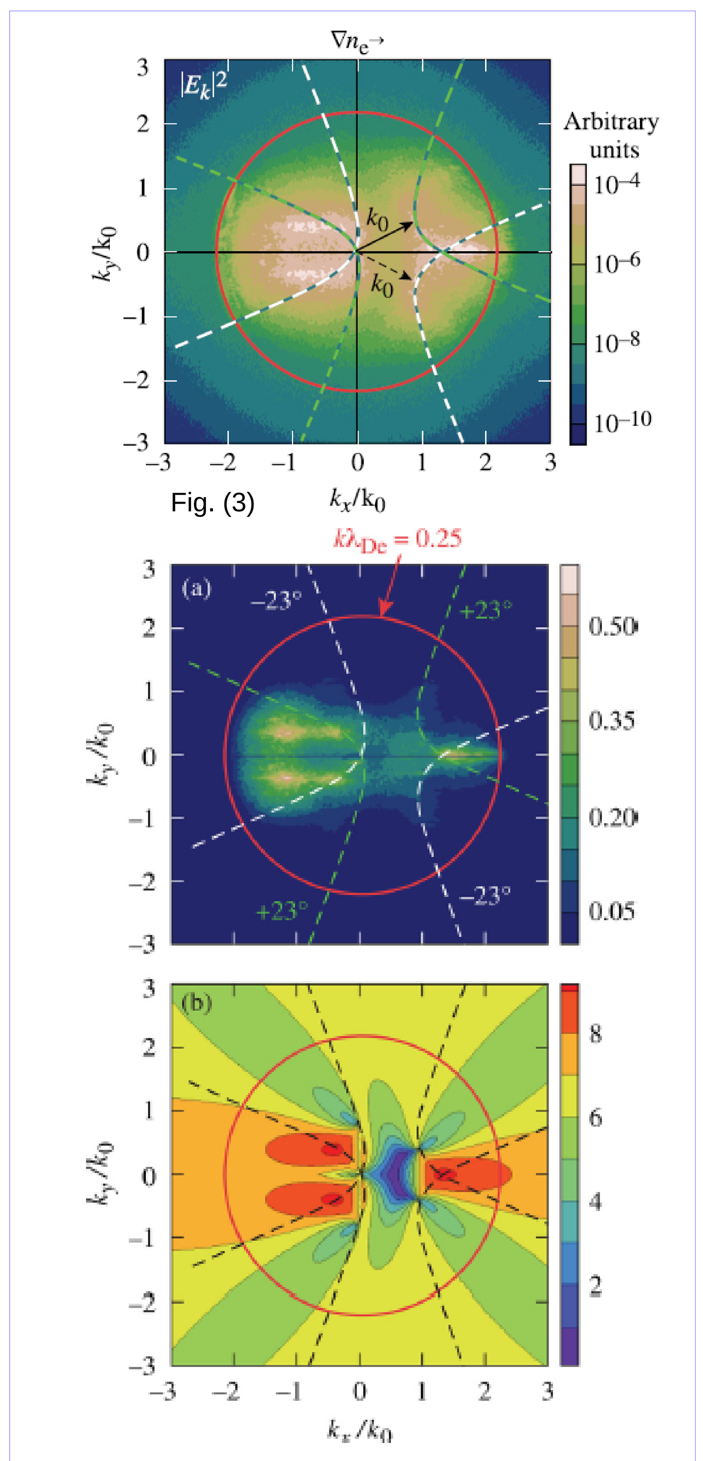


Fig. (3)

Growth rate of TPD instability

Governing wave equation describing TPD instability

$$\vec{\nabla}^2\vec{E} - \frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2} - \vec{\nabla}\vec{\nabla}.\vec{E} - \frac{4\pi e^2 n_e(x)}{mc^2}\vec{E} + \frac{3T_e}{mc^2}\vec{\nabla}\vec{\nabla}.\vec{E}$$

$$= \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\left(\vec{v}\vec{\nabla}.\vec{E}\right) + \frac{4\pi e n_e(x)}{c^2}\left(\frac{1}{2}\vec{\nabla}(\vec{v}.\vec{v}) - v\times\omega_c\right)$$

Homogeneous Plasma

$$n_e(x) = n_{0e}$$

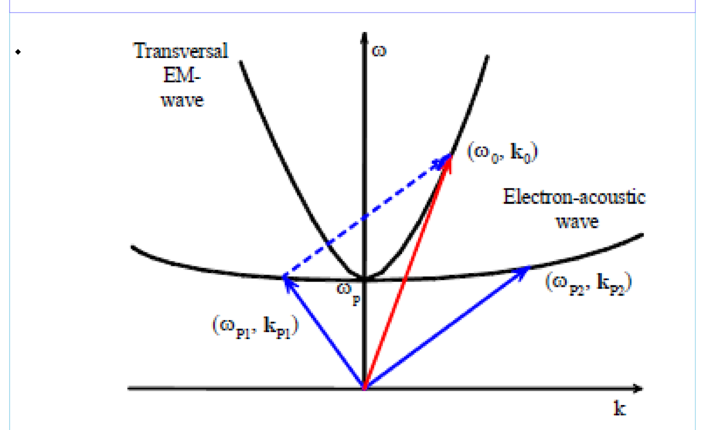
$$\gamma = \frac{k_0 v_0}{4}\left[\left(\frac{k_1^2}{k_2^2} + \frac{k_2^2}{k_1^2}\right)\frac{\omega_p^2}{\omega_1\omega_2} - \frac{\omega_p^4}{\omega_1^2\omega_2^2} - 1\right]^{1/2}$$

Inhomogeneous Plasma

$$n_e(x) = n_{0e}\left(1 + \frac{x}{L}\right)$$

$$\gamma = \frac{k_0 v_0}{4}\left[1 - \frac{3\left(\sqrt{3}/2\right)v_e^2}{\omega_p v_0}k_y\right] - \frac{\omega_p}{k_y L}$$

Ref.4-5



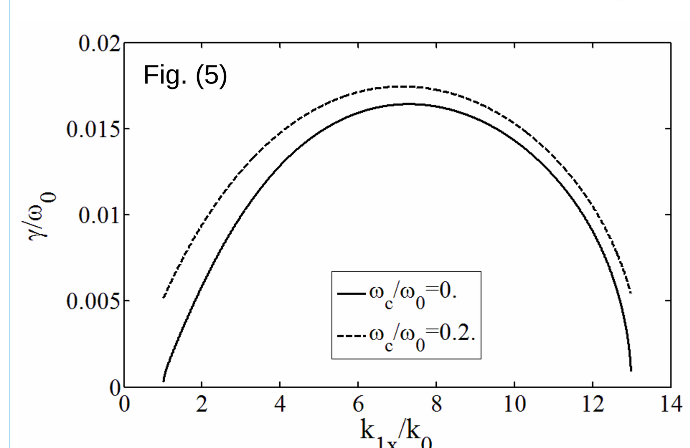
Two-plasmon decay instability in the interaction of electromagnetic wave with magnetized plasma

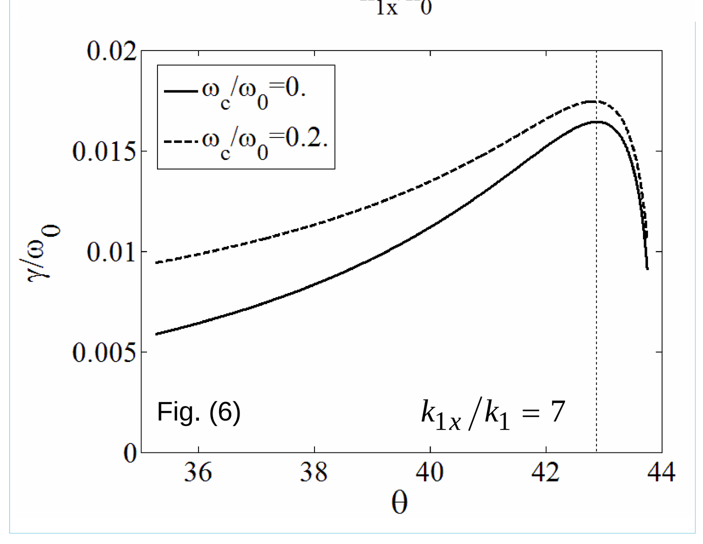
In the last part of this study, the two-plasmon decay instability in the interaction of an elec-tromagnetic wave with a homogeneous magnetized plasma has been investigated. In this decay, the incident light wave propagates through the plasma perpendicular to the exter-nal magnetic field and after scattering, it decays into two plasmons of the same frequency. Amplitude of the plasmons and amplitude of plasma density oscillations increase with time leading to generate the instability in plasma. Using the fluid theory and employing the Maxwell equation, fluid equation and the equation of motion for plasma electrons, the dis-persion relation of the plasmon is obtained and used to find the growth rate of the instabil-ity. The effect of external magnetic field on the growth rate of TPD instability in magnet-ized plasma has been illustrated in Fig.5 and Fig.6 for the values of $a_0 = \omega_p/\omega_0 = 0.1$ and, $k_{1y}^2 = k_{1x}(k_{1x} - k_0)$ according to the maximum growth rates lie on the *hyperbola*.

It is shown that applying the external magnetic field increases the growth rate. Moreover, the growth rate has a large value in the scattering angle near 43° .

$$\gamma^2 = \frac{\omega_p^4}{4\omega_1\omega_2}\left(\frac{\omega_p^2}{\omega_1^2 - \omega_c^2}\right)\left(1 - \frac{\omega_p^2}{\omega_2^2 - \omega_c^2}\right) + \frac{v_{0y}^2}{16\omega_1\omega_2}\left[\frac{k_{1x}k_{2x}\omega_p^4\omega_c^2}{\left(\omega_1^2 - \omega_c^2\right)\left(\omega_2^2 - \omega_c^2\right)}\right.$$

$$\left. - \frac{k_{1y}k_{2y}\omega_p^4\omega_1\omega_2}{\left(\omega_1^2 - \omega_c^2\right)\left(\omega_2^2 - \omega_c^2\right)} + \frac{k_2^2}{k_1^2}\frac{\omega_1^2\omega_p^2}{\omega_1^2 - \omega_c^2}k_{1y}^2 + \frac{k_1^2}{k_2^2}\frac{\omega_2^2\omega_p^2}{\omega_2^2 - \omega_c^2}k_{2y}^2 - \omega_1\omega_2 k_{1y}k_{2y}\right]$$





References

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