2.B Filamentation of Laser Light in Flowing Plasmas

The filamentation of laser light entering a laser-plasma corona has been of much recent interest,[1,2,3] as it may significantly affect the absorption efficiency and implosion uniformity of laser fusion experiments. Previous calculations[4] of this instability have employed a static pressure-balance equation to represent the plasma response to the ponderomotive force. Generally, however, the plasma will be moving with respect to the filaments, and so it is more realistic to use hydrodynamic equations to determine the plasma response. Here we examine the effects of plasma flow on the thresholds and growth rates for filamentation.

The geometry of the instability is shown in Fig. 12. Filamentation may be "seeded" by hot spots in the incident beam or refraction by density fluctuations in the outer corona. These initial intensity variations are

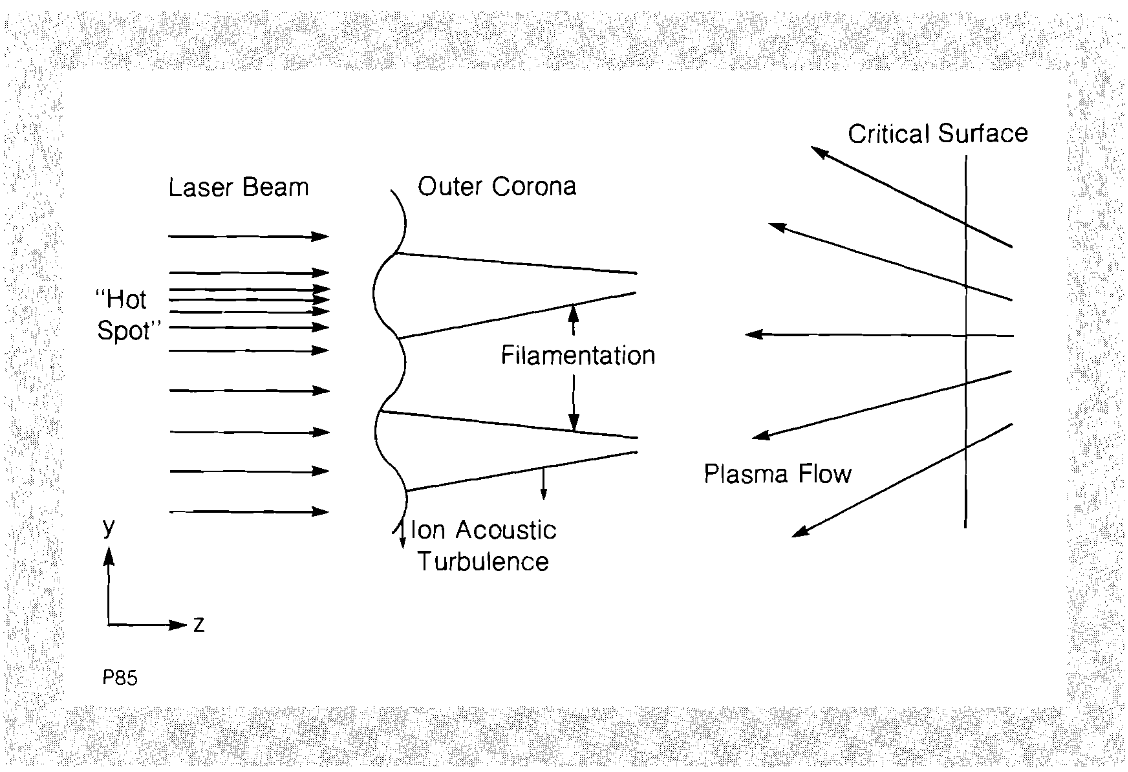

Fig. 12
Filamentation instabilities in laser-produced plasmas. Filamentation may be "seeded" by hot spots in the laser beam or refraction by density fluctuations in the outer corona.

then amplified by the instability. To calculate the spatial growth rate we work in the frame in which the critical surface and the intensity variations are stationary, and look for time-independent modes amplifying in the z-direction. For filaments arising from hot spots this will be the lab frame; for filaments arising from ion acoustic noise it will be a frame moving transverse to the incident light at approximately c_S, the ion sound speed. In this coordinate system we expect plasma flow velocities on the order of c_S in the z-direction, and somewhat less than this in the y-direction. (Of course, we could use the frame in which the flow velocity vanishes, but this would entail the solution of time-dependent equations and matching the solution to the moving perturbations.)

To obtain the growth rate for the instability, we consider the simple case in which the plasma and incident beam are uniform except for small perturbations in density and laser intensity. Solving the resulting linear electromagnetic and fluid equations, we obtain the dispersion relation for filamentation in flowing plasma:

$$\left[\frac{(n_o/2\varepsilon_o n_c)\,(v^2_{osc}/v^2_{th})\,(1+q^2)}{1+q^2+(i\nu/k_y c_s^2)\,(v_{oy}+qv_{oz})-(v_{oy}+qv_{oz})^2/c_s^2} - \varkappa^2(1+q^2)\right]\varkappa^2(1+q^2)$$

$$+\ 4\varkappa^2 q^2 = 0 \qquad (1)$$

Here n_o is the equilibrium density, v_{oy} and v_{oz} are the y and z components of the fluid velocity, respectively, n_c is the critical density for the laser light, v_{osc} is the quiver velocity of an electron in the electric field of the light, v_{th} is the average electron thermal velocity, ν is the damping rate of ion-acoustic waves, k_y and k_z are the y and z components of the wavevector of the perturbation, k_o is the wavenumber of the incident light, $\varkappa = k_y/k_o$, $q = k_z/k_y$, and $\varepsilon_o = 1 - n_o/n_c$. The spatial growth rate for the instability is given by the imaginary part of q. Equation (1) is our main result; in the following, we examine some of its consequences.

First we consider the effect of the transverse velocity v_{oy}, taking $\nu = v_{oz} = 0$. Assuming $|q| \ll 1$ the threshold condition becomes:

$$q^2 = \frac{\varkappa^2}{4} - \left(1 - \frac{v^2_{oy}}{c^2_s}\right)^{-1} \frac{n_o}{8\varepsilon_o n_c}\,\frac{v^2_{osc}}{v^2_{th}} < 0 \qquad (2)$$

This result agrees with Ref. (4) for $v_{oy} = 0$ and indicates that thresholds decrease and growth rates increase as $|v_{oy}|$ increases for $|v_{oy}| < c_s$; for $|v_{oy}| > c_s$ no growth occurs. The discontinuity in growth rate for $|v_{oy}| = c_s$ is due to breakdown of the assumption $|q| \ll 1$; to elucidate the actual behavior of the instability for $v_{oy} \sim c_s$ we plot solutions of the full dispersion relation (1) in Figs. 13(a) through 13(e). The solutions of (1) which represent filamentation are those roots which are continuous with the roots of (2) as a function of $\underline{v}_o$; other complex roots of (1) may be shown by Briggs-Bers analysis[5] to be evanescent, except for a small range of $\underline{v}_o$ where they represent Brillouin scattering. Figs. 13(a) through 13(c) show the effects of transverse velocity at various incident intensities for a typical value of k_y and no damping. In Figs. 13(a) and 13(b) filamentation is below threshold for $v_{oy} = 0$ but grows for a range of v_{oy} around $v_{oy} \sim c_s$. The range of instability increases with increasing v_{osc}/v_{th} until in Fig. 13(c) growth occurs even when $v_{oy} = 0$, though the growth rate still increases significantly as $v_{oy} \rightarrow c_s$. These plots also show that for $v_{oy} \sim c_s$ k_z has a real as well as an imaginary part, indicating that the filaments will grow at an angle to the incident light (they are perpendicular to Re($\underline{k}$)). Figures 13(d) and 13(e) show the effect of including Landau damping of ion motion. The maximum spatial growth rates are reduced but the instability grows for a wider range of transverse velocities. Finally, calculations with varying v_{oz} show that the component of flow velocity parallel to the incident light has little effect on filamentation.

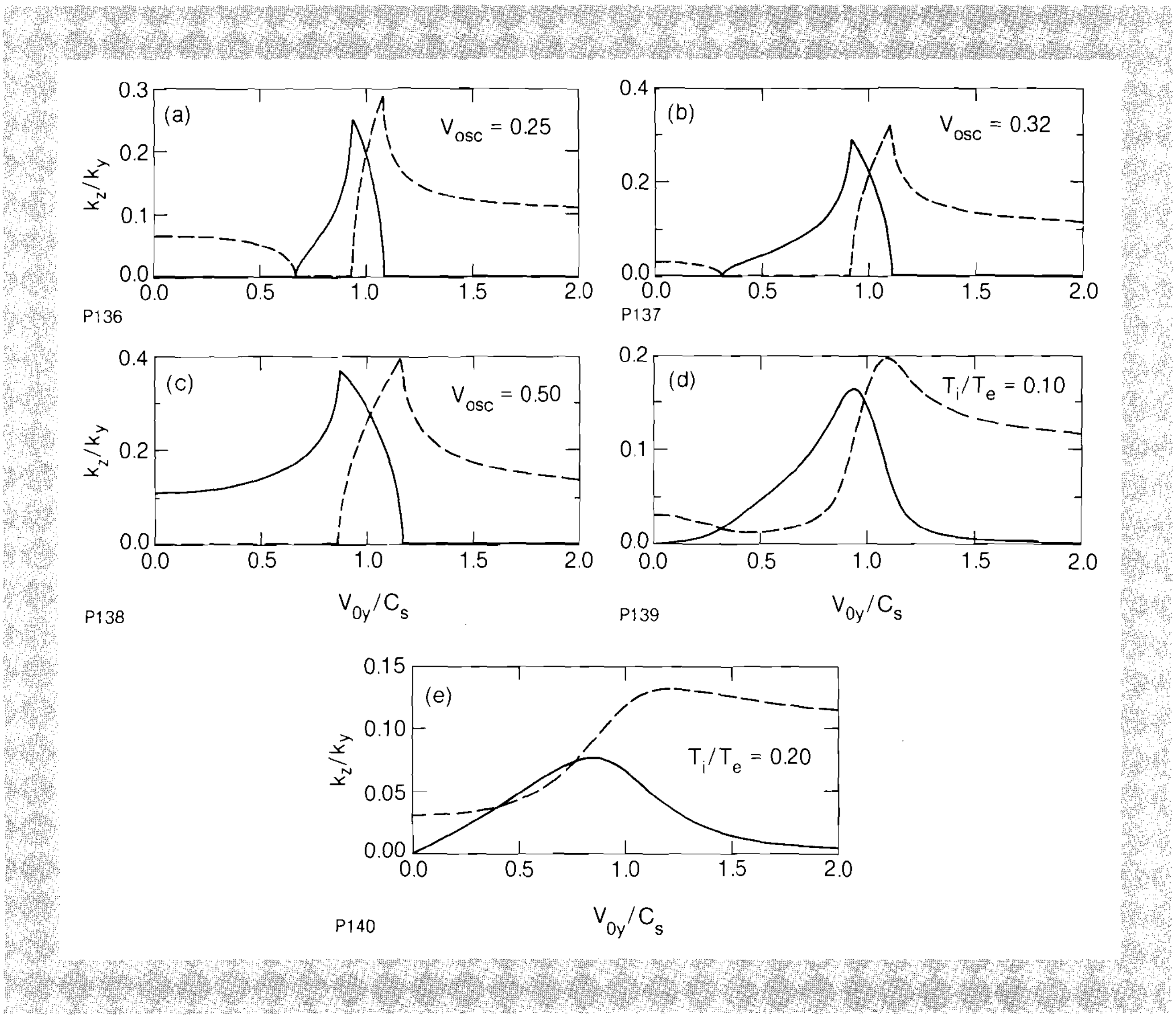

Fig. 13
Real (dashed) and imaginary (solid) parts of solutions to filamentation dispersion relation. For (a)-(c), $k_y/k_0 = 0.2$, $v_{0z} = 0$, $T_i/T_e = 0$. For (d)-(e), $k_y/k_0 = 0.2$, $v_{0z} = 0$, $v_{osc}/v_{th} = 0.32$.

In conclusion, we have derived the dispersion relation for filamentation in flowing plasmas. We find that flow velocities transverse to the incident light decrease thresholds and increase spatial growth rates. This result may be especially significant for filamentation due to refraction from acoustic turbulence in the outer corona, which may be expected to have significant transverse velocities.

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