라만 후방향 산란을 이용한 레이저 펄스 증폭에서 나타나는 증폭 특성의 시뮬레이션

Simulation of Amplification Characteristics of Ultrashort Laser Pulse Amplification using Raman Backscattering

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Recently, analysis of transient Raman backscattering in a plasma reported(2,3) that it is possible to reach 10^{17} W/cm^2 for 1 micrometer wavelength laser pulse with a counter-propagating pump pulse. The basic mechanism is like this : when the two counter-propagating waves in a plasma satisfy the condition of Raman backscattering, $\omega_0 = \omega_1 + \omega_p$, energy is transferred from the long pulse to the short pulse via three wave interaction(4).

An important feature of stimulated Raman backscattering is that the seed pulse can grow to much higher intensities than that of the pump pulse because the seed pulse continually encounters unperturbed region of the pump. However, the amplitude growing stops if the seed pulse amplitude becomes large enough to stimulate forward Raman scattering or make a wakefield in the plasma.

From one-dimensional simulation(1), seed pulse amplification by Raman backscattering with counter-propagating pump was shown to be possible. In this study, we present simulation results of amplification characteristics such as peak growth rate, pulse width compression, and energy transfer ratio. For the simulation, one dimensional fluid code was used to solve the following one-dimensional fluid equations of Raman backscattering:

$$\frac{\partial f}{\partial t} + i\,\delta\omega f \cong -\frac{c}{4} k_f a_s^* a_p,$$

$$\frac{\partial a_s}{\partial t} + \nu_{g,1}\frac{\partial a_s}{\partial x} \cong -\frac{c}{4} k_f \frac{\omega_p}{\omega_1} a_p f^*, \quad \frac{\partial a_p}{\partial t} - \nu_{g,0}\frac{\partial a_p}{\partial x} \cong \frac{c}{4} k_f \frac{\omega_p}{\omega_0} a_s f$$

where

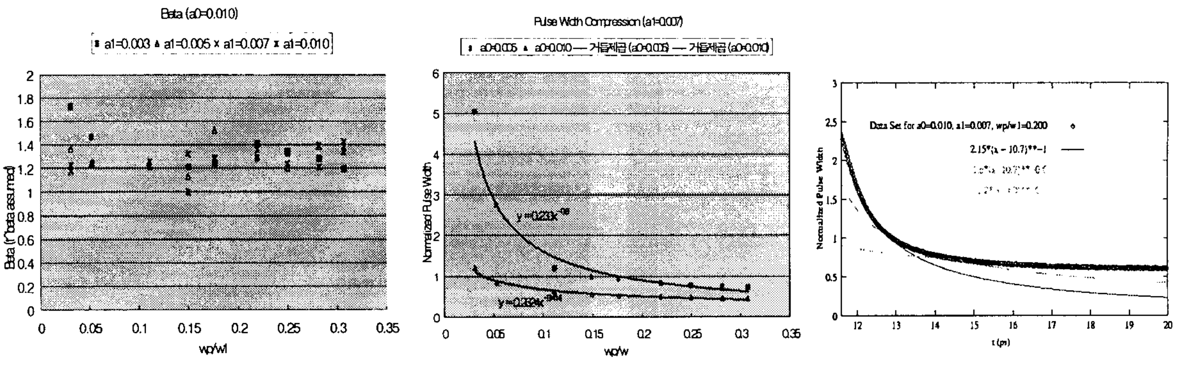
$k_f = k_1 + k_0,\quad \nu_{g,s} = c^2 k_s/\omega_s$

for $s = 0, 1$, and

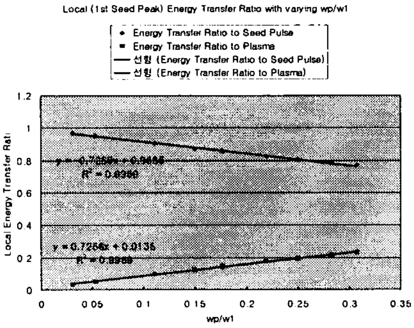
$\delta\omega = \omega_0 - \omega_1 - \omega_p$

Figure 1 shows the simulation results. It is known that peak energy growth rate follows $t^{-\beta}$ relation in nonlinear regime, and we calculated β for different seed pulse amplitudes with an independent parameter, ω_p/ω_1 in Fig. 1-(a). β does not change apparently with seed and pump pulse amplitude variation.

In Fig. 1-(b), the normalized pulse width of the seed pulse at $t = 19.0$ ps from start time of the simulation, which is equivalent to $x = 2700\ \mu m$ in $3000\ \mu m$ length plasma, is plotted against ω_p/ω_1 and compared with other cases of different pump amplitudes. It is found that the normalized pulse



(a) (b) (c)



(d)

Figure 1. Amplification characteristics of seed laser pulse amplification. (a) β with varying seed pulse amplitudes in nonlinear regime. (b) Pulse width variation with ω_p/ω_1 in nonlinear regime. The normalized pulse width of seed pulse follows approximately $(\omega_p/\omega_1)^{-\eta}$ relation. (c) Different scaling in different region of pulse width time evolution. (d) Decrease of local energy transfer ratio from local pump pulse energy to first seed pulse energy.

width of the seed pulse at $t=19.0$ ps shows $(\omega_p/\omega_1)^{-\eta}$ relation, and η is inversely proportional to the pump pulse amplitude. The normalized pulse width shows different scaling behaviour in time with three different regions in Fig. 1-(c). η is approximately -1, -0.6, and -0.3 in each region, and dominant physical process in each region should be investigated in future studies.

Local energy transfer ratio of pump pulse laser is defined as the ratio of the total energy transferred from the pump to the first peak of the seed to total energy depletion of the pump pulse in the spatial region occupied by the first seed pulse. This quantity is constant during time evolution of seed pulse with the same ω_p/ω_1 value, and linearly decreases as ω_p/ω_1 grows.

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