플라즈마 내에서 반대 방향으로 진행하는 펌프 레이저를 이용한 초단파 레이저 펄스 증폭 시뮬레이션

Simulation of Ultrashort Laser Pulse Amplification in a Plasma with a Counter-Propagating Pump

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It is necessary to generate a subpicosecond laser pulse with an ultrahigh intensity for the application to a laser wake field accelerator (LWFA) or inertial confinement fusion (ICF). Currently, chirped pulse amplification (CPA) reaches over TW/cm^2 intensities (without focusing in vacuum) by longitudinal compression of long laser pulses after amplification, far beyond the limitation by nonlinear modification of the refraction index. However, the gratings needed to stretch and compress the laser pulses will become quite large and expensive for the laser power above kJ per each pulse. For this reason, it is natural to exploit other methods to amplify a high-intensity short laser pulse.

Recently, analysis of transient Raman backscattering in a plasma reported[1,2] 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[3].

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.

In this study, we simulate the amplification of a short laser pulse by a counter-propagating pump in a plasma with a one-dimensional version of XOOPIC[4], an object-oriented electromagnetic and relativistic particle-in-cell code.

Figure 1 shows schematically the interaction of two laser pulses in a plasma. Two linearly polarized plane waves are launched from opposite sides of the plasma having an electron plasma frequency ω_p. The pump pulse with frequency $\omega_0 = 10\,\omega_p$ and amplitude a_0=0.01 is launched from the right-hand side and the seed pulse with frequency $\omega_1 = \omega_0 - \omega_p$ and amplitude a_1=0.01 is launched from the left-hand side. Here, $a_{0,1} = eE_{0,1}/mc^2k_{0,1}$ are the normalized electric field intensity. The used simulation parameters are 1 μm of wavelength, 37.3 fs FWHM of the seed pulse duration, and 11.2×10^{18} cm^{-3} of uniform plasma density.

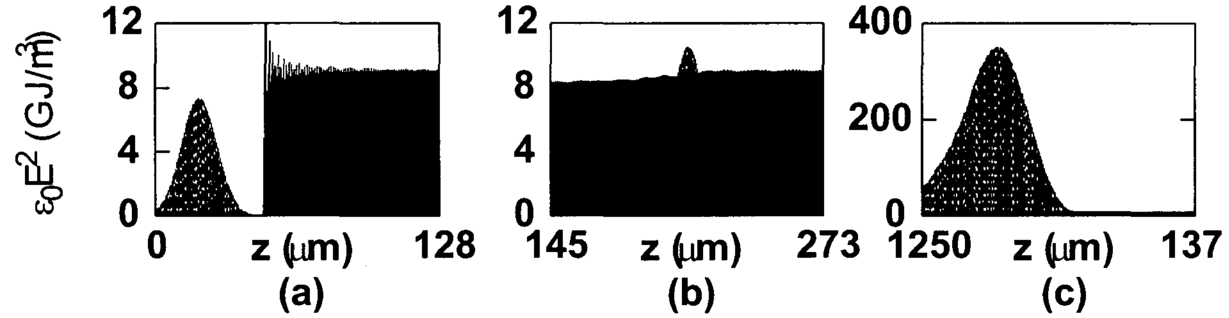

FIG. 1. Moving window diagram for the counter-propagating waves.

In Fig. 1(a), two waves start to interact in a plasma, and thus the seed pulse grows as shown in Fig. 1(b). At this time, the parameters satisfy the linear stage condition, $4\omega_1^2 a_0 a_1 < \omega_p^2$, where electron motion is determined by the space-charge electric field of the plasma wave rather than the ponderomotive force. At this stage, the seed pulse is broadened with a moving speed of c/2 at its peak. The linear growth rate is known as $a_0\sqrt{\omega_p\omega_0/2}$. After some amplification of the seed pulse, the parameters reach a nonlinear stage, $4\omega_1^2 a_0 a_1 \geq \omega_p^2$, where the ponderomotive force is more dominant than the space-charge electric field and the seed pulse undergoes substantial nonlinear contraction. As shown in Fig. 1(c), finally the seed pulse is amplified more than 50 times in its energy density after propagating 1.25 mm and the pump pulse is depleted almost 100%.

With the one-dimensional simulation, we investigate the amount of the seed pulse amplification and the efficiency of the energy transfer between two counter-propagating pulses over various parameter regimes. Moreover, with a two-dimensional simulation, it is also possible to exploit the effects of plasma channels and spatial pulse profiles on the laser pulse amplification by stimulated Raman backscattering. Finally, this study can give a guideline for an unprecedented experiment, too.

This work is supported by the Creative Research Initiatives of the Korean Ministry of Science and Technology.

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