New regimes of raman compression of laser pulses in plasma

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The bottleneck of the method of chirped pulse amplification, traditionally used for making powerful laser pulses, is its final stage when thermal damage can be done to diffraction gratings used for the compression of a laser pulse. In order to overcome this limitation, we suggest using the scheme of backward Raman amplification (BRA), where the compression of a laser pulse is based on the resonant energy transfer between two counter-propagating laser pulses interacting through the agency of a plasma wave.

This scheme, though, is prone to a variety of harmful effects such as plasma noise amplification, violation of the three-wave synchronism due to relativistic nonlinearity and/or plasma wave breaking, etc. Most of these effects can be mitigated by choosing the right parameters of laser pulses and plasma. This report is focused on finding such parameters.

The theoretical analysis was carried out within the framework of the hydrodynamic description of plasma and with taking into account the relativistic self-action of laser pulses. To describe laser pulses and plasma oscillations, a quasi-monochromatic approximation is used. The equations for the envelopes of two counter-propagating electromagnetic waves *a, b*, and the envelope of the plasma wave *f*, which may be near the breaking threshold, take the form of three-wave equations with additional terms:

∂*ta* + ∂*za* = –*bf* + i*Ka* – iα/2 ∂*zza*

∂*tb* – ∂*zb* = –*af\** + i*Kb* – iε|*b|*2*b* – iα/2 ∂*zzb*

∂*tf* = *ab\** + iκ*b* + iχ|*f|*2*f* – ν*f* ,

Here *t* and *z* are normalized to the inverse Raman gain increment 1/γ and *c*/γ (γ=1/*a*0β1/4ω), *a* and *b* are normalized to the pump amplitude *a*0; β=ωp2/ω2 is ratio of plasma density to the critical one; α=*a*0β5/4, ε=¾*a*0β3/4, χ = 8*a*0/β5/4 are dimensionless coefficients of plasma dispersion, relativistic and hydrodynamic nonlinearities, ν=νL/γ is dimensionless Landau damping coefficient; *K*=β/2γδn and κ=β½/γδn describe the influence of quasistatic plasma inhomogeneities.

An analytical and numerical study of these equations was carried out for various parameter values. It is shown that the main limiting factors are the excessively high chirp of the pump pulse and the excessively rare plasma in which the plasma wave-breaking can occur. The use of intense and short (about the plasma period) seed pulses allows to weaken the limitation on the maximum possible value of the pump chirp ρ (*a*~*a*0exp(iργ2*t*2)) but ρ > 1 still make Raman amplification hardly possible. On top of that, we suggest shifting the interaction origin to the edge of the plasma so that the density gradient will compensate the excessive frequency modulation of the pump.

At the same time, the pump chirp ρ ≈ 0.5, while weakly affecting the linear stage of the amplification of an intense short seed pulse, can compensate for the detuning of the three-wave synchronism due to the proximity to the plasma wave-breaking threshold up to the values χ ≤ 500. For a pump amplitude *a*0 ≈ 0.01 of the relativistic value it allows to effectively use in an experiment even fairly low plasma concentrations – down to the fractions of per cent of the critical one (β ≥ 0.002).