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Nonlinear Raman forward scattering of a short laser pulse in a collisional transversely magnetized plasma

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Nonlinear Raman forward scattering (NRFS) of an intense short laser pulse with a duration shorter than the plasma period through a homogenous collisional transversely magnetized plasma is investigated theoretically when ponderomotive, relativistic and collioninal nonlinearities are taken into account. The plasma is embedded in a uniform magnetic field perpendicular to both, the direction of propagation and electric vector of the radiation field. Nonlinear wave equation is set up and Fourier transformation method is used to solve the coupled equations describing NRFS instability. Finally, the growth rate of this instability is obtained. Thermal effects of plasma electrons and effect of the electron-ion collisions are examined. It is found that the growth rate of Raman forward scattering first decreases on increasing electron thermal velocity, minimizes at an optimum value, and then increases. Our results also show that the growth rate increases by increasing the electron-ion collisions. © *2013 American Institute of Physics*. [http://dx.doi.org/10.1063/1.4774390]

I. INTRODUCTION

Pulses with durations $c\tau_L > \lambda_p$ propagating in plasmas are subject to Raman scattering, where τ_L is the pulse duration and λ_p is the plasma wavelength.[1,2] Raman forward scattering (RFS) is an important nonlinear process in laser beat wave and laser wake field accelerators.[1] It decreases the laser-plasma coupling during confinement fusion experiments so the nonlinear saturation of the RFS at high pump wave power is also problems of considerable importance in the high-energy laser-plasma interactions. RFS plays a dominant role in the evolution of the pulse in distances less than a Rayleigh length.[3] It produces a plasma wave with large phase velocity (near the speed of light) that could accelerate charged particles to high energies. The accelerated relativistic electron in the forward direction appears to be correlated with the RFS and the intense electron heating is likely to play a major role in the temporal growth or inhibition of the instabilities.[4] Thus, RFS can be an interesting high-brightness source of moderately relativistic electrons. Acceleration to high energy is a result of the high phase velocity of the plasma wave at low plasma densities (close to c). Indeed, because the plasma wave must be in phase with modulations of the laser pulse energy for the wave to grow: The phase velocity of the plasma wave is equal to the group velocity of light in the plasma. For a plasma frequency ω_p much less than the laser frequency ω_0, the Lorenz factor of the plasma wave is given by $v_p \simeq \omega_0/\omega_p$. Hence, we can see that the maximum acceleration increases as the ratio ω_0/ω_p increases.[5,6] The plasmas employed in such experiments are of low density ($n \ll n_{cr}$, where n_{cr} is the critical density) and moderate temperature ($T_e < 100\,\text{eV}$).[7] In this process, a laser pump (ω_0) decays into a plasma wave and two sideband electromagnetic waves ($\omega_0 \pm \omega_p$) comoving with the pump, which then acts as a grating, scattering the pump and reenforcing the sidebands, where $\omega_p(=\sqrt{4\pi e^2 n_0/m})$ is the electron plasma frequency.[8–10] In RFS, scattered light wave copropagate and beat with the original (pump) light wave, thereby modulating the laser pulse. This modulation reinforces and amplifies the plasma oscillations, increasing the growth of scattered radiation. This is known as the Raman instability.[11] As a matter of fact, Raman scattering is an instability in which the beating of the incident laser-light wave (pump wave) with a scattered light wave derives a plasma wave and the beating of the plasma wave with the pump derives the scattered light wave.[12] The Raman forward instability has a growth rate that is smaller than that of the Raman backward instability, it is perhaps more disruptive since it can remain within the pulse for extended distances and grow to a large amplitude.[13] In the case of transversely magnetized plasma, Raman scattering process includes the decay of an electromagnetic pump wave into an upper hybrid wave and two scattered Stokes/anti-Stokes sidebands.[14] Forward propagating instabilities become dominant because the laser intensity is higher, ion dynamics can be neglected, and the noise sources are larger.[3]

Raman scattering in the interaction of laser pulses with plasma have been studied in detail by many authors both theoretically and experimentally. Turner *et al.*[15] have reported the first observation of up-shifted scattered light from RFS. Villeneuve and Baldis[16] have studied coupling between Raman forward scattering and Raman backward scattering experimentally in a preformed underdense parabolic shaped plasma irradiated with a CO_2 laser. Mori *et al.*[2] have analyzed the spatial-temporal growth of RFS. Antonsen and Mora[17] have studied numerically the leaky channel stabilization of Raman instability of an intense laser pulse in a tenuous plasma. Guerin *et al.*[18] have investigated Raman instability in an overdense plasma. They have shown analytically and numerically that Raman instability prevents any relativistic wave propagation in a cold and moderately dense plasma. Gupta *et al.*[19] have shown numerically that the

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