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STIMULATED RAMAN SCATTERING OF HIGH-POWER BEAM IN QUANTUM PLASMA: EFFECT OF RELATIVISTIC-PONDEROMOTIVE FORCE

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The present work explores stimulated Raman scattering of a high-power beam in quantum plasma due to the joint action of relativistic ponderomotive force (RP force). The RP force creates nonlinearity in the plasma's dielectric function. This results in a change in the density profile in a transverse direction to the axis of the pump beam. This change in density profile has a significant impact on all three waves involved in the process, viz., the input beam, the electron plasma beam, and the scattered wave. Second-order ODEs for all three waves, as well as the SRS back-reflectivity expression, are set up and further solved numerically. Impact of well-known laser-plasma parameters, quantum contribution, and combined action of RP force on beam waists of various waves, and also on SRS back-reflectivity are explored.
Keywords: *Relativistic-Ponderomotive forces; Back-reflectivity; Electron Plasma Wave; Dielectric function; Scattered Wave*
PACS: 52.38.Hb, 52.35.Mw, 52.38.Dx

1. INTRODUCTION

Among theoretical/experimental research groups, there has been interest in the interaction of ultra-intense lasers with plasmas, resulting from their applicability to laser-driven fusion [1-3] and the acceleration of charged species [4-9]. During laser-plasma interaction, distinct instabilities are produced, including scattering instabilities, filamentation, self-focusing, modulation instability, and trapping [3, 10-13]. There is a significant reduction in the coupling efficiency of lasers due to these nonlinear phenomena. These instabilities can lead to production of highly energetic electrons. These high-speed electrons preheat the fusion fuel and also cause great reduction in compression rate. Moreover, there is a modification in the irradiance distribution due to these nonlinear phenomena. The transition of lasers through plasmas is mainly controlled by Stimulated Raman Scattering (SRS) process. In fact, it helps in exploring the transmission of energy from lasers to plasmas [14-17]. SRS is a key research topic in laser-plasma interaction for theoretical/experimental researchers [18-22]. In SRS, the pump wave splits up into an electron plasma wave (EPW) and a scattered beam. EPW generates electrons travelling at extremely high speeds, which could, in fact, preheat the target core. A scattered beam helps in identifying the amount of wasted energy. So, Raman reflectivity is very crucial parameter for exploring percentage of useful/wasted energy during laser-plasma interaction. It has already been revealed from literature that mostly research on scattering instabilities is carried out through plane waves. If intensity associated with main beam is kept non-uniform, then self-focusing phenomenon becomes extremely dominant. Self-focusing greatly affects other nonlinear processes, including SRS, SBS, pair production, and harmonic generation [23-31]. So, the inclusion of the self-focusing phenomenon while exploring the SRS process becomes extremely important. Many research groups have explored inter-connection between self-focusing and SRS in the past [32-42]. Most of these studies were explored in classical plasmas. In case of classical plasmas, density is kept low and temperature is kept high. Whenever density is high and temperature is low, we obtain quantum plasmas [43-46]. Theoretical/experimental research groups are motivated to explore quantum plasmas due to their direct connection in diverse fields, including laser-driven fusion, quantum dots, and quantum optics [47-54]. In case of quantum plasmas, $\lambda_d \geq n_0^{-1/3}$ i.e. $n_0\lambda_d^3 \geq 1$. So, de-Broglie Wavelength is greater than or equal to average distance between electrons. For quantum plasmas, $T_f \geq T$. Where T_f and T are Fermi temperature and plasma temperature respectively. There has been keen curiosity of various researchers in exploring instabilities in quantum plasmas due to their relevance in light-matter interaction [55-57]. Also, notable attention has been received by laser-quantum plasmas interaction as a result of its direct involvement in exploring scattering instabilities, inertial fusion and X-ray lasers. Keeping in view these objectives, our aim in the present study is to explore Stimulated Raman Scattering of a laser in quantum plasma due to the joint action of RP force. The main beam (ω_0, k_0) interacts with EPW (ω, k) thereby producing a scattered wave $(\omega_0 - \omega,\ k_0 - k)$. Here, we have taken the back-scattering case for $k \approx 2k_0$. The carrier's redistribution takes place due to the joint action of the RP force, thereby causing self-focusing. The dispersion relation associated with EPW gets modified. Moreover, change in phase velocity of EPW is observed. The EPW also gets self-focused under suitable boundary conditions. Irradiance associated with scattered wave is directly proportional to irradiance related with main wave and EPW. So, self-focusing results in improvement in back-scattering.

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2. SOLUTION OF PUMP WAVE IN THERMAL QUANTUM PLASMA

Consider the transition of an intense laser beam having wave number k_0 and the angular frequency ω_0 along z-axis in TQP. We are considering the combined influence of RP force in the present investigation. Irradiance distribution for laser beam at $z = 0$ is expressed as

$$E_0 \cdot E_0^* = E_{00}^2 exp\left[-\frac{r^2}{r_0^2}\right] \tag{1}$$

In Eq. (1), E_{00} and r_0 represent maximum field amplitude and initial beam width at $z = 0$. Also, $r^2 = x^2 + y^2$. The TQP's dielectric function incorporating the Bohm potential, the Fermi pressure, and quantum involvement can be stated as [53-54].

$$\epsilon = 1 - \frac{\omega_p^2}{\gamma\omega_0^2}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\gamma}\right)^{-1} \tag{2}$$

In Eq. (2), $v_f = \sqrt{\frac{2K_B T_f}{m}}$ and $\gamma = (1 + \alpha E_0 E_0^*)^{1/2}$ denote Fermi speed and Lorentz factor respectively and $\delta q = \frac{4\pi^4 h^2}{m^2\omega_0^2\lambda^4}$. If $T_f -> 0$ is substituted, then cold quantum plasma's (CQP's) dielectric function is obtained. On the other hand, if $T_f -> 0$, $\frac{h}{2\pi} -> 0$, then classical relativistic plasma's (CRP's) dielectric function is obtained. Here, $\alpha = \frac{e^2}{m^2c^2\omega_0^2}$ and $\omega_p = \sqrt{\frac{4\pi n e^2}{m}}$ are known as nonlinear coefficient and plasma frequency respectively. The nonlinear ponderomotive force results in change in density of electrons. We can express this changed number density as [53-54]

$$n = n_0 exp\left(-\frac{mc^2}{T}(\gamma - 1)\right) \tag{3}$$

For TQP, one can express generalized dielectric function as

$$\varepsilon = \varepsilon_0 + \Phi\,(E_0 E_0^*) \tag{4}$$

In Eq. (4), $\varepsilon_0 = 1 - \frac{\omega_p^2}{\omega_0^2}$ & $\Phi\,(E_0 E_0^*) = \frac{\omega_p^2}{\omega_0^2}\left[1 - \frac{N_{0e}}{N_0}\right]$ are linear & nonlinear portions for ε respectively. Including the effect of nonlinear ponderomotive force, we can write nonlinear term $\Phi\,(E_0 E_0^*)$ for TQP as

$$\Phi(EE^*) = \frac{\omega_{p0}^2}{\omega_0^2}\left[1 - \frac{1}{\gamma}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\gamma}\right)^{-1} \exp\left(-\frac{mc^2}{T}(\gamma - 1)\right)\right] \tag{5}$$

Where, $\omega_{p0} = \sqrt{\frac{4\pi n_0 e^2}{m}}$.

The field E_i of the pump wave represents wave equation as;

$$\nabla^2 E_i + \frac{\omega_0^2}{c^2}\left[1 - \frac{\omega_p^2}{\omega_0^2}\frac{N_{0e}}{N_0}\right] E_i = 0 \tag{6}$$

One can write the solution for Eq. (6) following the approach [58-60] as

$$E_i = E_0 \exp[i(\omega_0 t - k_0(S_0 + z))] \tag{7}$$

$$E_0^2 = \frac{E_{00}^2}{f_0^2} exp\left[-\frac{r^2}{r_0^2 f_0^2}\right] \tag{8}$$

$$S_0 = \frac{1}{2} r^2 \frac{1}{f_0}\frac{df_0}{dz} + \Phi_0(z) \tag{9}$$

Here, f_0 is the pump wave's beam waist satisfying differential equation

$$\frac{d^2 f_0}{dz^2} = \frac{1}{k_0^2 r_0^4 f_0^3} - \frac{\omega_p^2}{\omega_0^2\varepsilon_0}\frac{\alpha E_{00}^2}{2r_0^2 f_0^3}\frac{exp\left(-\frac{mc^2}{T_e}\left[\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}} - 1\right]\right)}{\left(1+\frac{\alpha E_{00}^2}{f_0^2}\right)^{3/2}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)^2}\left[\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2}\right) + \frac{mc^2}{T_e}\sqrt{1 + \frac{\alpha E_{00}^2}{f_0^2}}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)\right] \tag{10}$$

Here, the boundary condition used is as follows, $f_0 = 0$ and $\frac{df_0}{dz} = 0$ at $z = 0$.

3. EXCITATION OF ELECTRON PLASMA WAVE

The nonlinear interaction between the pump wave and EPW leads to its excitation. For analyzing the excitation of EPW in TQP, the following standard equations are considered;

(a) Continuity Equation

$$\frac{\partial N}{\partial t} + \nabla \cdot (NV) = 0 \tag{11}$$

(b) Equation of motion

$$m\left[\frac{\partial V}{\partial t} + (V \cdot \nabla)V\right] = -e\left[E + \frac{1}{c}(V \times B)\right] - 2\Gamma m V - \frac{\gamma_e}{N}\nabla P \tag{12}$$

(c) Poisson's equation

$$\nabla \cdot E = -4\pi e N \tag{13}$$

In the above equations, the instantaneous electron density, fluid velocity, Landau damping parameter, and pressure term are expressed by N, V, Γ, and P respectively. For electron gas $\gamma_e = 3$. Further, by using perturbation analysis and the standard approach, we can obtain the following equation denoting the change in electron density as

$$\frac{\partial^2 n}{\partial t^2} + 2\Gamma\frac{\partial n}{\partial t} - 3v_{th}^2\nabla^2 n + \omega_p^2\frac{N_{0e}}{N_0}n = 0 \tag{14}$$

Following [58-60], the Solution of Eq. (14) can be expressed as

$$n = n_0(r,z)exp[i(\omega t - k(z + S(r,z)))] \tag{15}$$

Here, wave vector, angular frequency, and Eikonal for the EPW are denoted by k, ω and S respectively. Further, the dispersion relation for EPW is expressed as

$$\omega^2 = \omega_p^2\frac{N_{0e}}{N_0} + 3k^2v_{th}^2 \tag{16}$$

Further, on putting the Eq. (15) in Eq. (14) further separating real and imaginary terms, we have

$$2\frac{\partial S}{\partial z} + \left(\frac{\partial S}{\partial r}\right)^2 = \frac{1}{k^2 n_0}\nabla_\perp^2 n_0 + \frac{\omega_p^2}{3k^2v_{th}^2}\left[1 - \frac{N_{0e}}{N_0}\right] \tag{17}$$

$$\frac{\partial n_0^2}{\partial z} + \frac{\partial S}{\partial r}\frac{\partial n_0^2}{\partial r} + n_0^2\nabla_\perp^2 S + \frac{2\Gamma}{3v_{th}^2}\frac{\omega n_0^2}{k} = 0 \tag{18}$$

Following [58-60], the solution of Eq. (17) and (18) can be expressed as

$$n_0^2 = \frac{n_{00}^2}{f^2}\exp\left(-\frac{r^2}{a^2f^2} - 2k_i z\right) \tag{19}$$

$$S = \frac{1}{2}r^2\frac{1}{f}\frac{df}{dz} + \Phi(z) \tag{20}$$

Here, k_i denotes the damping factor and $'f'$ denotes the beam waist of EPW and 2nd order ODE satisfied by it is expressed as

$$\frac{d^2f}{dz^2} = \frac{1}{k^2a^4f^3} - \frac{\omega_p^2 f}{3k^2v_{th}^2}\frac{\alpha E_{00}^2}{2r_0^2f_0^4}\frac{exp\left(-\frac{mc^2}{T_e}\left[\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}-1\right]\right)}{\left(1+\frac{\alpha E_{00}^2}{f_0^2}\right)^{3/2}\left(1-\frac{k_0^2v_f^2}{\omega_0^2}-\frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)^2}\left[\left(1-\frac{k_0^2v_f^2}{\omega_0^2}\right)+\frac{mc^2}{T_e}\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}\left(1-\frac{k_0^2v_f^2}{\omega_0^2}-\frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)\right] \tag{21}$$

Here, the boundary condition used is $f = 0$ and $\frac{df}{dz} = 0$ at $z = 0$.

4. STIMULATED RAMAN SCATTERING

The total field vector E_T can be written as addition of fields of main wave E and scattered wave E_s. i.e.

$$E_T = E\exp(i\omega_0 t) + E_s\exp(i\omega_s t) \tag{22}$$

Now, the field vector E_T satisfies the following wave equation

$$\nabla^2 E_T - \nabla(\nabla \cdot E_T) = \frac{1}{c^2}\frac{\partial^2 E_T}{\partial t^2} + \frac{4\pi}{c^2}\frac{\partial J_T}{\partial t} \tag{23}$$

In above Eq., current density is written by J_T. Now, further considering scattered frequency terms, we have

$$\nabla^2 E_s + \frac{\omega_s^2}{c^2}\left[1 - \frac{\omega_p^2}{\omega_s^2}\frac{N_{0e}}{\gamma N_0}\right] E_s = \left[\frac{\omega_p^2 \omega_s n^*}{2c^2 \omega_0 N_0}\right] E_i - \nabla(\nabla \cdot E_i) \tag{24}$$

The result of Eq. (24) can be written as

$$E_s = E_{s0}(r,z)e^{+ik_{s0}z} + E_{s1}(r,z)e^{-ik_{s1}z} \tag{25}$$

Where $k_{S0}^2 = \frac{\omega_S^2}{c^2}\left[1 - \frac{\omega_p^2}{\omega_S^2}\right] = \frac{\omega_S^2}{c^2}\epsilon_{S0}$, with $\omega_S = \omega_0 - \omega$ and $k_{S1} = k_0 - k$.

By using Eq. (25) in Eq. (24), we get

$$-k_{S0}^2 E_{S0}^2 + 2ik_{S0}\frac{\partial E_{S0}}{\partial z} + \left(\frac{\partial^2 E_{S0}}{\partial r^2} + \frac{1}{r}\frac{\partial E_{S0}}{\partial r}\right) + \frac{\omega_S^2}{c^2}\left[\epsilon_{S0} + \frac{\omega_p^2}{\omega_S^2}\left(1 - \frac{N_{0e}}{N_0}\right)\right] E_{S0} = 0 \tag{26}$$

$$-k_{S1}^2 E_{S1}^2 + 2ik_{S1}\frac{\partial E_{S1}}{\partial z} + \left(\frac{\partial^2 E_{S1}}{\partial r^2} + \frac{1}{r}\frac{\partial E_{S1}}{\partial r}\right) + \frac{\omega_S^2}{c^2}\left[\epsilon_{S0} + \frac{\omega_p^2}{\omega_S^2}\left(1 - \frac{N_{0e}}{N_0}\right)\right] E_{S1} = \frac{1}{2}\frac{\omega_p^2}{c^2}\frac{n^*}{N_0}\frac{\omega_S}{\omega_0} E_0 exp(-ik_0 S_0) \tag{27}$$

Now, solution of Eq. (27) is expressed as

$$E_{S1} = E'_{S1}(r,z)e^{-ik_0 S_0} \tag{28}$$

Now, putting Eq. (28) in Eq. (27) and further ignoring space derivatives

$$E'_{S1} = -\frac{1}{2}\frac{\omega_p^2}{c^2}\frac{n^*}{N_0}\frac{\omega_S}{\omega_0}\frac{\hat{E}E_0}{\left[k_{S1}^2 - k_{S0}^2 - \frac{\omega_p^2}{c^2}\left(1 - \frac{N_{0e}}{N_0}\right)\right]} \tag{29}$$

Now, solution of Eq. (26) can be written as

$$E_{S0} = E_{S00}e^{ik_{S0}S_c} \tag{30}$$

Now, use Eq. (30) in Eq. (26) and combining the real part and imaginary part separately, we have

$$2\frac{\partial S_c}{\partial z} + \left(\frac{\partial S_c}{\partial r}\right)^2 = \frac{1}{k_{S0}^2 E_{S00}}\left(\frac{\partial^2 E_{S00}}{\partial r^2} + \frac{1}{r}\frac{\partial E_{S00}}{\partial r}\right) + \frac{\omega_p^2}{\epsilon_{S0}\omega_S^2}\left[1 - \frac{N_{0e}}{N_0}\right] \tag{31}$$

$$\frac{\partial E_{S00}^2}{\partial z} + \frac{\partial S_c}{\partial r}\frac{\partial E_{S00}^2}{\partial r} + E_{S00}^2\left(\frac{\partial^2 S_c}{\partial r^2} + \frac{1}{r}\frac{\partial S_c}{\partial r}\right) = 0 \tag{32}$$

Now, following approach of [58-60], Eqs. (31) and (32) have solutions,

$$E_{S00}^2 = \frac{B_1^2}{f_S^2} exp\left[-\frac{r^2}{b^2 f_S^2}\right] \tag{33}$$

$$S_c = \frac{1}{2}r^2 \frac{1}{f_S}\frac{df_S}{dz} + \Phi_S(z) \tag{34}$$

In Eqs. (33) and (34), the initial beam radius for the scattered wave is denoted by b and beam width of the scattered wave is represented by f_s and it satisfies the following 2nd ODE as

$$\frac{d^2 f_S}{dz^2} = \frac{1}{k_{S0}^2 b^4 f_S^3} - \frac{\omega_p^2}{\omega_S^2 \varepsilon_{S0}}\frac{\alpha E_{00}^2 f_S}{2r_0^2 f_0^4}\frac{exp\left(-\frac{mc^2}{T_e}\left[\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}} - 1\right]\right)}{\left(1+\frac{\alpha E_{00}^2}{f_0^2}\right)^{3/2}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)^2}\left[\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2}\right) + \frac{mc^2}{T_e}\sqrt{1 + \frac{\alpha E_{00}^2}{f_0^2}}\left(1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\sqrt{1+\frac{\alpha E_{00}^2}{f_0^2}}}\right)\right] \tag{35}$$

The boundary condition used in the present case is $f_s = 0$ and $\frac{df_s}{dz} = 0$ at $z = 0$.

5. BACK-REFLECTIVITY

From Eq. (19), we find that EPW is damped while travelling along the z-axis. So, with a decrease in z, the amplitude of the scattered wave decreases. The boundary condition used is

$$E_s = E_{s0}(r,z)e^{+ik_{s0}z} + E_{s1}(r,z)e^{-ik_{s1}z} = 0 \tag{36}$$

at $z = z_c$. At $z = z_c$, the amplitude for the scattered beam vanishes,

$$B_1 = \frac{\omega_p^2 \omega_s N_{00}}{2c^2 \omega_0 N_0} \frac{E_{00} e^{-ik_i z_c}}{\left[k_{s1}^2 - k_{s0}^2 - \frac{\omega_p^2}{c^2}\left(1 - \frac{N_{0e}}{N_0}\right)\right]} \frac{f_s(z_c)}{f_s(z_c) f(z_c)} \frac{\exp\left(-i(k_0 S_0 + k_{s1} z_c)\right)}{\exp\left(+i(k_{s0} S_c + k_{s0} z_c)\right)} \tag{38}$$

With condition, $\frac{1}{b^2 f_s^2} = \frac{1}{a^2 f^2} + \frac{1}{r_0^2 f_0^2}$.
Now, SRS back-reflectivity may be derived as,

$$R = \frac{1}{4}\left(\frac{\omega_p^2}{c^2}\right)^2 \left(\frac{\omega_s}{\omega_0}\right)^2 \left(\frac{N_{00}}{N_0}\right)^2 \frac{(L_1 - L_2 - L_3)}{\left[k_{s1}^2 - k_{s2}^2 - \frac{\omega_p^2}{c^2}\left(1 - \frac{1}{\sqrt{1 + \frac{\alpha E_{00}^2}{f_0^2}}}\left[1 - \frac{k_0^2 v_f^2}{\omega_0^2} - \frac{\delta q}{\sqrt{1 + \frac{\alpha E_{00}^2}{f_0^2}}}\right]^{-1} exp\left[-\frac{m_0 c^2}{Te}\left(\sqrt{1 + \frac{\alpha E_{00}^2}{f_0^2}} - 1\right)\right]\right)\right]^2} \tag{39}$$

Where

$$L_1 = \left(\frac{f_s}{f_0 f}\right)^2_{z=z_c} \frac{1}{f_s^2} exp\left(-2k_i z_c - \frac{r^2}{b^2 f_s^2}\right),$$

$$L_2 = -2\left(\frac{f_s}{f_0 f}\right)_{z_c} \frac{1}{f f_0 f_s} exp\left(-\frac{r^2}{2b^2 f_s^2} - \frac{r^2}{2a^2 f^2} - \frac{r^2}{2r_0^2 f_s^2}\right) exp(-k_i(z + z_c)) Cos(k_{s0} + k_{s1})[z - z_c],$$

$$L_3 = \frac{1}{f^2 f_0^2} exp\left(-\frac{r^2}{a^2 f^2} - \frac{r^2}{r_0^2 f_s^2} - 2k_i z_c\right)$$

6. DISCUSSION

Since the analytical results of Eqs. (10), (21), (35), and (39) are not feasible. So, the well-known RK4 method is used for doing numerical calculations of these equations for known laser-plasma parameters;

$$\alpha E_{00}^2 = 2.0, 3.0, 4.0\ ; \frac{\omega_p^2}{\omega_0^2} = 0.15, 0.20, 0.25\ ; T_f = 10^7 K, 10^8 K, 10^9 K$$

Eqs. (10), (21) and (35) contain two terms on RHS with some physical interpretation for each term. The first term on RHS of each equation is the diffractive term, while 2nd one is the focusing term. During the transition of these beams inside, there is a relative competition between these two terms. The dominance of the first term results in the defocusing of beams, whereas the dominance of the second term results in the focusing of beams. When these terms are exactly equal to each other, then the beam neither focuses nor defocuses. Then, a self-trapping case is found.

The alteration of beam waists f_0, f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct beam intensity αE_{00}^2 is shown in Figures 1(a), 1(b) and 1(c) respectively. Here, only the variation of beam intensity is taken, whereas other parameters are kept fixed. Black, green and red curves are for $\alpha E_{00}^2 = 2.0, 3.0$ and 4.0 respectively. The focusing behavior of all the beams involved is found to get decreased with increase in beam intensity. This is as a result of dominance of diffractive terms over focusing terms with increase in beam intensity.

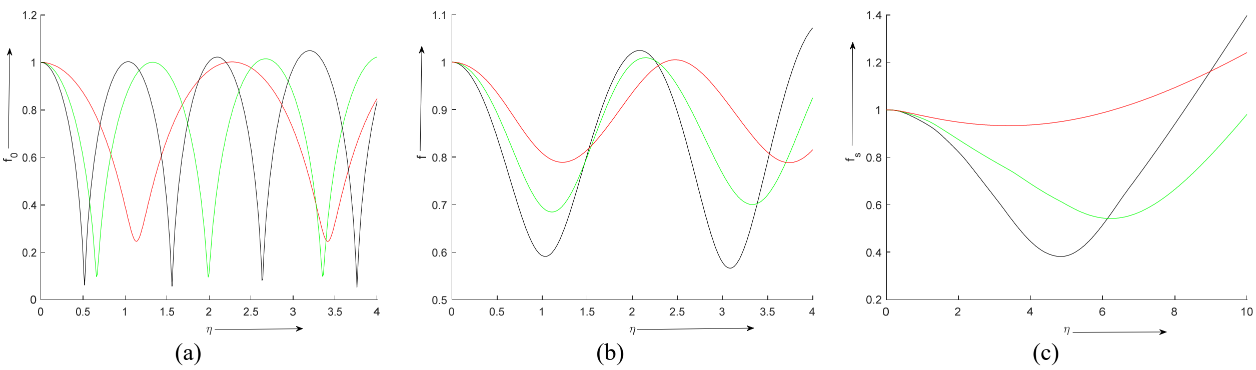
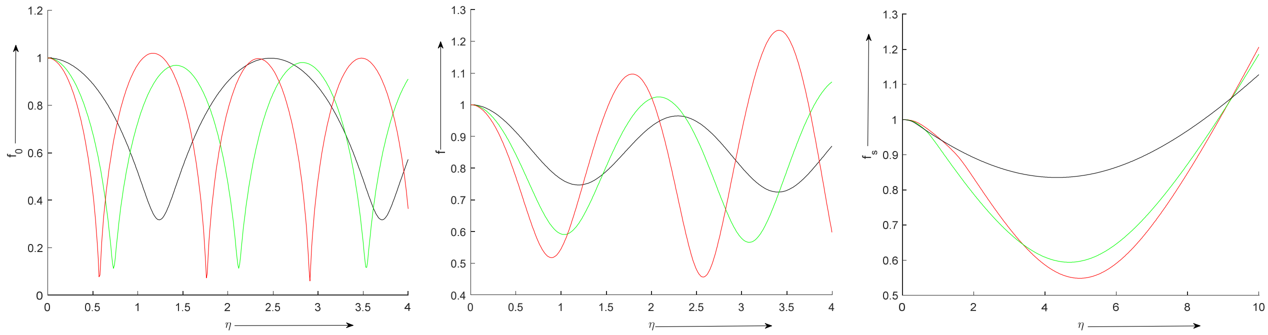


Figure 1. The alteration of beam waists f_0, f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct beam intensity αE_{00}^2 is shown in figures 1(a), 1(b) and 1(c) respectively. Black, green and red curves are for $\alpha E_{00}^2 = 2.0, 3.0$ and 4.0 respectively

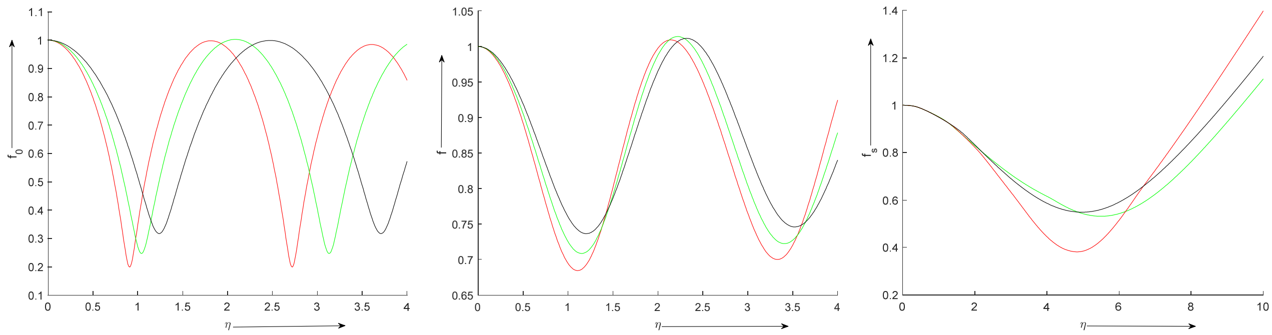
The alteration of beam waists f_0 , f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at a distinct plasma density $\frac{\omega_p^2}{\omega_0^2}$ is shown in Figures 2(a), 2(b) and 2(c) respectively. Here, only the variation of plasma density is taken, whereas other parameters are kept fixed. Black, green, and red curves are for $\frac{\omega_p^2}{\omega_0^2} = 0.15, 0.20$ and 0.25 respectively. The focusing behavior of all the beams is found to get increased with escalation in plasma density. This is due to the dominance of focusing terms over diffractive terms with increase in plasma density.

The alteration of beam waists f_0 , f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at a distinct Fermi temperature T_f values is shown in Figures 3(a), 3(b) and 3(c) respectively. Here, only the variation of the Fermi temperature is taken, whereas other parameters are kept fixed. Black, green and red curves are for $T_f = 10^7 K, 10^8 K$ and $10^9 K$ respectively. Focusing behavior of all the beams is found to get increased with the rise in Fermi temperature. This is due to supremacy of focusing terms over diffractive terms with increase in Fermi temperature.



(a) (b) (c)

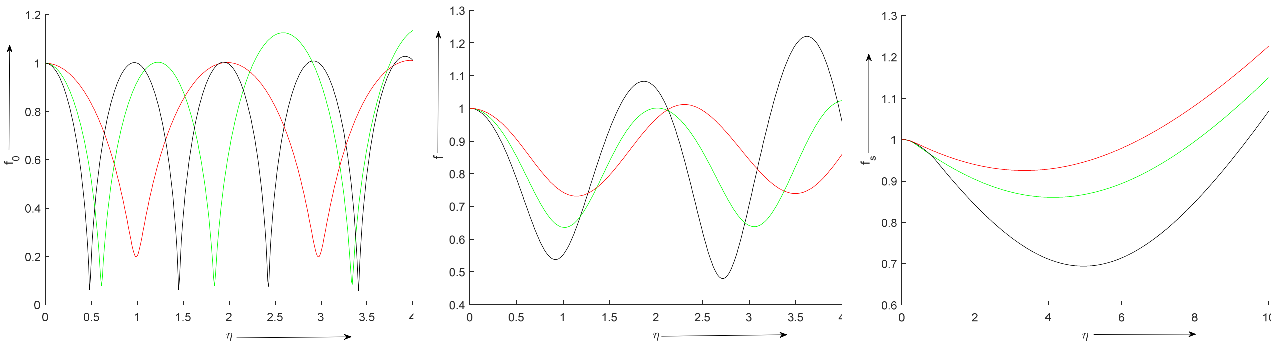
Figure 2. The alteration of beam waists f_0, f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct plasma density $\frac{\omega_p^2}{\omega_0^2}$ is shown in figures 2(a), 2(b) and 2(c) respectively. Black, green and red curves are for $\frac{\omega_p^2}{\omega_0^2} = 0.15, 0.20$ and 0.25 respectively



(a) (b) (c)

Figure 3. The alteration of beam waists f_0 , f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct Fermi temperature T_f values is shown in figures 3(a), 3(b) and 3(c) respectively. Black, green and red curves are for $T_f = 10^7 K, 10^8 K$ and $10^9 K$ respectively

The alteration of beam waists f_0, f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct plasma regimes are given in Figures 4(a), 4(b) and 4(c) respectively. Black, green and red curves are for RPTQP, RPCQP, and RPCRP respectively. From the figures, we find that focusing tendency of all waves involved is maximum in RPTQP system as compared to RPCQP and RPCRP systems respectively. Moreover, focusing tendency of all the waves is found to be more in RQCQP case in comparison to RPCRP case.



(a) (b) (c)

Figure 4. The alteration of beam waists f_0, f and f_s with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct plasma regimes are given in figures 4(a), 4(b) and 4(c) respectively. Black, green and red curves are for RPTQP, RPCQP, and RPCRP respectively

The alteration of SRS back-reflectivity R with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct beam intensity αE_{00}^2 is shown in Figure 5(a). Red and black curves are for $\alpha E_{00}^2 = 2.0$ and 4.0 respectively. Increase in laser intensity results in decrease in SRS reflectivity on account of decrease in self-focusing of various waves at increasing beam intensity.

The alteration of SRS back-reflectivity R with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct plasma density $\frac{\omega_p^2}{\omega_0^2}$ is shown in Figure 5(b). Red and black curves are for $\frac{\omega_p^2}{\omega_0^2} = 0.15$ and 0.25 respectively. Increase in plasma density results in increase in SRS reflectivity which is due to enhancement in self-focusing of various waves at increasing plasma density.

The alteration of SRS back-reflectivity R with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct Fermi temperature T_f is shown in Figure 5(c). Red and black curves are for $T_f = 10^7 K$ and $10^9 K$ respectively. Increase in plasma Fermi temperature results in increase in SRS reflectivity due to increase in self-focusing of various waves at increasing Fermi temperature.

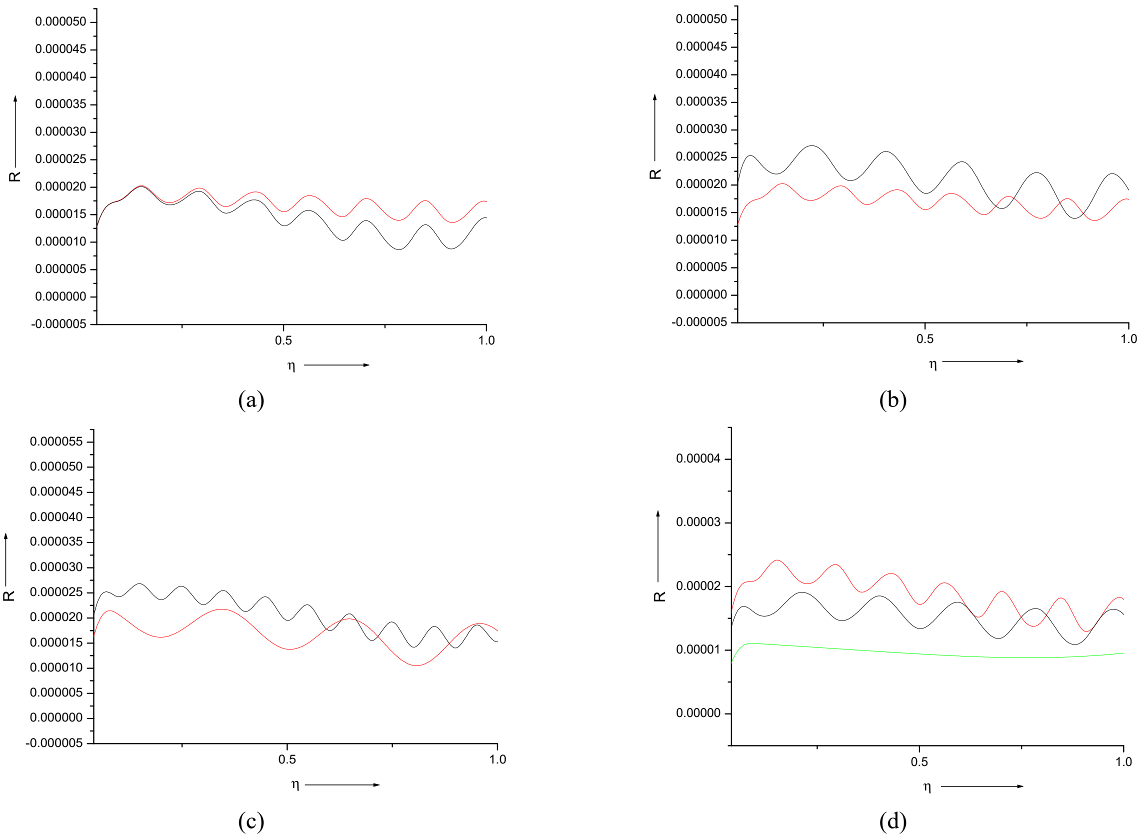


Figure 5. The alteration of SRS back-reflectivity R with $\eta(= z/k_0 r_0^2)$ at (a) distinct beam intensity αE_{00}^2. Red and black curves are for $\alpha E_{00}^2 = 2.0$ and 4.0 respectively, (b) distinct plasma density $\frac{\omega_p^2}{\omega_0^2}$. Red and black curves are for $\frac{\omega_p^2}{\omega_0^2} = 0.15$ and 0.25 respectively, (c) distinct Fermi temperature T_f. Red and black curves are for $T_f = 10^7 K$ and $10^9 K$ respectively, (d) distinct plasma regimes. Red, black and green curves are for RPTQP, RPCQP, and RPCRP respectively

The alteration of SRS back-reflectivity R with normalized distance $\eta(= z/k_0 r_0^2)$ at distinct plasma regimes is shown in Figure 5(d). Red, black and green curves are for RPTQP, RPCQP, and RPCRP respectively. From the figure it is clear that SRS back-reflectivity is maximum in RPTQP followed by RPCQP and RPCRP. This behavior is exactly in accordance with self-focusing of distinct waves as observed in figures 4(a), 4(b) and 4(c) respectively.

7. CONCLUSIONS

The present research deals with the SRS of the laser beam in TQP due to the joint action of RP forces. The results obtained from the present problem are as follows:

(1) Focusing tendency of distinct waves involved is increased with a rise in plasma density, Fermi temperature, and with a decrease in beam intensity.

(2) Inclusion of quantum effects results in an enhancement in the focusing tendency of various waves involved.

(3) There is a rise in SRS back-reflectivity with an increment in density of plasma, Fermi temperature, and with a decrease in beam intensity.

(4) There is an enhancement in SRS back-reflectivity with the inclusion of quantum effects.

These results are really useful in laser-driven fusion.

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СТИМУЛЬОВАНЕ КОМБІНАЦІЙНЕ РОЗСІЯННЯ ПОТУЖНОГО ПРОМЕНЯ В КВАНТОВІЙ ПЛАЗМІ: ВПЛИВ РЕЛЯТИВІСТСЬКО-ПОНДЕРОМОТОРНОЇ СИЛИ

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У цій роботі досліджується вимушене комбінаційне розсіювання потужного променя в квантовій плазмі внаслідок спільної дії релятивістської пондеромоторної сили (RP force). RP сила створює нелінійність у діелектричній функції плазми. Це призводить до зміни профілю густини в поперечному напрямку до осі променя накачування. Ця зміна профілю густини має суттєвий вплив на всі три хвилі, що беруть участь у процесі, а саме: вхідний промінь, промінь електронної плазми та розсіяну хвилю. Встановлено та додатково чисельно розв'язано ODE другого порядку для всіх трьох хвиль, а також вираз для зворотного відбиття SRS. Досліджено вплив відомих параметрів лазерної плазми, квантового внеску та комбінованої дії пондемоторної сили на перетяжки пучка різних хвиль, а також на зворотне відбиття SRS.

Ключові слова: *релятивістсько-пондеромоторні сили; зворотне відбиття; електронно-плазмова хвиля; діелектрична функція; розсіяна хвиля*