Chapter V

STIMULATED RAMAN SCATTERING (SRS) IN A TWO-ELECTRON TEMPERATURE PLASMA

5.1 Introduction

The stimulated Raman scattering has received considerable attention during the last few years. Forslund et al. 1973 have analysed the nonlinear development of the Brillouin and Raman backscatter instabilities in inhomogeneous plasmas using the nonlinear fluid dynamics. The expressions for the growth rate and threshold power required for stimulated Raman scattering in an infinite homogeneous isotropic plasma have been derived by Drake et al. 1974. An absolute Raman scattering instability was analysed by White et al. 1974 in inhomogeneous plasma wherein the amplitudes of the decay waves are limited by the fact that they have convected out of the region of instability. Cairns 1975 has examined the stimulated Raman scattering in an inhomogeneous plasma and demonstrated that there may be an exponentially growing decay which owes its existence to reflection of the electromagnetic decay wave.
Maraghechi and Willet 1979 have investigated the stimulated Raman backscattering of an intense electromagnetic wave propagating in the extraordinary mode along a uniform static magnetic field. The dispersion relation for a homogeneous magnetized plasma in the presence of the circularly polarized pump wave is developed in the cold-plasma approximation with the pump frequency above the plasma frequency. The effects of the static magnetic field parallel to the direction of propagation on the threshold and the growth rate are studied numerically. Stimulated Raman scattering in laser target plasma can have potentially serious consequence as far as the efficient coupling of radiation to laser produced plasmas is concerned (Estabrook et al. 1980) wherein the instability — a three-wave parametric process in which the incident laser decays into an electron plasma wave and a scattered light-wave — generates very high energy electrons which can preheat the interior of the fusion targets. Furthermore, for reactor size targets a sizeable fraction of the incident laser light may be scattered out of the plasma by this process. Raman instabilities which appear in laser-produced plasmas when the plasma density is less than the quarter critical density, can lead to hot-electron production. These hot electrons could in turn preheat the
fuel in laser fusion applications and are therefore of significant concern. Of the various Raman instabilities in inhomogeneous plasmas, sidescattering has the lowest threshold and the highest growth rate. Hence, it is a natural focus of theoretical concern.

Ramkin and Boyd 1985 have presented a theory of stimulated Raman sidescattering in magnetised plasmas based on the solution of the Vlasov - Maxwell equations where the incident laser light in the form of extraordinary mode radiation decays into light waves which propagate along the uniform magnetic field as right or left circularly polarized waves. They have discussed the possible relevance of the theory to experiments in which the structure is obtained in radiation at one-half of the laser frequency. The theory of the Raman sidescattering instability in an inhomogeneous plasma is analysed by Menyuk et al. 1985. The growth rate is found from the eigenvalue of a second-order ordinary differential equation in the Fourier domain. The normalized growth rate depends on a single parameter involving laser strength, gradient scale length and resonant density.

In this Chapter, we have analysed the stimulated
Raman scattering of an electromagnetic wave in a two-electron temperature plasma. Such type of electron distributions are rather frequently encountered for example in hot turbulent plasmas. Also strong electron beam plasma interactions can result in such electron distributions and very often simple hot-cathode discharge plasmas also have double-electron-temperature distributions (Jones et al. 1974). In Section 5.2 we have derived the dispersion relation of an electron-plasma wave in a two-electron-temperature plasma using the momentum-transfer equation and the continuity equation. The dispersion relation has been solved to obtain the ratio of the growth rates $\gamma_1$ (in the presence of hot and cold electrons) and $\gamma_2$ (in the absence of hot electrons) of the excited modes. In Section 5.3 we have presented discussion of our result and we have found that the increase of hot electrons can control the growth rate of the excited electron-plasma mode and the growth of the stimulated Raman scattering.

5.2 Dispersion Relation of an Electron-Plasma Wave

We use the usual basic equations:

$$\frac{\delta \vec{v}_c}{\delta t} = \frac{-e}{m} \vec{E} - \left[ \frac{e}{m c^2} (\vec{v}_c \times \vec{B}) + (\vec{v}_c \cdot \vec{V}) \vec{v}_c \right] - \frac{\nu_c^2}{n_{oc}} \frac{Vn_c}{n_{oc}},$$  \hspace{1cm} (5.1)
\[
\frac{\partial \mathbf{v}_h}{\partial t} = \frac{-e}{m} \mathbf{E} - \left[ \frac{e}{mc} (\mathbf{v}_h \times \mathbf{B}) + (\mathbf{v}_h \cdot \mathbf{V}) \mathbf{v}_h \right] - \frac{\mathbf{v}_{th}}{n_{oh}}, \quad (5.2)
\]

\[
\frac{\partial n_c}{\partial t} + \mathbf{v} \cdot (n_c \mathbf{v}_c) = 0, \quad (5.3)
\]

\[
\frac{\partial n_h}{\partial t} + \mathbf{v} \cdot (n_h \mathbf{v}_h) = 0, \quad (5.4)
\]

\[
\mathbf{v} \cdot \mathbf{E} = -4\pi e (n_h + n_c) \quad (5.5)
\]

and

\[
\frac{\partial \mathbf{v}_o}{\partial t} = \frac{-e \mathbf{E}_o}{m} \quad (5.6)
\]

where the suffixes 't', 'h' and 'c' denote the thermal term, the high-and low-temperature electronic terms respectively. The quantity in the square bracket in equations (5.1) and (5.2) is the ponderomotive force on electrons (Sodha et al. 1974). \( \mathbf{v}, \mathbf{E}, \mathbf{B} \) and \( n \) are the velocity, the electric field, the magnetic field and the number density respectively. \( n_o, \mathbf{v}_o \) and \( \mathbf{E}_o \) are the zeroth order number density, velocity of the particle and electric field respectively. \( e, c' \) and \( m \) are the charge, the speed of light and the mass of the electron respectively.
Equations (5.1) and (5.2) can be rewritten in the term of ponderomotive force as

\[ \frac{\partial \tilde{v}_c}{\partial t} = \frac{1}{m} \left( e \tilde{E} + \tilde{F}_p \right) - v_{tc}^2 \frac{Vn_c}{n_{oc}} \] (5.7)

and

\[ \frac{\partial \tilde{v}_h}{\partial t} = \frac{1}{m} \left( e \tilde{E} + \tilde{F}_p \right) - v_{th}^2 \frac{Vn_h}{n_{oh}} \] (5.8)

where \( \tilde{F}_p \) is the ponderomotive force (it is the same for the high-temperature and low-temperature electrons) and it can be expressed as

\[ \tilde{F}_p = \left[ \frac{e}{c} \left( \tilde{v}_c(h) \times B_0 \right) + m \left( \tilde{v}_c(h) \cdot \nabla \right) \tilde{v}_c(h) \right] \]

and also the electric field \( \tilde{E} \) can be written as \( -\nabla \phi \).

Now, we consider the dependence of all quantities as \( \exp \left[ i (kx - \omega t) \right] \) and with the help of equations (5.3) and (5.7), one gets

\[ n_c = - \left[ \frac{ek^2 \left( \frac{\phi}{k} + \frac{\partial \phi}{\partial x} \right)}{m(\omega^2 - k^2 v_{tc}^2)} \right] n_{oc} \] (5.9)
where \( \phi_p \) is the ponderomotive potential which is related as \( F_p = -e\phi_p \) and by combining the equations (5.4) and (5.8), we get

\[
n_h = -\left[ \frac{ek^2(\phi + \phi_p)}{m(\omega^2 - k^2v_{th}^2)} \right] n_{oh} . \tag{5.10}
\]

Equations (5.5), (5.9) and (5.10) give the value of \( n \) as

\[
n = n_c + n_h = -\frac{k^2(\chi_1 + \chi_2)\phi_p}{4\pi e e} , \tag{5.11}
\]

where

\[
\epsilon = 1 - \chi_1 - \chi_2 , \tag{5.12a}
\]

\[
\chi_1 = \frac{\omega_{pc}^2}{(\omega^2 - k^2v_{tc}^2)} . \tag{5.12b}
\]

and

\[
\chi_2 = \frac{\omega_{ph}^2}{(\omega^2 - k^2v_{th}^2)} . \tag{5.12c}
\]

\( \omega_{pc}(\hbar) \) is the plasma frequency which is expressed as

\[
\omega_{pc}^2 = \frac{4\pi e^2 n_{pc}}{m} . \tag{5.12d}
\]
and
\[ \omega_{ph}^2 = \frac{4 \pi e^2 n_{oh}}{m}. \]  

(5.12e)

The nonlinear current density \( \vec{J}_1 \) can be expressed as
\[ \vec{J}_1 = -n_0 e \vec{v}_1 - ne \vec{v}_0 \]  

(5.13)

where \( \vec{v}_1 \) is the velocity of the particle due to the scattered wave. \( \omega_1 \) is the frequency of the scattered wave. Considering the \( x \)-component of equation (5.13) and substituting the values of \( \vec{v}_1 \) and \( n \) (from equation (5.11)), we get

\[ J_{1x} = \frac{ie^2 n_0 E_{1x}}{m \omega_1} - \frac{ie^2 k^2 E_{0x} E_{1x} (X_1 + X_2)}{16 \pi \omega_1 \omega_0 m^2 (1-X_1 - X_2)}. \]  

(5.14)

The wave equation of the scattered wave can be written as
\[ \left( k_1^2 - \frac{\omega_1^2}{c^2} \right) E_1 = - \left( \frac{4 \pi}{c^2} \right) \frac{\delta \vec{J}_1}{\delta t}. \]  

(5.15)

Now, in the \( x \)-component of the wave equation of the
scattered wave, we substitute the value of $J_{1x}$ from equation (5.14) and then one gets

$$(k_1^2 c^2 - \omega_1^2 - \omega_p^2) = \frac{e^2 k^2 E_{ox}^2 (\chi_1 + \chi_2)}{4 m^2 \omega_0^2 \zeta}.$$  \hspace{1cm} (5.16)

This is the dispersion relation of an electron-plasma wave in a two-electron-temperature plasma.

5.3 Growth Rate and Discussions

In the presence of two different kinds of electrons (hot and cold), the growth rate is $\gamma_1$. And in the absence of hot electrons it is given by $\gamma_2$. Following Sharma et al. 1979, we get from the equations (5.16), (5.12b) and (5.12c) as

$$\gamma_1^2 = \frac{e^2 k^2 E_{ox}^2 \omega_r}{16 m^2 \omega_0^3} (1 - \frac{\omega_{ph}^2}{\omega_p^2} \frac{\omega_r^2}{k^2 v_{th}^2}) \hspace{1cm} (5.17)$$

and from the equations (5.16) and (5.12b) as

$$\gamma_2^2 = \frac{e^2 k^2 E_{ox}^2 \omega_r}{16 m^2 \omega_0^3}$$  \hspace{1cm} (5.18)
where $\omega_r$ is the real frequency of the excited mode. We have used the approximation $v_{tc} < \omega \frac{k}{k} v_{th}$. Therefore

$$\frac{\gamma_1}{\gamma_2} = \left[ 1 - \left( \frac{n_{oh}}{n_{oc}} \right) \left( \frac{\omega_r^2}{k^2 v_{th}^2} \right) \right]^{1/2}. \quad (5.19)$$

It is evident from the equation (5.19) that the presence of hot electron-component in the plasma reduces the growth rate of the excited mode. Thus, the growth rate of the stimulated Raman scattering can be controlled by injecting hot electrons. Similar type of result has been obtained by Estabrook and Krue 1983 who have pointed out that the self-generated magnetic field can significantly reduce the level of Raman scattering in the nonlinear regime by inhibiting the transport of the hot electrons produced by the instability. This enhances the damping of the unstable plasma waves by locally increasing the hot-electron density and the enhanced damping reduces the level of the scattering and absorption. Goswami et al., 1977 have found that in a two temperature electron-plasma, the presence of a small amount of relatively cold electrons reduces the growth rate of the ion-acoustic drift-dissipative mode in an inhomogeneous plasma. Jones et al., 1975 have also investigated the propagation of ion-acoustic
waves in a two-temperature electron plasma both experimentally and theoretically and have found that the presence of even a small fraction of the low-temperature electrons can reduce the growth rate of the ion-acoustic wave. We find that the high temperature-electrons are controlling the growth of the excited electron plasma mode.
References


