Degenerate Resonant Four Wave Mixing of Laser Radiation in a Plasma

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Although four wave mixing has been demonstrated in solids, liquids and gases using both resonant as well as non-resonant media, no conclusive demonstration of this phenomenon in plasmas has been reported. In plasmas there are two mechanisms that can excite standing density gratings necessary for degenerate four wave mixing (DFWM): the ponderomotive force resulting from the beating of each of the two pump waves with the probe wave and the thermal force resulting from localized collisional heating. In addition, there are two strong resonances in an unmagnetized plasma: the ion acoustic resonance and the Bohm-Gross resonance occurring close to the electron plasma frequency. Four wave mixing at these resonances is expected to yield higher probe beam reflectivities compared to the DFWM alone. The third order susceptibility $\chi_3$ responsible for DFWM in a plasma is given by

$$\chi_3 = \frac{n_0/n_e^2}{8(4\pi)^2(T_e + T_i)} \left[ 1 + \sum \frac{n_0 \nu_e}{k_g^2 \kappa_e} \right].$$

The first term is the contribution to $\chi_3$ due to ponderomotive force whereas the second term is the additional contribution to $\chi_3$ due to collisional heating. Here $\nu_e$ is the electron-ion collision frequency, $\kappa_e$ is the electron thermal conductivity and $k_g$ is the wavenumber of the plasma grating. When the electron mean free path becomes small compared to the grating wavelength, the thermal contribution to $\chi_3$ can be significant. We will report experimental observation of such a collisionally dominated DFWM in a plasma using CO$_2$ laser light.

When the pump and the probe beat in the plasma at the ion acoustic frequency, the grating density fluctuations are enhanced by a factor $\frac{\text{Re} \omega}{\text{Im} \omega}$ compared to the DFWM case. Since this ratio is a function of the electron to ion temperature ratio, whereas the ion acoustic frequency is a function of $(ZT_e + 3T_i/M)^{1/2}$, we can obtain ion and electron temperatures. We have also observed this signal enhancement by beating the pump and the probe waves at the ion acoustic resonance in the plasma.

Finally, we shall present evidence of FWM at the electron plasma frequency resonance. A series of Stokes and anti-Stokes sidebands to the pump frequency are observed each separated by the electron plasma frequency.

Applications of DFWM and resonant four wave mixing in a plasma will be mentioned.