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Angular dependence of $3\omega_0/2$ spectra from laser-produced plasmas*

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Abstract

Scattered light at three-halves of the incident laser frequency from solid targets is observed at five different angles. When the incident laser intensity is low enough, rescattering of two plasmon decay (TPD) instability electron plasma waves by ion acoustic waves is not significant. In this regime, Thomson scattering measurements of the electron temperature and the plasma flow velocity allow quantitative comparison of the angular dependence of the spectrum to theory.

1. Introduction

When an intense laser pulse interacts with a high density plasma, emission near $3\omega_0/2$ is observed, where ω_0 is the frequency of the incident laser. This emission has been studied for a number of years, and it is understood to be the result of the scattering of laser photons from electron plasma waves (epw's) produced by the two-plasmon decay (TPD) instability [1-3]. TPD continues to be of importance to laser-plasma interactions and to electromagnetic wave modification of the ionosphere [4,5]. The TPD instability occurs around $n_c/4$, where n_c is the critical density at which the plasma frequency equals ω_0 , and it results in the generation of pairs of epw's, one of which propagates up the density gradient and away from the incident laser, and the other propagates down the density gradient and towards the incident laser. In the absence of nonlinear processes, the epw's must propagate to densities where the momentum and energy matching conditions are satisfied to scatter laser photons to produce $3\omega_0/2$ light.

Linear theories have been developed to predict the observed $3\omega_0/2$ spectra as a function of observation angle relative to the incident laser, [6-11] and a successful theory would allow us to relate the observed spectrum to the electron temperature which would be a powerful diagnostic tool of laser-produced plasmas because $3\omega_0/2$ emission is easy to detect. Observations, [12-19] however, have generally not matched theories; a particular example is the observation of blue-shifted photons scattered back towards the incident laser. In a recent series of experiments, [20-22] we have presented evidence that stimulated Brillouin scattering (SBS) ion waves, a mechanism not included in previous theories, play a dominant role in rescattering the TPD plasma waves and shifting the wavelength of the $3\omega_0/2$ light. It follows that the red-shifted photons also get redistributed in angle which can complicate the interpretation of the spectra when SBS is present. Nonlinear simulations [4] of CO_2 laser experiments [5] have also shown that strong turbulence, which can seed SBS, can scatter the epw's to locally produce $3\omega_0/2$, and therefore modify the observed spectrum.

In this presentation we show the results of experiments for which the observed $3\omega_0/2$ spectrum can be explained by linear theory. The observed $3\omega_0/2$ spectra can be predicted from the calculated TPD wavenumber distribution provided (1) the plasma waves are able to propagate to lower densities where they can k-match with incident laser photons to produce $3\omega_0/2$ photons, and (2) collisional damping of the epw's is taken into account. Collisional damping alters the $3\omega_0/2$ spectrum such that the spectral peak does not correspond to the epw with the maximum TPD growth.

2. Experimental results

This experiment has two important points: (1) we have used Thomson scattering to measure the electron temperature and flow velocity of the plasma, and (2) we have made our observations while SBS is below threshold [20-22] so that we can directly compare observed $3\omega_0/2$ angular distributions with existing linear theories. By measuring the $3\omega_0/2$ spectrum at five different angles, we are able to eliminate several proposed theories. The conditions for our experiments are such that TPD is much less strongly driven than those which have been discussed in more recent work [4,5].

The present experiment was performed using the Janus laser at Lawrence Livermore National Laboratory. A single incident laser pulse was used to form the plasma and generate the $3\omega_0/2$ emission. The laser pulse was Gaussian in time (1 ns FWHM) and 1.064 μm wavelength with a nominally top-hat spatial profile at the target plane. The beam was focused with a 1-m focal length, f/8.5 lens. The focal spot and energy of the beam were varied during the experiment; these will be described in the later description of the data. The target was a carbon (graphite) wheel which was irradiated edge-on and rotated to expose a fresh surface before each irradiation.

Light near $3\omega_0/2$ was collected from five angles with respect to the incident laser: 91° , 110° , 135° , 170° and 180° (0° is in the direction of laser propagation). At each position, lenses image the target onto optical fibers. The optical fiber signals are coupled to a 1.25 meter spectrometer using a 6:1 optical fiber splitter to combine the signals at the input slit of the spectrometer; a streak camera (S-20) records the spectrometer output and a CCD records the streak record. The collector signals are separated by staggering the fiber lengths so that each collector signal arrives at the streak camera in approximately 2 ns intervals.

We duplicated our earlier observation of a threshold intensity below which the $3\omega_0/2$ signature reduced from a double-peaked structure to a single, red-shifted peak. This is illustrated in Fig 1 in which we compare the spectra from shots with spot diameter of 215 μm , 23 J ($I = 6.4 \times 10^{13} \text{ W/cm}^2$) and with spot diameter of 250 μm , 21.5 J ($I = 4.4 \times 10^{13} \text{ W/cm}^2$). An intensity change of only 30% leads to a significant modification of the observed spectrum. We have earlier proposed that this effect is due to scattering of the electron plasma waves produced by the two-plasmon decay (TPD) instability to new angles by SBS ion waves. Note that the difference in wavelength between the two red shifted peaks is about 10 \AA , a significant difference which can be misleading when one is trying to compare to the predictions of linear theory. To emphasize this point, we plot the

measured electron temperature and the measured wavelength shift at an angle of 180 degrees as a function of the incident laser intensity (see Fig. 2). The wavelength shift shows a steady increase above 5×10^{13} W/cm² to a value which is twice that at 4×10^{13} W/cm², a variation which is not seen in the Thomson scattering measurement.

3. Summary

In conclusion we have described an experiment which will allow quantitative comparison to linear theory. In general, interpretation of the $3\omega_0/2$ spectrum to provide an electron temperature will be difficult since ion wave processes such as SBS or strong Langmuir turbulence are likely to be involved.

4. Acknowledgements

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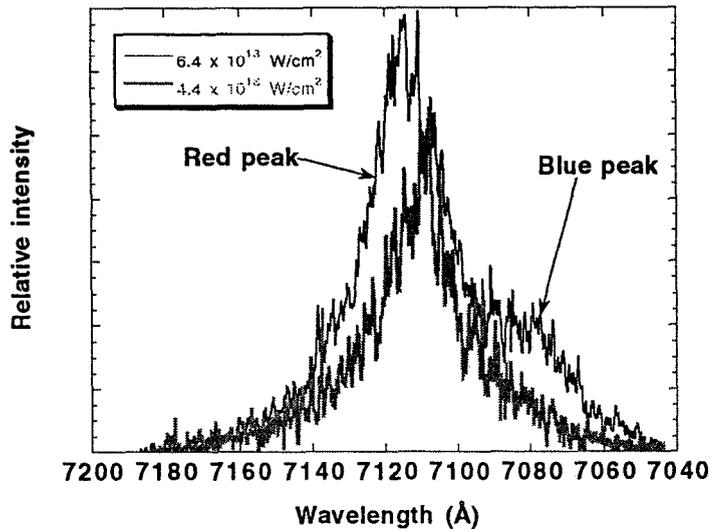


Figure 1. Comparison of 180 degree backscatter spectra for incident laser intensities of $4.4 \times 10^{13} \text{ W/cm}^2$ and $6.5 \times 10^{13} \text{ W/cm}^2$ showing the appearance of the blue-shifted peak.

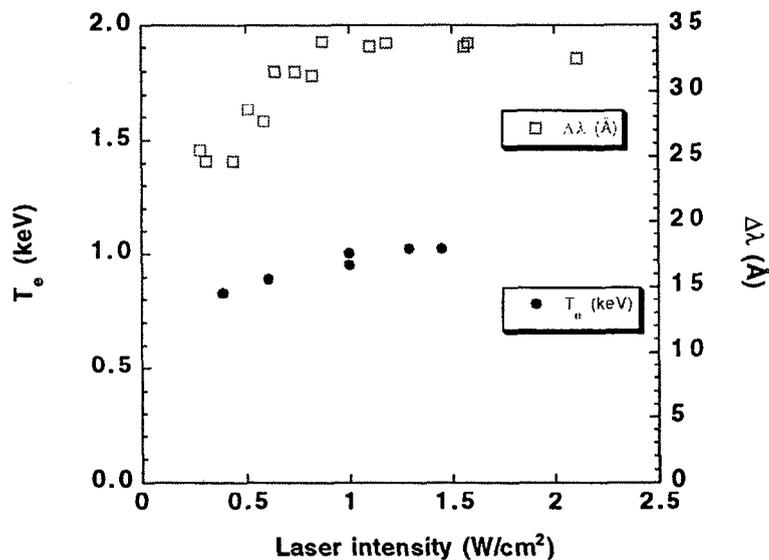


Figure 2. Comparison of the dependence of (a) T_e given by Thomson scattering, and (b) the observed spectral shift on the incident laser intensity for light scattered 180 degrees..