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Absorption and x-ray measurements from ultra-intense laser-plasma interactions

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ABSTRACT

The interaction of subpicosecond 1.06 mm laser light at intensities up to 10^{18} W/cm^2 with dense preformed plasmas is investigated by measurements of the absorption of the laser light in the plasma and by measurements of the production of bremsstrahlung x-rays. Absorption measurements are made by collecting the scattered light in an Ulbricht sphere. Light scattered in the backward and specular directions is collected separately. Measurements are presented for both high and low Z targets. X-ray production is measured using a nine channel filter/scintillator spectrometer.

1. INTRODUCTION

Experimental work dating back 10 years[1] suggests the existence of new mechanisms for the absorption of ultra-intense laser light interacting with solid targets. Various explanations have been put forward for the increase in absorption at high intensity observed in ref. 1 including rippling of the critical surface[1], the J x B effect[2], and vacuum heating[3]. While the previous experiment was performed with a CO_2 laser and consequently had both a long wavelength (10.6 μm) and a long pulse length (750 psec), recent advances in pulse compression techniques[4] have opened an analogous intensity window for 1 μm solid state lasers. This has sparked renewed interest in this area[5,6,7,8] including this work to measure the absorption of the laser light as well as the production of hard x-rays.

2. LASER

The 1.06 μm Nd-glass laser[9] produces 800 fsec pulses and intensities on target of up to 10^{18} W/cm^2. The main pulse is preceded by a 150 psec long prepulse of much lower intensity which creates a preformed plasma. The laser is usually polarized in the plane of incidence (p-polarization) and strikes the target at an angle of 22.5° from the normal. For some measurements the polarization was rotated by 90° (out of the plane of incidence, s-polarization) by inserting a quarter wave plate between the last turning mirror and the f/8 focusing lens.

3. ABSORPTION MEASUREMENTS

The experimental setup for the absorption measurement is shown in Fig. 1. The incident and backscattered energies are monitored using the leakage through the last dielectric turning mirror. This leakage is measured using a combination of neutral density filters, focusing lenses and commercial pyro-electric energy meters. After this turning mirror the beam is focused by an f/8 lens (which serves as the window of the vacuum chamber) onto a target located inside an Ulbricht sphere[10]. The specular reflection from the surface of the target is brought out through a hole in the side of the sphere and measured separately. Light which is scattered at an angle such that it does not return through the focusing optics and does not pass through the hole in the specular direction is collected in the sphere. The inner surface of the sphere is coated with a diffuse white reflector which rescatters this light many times. These repeated diffuse scatterings of the light inside the sphere cause this light to be homogeneous and independent of the angular distibution of the initial scattering. This light level is then measured using a combination of photodiodes and neutral density filters. The relation between the photodiode signal and the total energy in the sphere is obtained by moving the target out of the laser

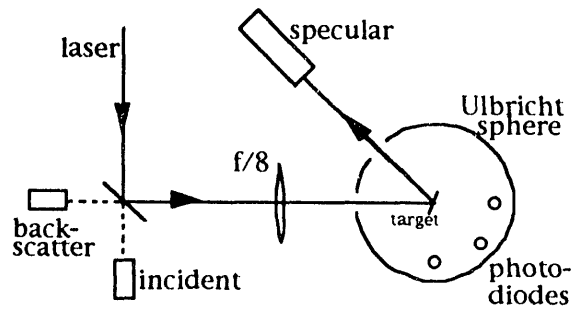

Fig. 1. A schematic of the experimental setup used in the absorption measurement. Incident and backscattered energies are monitored using the leakage through the last turning mirror. Specularly scattered light leaves the sphere through an f/8 hole and is also measured seperately. Light scattering at other angles is collected in the Ulbricht sphere.

beam and allowing the unfocused light to strike the back wall of the sphere. The response of the sphere falls off rapidly with longer wavelengths due to a fall off in the response of the silicon photo diodes.

3.1 Absorption on hydrocarbon

Measurements of the scattering of p-polarized light from a hydrocarbon (formar) target are shown in the Fig.2. The upper part of the figure shows the fraction of the incident energy observed in the sphere, in the specular direction, and in backscatter. Each triplet of points on this plot represents a single laser shot. The majority of the scattered light is found in the sphere with small contributions in the other two. The fractional energy in the backscatter is seen to rise with increasing intensity while that in the specular is seen to fall. The absorption shown in the lower part of the figure is inferred from the missing energy after summing the three components. It is seen to initially decrease as the intensity is increased above the minimum of 10^{16} W/cm^2.

3.2 Absorption on aluminum and tantalum

Fig. 3 shows the measured absorption of p-polarized light on targets of aluminum and tantalum as as well as the absorption of s-polarized light on tantalum targets. The measured absorption for aluminum is very similar to that for CH shown in the bottom half of Fig.2. The tantalum data is also similar at intensities below $1 \cdot 10^{17}$ W/cm^2, but shows slightly higher absorption above this intensity. Somewhat surprizingly, this data also shows no significant dependence on the polarization of the laser light. This will be discussed in the next section. The cause of the large absorption measured for the four p-polarized shots near $2 \cdot 10^{17}$ W/cm^2 is not known.

3.3 Interpretation of the absorption measurements

Resonance absorption[11] is expected to play a major roll at these intensities. As this process is effective only for p-polarized light, the lack of apparent sensitivity of the absorption to the polarization may appear puzzling. In fact, previous work suggests several possibilities for this[12,13]

While the data appears to show a small increase at the highest intensity, it is probably consistent with flat given the shot-to-shot fluctuations and the systematic uncertainties in the calibration of the sphere.

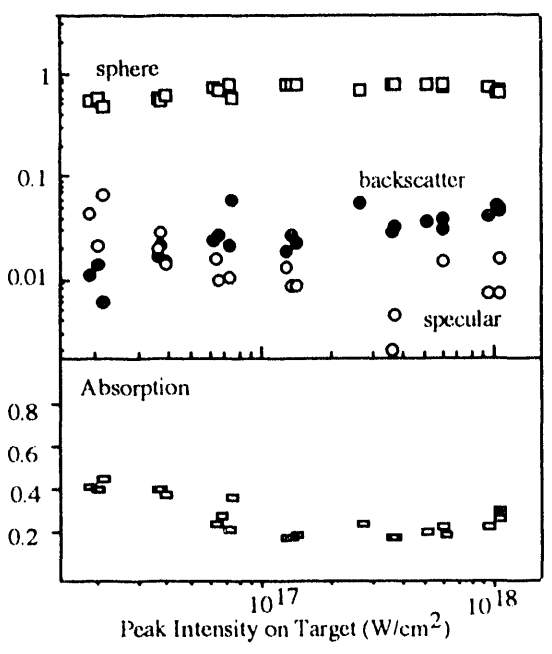

Fig. 2. Measurements of the light scattered from hydrocarbon targets. On the top, the fraction of the incident light found in the three channels as a function of the intensity on target. On the bottom, the absorption as inferred from the energy not found in any of the three channels.

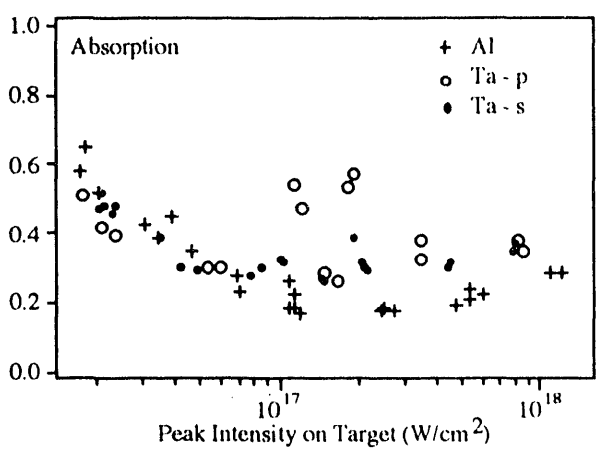

Fig. 3. Absorption measurements made using aluminum (p-polarization) and tantalum (p- and s-polarization).

4. X-RAY MEASUREMENTS

The new absorption mechanisms discussed in the references above all have in common the generation of super thermal electrons. The production of such electrons was inferred in ref. 1 from the production of hard x-rays, and has been examined in some detail in another similar 10 μm experiment[14].

We have constructed a nine channel filter/scintillator spectrometer to measure the x-rays produced in these interactions. It is shown schematically in the Fig. 4. X-rays produced in the interaction of the laser with the target pass through various filters located in front of the pinholes in the first lead brick. The x-rays transmitted through the filters are detected using NaI(Tl) crystals coupled to phototubes. The NaI(Tl) crystals and phototubes are behind pinholes in a second set of lead bricks located on the other side of the laboratory. Lead shielding is provided on all sides of these crystals and phototubes. This spectrometer covers an energy rangeof approximately 10 keV to 500 keV. Because the only filters available in this energy range have "high-pass" characteristics, a non-trivial unfolding procedure is needed to extract the spectrum from the data[15]. The responses of the nine channels verses x-ray energy are shown in Fig. 5. These curves include the effects of the 5 meters of air as well as the response of the NaI(Tl).

The result of such an unfolding is shown in the figure above. This figure is the result of a single shot at an intensity of 10^{16} W/cm^2 and was taken with a tantalum target. The curve in the lower part of the figure shows evidence of two different slopes in the distribution of x-ray energies. The steeper of the two slopes corresponds to a temperature of 35 keV and a yield of 0.2% of the incident energy (assuming an isotropic distribution into 4π). These numbers can be compared to the empirical scaling laws of ref. 7 which predict a similar temperature of 40 keV and a somewhat lower yield of 0.05% at this intensity. The second temperature observed is at least 150 keV and is presumably due to a coherent process in the underdense part of the plasma (simulated Raman scattering, etc.). The upper part of this figure shows the responses of the various channels as a function of the x-ray energy.

6. ACKNOWLEDGEMENTS

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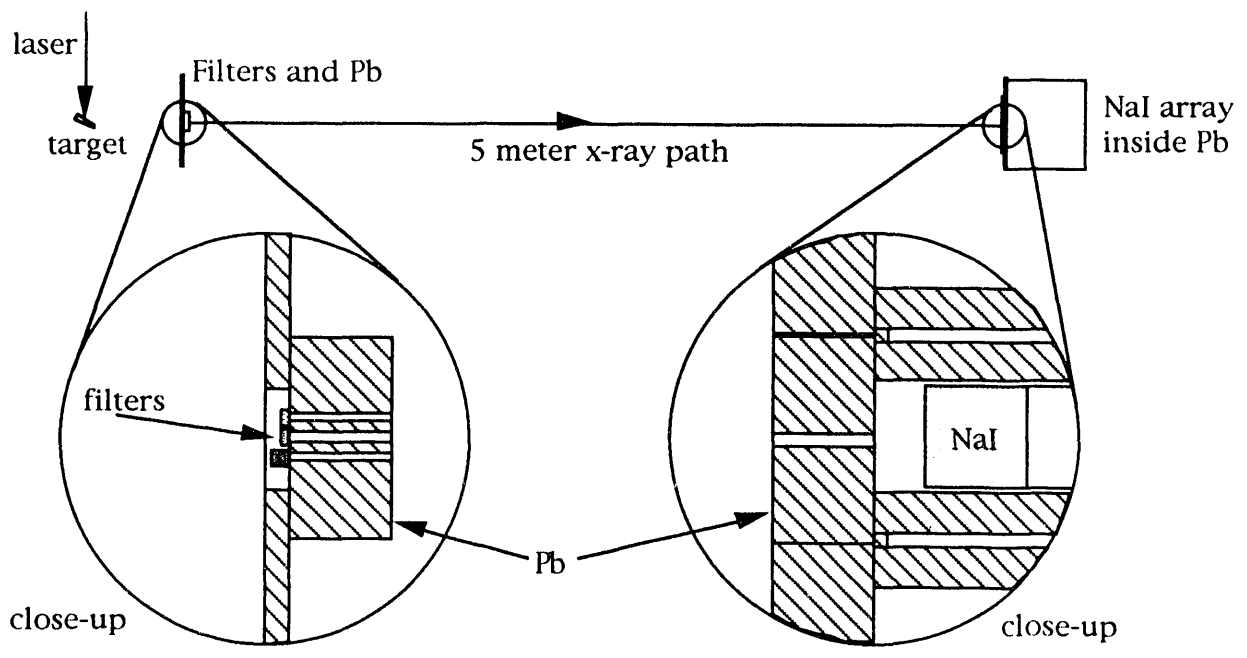

Fig. 4. Schematic of the 9 channel spectrometer used to measure the x-ray spectrum.

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