CONF-770511-2

Lawrence Livermore Laboratory

THEORETICAL INTERPRETATION OF ANGLE- AND POLARIZATION-DEPENDENT LASER LIGHT
ABSORPTION MEASUREMENTS

J. J. Thomson, W. L. Kruer, A. B. Langdon, C. E. Max, and W. C. Mead

MASTER

June 21, 1977

This paper was prepared for submission to Applied Physics Letters for publication and was presented at the Anomalous Absorption Conference Vancouver, B.C., May 10-12, 1977

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

THEORETICAL INTERPRETATION OF ANGLE- AND
POLARIZATION-DEPENDENT LASER LIGHT
ABSORPTION MEASUREMENTS

J. J. Thomson, W. L. Kruer, A. B. Langdon
C. E. Max, W. C. Mead

Lawrence Livermore Laboratory
University of California
Livermore, California 94550

ABSTRACT

We show that recently published observations of angle- and polarization-dependent absorption of intense laser light are consistent with computer simulations of resonance absorption in a steepened plasma profile, with the addition assumption of a modestly rippled critical surface. About 10% absorption seems to be due to mechanisms not addressed in the simulations.

Work performed under the auspices
of the U.S. Energy Research &
Development Administration under
contract No. W-7405-Eng-48.

NOTICE
This report was prepared as an account of work
sponsored by the United States Government here-
after the United States and the United States Energy
Research and Development Administration, neither
their employees nor any of their contractors,
subcontractors, or their employees, makes any
warranty, express or implied, or assumes any legal
liability or responsibility for the accuracy, completeness,
or usefulness of any information appearing herein, or
represents that its use would not
infringe privately owned rights.

Determination of the magnitude and angular dependence of absorption of high intensity laser light by plasma is of great importance to the laser fusion program. Recently, measurements have been made of angle- and polarization-dependent light absorption¹ in the intensity regime of $10^{15} - 10^{16}$ W/cm². In this letter, we discuss a simple model that has as its basic elements resonance absorption and absorption due to driven ion waves in a steepened density profile plus a modulated critical surface. Although not a unique interpretation of the data, this model gives good agreement with the shape of the experimental absorption curve, leaving about 10% angle- and polarization-independent absorption still to be accounted for.

Resonance absorption has two signatures: polarization dependence and angular dependence.² The polarization dependence occurs because charge density fluctuations are driven only if the light electric field has a component in the direction of the density gradient. This is the case if the electric field vector is in the plane of incidence (p-polarization), but not if it is normal to the plane of incidence (s-polarization). In order to resonantly excite charge density fluctuations, the field must tunnel from the turning point $n_c \cos^2 \theta$ to n_c . Here n_c is the critical density and θ is the angle of incidence. If θ is too large, the tunnelling distance is too great for effective absorp-

tion. On the other hand, if θ is too small, the component of the field in the density gradient direction vanishes, giving zero absorption. There is an optimum angle for absorption, given by $\sin\theta \approx (k_0 L)^{-1/3}$, where k_0 is the free-space wave number and L is the density scale length.²

Computer simulations of intense p-polarized plane light waves obliquely incident on a plasma have been performed in order to find the absorption in a self-consistent density profile.³ Characteristically, for the intensity regime of interest, a density plateau at $.5 - .7 n_c$ is formed, with a steep step through n_c . Fig. 1 shows the experimental points for p-polarization together with the predictions of the computer simulations. Note that they agree in that there is an absorption peak and that it is at about 20° (corresponding to $L \approx 1.5 \text{ cm}$). However, the experimental peak is lower and broader, and there is significantly more absorption at low and high angles than the simulations of the ideal model predict.

To obtain a theoretical prediction of s-polarization absorption, we assume that the 15% absorption at $\theta = 0$ in the simulations is due to ion density fluctuations driven by the laser light (the analogue of oscillating-two-stream and parametric decay in a uniform plasma). If the density step at n_c is steep, then this absorption would be constant in s-polarization as long as the turning point of the light stays above the plateau, i.e., $\theta \gtrsim 45^\circ$. Accordingly, we take s-polarization absorption to be constant for $\theta < 45^\circ$. Comparing this model to the experimental points in Fig. 2,

we see that the shape is roughly correct, but the experimental absorption is consistently higher.

The next element we add to the theoretical model is modulation of the critical surface. This effect is strongly suggested both experimentally and theoretically. In experiments similar to those of Ref. 1, a group at NRL observes only about 2% of the incident light back scattered into their f-14 lens, suggesting an rms scattering angle of $\sim 5^\circ$.⁴ In the experiments of Ref. 1, about 1% of the incident light is back-scattered into the f-10 lens, suggesting an rms scattering angle of $\sim 6^\circ$. In both experiments the scattered light was in a cone of $\sim 20^\circ$ - 30° half angle, again suggesting surface inhomogeneities. Recently Attwood of LLNL has interferometrically probed the plasma blowoff from plane disks in the intensity regime of interest,⁵ finding direct evidence of plasma inhomogeneities.

A probable source for modulation of the critical surface is the intensity variation of the incident light. In the experimental intensity regime, light pressure may be equal to or greater than the plasma pressure. The laser beam used had a clover-leaf pattern, with intensity structures on the order of 10 μm in diameter. We have performed computer simulations similar to those of Ref. 3, but with hot spots similar to those observed on the laser beam, rather than plane waves. We found considerable denting of the critical surface on picosecond time scales, leading to absorption in the range of 25% - 45% for normal incidence. The mechanism is resonance absorption on the sides of the density depression. The long-time

behavior of these dents is not yet understood; however, it is clear that this mechanism can give significantly increased absorption.

Another source for such random inhomogeneities is the instability of the critical surface, an effect which also has been seen in computer simulations.⁶ However, the importance of such critical surface instabilities has not yet been established, since the rippling occurs primarily out of the plane of polarization of the light.⁷

A simple model can show the effect of these plasma inhomogeneities on the absorption of laser light. We assume that the tilt angle, ϵ , is uniformly distributed from $-\epsilon_{\max}$ to $+\epsilon_{\max}$, with equal probability of being in or out of the plane of incidence. If the tilt is in the plane of incidence, the effect is to change the local incidence angle from θ to $\theta + \epsilon$, thus averaging over the theoretical absorption curve. If the tilt is out of the plane of incidence, the effect is to change the polarization of a fraction of incident light: s polarization becomes p, and vice versa. The power fraction changed is

$$f_{DF} = \frac{1}{2} \frac{\sin^2 \epsilon}{\sin^2 \theta + \cos^2 \theta \sin^2 \epsilon} \quad (1)$$

for both incident polarizations. The equivalent incidence angle is changed from θ to

$$\theta' = \cos^{-1} [\cos \theta \cos \epsilon] \quad (2)$$

We use these relations and average over the absorption model discussed above to get absorption vs. angle for a given θ_{max} . The solid lines on the figures show the resulting absorption curve for $\theta_{\text{max}} = 15^\circ$. This choice of θ_{max} was suggested by the simulations modelling hot spots. Note that the agreement is much improved, although a discrepancy of about 10% angle- and polarization-independent absorption remains. Adequate agreement is seen for θ_{max} between 10° and 20° . This corresponds to an rms angle $\theta \sim 6^\circ - 11^\circ$, in rough agreement with the experimentally inferred values of $5^\circ - 6^\circ$.

The extra 10% absorption left over may be due to one or more of several absorption processes. The $2\omega_p$ instability is estimated to give $\leq 5\%$, primarily because of steepening of the plasma profile by plasma waves near $\frac{1}{4} n_c$.⁷ Self-generated magnetic fields near n_c of several megagauss can give $\sim 10\%$ absorption due to linear conversion of the extraordinary mode.⁸ Ion density fluctuations of magnitude ~ 10 in the underdense plateau have been estimated to give $\sim 10\%$ absorption in short pulse length experiments.^{9,10} No data is yet available to distinguish among these absorption mechanisms.

In conclusion, we find that the experimentally observed absorption curve of Ref. 1 is well modelled by computer simulations in which the dominant absorption mechanism for p-polarization is resonance absorption with the additional assumption of a modestly rippled critical surface. In this interpretation, there is about 10% apparently angle- and polarization-independent absorption occurring from other absorption mechanisms.

ACKNOWLEDGMENT

This paper was presented at the Anomalous Absorption Conference, Vancouver, B.C., May 10-12, 1976.

REFERENCES

1. K. Manes, V. Rupert, J. Auerbach, P. Lee, J. Swain, to be published, Phys. Rev. Lett.
2. V. L. Ginzburg, The Propagation of Electromagnetic Waves in Plasmas, Pergamon, New York, 1964.
3. K. G. Estabrook, E. Valeo, W. L. Kruer, Phys. Fluids 13, 1151 (1975).
4. B. H. Ripin, private communication. Also see B. H. Ripin, Appl. Phys. Lett. 30, 134 (1977).
5. D. Attwood, private communication.
6. Kent Estabrook, Phys. Fluids 10, 1733 (1973).
7. A. B. Langdon, B. F. Lasinsky and W. L. Kruer, to be published; A. B. Langdon, B. F. Lasinsky, in Methods in Computational Physics, Vol. 6, ed. by B. Alden and S. Fernbach, Vol. ed. J. Killeen (Academic Press, New York, 1976).
8. W. L. Kruer and Kent Estabrook in Laser Interaction and Related Plasma Phenomena, Vol. 4 (Plenum, N. Y. 1977) p. 700-740.
9. R. J. Faehl and W. L. Kruer, Phys. Fluids 20, 55 (1977).
10. W. Manheimer, D. G. Colombant and B. H. Ripin, Phys. Rev. Lett. 39, 1135 (1977).

SOURCE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research & Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights."

"Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research & Development Administration to the exclusion of others that may be suitable."

FIGURE CAPTIONS

Fig. 1 Absorption vs. angle in p-polarization. Dashed line is from computer simulations; solid line includes random angles with $\theta_{\max} = 15^\circ$

Fig. 2 Absorption vs. angle in s-polarization. Dashed line is for smooth surface; solid line includes random angles with $\theta_{\max} = 15^\circ$.

Fig. 1

Fig. 2