at $d \sim 300$ Å), we have plotted $N(2, \omega)$ in Fig. 3 (curved solid line). The agreement with the experimental data is seen to be good.

We have considered two other possibilities. The first assumes that the vortices move with the local superfluid velocity, and the results obtained from Eq. (2) are shown in Fig. 3. In the other, the superfluid is taken to flow with the substrate outside the critical radius r_c. It is then necessary to postulate a mechanism to contribute to the velocity field without contributing to the phase slippage in Eq. (2), or else $\Delta d_{20}(\omega)$ for $r_c < 2$ will simply be the same as that at high temperatures. The N for this assumption is also plotted in Fig. 3. The critical velocity is lower (~17 cm/sec). The thickness difference calculated using this model, shown in Fig. 2, exhibits a negative region between $r = v_c/\omega$ and $r = (2)^{1/2}v_c/\omega$. The difference $\Delta d_{20}(\omega)$ tends to be negative in this region but it cannot be studied satisfactorily with the present apparatus. Moreover there are a number of other possible explanations. For example, if the film is not completely homogeneous in thickness, the revolving substrate may create some flow patterns in the film even before ω_c, which would result in a larger thickness decrease on the outside in accordance with Bernoulli's equation.[13]

In summary we have shown that the normal fluid in a He II film rotates with the substrate, whereas the superfluid remains at rest until the linear velocity of the substrate exceeds the translational critical velocity of the film. The most plausible velocity field is one in which the superfluid velocity is less than the velocity of the substrate by the critical velocity.

We are grateful to T. C. Padmore, G. M. Graham, P. W. Anderson, and A. L. Fetter for helpful discussions.

*Work supported by the National Research Council of Canada.

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Second-Harmonic Generation in an Inhomogeneous Laser-Produced Plasma

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(Received 17 October 1974)

It is experimentally shown that specular second-harmonic emission from a dense, inhomogeneous plasma produced by laser irradiation of plane solid targets occurs on oblique reflection of a p-polarized light wave, in agreement with theoretical predictions.

Oblique reflection of a p-polarized electromagnetic wave from an overdense, inhomogeneous plasma[1-3] should, according to theoretical predictions,[4,5] be accompanied by second-harmonic (SH) emission with the following characteristic features: (i) The intensity of SH radiation increases quadratically with the intensity of the incident electromagnetic wave. (ii) Resonant behavior of the electric field at the critical layer and strong SH generation occur only for a p-polarized wave ($\vec{E}$ in the plane of incidence). (iii) The SH radiation is emitted specularly in the same direction as the reflected electromagnetic wave. (iv) For a given length L of plasma inhomogeneity and wavelength λ of the electromagnetic wave there is an optimum angle of incidence θ for maximum SH generation: $(2\pi L/\lambda)^{2/3}\sin^2\theta \simeq 0.6$; in particular, SH generation becomes zero for $\theta = 0°$ (normal incidence). In this paper we present experimental results which afford strong evidence that this process is important for SH generation in the dense plasma produced by laser irradiation tion of a solid target.[6-10]

The experiments were carried out at the Garching neodymium-laser facility ($\lambda = 1.06$ μm) with 20-J, 5-nsec pulses focused onto plane solid targets. A time-averaged intensity $\varphi \approx 4\times 10^{14}$ W cm^{-2} was measured in the plane of narrowest cross section of the $f = 75$-mm aspherical focusing lens (solid angle $\Omega = 1$). The angular distribution of SH radiation (isolated by an interference filter) was determined by photographic means within the solid angle of the focusing lens. For this purpose the focusing lens was imaged with the aid of a beam splitter and a lens onto Polaroid 3000 film, as described previously.[11] The energy of SH radiation was measured with a fast photodiode (Valvo XA 1003, S-4 cathode) whose quantum efficiency was known. The characteristic patterns of SH radiation shown in Figs. 1 and 2 were observed with plane targets of tungsten, copper, and glass, adjusted normal to the optical axis and to a position near the focal plane of the lens where maximum SH emission occurred; shifting the target towards or away from the lens lead to a decrease of SH emission with a half-width of ~70 μm and, in general, lowered the contrast of the SH patterns. With plane targets of solid hydrogen and deuterium where the backscattered laser radiation is known to be perfectly collimated,[11] SH patterns of the type described below could not be observed; in this case, SH emission was essentially diffuse, sometimes even with a slight preference in the direction of collimated backscatter. The origin of SH emission in this case will not be discussed in this paper. The properties of the plasma produced in our experiment have been investigated previously.[12-14]

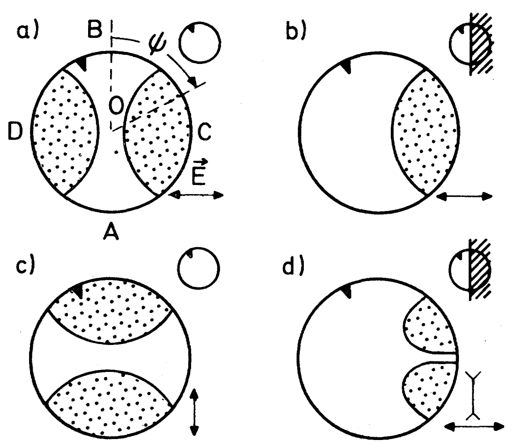

FIG. 1. Schematic representation of SH intensity distribution in the plane of the focusing lens. The small circles in the upper right corner show the cross section of the incident laser beam: (a) and (c) full round beam; (b) and (d) right half of the beam masked. Arrows show direction of electric field vector of the incident, linearly polarized, laser beam. In (d) an analyzer which transmits only the vertical $\vec{E}$ component of SH radiation has been placed in front of the film.

Figure 1 shows schematically the SH intensity distribution (dotted areas) in the plane of the focusing lens for a round incident laser beam [Figs. 1(a) and 1(c)], a beam with the right half masked by the edge of a sheet of cardboard [Figs. 1(b) and 1(d)], and two orthogonal directions of the electric field vector of the linearly polarized beam [Figs. 1(a), 1(b), and 1(d) and Fig. 1(c), respectively]. Figure 2 shows an original Polaroid positive for the case sketched in Fig. 1(b), obtained with a copper target, and Fig. 3 shows the energy of SH radiation backscattered through the lens as a function of the incident laser energy.

For comparison of the experimental results with the theoretical items (i)–(iv) it is assumed (as is discussed below) that each laser-light ray incident through the focusing lens is reflected from a plane plasma mirror produced by laser heating of the target surface.

First, we note with respect to (i) that Fig. 3 is in agreement with the predicted quadratic intensi-

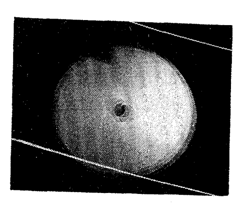

FIG. 2. Original photograph (positive) on Polaroid 3000 film for the case sketched in Fig. 1(b).

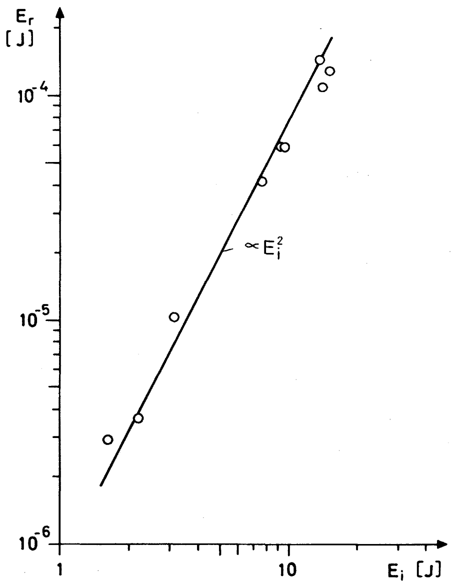

FIG. 3. Energy of SH radiation (backscattered through the focusing lens) as a function of incident laser energy for a plane tungsten target.

ty dependence of SH generation (focal-spot size and laser-pulse duration were kept constant during the measurements).

The shape and polarization dependence of the patterns shown in Figs. 1(a)–1(d) agree with (ii), as can be seen in the following way: For example, the SH emission observed in Fig. 1(a) near C (dotted area) is produced by laser-light rays (with the fundamental frequency) which on their way from the laser to the target penetrate through the lens near D, are then specularly reflected from the plane target (located on the optical axis O behind the lens), and penetrate through the lens again on their way back to the laser near C. The important point is that a laser-light ray with the path characteristic D-O-C is p-polarized (with the electric field vector in the plane of incidence defined by D-O-C and the optical axis) and is therefore expected to be accompanied by SH emission after specular reflection. Thus bright SH emission is expected in the vicinity of D in agreement with the observation [these considerations apply to Figs. 1(b) and 2 as well]. In contrast, a light ray A-O-B is s polarized (electric field vector normal to the plane of incidence) and therefore produces no SH radiation at B. The same arguments can be applied to the light rays traveling in the opposite direction (C-O-D and B-O-A); this readily explains the SH double pattern observed in Fig. 1(a) for the incident full, round laser beam. Other light rays should produce SH radiation according to the projection of the electric field vector onto their plane of incidence; as far as we can judge from the intensity distribution shown by the Polaroid positives, the observed angular distribution corresponds to the expected $\sin^4\psi$ dependence [for definition of ψ see Fig. 1(a)]. The center of the lens remains dark because no SH radiation is produced in normal reflection. One half of the double pattern produced by the full, round beam in Fig. 1(a) has disappeared in Fig. 1(b) simply because the light rays which after specular reflection would appear around D have been blocked already in the incident beam. Figure 1(c) does not present any basically new aspects compared with Fig. 1(a) but clearly demonstrates that the symmetry of the observed patterns is determined by the direction of the electric field vector and not by nonuniformities of the incident beam. The polarization of SH radiation has been checked by placing an analyzer in front of the film [Fig. 1(d)]. It was oriented in such a way that it would *not* transmit the electric field component of SH radiation which is parallel to the electric field vector of the incident laser beam. Linearly polarized SH radiation with the electric field vector parallel to that of the incident laser radiation is expected along the line O-C (produced by the p-polarized laser-light rays incident along the line O-D). In fact, SH radiation along this line is suppressed by the analyzer and thus found to be linearly polarized as expected.

As regards (iii), photographs of the type sketched in Fig. 1 and shown in Fig. 2 were taken at the laser frequency in order to investigate the angular distribution of backscattered laser radiation. In general, we find two types of backscatter: collimated backscatter,[11] which is insensitive to inclination of the target relative to the optical axis, and specular reflection whose angular distribution peaks around the specular reflection angle. For the targets investigated here specular reflection amounts to ~10% of the incident laser radiation (the total amount of backscatter being about 20–30%). The characteristic polarization dependence of Fig. 1 is observed *only* in the presence of specularly reflected laser light.

Formally, at least, the relation quoted under (iv) allows the density gradient near the critical layer to be estimated from the θ distribution of SH emission. Emission is maximum at the periphery of the lens ($\theta = 25°$), and hence $L \leq \lambda = 1$ μm. The low conversion rate (~10^{-5} according to Fig. 3) also indicates such a steep density gradient; conversion rates calculated for smooth density gradients as evaluated from x-ray pinhole photographs (typically 20–50 μm[14]) seem inconsistently high (for example, 8×10^{-2} for $\varphi=4\times10^{14}$ W cm^{-2}, $L=30$ μm, $Z_{\text{eff}}=6$[4]). We note that, if the steepening of the density profile were localized at the (moving) critical layer where the SH radiation is produced, it would obviously be undetectable by tangential (time-integrated) x-ray pinhole photography.

As our discussion has shown, the features of SH generation observed in our experiment, in particular the characteristic polarization and intensity dependence, are as expected for oblique reflection from an inhomogeneous plasma.[4,5] Since SH generation and resonant absorption[3] are intimately connected, the observations also afford indirect evidence that the latter process occurs in laser-produced plasmas.

Since the interpretation of the experimental results has been based on an idealized theoretical treatment,[4,5] it seems appropriate to conclude the paper with a short discussion of how this circumstance limits the conclusions drawn above in particular with respect to (iv). Since SH generation is a nonlinear process where the superposition principle does not hold, deviations from the predicted angular distribution may be expected because of the angular spread of the incident light rays. In addition, experiments with relatively small circular diaphragms in the incident beam between O and D [see Fig. 1(a)] have shown that the specularly reflected laser light is blurred around the specular angle; this indicates that the critical layer under experimental conditions is not perfectly plane and smooth, but is probably deformed because of hydrodynamic motion of the plasma and/or becomes rough during interaction. These complications mostly affect the estimate of the density gradient made above and make it to some extent uncertain. It is felt, however, that the evidence obtained here for a local steepening of the density profile near the critical layer should not be ignored since occurrence of this effect as a consequence of light pressure is strongly suggested by recent numerical simulations.[15]

The authors would like to thank Dr. D. Biskamp and Dr. P. Mulser for useful discussions and P. Sachsenmaier for his most valuable assistance with the experiments. The work was performed under the terms of the agreement on association between Max-Planck-Institut für Plasmaphysik and EURATOM.

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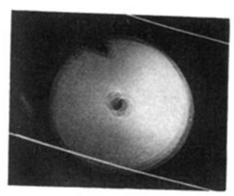

FIG. 2. Original photograph (positive) on Polaroid 3000 film for the case sketched in Fig. 1(b).