Effect of linear absorption on self-focusing

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Received April 7, 1988; accepted June 13, 1988

We report the effect of linear absorption on self-focusing. Our experimental results show that power loss due to linear absorption before focus is responsible for the increase in the threshold power for self-focusing and that the critical power is independent of the linear absorption.

This Letter reports the effect of linear absorption on self-focusing (SF) of high-power beams in CS_2. We find at the threshold for SF in CS_2 that the power arriving at the focus is independent of the linear absorption and that this power is equal to the critical power for SF without absorption ($\simeq$7 kW at 0.53 μm). These results agree with numerical studies[1–3] of SF in the presence of linear absorption, which predict that as long as the absorption length is greater than the SF length, increasing absorption will not prevent the collapse of the beam to a singularity. Theoretical models[3–5] predict that although the *observed* threshold power P_t for SF increases with linear absorption, the critical power P_c for SF remains constant. There is a large body of theoretical and experimental work published on SF. However, there is little experimental information on the role of linear absorption in SF. Wang and Racette[6] investigated the effect of increasing linear absorption on SF in CS_2 in the small range of α = 0.002–0.01 cm^{-1}, where α is the linear absorption coefficient. Their results, contrary to the theoretical model of Kelly,[4] showed that the critical power for SF increased with absorption. Wang and Racette attributed this disagreement to the oversimplified theory used to calculate the critical powers in their paper. To our knowledge, the data presented in this Letter are the first experimental verification of a self-focusing theory including linear absorption.

In our experiments, we investigated the effect of linear absorption on the critical power for SF in CS_2 by using $\simeq$30-psec (FWHM) frequency-doubled pulses at 0.53 μm from a mode-locked Nd:YAG laser. The dominant nonlinearity in CS_2 for this pulse width is the reorientational Kerr effect.[6,7] Following Wang and Racette,[6] the linear absorption was varied by dissolving a controlled amount of iodine in CS_2. We varied α from 0.002 to 0.81 cm^{-1}.

The threshold power for SF was measured using the power-limiting method. This method is described in detail in Ref. 7, and the experimental arrangement is shown in Fig. 1. The TEM_{00} beam is focused into the nonlinear material, and the peak on-axis fluence transmitted through the nonlinear material is monitored in the far field. With powers below the critical power for SF, the on-axis fluence at the detector increases linearly with incident power. Above the critical power for SF the on-axis fluence remains essentially constant with increasing incident power (i.e., the system acts as an optical power limiter[7]). The input power at which the output is limited marks the onset of SF. In addition, this power is characterized by the appearance of optical breakdown at the beam focal position.

The linear absorption of the solution of iodine in CS_2 was measured using a spectrophotometer. To ensure that there was no optical nonlinearity associated with the presence of iodine, different concentrations of iodine in alcohol were tested in the same setup (alcohol has a small nonlinear refractive index). For incident powers of up to ten times greater than P_c for CS_2 and concentrations of up to 4.3 × 10^{-3} g/cm^3, no nonlinear refraction, nonlinear absorption, or saturation was observed. This also confirmed the linearity of the optical setup.

The single-mode TEM_{00} beam of radius ω_0 = 1.0 mm (half-width 1/e^2 maximum in irradiance) was focused with a 7.5-cm focal-length lens into the center of a 2-cm-long CS_2-filled glass cell. The on-axis fluence transmitted through the cell was monitored by detector D2 (see Fig. 1) behind a pinhole in the far field. Figure 2 shows the results of the power-limiting experiment for neat CS_2 and CS_2 with an iodine concentration of 4.4 × 10^{-4} g/cm^3. The absorption coefficient α corresponding to this concentration is 0.81 cm^{-1}, and neat CS_2 at 0.53 μm has α = 0.002 cm^{-1}. The critical power for SF for neat CS_2 from the experiment is seen to be $\simeq$7.0 kW. This gives a nonlinear refractive index n_2 of 1.4 × 10^{-11} esu, which is in good

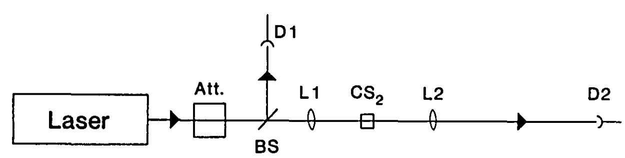

Fig. 1. Experimental setup. L1 and L2, lenses; D1 and D2, detectors; BS, beam splitter.

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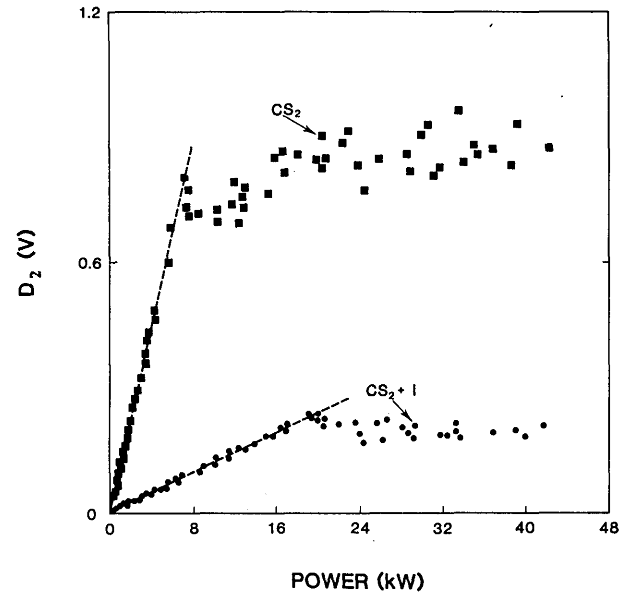

Fig. 2. Signal on D_2 versus incident power at 0.53 μm for neat CS_2 (squares) and 4.4 × 10^{-4} g/cm^3 of iodine in CS_2 (circles). The focus is positioned in the center of the sample (i.e., 1 cm inside the CS_2).

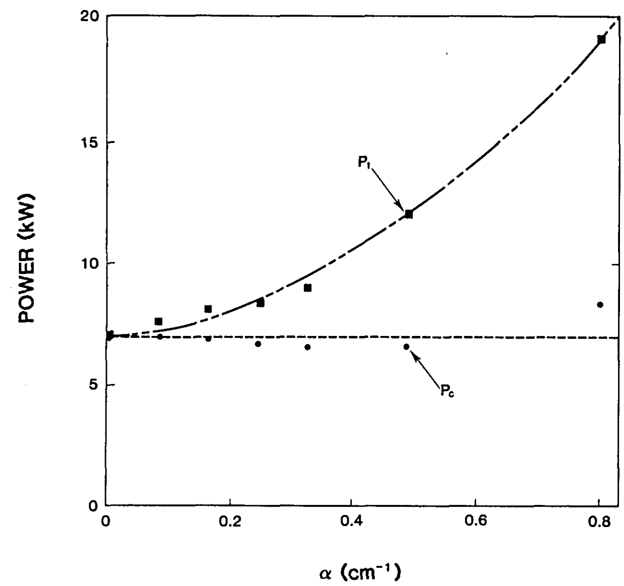

Fig. 3. Threshold power, P_t, and critical power, P_c, for self-focusing versus linear absorption coefficient α with the focus at the center of the 2-cm cell.

agreement with previous measurements using picosecond excitation at this wavelength.[7–9] At the higher absorption of 0.81 cm^{-1} the threshold power for SF increases by approximately a factor of 3, to 19.2 kW. The refractive-index change responsible for SF depends on the beam irradiance. In the sharp focusing geometry the high irradiance required for a significant refractive-index change is achieved only near the focal position. Therefore, as the incident power is increased, the nonlinear refraction first occurs near the focus. Then, if the power delivered to the focal volume is equal to the critical power for SF, the nonlinear change of the refractive index overcomes the linear diffraction and the beam collapses within the CS_2, causing optical breakdown. In our experiment, the power at the focal position can be calculated by subtracting the power loss due to linear absorption before focus from the threshold power. Taking the absorption into account, the threshold power of 19.2 kW measured in this experiment corresponds to a critical power of 8.5 kW, which is only 20% different from that for neat CS_2. Figure 3 presents the results of measurements of the threshold power for other intermediate absorption coefficients at 0.53 μm with the focus 1 cm inside the CS_2 cell. The average value of the criti-

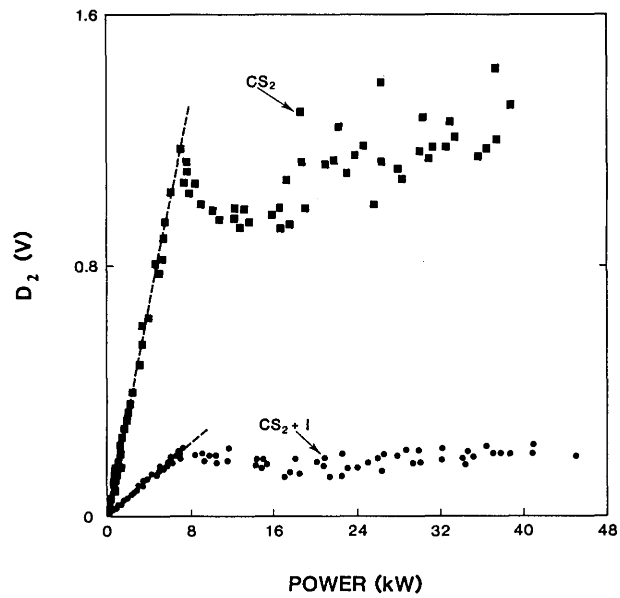

Fig. 4. Signal on D_2 versus incident power at 0.53 μm for neat CS_2 (squares) and 4.4 × 10^{-4} g/cm^3 of iodine in CS_2 (circles). The focus is positioned at 1 mm inside the sample.

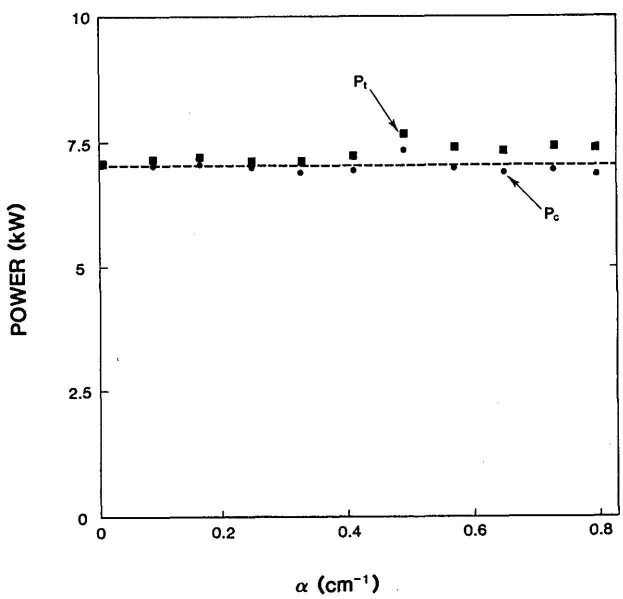

Fig. 5. Threshold power, P_t, and critical power, P_c, for self-focusing versus linear absorption coefficient with the focus 1 mm inside the sample.

cal power is 7.0 ± 0.7 kW. It is clear that although P_t, the threshold power for SF, changes by a factor of 3, the critical power P_c remains constant.

In the next set of experiments, keeping all conditions the same, the focus of the beam was moved toward the front surface of the cell (i.e., 1 mm inside CS_2). Since in this case the beam does not lose significant power before reaching the region of nonlinear interaction (the Rayleigh range), it was expected that the threshold power as well as the critical power would not vary significantly. The results of the power-limiting experiment under this condition for neat CS_2 and 4.4×10^{-4} g/cm^3 of iodine in CS_2 are shown in Fig. 4. The variation of the threshold power is less than 5%, with a large increase in linear absorption. Figure 5 presents the results of measurements of the threshold power versus absorption at 0.53 μm with the focus 1 mm inside the CS_2 cell. The critical power is constant and equal to 7.0 ± 0.1 kW, in agreement with theory.[1–3]

We have shown that the increase of the threshold power for SF with linear absorption is simply due to the linear loss of power in the beam before it reached the focal position. The fact that P_c remains constant with increasing linear absorption allows the design of optical power limiters including linear absorption losses. Thus, it should be possible to design an optical limiter for both pulsed and cw beams using a combination of the rapid-response Kerr nonlinearity and the slow-response thermal nonlinearity, with the thermal nonlinearity being introduced by the addition of linear absorption.

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