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Application of Image Relaying to Nonlinear Beam Distortion Measurements
and Profile Shaping

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Abstract

Image relaying of the defining aperture in a top-hat z-scan technique allows both accurate nonlinear index measurements as well as controllable reshaping (for example, flattening) of the beam profile at the image plane.
Application of Image Relaying to Nonlinear Beam Distortion Measurements
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Summary

In the course of attempting to increase the accuracy with which we could make measurements of the nonlinear index of refraction ($n_2$) of optical materials by the z-scan technique, we found a number of advantages that result from relay imaging the input beam, as well as some surprising observations that permit a substantial fraction of a gaussian beam to be converted to a near flat-top or other smoothly varying distribution. The method we are using is actually a modification of the "top-hat" z-scan technique which has the advantages described in Ref. 2 of higher sensitivity and smaller uncertainties introduced by beam-quality considerations than the gaussian-beam technique. We find, however, that we obtain comparable $n_2$ measurements by the two techniques. The additional modification we have made to the top-hat technique, which uses an apertured expanded beam rather than a gaussian as the input beam, is to place the defining aperture for the top hat at the front focal plane of the lens that focuses the beam into the sample and then reimaging the input aperture with a second lens onto a ccd camera (Fig. 1). Reimaging eliminates diffraction fringes from the aperture and provides a stationary image even for a wedged sample; recording the entire image permits minimization of spurious effects such as varying interference fringes.

Calculations of the image distribution by means of a diffractive optical propagation code that incorporates self focusing reveal that the changes induced by self focusing occur entirely within the image, with negligible spill-over beyond the boundary of the image of the aperture. This result holds most strictly for a flat-top input beam and samples thin compared to the Rayleigh range of the
focused beam, but relaxation of these conditions does not strongly affect this result. Calculations for a truncated gaussian rather than a flat top show little change in the magnitude of the z-scan signal; for example, truncating a gaussian at 82\% of the peak reduces the amplitude of the z-scan signal by 4\% as compared with a flat top beam that yields the same focused intensity. For an initially gaussian input beam, this permits a larger fraction of the beam to be utilized for z-scan measurements because the beam need not be expanded as much in order to obtain a very flat distribution.

The imaged beam also shows a smoothly varying change in the intensity distribution, as illustrated in Fig. 2a. This suggests that it should be possible to turn an apertured gaussian distribution into a nearly flat-top distribution, or into some other desired profile, as shown experimentally in Fig. 2b. The technique also provides some degree of optical limiting on the central region of an imaged truncated gaussian. While there are restrictions to the utility of this technique, arising for example from the temporal intensity distribution of the pulse and from limitations imposed by damage to the nonlinear medium, we feel that there may be circumstances where this technique can provide some flexibility to an optical designer.

Calculations of the beam distortion expected in this geometry for both flat-top and truncated gaussian beams will be presented, as well as $n^2$ measurements that include laser glasses at 1064 nm and fused silica and KDP at 1064 nm and 355 nm. Previous measurements of fused silica at 355 nm have exhibited a large spread; the present measurements are in agreement with the lower range of these values.

Figure Captions

Fig. 1 Relay-imaged top-hat z-scan configuration places defining aperture at front focal plane of lens that focuses into nonlinear sample and utilizes second lens to image aperture onto detector.

Fig. 2. a) Calculated intensity distribution at image plane for 1064-nm gaussian with waist $w_0=1.1$ cm apertured at 0.7-cm dia (81.6%), with and without nonlinear medium placed 1.4 cm before focus of a 43-cm lens and reimaged with a 25-cm lens. Calculation is for phase shift at focus of $\Delta \Phi = (2\pi/\lambda)\gamma I_0 = 0.288$ rad where $\gamma$ is the nonlinear index coefficient in cm$^2$/Watt.

b) Observed image under conditions similar to calculation in (a), although with pulse having ~30% of energy in finite rise and fall. Background light beyond image edge is from small-angle scattering in absorbing filters in front of ccd.
Nd:YAG Laser
\( w_0 = 1.1 \text{ cm} \)

Aperture
dia. = 0.7 cm

\( f_1 = 43 \text{ cm} \)

Sample

\( f_2 = 25 \text{ cm} \)

Reference arm
(similar to sample arm)

Energy Monitor

CCD camera
at image plane

Figure 1.
Fig. 2-(a) Sample at 10 cm after the focus

Sample at 1.4 cm before the focus

Fig. 2-(b) Sample at 10 cm after the focus

Sample at 1.4 cm before the focus

Intensity vs. Y-Direction (cm)

(Calculated)

(Experiment)