Bright spot behind the shadow of an illuminated object (or an intensity dip) moving along the surface of a nonlinear medium

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A new type of nonlinear refraction is studied: The formation of a bright spot behind the edge of a shadow of an illuminated object (a disk, a sphere, a half-plane, or a strip) which moves in the ray or which changes the shape of the ray in front of a layer of a nonlinear medium. The edge intensification of the brightness is measured and several photographs are shown. The observed effects are explained.

A special type of self-focusing (see the review in Ref. 1)—self-focusing in the intensity dips [where $(dn/dr) < 0$]—the so-called "banana" self-focusing, which was first reported in Refs. 2 and 3 and studied in detail in Refs. 4–8, is an important feature in media in which the refractive index decreases as a result of laser heating (such media are widely used ordinary media). A sufficiently large change in the refractive index in this case causes the formation of a focal point in the region in which the intensity initially decreases at a certain distance, $L \sim a/\sqrt{\Delta n}$, which is greater than the radius of this region.

In this letter we report the results of a study of a new type of nonlinear refraction: edge self-focusing which arises as a result of the motion of a shadow or as a result of an intensity dip in the radiation flux. The intensity of a bright spot trailing the shadow here may be much more brilliant than that in the central region of the banana self-focusing.

The schematic diagram of the apparatus is shown in Fig. 1. A neodymium laser

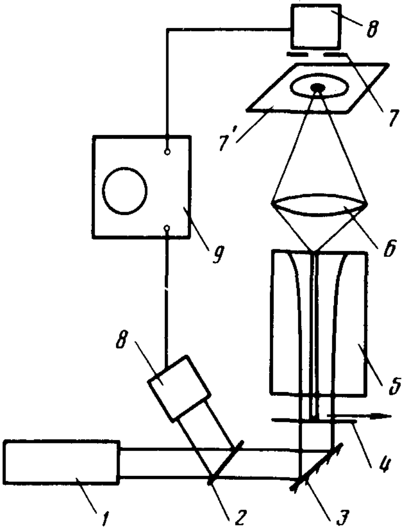

FIG. 1. Experimental arrangement.

(1) using a GSGG crystal with a wavelength of 1.06 μm, a pulse repetition rate of 10 Hz, and a free-running energy per pulse of 0.1 J is aimed by a mirror (3) into a cell (5) containing a nonlinear medium (alcohol, water) in which the nonlinear refraction occurs.[2] The length of the nonlinear layer l is commensurate with the length l_a of the light absorption, $l \cong l_a \cong 7$ cm. The radiation profile at the surface is focused by a lens (6) on the surface of a visual display screen (7′) or on a plate (7) with an aperture, through which the light with a local intensity strikes a photoaxial cell (8) which directs the signal to an oscilloscope (9) through an integrating cell which smooths out the lasing spikes. The photoaxial control cell used for monitoring and measuring the incident light detects the light from a glass plate (2).

An object (a half-plane, a strip, or a disk) which creates a shadow (or an intensity dip) in the ray before it enters the nonlinear medium was mounted in a glass plate (4) which could be moved in the desired direction by means of the sample driver. The velocity and acceleration of the shadow were controlled from the image on the display screen, and the trajectory was carefully traced, facilitating the photoelectronic measurement of the local intensity.

A bright, nonstationary, banana self-focuisng spot, which was formed as a result of placing a stationary disk on the surface of the medium and applying a given power, faded upon establishment of the process (upon replacement of the substance due to the convection). The aperture through which the light was transmitted to the meter was positioned at this point.

The motion of the object led to the appearance of a moving dark spot, followed immediately by a very bright spot of light (see Fig. 2a and, for comparison, the nonstationary banana in Fig. 2b and the stationary banana in Fig. 2c).

The measurements have shown that a moving bright spot is several times brighter (3–5 times) than a moving banana self-focusing spot (see Figs. 3a and 3b). The brightness peaked during the inital motion.

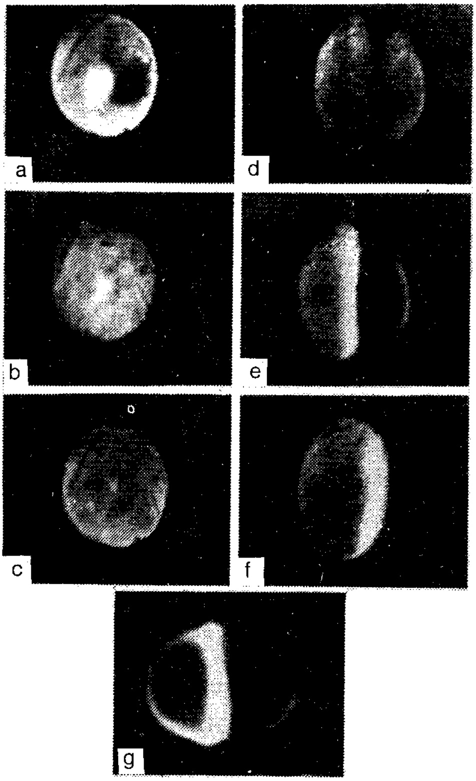

FIG. 2. Photographs of the images at the boundary of the medium. (a) For the motion (from left to right) of a round object; (b) for a nonstationay banana self-focusing; (c) for stationary banana self-focusing; (d) for a stationary strip; (e) for a moving strip (from left to right); (f) for a moving half-plane. The photographs show images situated 15 cm from the boundary of the medium. (f) For the motion of a strip from left to right .

The oscilloscope traces of the signal from the photodetector show the brightness and the time over which it increases when the spot is in motion. At a velocity $v = 0.5$ cm/s and a spot size of 1 or 2 mm, the brightness increases in 0.3 s (based on a signal decay by a factor of e).

The appearance of a bright spot is caused by a nonlinear variation in the contrast of the refractive index $\Delta n l^2/a \cong a$, i.e., $n'_T \Pi^2/C\rho l_a v \cong a$, where I is the light intensity, l_a is the absorption length, and $C\rho$ is the volume heat capacity, and by the formation of a distributed lens as a result of heating and relaxation. Because of the geometry and contrast, this lens turned out to be more efficient than in the case of banana self-focusing.

We have also studied the refraction near the edge of the direct shadow of a strip or a half-plane moving in the beam before it entered the medium. I other words, we studied the refraction resulting from the change in the shape of the beam. The most graphic images are those of a moving strip which are seen when the brightness of light in front of the shadow of the strip is contrasted with that behind it (see Fig. 2, d and e), where the bright strip of higher intensity accompanies the motion of the shadow, where the image is produced in the case of a stationary strip under the same conditions (Fig. 2, d and e), and where the image is produced when the plane moves to the right (Fig. 2f).

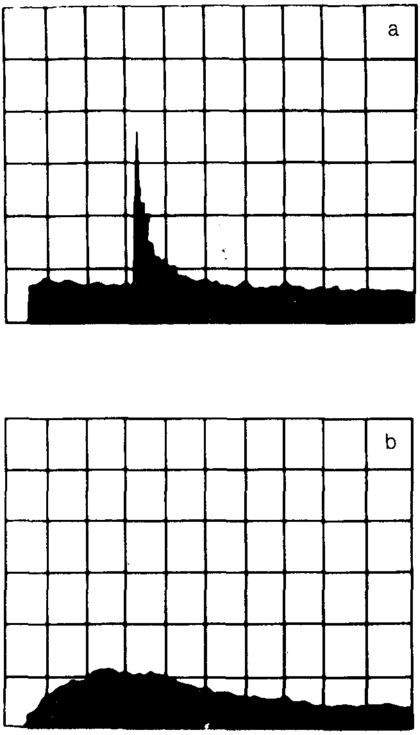

FIG. 3. Oscilloscope traces of the photoelectronic detection of the change in the intensity distribution at the layer boundary of the medium. (a) For a moving object; (b) for a banana self-focusing. The sweep rate is 1s/div.

Similar effects occurring at a certain distance from the nonlinear medium were also studied. In this case, the lens was removed and the display screen and the meter were placed 15 cm from the medium. For comparison, we consider a moving strip in Fig. 2g.

In describing the observed effect we will first show that the intensity always increases behind the moving object. Introducing the initial intensity of light (the intensity of light before it strikes the layer) in the form $I(x - vt)$, we find that the slope angle is $\theta \cong (\partial n/\partial x)\ l = (n'_T l/C\rho l_a)(\partial/\partial x)\int I dt \sim -(1/v)I$ [since at $v = \text{const}$ we have $(\partial/\partial x) = -(1/v)(\partial/\partial t)$] and that $\theta > 0$ in the clockwise direction up the n scale.

The condition under which the rays are bunched, $\partial\theta/dx < 0$, will then be satisfied for $-(n'_T/v)(\partial I/\partial x) < 0$, and for $n'_T < 0$, for $(1/v)(\partial I/\partial x) < 0$, i.e., behind the detecting edge, while the rays are sloped in the direction of the motion.

We can write the detecting intensity, for example, in the form $I \sim 1 - \exp[-\alpha(x_t - x)]$ or in the form $I \sim (x_t - x)^m$, were $x_t = vt$ is the coordinate of the detecting front. For the uniform motion we immediately find $\theta \sim (\partial/\partial x)\int_{t_x}^{t} I dt \cong I$. We can thus choose any type of functions for analysis, without taking special measures to integrate them.

A moving strip, for example, can easily be simulated as a hyper-Gaussian function, $I \sim 1 - \exp[(x - vt)^{2m}/a^{2m}]$ and $\theta \sim (-n'_T)(1/v)I$. For any type of motion

$v(t)$ a sharp edge can be used to find θ. In this case, we have $\Delta n \sim n'_T \int_{t_x}^{t} I dt$, where t_x is the time the edge passes through the point x. From the specification of $x_k(t)$ we find $t_k(x)$ and $\theta \sim (\partial n/\partial x) \sim -n'_T(\partial t_k/\partial x) I = -[n_T/v(t)]I$. We thus immediately see that rays slope in the direction of motion of the edge of the object.

In the image plane the corresponding coordinate of the ray is $X = x + \theta(x)l$ an the maxima of the bunching of rays are determined from the condition $X'_x \cong 0$.

In the media with $n'_T > 0$ the maximum moves in front of the moving edge.

We immediately see that the effect can be enhanced by choosing $v(t)$ appropriately, by changing the surface curvature, or by specifying $I(x,t)$. These focusing capabilities set this geometry apart from weaker effects occurring at the edge of a moving solid ray which is responsible for the defocusing refraction at the curved edge of the shadow in front of the moving ray.

The phenomena described here can occur as a result of exposure of an object to light which moves in a nonlinear medium or as a result of motion of the medium. These phenomean can be used to increase the intensity of light, to improve the identification capability, and in other applications.

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