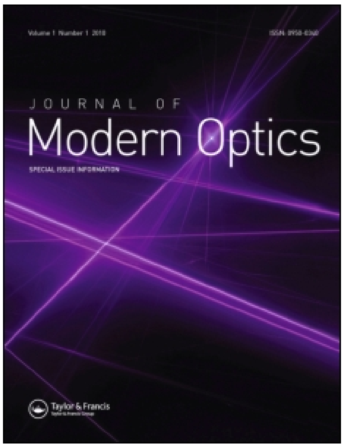

Journal of Modern Optics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713191304

Pulse Propagation in a Gaseous Laser Amplifier

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To cite this Article Aboites, V. andTorres-Cisneros, G. E.(1988) 'Pulse Propagation in a Gaseous Laser Amplifier', Journal of Modern Optics, 35: 11, 1865 — 1868
To link to this Article: DOI: 10.1080/09500348814552041
URL: http://dx.doi.org/10.1080/09500348814552041

JOURNAL OF MODERN OPTICS, 1988, VOL. 35, NO. 11, 1865–1868

Pulse propagation in a gaseous laser amplifier

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(*Received 15 February 1988 and accepted 20 May 1988*)

Abstract. It is shown that some transversal profile modifications, such as 'overshoot' at the edges of laser pulses propagating through gaseous laser amplifiers, can be qualitatively explained when diffusion of the active centres of the amplifier is taken into account. The necessary conditions for this situation to occur are also discussed and numerical results are presented which are in good agreement with previously obtained experimental results.

1. Introduction

The propagation of a laser pulse through an amplifier is an important practical problem which has been studied by several authors. In this paper, computational results are presented for the case in which the amplifier medium is gaseous. It is shown that some profile modifications, such as 'overshoot' at the edges of the laser pulse, can be qualitatively explained when diffusion of the active centres is taken into account. This is in agreement with experimental results obtained elsewhere [1].

2. Computer simulation

A computer code was developed to solve the photon transport equation [2, 3] in a cylindrical amplifier

$$\mathrm{d}S/\mathrm{d}z = [K(r, z) - p]S, \qquad (1)$$

where $S = S(r, z)$ is the photon density of the laser pulse propagating through the amplifier, p is the averaged coefficient of losses, z and r are the longitudinal and radial coordinates, respectively, and $K(r, z)$ is the amplification coefficient which is given by [4, 5]

$$K(r, z) = K_0/\{1 + [S(r, z)/S_0]\}, \qquad (2)$$

where K_0 is the unsaturated amplification coefficient and S_0 is the saturation parameter. It is assumed that an incoherent two-level resonant interaction takes place between a high and low energy level of population density N_2 and N_1 respectively, where the total population density $N_1 + N_2$ is fixed. The amplification coefficient given in equation (2) is also related to the optical cross-section of the resonant atomic transition o_{12} and to the atomic population inversion density $(N_2 - N_1)$ through the equation [2, 6]

$$K(r, z) = (N_2 - N_1)o_{12}. \qquad (3)$$

Given an initial laser pulse of photon-density distribution $S(r, 0)$, equation (1) gives the amplification of this pulse and, according to equation (2), this amplified pulse will cause a larger diminution of the amplification coefficient K in the regions where the photon density S is larger. For example, if a laser pulse with an initial Gaussian transverse profile is propagating, the amplification coefficient will diminish faster along the axis of the amplifier than far off-axis, causing a spatial inhomogeneity in the distribution of the amplification coefficient.

Diffusion of the active centres will therefore occur according to the diffusion equation

$$J(N_2) = -D\,\mathrm{d}N_2/\mathrm{d}r, \tag{4}$$

where $J(N_2)$ is the radial flux density of the population density N_2 and D is a dimensional parametrized diffusion coefficient. An analogous equation holds for N_1.

In order to observe any diffusion effect the laser pulse-length t (f.w.h.m.), should be larger than the mean free time between collisions w of the amplifier gas molecules. The condition may be expressed as

$$tf \gg 1, \tag{5}$$

where $f = 1/w$ is the collision frequency. Also, the excited mean lifetime of the active centres T, must be of the same order or larger than the pulse length t, that is

$$T \geqslant t. \tag{6}$$

Under these assumptions, we numerically solved equations (1), (2) and (4) for normalized incident pulses, zero loss-coefficient (this coefficient does not have a significant bearing on the physics of the problem) and various different initial conditions. Given an initial pulse distribution, equation (1) gives the amplified pulse-distribution after the propagation of the pulse through a differential of space Δz. Then, equation (2) gives the modification to the initial amplification-coefficient distribution caused by the propagation of the pulse through Δz. Finally, equation (4) gives the change to the amplification-coefficient distribution due to diffusion of the active centres. This cycle is repeated until the total length of the amplifier has been reached.

The initial photon-density distribution was of the form $S(r, 0) \sim \exp(-r^{10})$. Figure (1 (*a*)) shows the initial time-integrated radial transverse profile and figures 1 (*b*, *c*, *d*) shows the results obtained for the same profiles for a maximum value of 40%, 12% and 3% of the saturation value and with diffusion coefficient $D = 0{\cdot}032$ and amplification coefficient $K_0 = 0{\cdot}06$.

It can be seen that a peak develops on the side of the pulse profile due to the radial diffusion of the active centres from the sides of the amplifier towards its axis. It can also be observed that, the larger the saturation percentage of the incident beam, the more significant are the diffusion effects. This is an expected result because, the larger the saturation percentage of the incident beam, the larger will be the gradient of active centres between the sides of the amplifier and the central region where the beam is propagating, and therefore the stronger are the diffusion effects. Figure 2 shows the experimental results [1] of the time-integrated transverse energy-density distribution obtained when a 750 ps laser pulse propagates through a high-power iodine laser amplifier for the same saturation values as those we have simulated. Figure 2 (*a*) shows the profile of the incident beam and figures 2 (*b*)–(*d*) show the results obtained for saturation values of 40%, 12% and 3% respectively.

Figure 3 shows the radial and temporal profile of the initial and the final pulse calculated by our program for a saturation value of 40% with the same parameters as in figure 1. It can be seen that, initially, the pulse is strongly amplified but that the

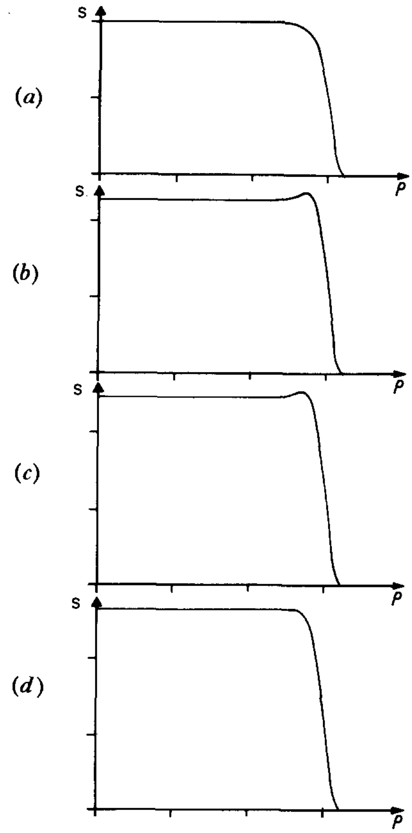

Figure 1. Computer results for the time-integrated transverse energy profiles: (*a*) incident beam profile (in arbitrary units); (*b*)–(*d*) results obtained for saturation values of 40%, 12% and 3% respectively.

amplification-rate diminishes as the pulse propagates due to the reduction of excited active centres. Once again, growth of a peak and an 'overshoot' on the side of the pulse is due to radial diffusion of excited active centres from the sides of the amplifier towards its centre.

As we can see, there is a reasonably good qualitative agreement for the overall effect between the experimental results and those obtained with our computer model. In [1], a computer simulation was developed to qualitatively explain their experimental results. Their model consisted of the numerical solution of the paraxial wave equation with gain including the effect of diffraction rather than of diffusion as we have considered here.

3. Conclusion

It is shown that a simple numerical model for studying the propagation of laser pulses through gas laser amplifiers, taking the diffusion of active centres into account, explains reasonably well previously obtained experimental results.

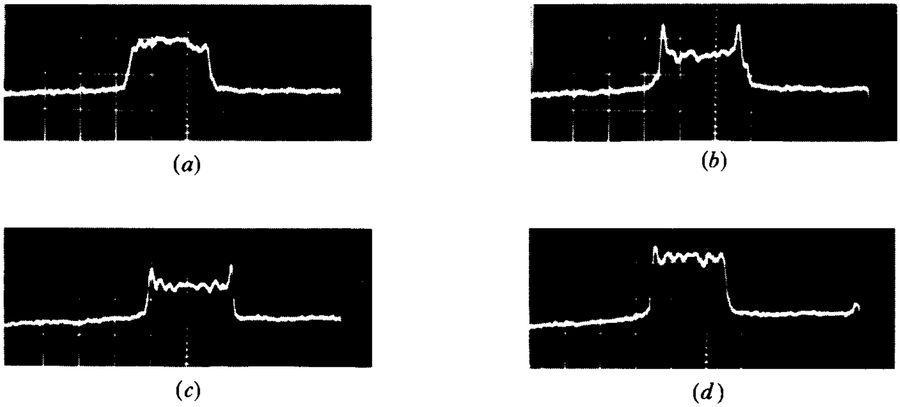

Figure 2. Experimental results for the time-integrated transverse energy distribution obtained when a laser pulse propagates through a high-power iodine laser amplifier (all at 100 mV and 5 μs): (*a*) incident beam profile; (*b*)–(*d*) result, obtained for saturation values of 40%, 12% and 3% respectively. (Taken from [1].)

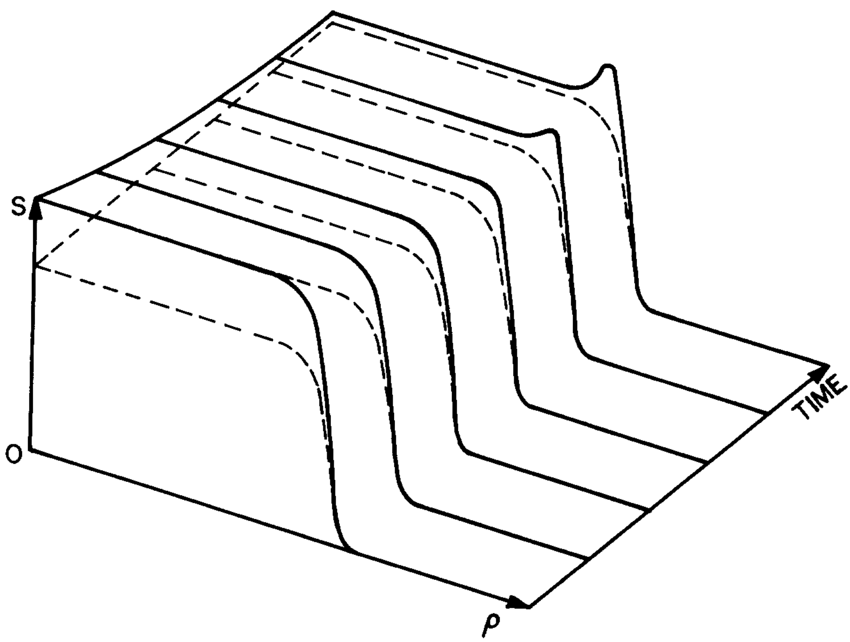

Figure 3. Radial and temporal profile of initial and final pulses calculated by our program for a saturation value of 40%.

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