NONLINEAR AMPLIFICATION OF STRONG LIGHT-PULSE IN MULTICOMPONENT MEDIA

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From the energy balance equations general dependences have been found which permit the variations to be analyzed of time- and space-distribution of the radiation intensity, in a multicomponent medium containing L classes of active centres interacting with the radiation through a single or multiphoton resonance process. Taking advantage of the obtained dependences and numerical solutions to the propagation equations, the basic features have been analyzed of the non-linear amplification of a light pulse in the medium with a single-photon amplification and two-photon absorption. The results have been presented of the preliminary experimental studies on the amplification of a nanosecond laser pulse in such a medium.

1. Introduction

Controlling the parameters of high-power laser pulses is one of the major problems of the laser technology and related fields. The immediate interest of these problems is connected with a wide spectrum of physical and technological application of the laser radiation and, among other things, researches carried out on a large scale into the laser-induced thermonuclear fusion [1–4].

There exists a distinct possibility of controlling certain parameters of nano- and pico-second pulses with the aid of resonance non-linear, optical phenomena.

In a number of works dealing with the formation of high-power pulses, the possibility

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of effecting certain processes of controlling (such as variation of the pulse length, slope of the fore front, contrast etc.) was justified on the strength of non-linearity of the saturation type. Some of the works, both theoretical and experimental [5–12], indicate the possibility of utilizing to this end the multiphoton processes as well. It has been demonstrated in these works, in particular, that the resonance two-photon processes are sufficiently effective to be applied in practice. In [12, 13] it has been found experimentally that at reasonably high intensities $\left(\sim 10^8 \div 10^{10} \frac{\mathrm{W}}{\mathrm{cm}^2}\right)$ there may occur noncoherent saturation of the two-photon absorption.

The possibility of controlling the pulse parameters may be appreciably widened if a multi-component medium is utilized as a laser medium, that is a medium containing several types of active centres[1] which are introduced into one host as admixtures or are present in several hosts arranged in the form of layers in the path of radiation. Effects may be obtained in such a medium, which it is impossible to obtain in each of the classes separately. In this paper the energy balance equations have been used for describing the non--coherent propagation of a light pulse in a multi-component medium containing active centres interacting with the radiation through a one- or a two-photon process. On the basis of these equations general dependences have been formulated which permit an effective analysis to be made of the time-space parameters of the radiation. Some of the effects have been analyzed which accompany the non-linear pulse amplification in a two-component medium with a single-photon amplification and two-photon absorption. The results have been presented of preliminary experimental studies on the non-linear amplification of a nanosecond pulse in such a medium.

2. *Model of medium. Equations of propagation*

We shall consider the noncoherent interaction of the light pulse of a frequency ω with a medium containing L classes of active centres not interacting with one another. Two energy levels, between which there occurs an m-photon ($m = 1, 2$) stimulated transition under the influence of the pulse field, will be designated by E_m^a, E_m^b. Among the L classes of active centres, L_1 classes will be distinguished wherein the population variation of these levels takes place, through a single-photon process ($E_1^a - E_1^b \approx \hbar\omega$), and L_2 classes, wherein this variation takes place through a two-photon process ($E_2^a - E_2^b \approx 2\hbar\omega$), so that $L_1 + L_2 = L$.

Each of these classes will be annotated by the subscript "lm"($l = 1, 2, \ldots, L_m$, $m = 1,2$) and characterized by the quantities: N_{lm}, σ_{lm}, T_{lm}, s_{lm}, where: N_{lm} — effective difference of population densities of the levels a, b; $\sigma_{lm} J^{m-1}$ — cross section for the m-photon transition; $J\hbar\omega$ — intensity; T_{lm} — effective relaxation time of the population difference of the levels a, b; s_{lm} — parameter dependent upon the work diagram of the active centre (in the two-level diagram $s_{lm} = 2$, the three-level diagram — $s_{lm} = 1$ and so on).

[1] Atoms, ions and molecules with normal or inversion population.

The propagation equation is taken to be in the form

$$\left[\frac{1}{v}\frac{\partial}{\partial t}+\frac{1}{r^a}\frac{\partial}{\partial r}r^a-K(t,r,\Theta)\right]J(t,r,\Theta)=0 \tag{2.1}$$

$$K=\sum_{m=1}^{2}\sum_{l=1}^{Lm} m\sigma_{lm}N_{lm}(t,r,\Theta)J^{m-1}(t,r,\Theta)-\varrho \tag{2.2}$$

$$\frac{\partial N_{lm}}{\partial t}+\frac{N_{lm}-N_{lm}^e}{T_{lm}}+s_{lm}\sigma_{lm}N_{lm}J^m=0,\quad l=1,2,\dots L_m,\quad m=1,2, \tag{2.3}$$

where t is the time, r — spatial variable, Θ — parameter defining the direction of the light ray in the laser beam, ϱ — non-resonant loss factor, v — velocity of light in the medium, N_{lm}^e — difference of population densities in the state of thermodynamic equilibrium, and $a = 0, 1, 2$ respectively, for the radiation beam with a plane, cylindrical or spherical wave front. The function K will be referred to as the medium-amplification function. The equations (1)–(2) can be sometimes conveniently analyzed in the variables $r, \tau = t-\frac{r}{v}$.

In these variables the transport equation has the form

$$\left[\frac{\partial}{\partial r}+\frac{a}{r}-K(\tau,r,\Theta,J)\right]J(\tau,r,\Theta)=0 \tag{2.4}$$

In the case of a quasistationary saturation, that is at $\tau_p \gg T_{lm}$ (τ_p — pulse with at half height), we obtain from equation (2.3)

$$N_{lm}=N_{lm}^e[1+s_{lm}\sigma_{lm}T_{lm}J^m]^{-1}. \tag{2.4'}$$

As is evident, the population difference is a function of the momentary pulse-intensity. The saturation parameter is expressed by the quantity

$$J_{lm}^s=[s_{lm}\sigma_{lm}T_{lm}]^{-\frac{1}{m}}. \tag{2.5}$$

At $\tau_p \ll T_{lm}$ (non-stationary saturation), from the equation (2.3) we have

$$N_{lm}=N_{lm}^e\exp\left[-s_{lm}\sigma_{lm}\int_{-\infty}^{t}J^m dt\right]. \tag{2.6}$$

In this case the saturation parameter has the explicit form solely for $m=1: \varepsilon_l^s=[s_{l_1}\sigma_{l_2}]^{-1}$.

3. *Pulse-length variation in non-linear medium*

In order to describe the pulse-length variation in the medium the function of time compression is introduced

$$T=-\frac{1}{\tau_p}\frac{d\tau_p}{dr} \tag{3.1}$$

where τ_p is the effective pulse length defined by the relations[2]

$$\tau_p(r) = \tau_2(r) - \tau_1(r), \quad J[r, \tau_1(r)] = \tfrac{1}{2} J_h(r) = J[r, \tau_2(r)]. \tag{3.2}$$

In the expressions (3.2) $J_h(r) = J(r, \tau_h)$, while τ_h, τ_1, τ_2 are the points, respectively, at the maximum, the fore- and the rear pulse front. From the definition of T it follows that at $T > 0$ there occurs a pulse compression, while at $T < 0$ — a pulse widening. By differentiating (3.2) and making use of (2.4) we obtain

$$T = \frac{\delta_1}{2}[K(r, J_h, \tau_h) - K(r, \tfrac{1}{2} J_h, \tau_1)] + \frac{\delta_2}{2}[K(r, J_h, \tau_h) - K(r, \tfrac{1}{2} J_h, \tau_2)], \tag{3.3}$$

where $\delta_1, \delta_2 > 0$ are the slope coefficients, respectively, of the fore- and the rear front, defined by the relations

$$\left.\frac{\partial J(\tau, r)}{\partial \tau}\right|_{\tau_1} = \frac{1}{\delta_1(r)} \cdot \frac{J_h(r)}{\tau_p(r)}, \quad \left.\frac{\partial J(\tau, r)}{\partial \tau}\right|_{\tau_2} = -\frac{1}{\delta_2(r)} \cdot \frac{J_h(r)}{\tau_p(r)}.$$

For the monotonic functions of amplification the coefficients δ_1, δ_2 are usually slow--changing functions of r, in comparison with $J_h(r)$ and $\tau_p(r)$.

As is seen from (3.3) and (2.6) at a non-stationary interaction, both the direction and the speed of the pulse length variation depended substantially upon the pulse shape and, in particular, upon its symmetry.

$\delta_1 \gg \delta_2$ is a satisfactory condition for the pulse compression to take place in the non-stationary case in the medium with $K > 0$.

If K does not depend explicitly upon the time, we obtain from (3.3)

$$T = \frac{\delta_1 + \delta_2}{2}[K(r, J_h) - K(r, \tfrac{1}{2} J_h)]. \tag{3.4}$$

In this case the direction of variations of τ_p does not depend upon the pulse shape; it is only the speed of these variations that depends upon the pulse shape. Moreover, the variation speed of τ_p in contrast to the non-stationary case, depends only slightly upon the pulse symmetry. The satisfactory condition of the pulse compression is $\frac{\partial K}{\partial J} > 0$.

The dependence of τ_p upon the pulse peak-intensity J_h, in the absence of the explicit dependence of K upon r, τ and small divergence of radiation, may be defined from the formula

$$\tau_p = \tau_p^0 \exp\left[-\int_{J_h^0}^{J_h} \frac{T(J_h)}{J_h K(J_h)} dJ_h\right], \tag{3.5}$$

where

$$\tau_p^0 = \tau_p(r = r_0), \quad J_h^0 = J_h(r = r_0).$$

[2] The dependence upon the parameter Θ is disregarded as being insignificant here.

For a multicomponent medium with the amplification function (2.2), the function of the compression takes the form:

$$T = \frac{\delta_1}{2}\sum_{m=1}^{2} J_h^{m-1}\sum_{l=1}^{Lm}[\beta_{lm}(J_h, \tau_h)-2^{1-m}\beta_{lm}(\tfrac{1}{2} J_h, \tau_1)]$$

$$+\frac{\delta_2}{2}\sum_{m=1}^{2} J_h^{m-1}\sum_{l=1}^{Lm}[\beta_{lm}(J_h, \tau_h)-2^{1-m}\beta_{lm}(\tfrac{1}{2} J_h, \tau_2)], \tag{3.6}$$

where

$$\beta_{lm} = m\sigma_{lm}N_{lm}.$$

In the case of a quasistationary saturation in a single-component medium we obtain from (3.6), (2.4) and (2.5)

$$T = \frac{\delta_1+\delta_2}{2}\beta_{lm}^e(J_{lm}^s)^{m-1}P_h^{m-1}\frac{(2^m-2)-P_h^m}{(1+P_h^m)(2^m+P_h^m)}, \tag{3.7}$$

where

$$\beta_{lm}^e = m\sigma_{lm}^e N_{lm}^e, \qquad P_h = J_h/J_{lm}^s.$$

As is evident, at $m = 1$ the direction of τ_p variation depends only upon the sign β_{lm}^e, the pulse compression occurring in the absorbing medium ($\beta_{lm}^e < 0$). For $m > 1$ the direction of τ_p variation is defined both by the sign β_{lm}^e and the magnitude of the pulse peak-intensity; in the absorbing medium the pulse compression occurs for $P_h > (2^m-2)^{1/m}$, whereas the pulse widening occurs for $P_h < (2^m-2)^{1/m}$.

The function T takes a particularly simple form in the case of the small signal ($P_h \ll 1$) namely

$$T = (1-2^{1-m})\frac{\delta_1+\delta_2}{2}\beta_{lm}^e J_h^{m-1}. \tag{3.8}$$

4. *Effect of medium upon transverse-distribution variation of radiation intensity*

In a medium with slight dependence of the refractive index upon the radiation intensity, useful information on the width variation of the transverse distribution of the radiation intensity may be obtained from the analysis of the function of the spatial compression, defined analogously to the function (3.1)

$$S = -\frac{1}{\Theta_p}\frac{d\Theta_p}{dr}, \tag{4.1}$$

where Θ_p is the angular width of the distribution, defined by the relations[3]

$$\Theta_p(r) = \Theta_2(r)-\Theta_1(r), \quad J[r, \Theta_1(r)] = J[r, \Theta_2(r)] = \tfrac{1}{2} J_W(r). \tag{4.2}$$

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[3] In this case the dependence upon τ is disregarded.

In these relations $J_W(r) = J(r, \Theta_W)$ while $\Theta_W, \Theta_1, \Theta_2$ are the angular co-ordinates, respectively, for the maximum and the slopes of the distribution.

Analogously to what was done for function T, the general inter dependence may be found between the functions S and K. In the case where $K(\Theta) = K(-\Theta)$ and $J^0(\Theta) = J^0(-\Theta)$ this dependence has the form

$$S = \gamma[K(r, \Theta = 0, J_W) - K(r, \Theta = \tfrac{1}{2}\Theta_p, \tfrac{1}{2}J_W)], \tag{4.3}$$

where the coefficient γ is defined by the formula

$$\frac{\partial J(\Theta, r)}{\partial \Theta}\bigg|_{\Theta_{1(2)}} = \frac{+}{(-)}\frac{1}{\gamma(r)} \cdot \frac{J_W(r)}{\Theta_p(r)}.$$

It will be seen from (4.3) that the intensity distribution variation in the medium is due to the non-linearity of the interaction and the distribution non-homogeneity of the active centres in the plane normal to the main propagation direction $\Theta = 0$. If this type non-homogeneity does not occur and K does not depend explicitly upon time, then (4.3) becomes an expression analogous to (3.4), as a result of which all dependences obtained from (3.4) for τ_p are also valid for Θ_p. At the explicit dependence of $K(\tau)$ such a symmetry does not occur.

5. Non-linear pulse amplification in medium with single-photon amplification and two-photon absorption

Taking advantage of the equations and dependences formulated in the proceding sections we shall consider some of the aspects of the non-linear light-pulse amplification in a medium which contains both the active centres amplifying the radiation in a single-photon process and the centres absorbing the radiation in a two photon-process.

In such a medium, at a slight radiation divergence, the propagation equations take the form

$$\frac{1}{v}\frac{\partial J}{\partial t} + \frac{\partial J}{\partial r} = [\sigma_{11}N_{11} - 2\sigma_{12}N_{12}J - \varrho]J \tag{5.1}$$

$$\frac{\partial N_{1m}}{\partial t} + \frac{N_{1m} - N_{1m}^e}{T_{1m}} = -s_{1m}\sigma_{1m}N_{1m}J^m, \quad m = 1, 2, \tag{5.2}$$

where the subscript "11" designates the amplifying centres and the subscript "12" — the absorbing centres. We shall consider the case of a small signal (which causes no substantial population variation) as well as a quasistationary ($\tau_p \gg T_{12}$) and nonstationary ($\tau_p \ll T_{12}$) saturation of a two-photon absorption.

5.1. Small signal

The transport equation in the variables r, τ has the form

$$\frac{\partial J(\tau, r)}{\partial r} = [\alpha - \beta J - \varrho]J, \tag{5.1.1}$$

where

$$\alpha = \sigma_{11}N_{11}^{e} > 0, \qquad \beta = 2\sigma_{12}N_{12}^{e} > 0.$$

The amplification function $K = \alpha - \beta J - \varrho$ decreases in this case linearly with the radiation intensity. Its magnitude $J_g = \frac{\alpha-\varrho}{\beta}$ is the limiting intensity; at both $J_h^0 < J_g$ and $J_h^0 > J_g$ the radiation intensity tends asymptotically to the value J_g. It will be clear from the solution to the equation (5.1.1) which has the form

$$J(\tau, r) = J^0(\tau)e^{(\alpha-\varrho)l}\left\{1+\frac{J^0(\tau)}{J_g}\left[e^{(\alpha-\varrho)l}-1\right]\right\}^{-1}, \tag{5.1.2}$$

where $l = r - r_0$. Since $K(J)$ is a decreasing function, the pulse undergoes a widening in the medium at a relative velocity

$$T = -\frac{\delta_1+\delta_2}{4}\beta J_h. \tag{5.1.3}$$

The dependence τ_p upon the peak pulse-intensity has the form (see formula (3.5))

$$\tau_p = \tau_p^0\left|\frac{J_h^0-J_g}{J_h-J_g}\right|^{\delta/2}, \tag{5.1.4}$$

where $\delta/2$ is the mean value of the function $\frac{1}{2}[\delta_1(J_h)+\delta_2(J_h)]$ in the variation interval under consideration. From (5.1.2) and (5.1.4) one can obtain the dependence $\tau_p(l)$

$$\tau_p(l) = \tau_p^0\left\{1+\frac{J_h^0}{J_g}\left[e^{(\alpha-\varrho)l}-1\right]\right\}^{\delta/2}. \tag{5.1.5}$$

It is evident, that if $a > \varrho$ then, at $l \to \infty$ for a pulse with infinite fronts, $\tau_p \to \infty$. The shape of a pulse with finite fronts tends to become rectangular.

5.2. Quasi-stationary saturation of two-photon absorption

The transport equation at $\varepsilon \ll \varepsilon_{11}^{s}$ takes the form

$$\frac{\partial P(\tau, r)}{\partial r} = P\left[\alpha - \frac{\beta_s P}{1+P^2} - \varrho\right], \tag{5.2.1}$$

where

$$\beta_s = 2\sigma_{12}N_{12}^{e}J_{12}^{s}, \qquad P = \frac{J}{J_{12}^{s}}, \qquad J_{12}^{s} = (s_{12}\sigma_{12}T_{12})^{-1/2}.$$

The solution to the equation (5.2.1) is given in the implicit form. The amplification function is defined by the relation

$$K = \alpha - \frac{\beta_s P}{1+P^2} - \varrho. \tag{5.2.2}$$

The dependence $K(P)$ is represented in Fig. 1a. The value P_1, P_2 in this figure are given by the expression

$$P_{1(2)} = \frac{\beta_s(\mp)\sqrt{\beta_s^2-4(\alpha-\varrho)^2}}{2(\alpha-\varrho)}$$

It will be seen that, at $\beta_s > 2(\alpha-\varrho)$ the medium is an amplifying one solely for the intensities lower than P_1 or higher than P_2. The point P_1 is a stable one so that a deviation from this point in the direction of higher or lower intensities leads, in the course of propagation, to a return of the radiation intensities to the value P_1. The point P_2 is an unstable one.

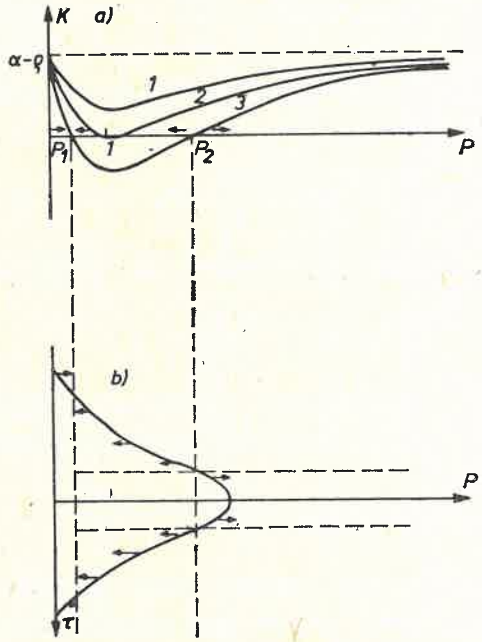

Fig. 1a. Dependence of amplification function of two-component medium upon intensity at quasistationary saturation of two-photon absorption; curves: $1-\beta_s < 2(\alpha-\varrho)$; $2-\beta_s = 2(\alpha-\varrho)$; $3-\beta_s > 2(\alpha-\varrho)$, b. direction of pulse intensity variation in a medium with $\beta_s > 2(\alpha-\varrho)$

The existence of the stable point of the amplification function at $\beta_s > 2(\alpha-\varrho)$ offers the possibility of utilizing the two-component medium under study for stabilizing the power of strong laser pulses. By selecting appropriately the parameters α, β_s, ϱ, one can obtain, at the medium-output, a pulse of the wanted peak power.

In Fig. 1b can be seen the characteristic features of the pulse evolution in the two-component medium. If $P_h^0 > P_2$, then the base and the apex of the pulse undergo an amplification, whereas the central parts of the pulse slopes are being absorbed. The variation rate of the pulse length at its half-height is described by the time-compression function having the form

$$T = \frac{\delta_1+\delta_2}{2}\beta_s P_h \frac{P_h^2-2}{(1+P_h^2)(4+P_h^2)}. \tag{5.2.3}$$

Fig. 2 shows a graph of the dependence $T(P_h)$. By making use of this graph as well as the graphs in Fig. 1a, the pulse evolution in the two-component medium may be studied at various input parameters of the pulse and medium. By way of example let $\beta_s > 2(\alpha-\varrho)$ and $\sqrt{2} < P_h^0 < P_2$. It will be seen from Fig. 1a and 2 that in this case P_h will decrease

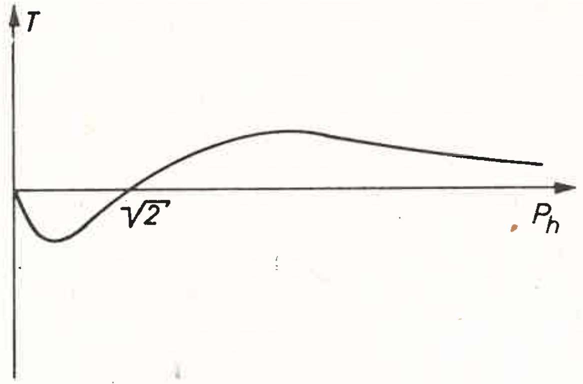

Fig. 2. Dependence of time-compression function upon peak pulse-intensity at quasistationary saturation of two-photon absorption

asymptotically to the value P_1, while the pulse length at half-height will decrease at first, and then, from the value $P_h = \sqrt{2}$ on, increase.

As shown above, the basic feature of the medium under analysis, at $\tau_p \gg T_{12}$ and $\varepsilon \ll \varepsilon_{11}^s$ is the non-monotone dependence $K(P)$ and the possibility of the occurrence of two zero-places of the amplification function. This feature of the medium has a decisive influence upon the pulse evolution also when $\varepsilon \sim \varepsilon_{11}^s$. In this case, too, the parameters α, β_s, ϱ can be selected in such a way that the momentary dependence $K(P_h)$ should have two zero-places. The basic, qualitative difference between the two cases is the absence of the amplification symmetry of the fore and the rear front at $\varepsilon \sim \varepsilon_{11}^s$. The nature of the pulse evolution at $\varepsilon \sim \varepsilon_{11}^s$ is determined not only by the parameter P_h^0 but also by $\varepsilon_h^0 = \int_{-\infty}^{\tau_h} J^0(\tau)\,d\tau$, that is the energy carried by the pulse fore-front.

The results are represented in Figs 3 and 4 of the numerical analysis of the transport equation which at $\varepsilon \sim \varepsilon_{11}^s$ has the form

$$\frac{\partial P(\tau, r)}{\partial r} = P\left[\alpha \exp\left(-\lambda \int_{-\infty}^{\tau} P d\tau\right) - \frac{\beta_s P}{1+P^2} - \varrho\right],$$

where $\lambda = \dfrac{J_{12}^s}{\varepsilon_{11}^s}$. In the two figures the pulse entering the medium has the Gaussian form and the peak intensity value is the same: $P_h^0 = 2.5 > P_2 > 0$, whereas the value of ε_h^0 are different. Substantial differences can be seen in both the variation of P_h and τ_p and the pulse shape in the two cases.

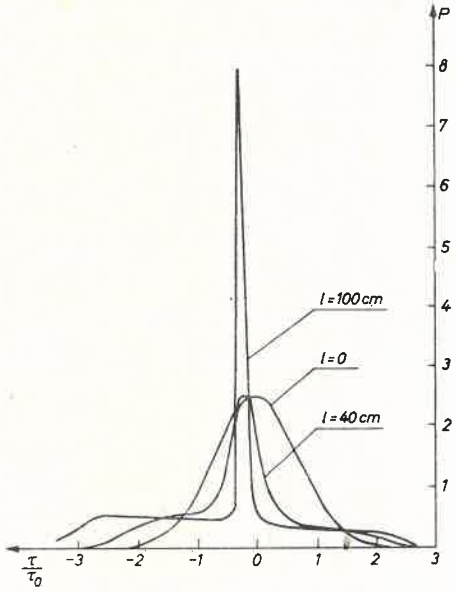

Fig. 3. Gaussian-pulse evolution in two-component medium at quasistationary saturation of two-photon absorption. $\alpha = 0.1\ \text{cm}^{-1}$, $\varrho = 0.01\ \text{cm}^{-1}$, $\beta_s = 0.2\ \text{cm}^{-1}$, $\lambda = 10^9\ \text{s}^{-1}$, $P_h = 2.5$, $\varepsilon_h^0 = 0.25\,\varepsilon_{11}^s$

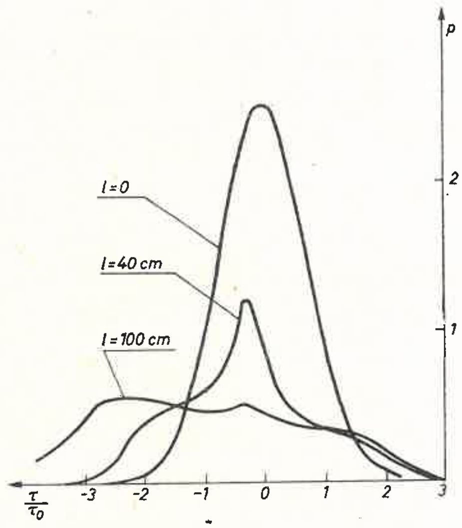

Fig. 4. Gaussian-pulse evolution in two-component medium at quasistationary saturation of two-photon absorption. $\alpha = 0.1\ \text{cm}^{-1}$, $\varrho = 0.01\ \text{cm}^{-1}$, $\beta_s = 0.2\ \text{cm}^{-1}$, $\lambda = 10^9\ \text{s}^{-1}$, $P_h^0 = 2.5$, $\varepsilon_h^0 = 0.4\,\varepsilon_{11}^s$

5.3. Nonstationary saturation of the two-photon absorption

A detailed quantative analysis of this case can be carried out only on the strenght of a numerical solution to the transport equation, which a $\varepsilon \ll \varepsilon_{11}^{s}$ has the form

$$\frac{\partial J(\tau, r)}{\partial r} = J\left[\alpha - \beta J \exp\left(-s_{12}\sigma_{12} \int_{-\infty}^{\tau} J^2 d\tau\right) - \varrho\right]. \qquad (5.3.1)$$

Certain qualitative features of the non-linear pulse-amplification may be revealed by analyzing the medium-amplification function

$$K = \alpha - \beta f(\tau) J_h \exp\left[-F(\tau) J_h^2\right] - \varrho, \qquad (5.3.2)$$

where

$$f(\tau) = \frac{J(\tau)}{J_h}, \quad F(\tau) = s_{12}\sigma_{12} \int_{-\infty}^{\tau} f^2(\tau')d\tau'.$$

Since K depends explicitly upon τ, the nature of the pulse evolution in the medium will to a large extent depend upon its shape. Nevertheless, a number of features can be distinguished which are common to pulses of different shapes.

The dependence of the amplification function in the pulse maximum K_h upon its peak intensity is shown in Fig. 5. As with the quasi-stationary saturation of the two-photon absorption this dependence is of a non-monotone nature. As a result of this there is a

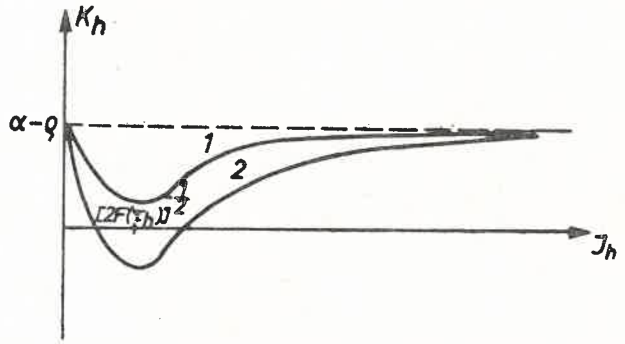

Fig. 5. Amplification function of two-component medium in pulse time-maximum at nonstationary saturation of two-photon absorption. $1-\beta < \sqrt{2eF(\tau_h)}\,(\alpha-\varrho)$; $2-\beta > \sqrt{2eF(\tau_h)}\,(\alpha-\varrho)$

possibility of both a pulse-compression and a pulse-widening in the medium. By making use of (2.6) and (3.6) it can be demonstrated that the function of time-compression in the case under consideration is negative in the region of low values of J_h and positive in the region of high ones, in comparison with

$$[2F(\tau_h)]^{-1/2}.$$

The characteristic features of the dependence $K(\tau)$ are its non-monotone character and the occurrence of the amplification-function minimum at the pulse fore-front. In consequence of these features there should be a displacement of the pulse maximum in the direction of the increasing values of τ as well as a shortening of the forefront in the case of an intense saturation and its lengthening in the case of a weak saturation of the absorption. An appreciable pulse compression, connected with the shortening of its fore-front in the case of an intense saturation, is possible for the asymmetric pulse with a gentle fore-front and sharp rear-front that is at $\delta_1 \gg \delta_2$. On the whole, however, with the quasista-

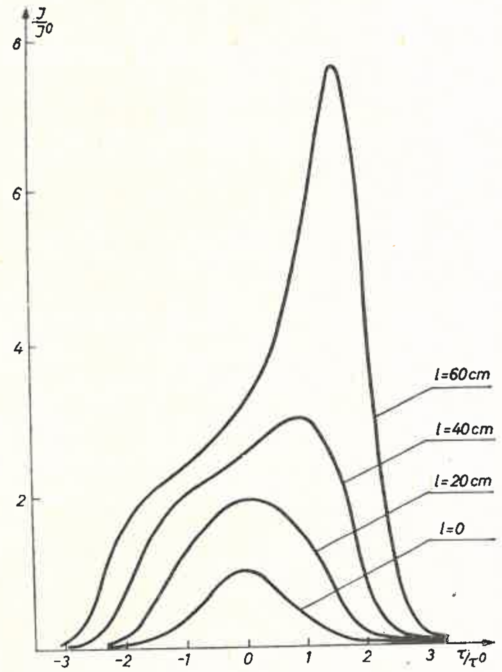

Fig. 6. Gaussian-pulse evolution in two-component medium at nonstationary saturation of two-photon absorption. $\alpha = 0.12\,\mathrm{cm}^{-1}$, $\varrho = 0.02\,\mathrm{cm}^{-1}$, $\beta = 10^{-29}$ cms, $s_{12}\delta_{12} = 2 \cdot 10^{-47}\,\mathrm{cm}^4\mathrm{s}$, $J_h^0 = 5 \cdot 10^{27}\,\frac{\text{Photon}}{\mathrm{cm}^2\,\mathrm{s}}$

tionary saturation of the two-photon absorption considerably higher compressions can be obtained than with the nonstationary saturation.

The corraboration of some of the conclusions here formulated can be found in Fig. 6, wherein the evolution is shown of the Gaussian pulse in the medium with $\beta < \sqrt{2F^0(\tau_h^0)e}\,(\alpha - \varrho)$, obtained from numerical solution of the equation (5.3.1).

5.4. Experiment

The purpose of the preliminary, experimental investigations of the non-linear pulse--amplification in the medium with a single-photon amplification and two-photon absorption has been a qualitative verification of some of the theoretical conclusions concerning the pulse-length and -shape variation in such a medium. The investigations were carried out in the setup reproduced in Fig. 7.

A generator on YAG: Nd^{3+} crystal with magnification modulation by a Pockels cell and a formation system composed of two Pockels cells — produced a pulse with a sharp fore-front of a length (at half-height) of ~10ns. After passing through two amplifiers the pulse entered the two-component medium under study, consisting of two amplifiers on ED-2 type neodymium glass and two plane parallel GaAs plates, each of a thickness

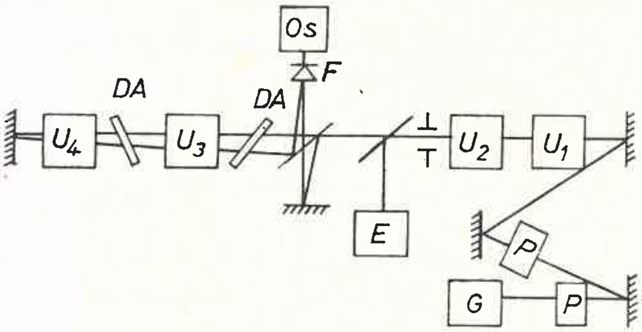

Fig. 7. Diagram of experimental setup, G — generator, P — Pockels' cells, U_1, U_2, U_3, U_4 — amplifiers, DA — two-photon absorbent, E — energy meter, F — photo-diode, Os — oscilloscope

of 0.05 cm. These plates played the role of a two-photon absorbent. The linear damping in the two GaAs plates was about fourfold, whereas the amplifiers U_3 and U_4 amplified the weak signal about seven times. With the radiation energy densities applied the amplifiers U_3 and U_4 worked within the linear range and did not deform the pulse.

Typical oscillograms of the pulse entering (on the left hand side) and leaving the two-component medium, obtained at various intensity values of the incoming pulse, are shown in Fig. 8. As is evident, for the lower intensities there occurs the widening of the pulse in the medium, whereas at higher intensities (osc. 3) the length of the pulse entering and leaving the medium is approximately the same, while the pulse shape is undergoing substantial variation. With the increase in the input intensity, the shape of the pulse leaving the medium varies from asymmetric with a short fore-front, through symmetric, to asymmetric with a long fore-front. The pulse apex shifts in the direction of the increasing values and this shift, at $J_h^0 \hbar\omega \sim 8 \cdot 10^7 \frac{\mathrm{W}}{\mathrm{cm}^2}$ is from 6 to 10 ns depending upon the shape of the pulse entering the medium. The amplification of the two-component medium $\left(\text{relation } \frac{J_h}{J_h^0}\right)$ decreases, within the range of intensity variation under study, in a mono-tone way with the increase in J_h^0 from the value ~1.8 for $J_h^0 \hbar\omega < 10^6 \frac{\mathrm{W}}{\mathrm{cm}^2}$, to ~0.8 for $J_h^0 \hbar\omega \sim 8 \cdot 10^7 \frac{\mathrm{W}}{\mathrm{cm}^2}$.

The picture presented here is in a qualitative accord with the picture of the non-linear amplification in the two-component medium at the nonstationary saturation of the two-photon absorption (see Section 5c and Fig. 6). A stronger absorption of the pulse fore-front as well as the accompanying lengthening of the fore-front and the shift of the apex in the direction of the increasing values of τ — is particularly clearly seen in the oscilogram 3.

The variation of the pulse parameters in the experiment under consideration was relatively insignificant, since the total length of the absorption path in GaAs was scarcely 0.2 cm. It is clear that by lengthening this path the effectiveness of the pulse formation in a two-component medium of the type under study — can be substantially enhanced.

6. Conclusion

The above considered two-component medium constitutes one of the simplest cases of a multi-component medium. As shown in Section 5 it possesses a number of properties which permit some of the parameters of a strong laser pulse to be controlled. The range of the parameters that can be controlled widens considerably if the medium is composed of a greater number of components. In particular, a three-component amplifier containing, beside single-photon amplifying centres, also single- and two--photon absorbing centres, enables already such processes to be implemented as: stabilization, discrimination and filtration of radiation power and energy, pulse shortening and lengthening, profiling the pulse time-shape and the spatial distribution of the radiation intensity. These processes may occur for both nanosecond and picosecond pulses. A multi-component medium placed in a laser resonator should also be characterized by a variety of work regimes. A sufficient effectiveness of the occurrence, in such a system, of two-photon processes, can be secured by an appropriate configuration of the resonator ensuring, for instance, the focusing of radiation in the layer of a two-photon absorbent. It appears, that both the multi-component amplifiers and multi-component generators, in view of their possibility of controlling the parameters of a strong laser radiation, may still further extend the application range of the radiation.

The problem of the pulse amplification, in a multi-component medium, may be viewed from a different stand-point as well. The laser media, which at relatively low radiation intensities may be treated as single-component media, in the regions of high intensities may show the features of two- or three-component media of the type under consideration. Examples of such media are the most widely used laser solid media, namely those of ruby-crystal- and neodymium glass-amplifiers. In these amplifiers, at $J \gtrsim 10^9 \div 10^{10} \frac{\mathrm{W}}{\mathrm{cm}^2}$, the two-photon radiation absorption occurs effectively enough [14, 15], so that, for a better understanding of their performance, they should be regarded as two-component amplifiers. From this point of view, then, a multi-component amplifier is a simple, though practically important, generalization of the traditional model of a laser amplifier.

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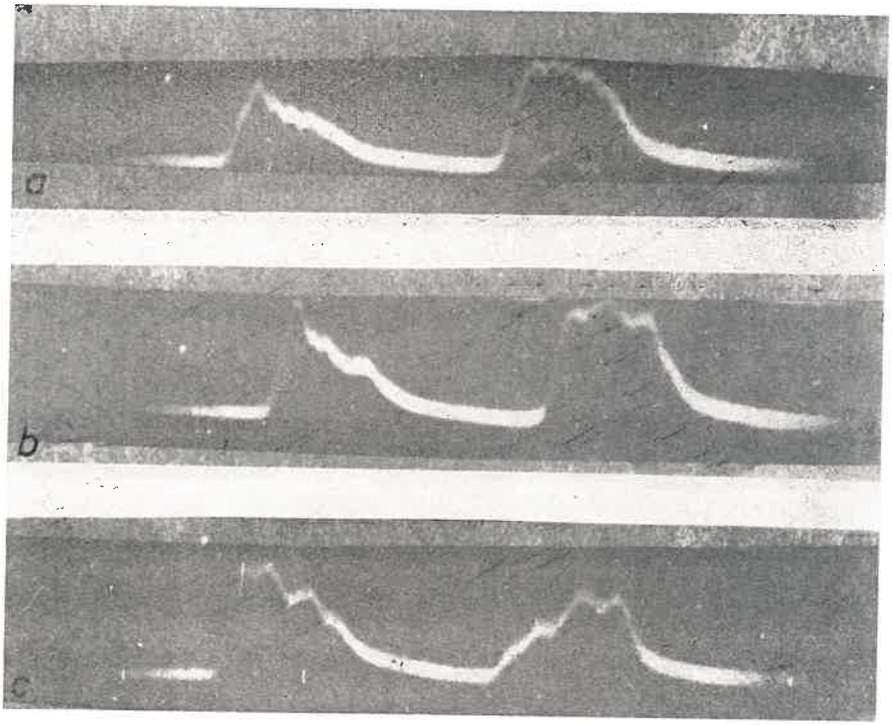

Fig. 8. Oscillograms of a pulse entering on the left-hand side and leaving the two-component medium

a — $J_h^0 \approx 1.5 \cdot 10^7 \frac{W}{cm^2}$, b — $J_h^0 \approx 4 \cdot 10^7 \frac{W}{cm^2}$, c — $J_h^0 \approx 8 \cdot 10^7 \frac{W}{cm^2}$

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