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THE EFFECT OF THE UNEXCITED PART OF THE LASER ACTIVE MATERIAL ON GENERATION

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Abstract: The effect of the unexcited part of the laser active material (ruby rod) on generation has been investigated for stationary and nonstationary pumping pulse. It was found that a single spike pulse is obtainable with a given nonstationary pumping, if the length of the unexcited part is chosen properly.

1. Introduction

In majority of cases, a part of the laser active material remains always unexcited when placed in a laser resonator. On the other hand, such an excitation can occur at which the laser active material may get excited in an inhomogeneous way, because of the spatial inhomogeneous radiation of the pumping light source. The question arose, what kind of an effect is exerted by the unexcited active material on the parameters of generation.

For an easier mathematical treatment, the inhomogeneities of excitation for ruby laser will be examined according to the following model. Let us assume that part L_1 of the active material length of L_0 is exposed to a homogeneous excitation, while part L_2 has remained unexcited (Fig. 1). Let N_0 be the number per cm^3 of the active ions of Cr^{3+}. Let $N = N_1 - N_2$ and $M = M_1 - M_2$ designate the rate of inversion in the excited and unexcited parts respectively, where N_1 and M_1 are denoting the concentration of ions in the ground state, and N_2 and M_2 in the excited state respectively. The lifetime of photons in the resonator, following(1), is $T = t_0/\gamma$, where t_0 means the transit time of the photons through the resonator, and γ is the loss factor. Let the number of photons per unit volume, on the wave-

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length of laser radiation, be Q, the absorption effect cross section σ and the quantum yield of the luminescence η. Let the number of photons, irradiated by the exciting light source into unit volume in unit time be W/t, where $W(t) = W_0 F(t)$. The investigations were made in the case of $F(t) =$ const. and $F(t) = t/\tau_0 \exp(1 - t/\tau_0)$, respectively ($W_0$ changed between 10^{22} and 10^{25} photons/cm^{3}s and $\tau_0 = 0.3$ ms).

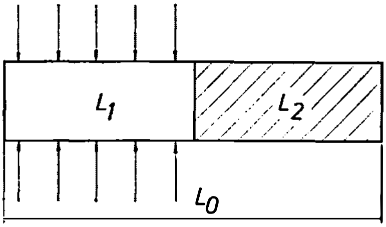

Fig. 1

According to[1], the time-change of the density of photons and of the inversions within the excited and unexcited parts may be expressed by the following equations, with the qualification that in our case the role of the Q-switch will be taken over by the unexcited part

$$\frac{dQ}{dt} = \left[\frac{\sigma}{t_0}(L_1 N - L_2 M) - \frac{1}{T}\right] Q + \left[\frac{L_1 N - L_2 M}{2\tau L_0} k + \frac{N_0 k}{2\tau}\right],$$

$$\frac{dN}{dt} = \left[-\frac{2\sigma L_0 Q}{t_0} - \frac{1}{\tau}\right] N + 2W(t) \cdot \eta - \frac{N_0}{\tau},$$

$$\frac{dM}{dt} = \left[-\frac{2\sigma L_0 Q}{t_0} - \frac{1}{\tau}\right] M + \frac{N_0}{\tau},$$

where τ is the lifetime of the excited Cr^{3+} ions, k is the ratio of the spontaneously emitted photons, which falls into the solid angle $d\omega$ formed around the optical axis of the resonator containing the active material.

The solution of the above differential equation system with the succesive approximation method, on the basis of the procedure given in[1] was performed by means of a computer of a CDC—3300 type, under the following initial conditions: at the moment when $t = 0$, $N = -N_0$, $M = N_0$ and $Q = 0$. The parameters characterizing the active material and the excitation were as follows

$$\sigma = 1.6 \cdot 10^{-20}\ \text{cm}^2,$$

$$L_0 = 15\ \text{cm},$$

$$t_0 = 8.8 \cdot 10^{-10},$$

$$
\begin{aligned}
N_0 &= 1.6 \cdot 10^{-3}\ \mathrm{s},\\
\tau &= 3 \cdot 10^{-3}\ \mathrm{s},\\
W_0 &= (10^{22} - 10^{25})\ \mathrm{photons/cm^3\ s}.\\
T &= 1.76 \cdot 10^{-8}\ \mathrm{s},\\
\gamma &= 0.05,\\
\eta &= 0.7,\\
\Delta t &= 1 \cdot 10^{-9}\ \mathrm{s},\\
k &= 1 \cdot 10^{-5},
\end{aligned}
$$

To reach the aim of our investigations, the value of parameter L_2 was changed between 0 and 7.5 cm $(L_1 + L_2) = L_0$.

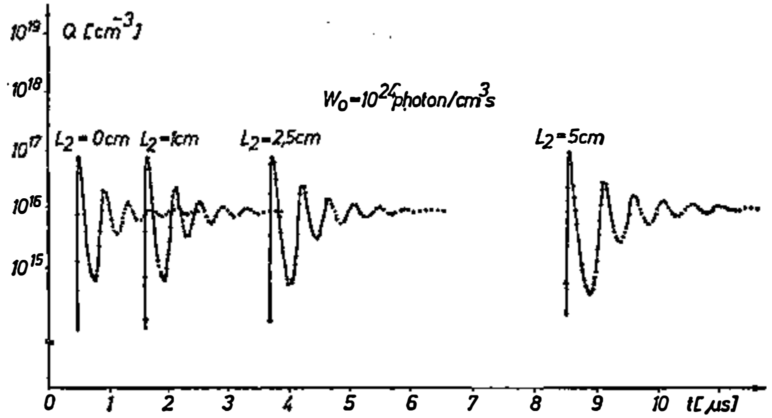

Fig. 2

2. *Results*

Fig. 2 shows the time change of a number of photons Q, per unit volume of the resonator in case of $F(t) =$ const. and $W_0 = 10^{24}$ photons/cm³ s, L_2 having different values from the beginning of the excitation ($t = 0$). It can be seen that reaching the value of the stationary number of photons is preceded every time by a damped oscillation of a the number of photons. This transient effect will also occur when the laser active material is ideally excited ($L_2 = 0$). Furthermore, it can be seen that by increasing L_2, the development of the first maximum is delayed, *i. e.* the measure of loss is increasing. If the number of photons generated by the

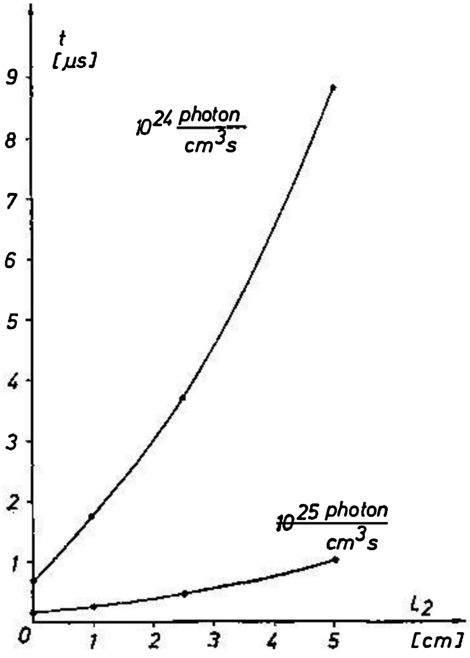

Fig. 3

exciting light source is increased, the results *vs.* parameter L_2 is quite similar to the previous one, but the develompent of the first maximum will occur earlier. The solutions of the equation system will give a periodically changing density of photons for an excitation of constant size, while the time intervals of attaining the stationary value increases if the length of the unexcited part is increased as well. Our result is in agreement with that of Ref.[21].

Fig. 3. shows the development of the first maximums *vs.* parameter L_2 for the different values of W_0.

The data furnished by the computer show that the period Δt of the oscillation of the number of photons *vs.* parameter L_2 increases mildly from 0.44 μs to 0.56 μs, while L_2 changes between 0 and 5 cm.

In the following we will treat non-stationary excitation. The solutions of the differential equation system for the above parameters and initial values and with respect to the non-stationary excitation $W(t) = W_0 \cdot F(t)$, will give the following results for the values Q, N and M *vs.* the time and parameter L_2.

In Fig. 4a time function of inversion N is shown. By increasing the pumping light intensity inversion N is being increased as well, though the density of photons Q changes very little in the meantime (Fig. 4b). By further increasing the inversion, the density of photons is abruptly increased in the resonator and the absorption of the unexcited part decreases (Fig. 4c). The increase in density of the photons, as well as the decrease in measure of the absorption will strenghten each other, that is why the density of photons can attain a very high value in the re-

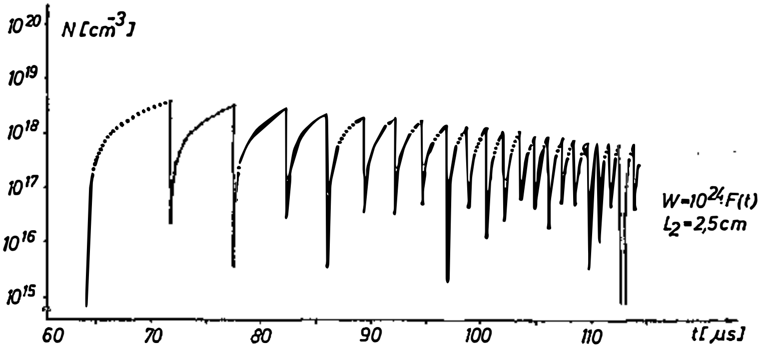

Fig. 4a

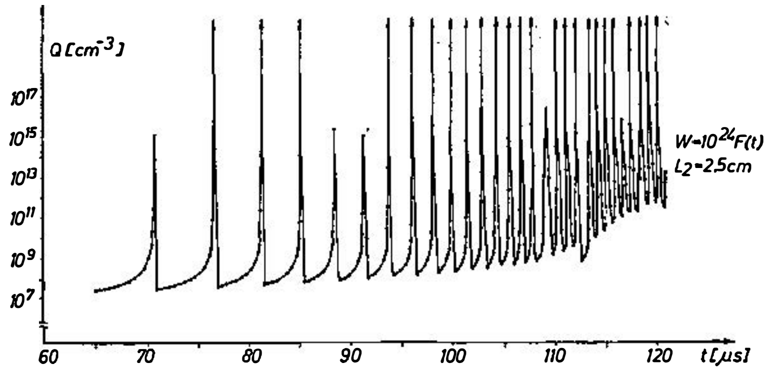

Fig. 4b

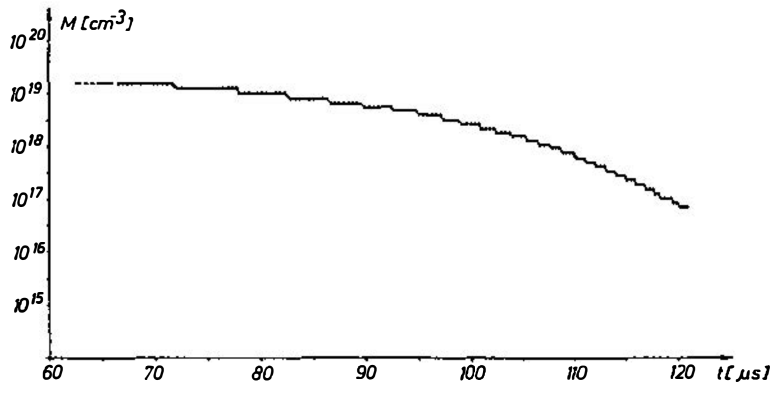

Fig. 4c

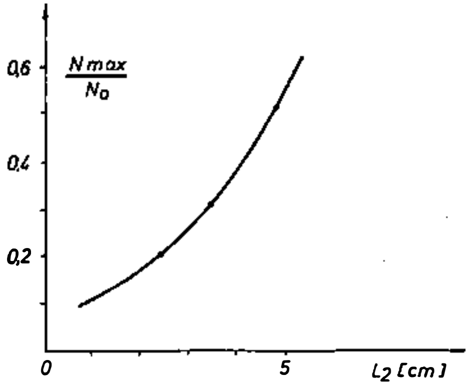

Fig. 5

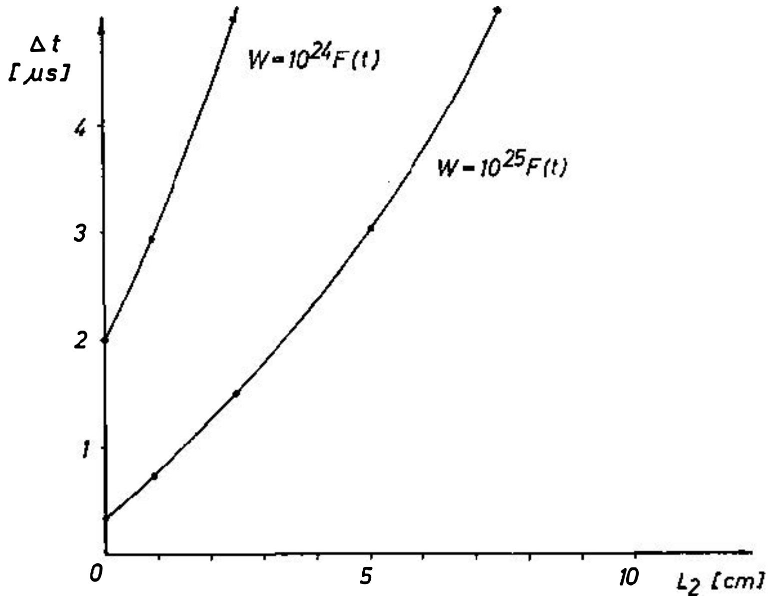

Fig. 6

sonator during a very short time. At the same time, it results in the decreasing of inversion N; most of the photons will be absorbed in the excited part and that will bring about a sudden bleaching.

The differential equations given above bring into connection the maximum inversion and the excited part. The result is that by increasing L_2 the measure of inversion is increased as well (Fig. 5). It may be of interest to observe that the inversion reaches its maximum value before the first pulse every time. Furthermore, in the exciting intensity range investigated by us, the intervals between the succesive pulses are decreasing in time.

Calculations were made for different values of W_0 with the result that the maximum value of the inversion had been affected very little by the changes in value and that the maximum value of the developing inversion depended on the value of L_2 alone. Furthermore, by increasing L_2, the interval of the spike pulses was increased as well and another solution offered ($W(t) = 10^{24} \cdot F(t)$, $L_2 = 5$ cm), where the first pulse occured at 80 μs, but the second pulse was not developing even at 300 μs (this being the maximum exciting pulse). According to our calculations, a given $W(t)$ results in an L_2 value, where only a single spike pulse appears with non-stationary excitation, i. e. the system works in a monopulse operation. The FWHM of this spike pulse is in the order of magnitude of *ns*.

In Fig. 6. the time difference between the first and second pluse is given vs. two different exciting intensities and parameter L_2, that also supports the development of the monopulse which can be realized following to the method given above.

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References

1) W. Schmidt, Lichtabsorpcion in Lösungen organischer Farbstoffe bei hochen Bestrahlungstarken, Inaugural-Dissertation, Görich Weiershauser, Marburg 1966;

2) D. Röss, Laser Lichtverstärker und Oszillatoren, Akadem. Verlagsgesellschaft, Franfurt am Main 1966; D. Röss Z. Naturforsch **19**a 3 (1964) 387, M. Birnbaum and T. L. Stocker, Appl. Phys. Lett. **3**, **9** (1963) 164.