

Coherent amplification of light in ruby at 105 °K

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(Submitted October 14, 1974)

ZhETF Pis. Red. 20, No. 10, 664-668 (November 20, 1974)

We investigated coherent amplification of light in ruby at 105 °K. At an average incident-pulse duration 36 psec, the average duration of the amplified pulses was 18 psec. The minimum duration of the amplified pulses, 14 psec, is smaller than the reciprocal width of the ruby luminescence line (approximately 20 psec).

The phenomenon of coherent interaction of radiation with matter was investigated mainly in absorbing media, where it was manifest in the form of self-induced transparency.^[1] This effect was investigated in ruby at 4 °K^[1,2] and 105 °K.^[3] Only theoretical papers have been published on the coherent interaction in amplifying media.^[4,5] It follows from them that, in the case of coherent interaction between a light pulse and an amplifying medium, its "area" (the quantity $\theta = (d/\hbar) \int_{-\infty}^{\infty} E(t) dt$, where E is the amplitude of the light field and d is the matrix dipole moment of the transition, with $d = 0.5 \times 10^{-20}$ cgs esu for Cr^{3+}) tends to a stationary value π in the course of propagation, the maximum amplitude increases, and the waveform changes. The question of the change in the duration of such a pulse in the course of propagation has not been sufficiently well discussed. Whereas it is shown in^[6] that its duration is limited only by the inactive losses in the amplifying medium, it

is concluded in^[4] on the basis of a numerical calculation that the final pulse duration cannot be less than the reciprocal of the inhomogeneous amplification line width.

The coherent amplification of a π pulse was investigated by us in ruby at an approximate temperature 100 °K. The experimental setup is shown in Fig. 1. The radiation source was a mode-locking ruby laser at low temperature; this laser produced almost a single pulse of 35 psec duration at half-height.^[7] The beam from the laser was directed to a saturable filter to suppress the weak pulses that accompany the main pulse, and was then contracted by a factor of two in the transverse direction with the aid of a telescope (it is shown in^[3,7] this corresponds to the production of a π pulse) and was incident on an amplifying ruby-crystal rod 11 cm long. The temperature of the amplifying rod was assumed

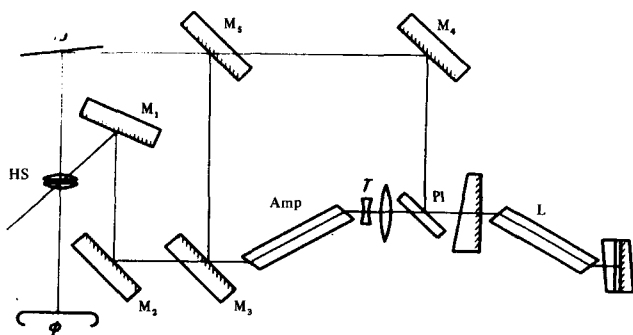


FIG. 1. Experimental setup: L—ruby laser, T—telescope, Amp.—amplifier, Pl—glass plate, M_1 , M_2 , M_3 , M_4 , M_5 —mirrors, Pa—sheet of paper, HS—high-speed shutter, C—photographic camera.

equal to the temperature of the laser rod, 90°K. The pumping energies of the two rods were exactly equal, and the attained weak-signal gain per pass was of the order of 30.

The durations of the incident and transmitted pulses were measured simultaneously with a high-speed optical shutter.^[8,9] The general idea of this method consists in the following: The investigated light pulse is directed into a scattering medium. The image of the light-beam trajectory is photographed with an ordinary optical system, but the scattered radiation passes in this case through an optical shutter whose opening time is of the order of several picoseconds. From the length of the photographed track, knowing the velocity of light in the medium, it is possible to calculate the pulse duration. We used a shutter based on a saturable filter (saturated solution of cryptocyanine in acetone). During the course of the measurements, the radiation passing through the amplifier was split into two beams, one of which was incident at a glancing angle on a sheet of white paper, which was used as a scatterer, while the other was used to open the shutter. The instant of shutter opening was regulated with a delay made up of mirrors M_1 and M_2 (see Fig. 1). Part of the laser output radiation, reflected from a glass plate located at the entrance to the amplifier, was also directed to the sheet of paper, to ensure simultaneous measurement of the durations of the incident and transmitted pulses.

If it is assumed that the dye relaxation in the shutter is instantaneous, then it is readily seen that in this procedure one registers a second-order correlation function, just as in the method of two-photon luminescence.^[10] The advantage of the employed method is that the maximum ratio of the contrast can be made of the order of a hundred, unlike that of the value 3 in the two-photon luminescence method. Calculations analogous to those in^[11] show that when registering a pulse whose envelope vanishes outside a certain time interval the contrast ratio is equal to $1/\eta$, where η is the initial transmission of the filter in the shutter (in our case $\eta < 0.1\%$). At the same time, the contrast ratio when a Gaussian random process is registered is close to 1.5.

On the basis of the obtained track photographs, starting from the known length of the delay lines, one could

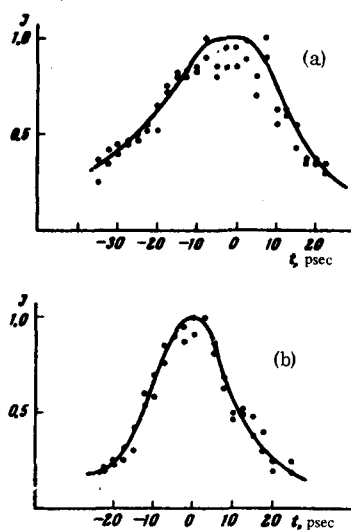


FIG. 2. Relative intensities of the tracks of the output laser (a) and amplified (b) pulses.

ascertain that the propagation velocity of the pulse envelope in the amplifier is equal to the velocity of light (accurate to 1%). The results of the photometry of one pair of tracks are shown in Fig. 2. A certain contraction of the pulses as a result of passage through the amplifier is observed.

The microphotograms of the tracks, assuming instantaneous shutter relaxation, were used to calculate the pulse durations. This calculation should overestimate the durations. However, the error due to the finite relaxation time does not exceed 20%, since the relaxation time of the cryptocyanine in the saturated solution is about 10 psec and is shorter than the pulse duration. The measurements of the relaxation time of the cryptocyanine were made by O. P. Varnavskii by a method analogous to that in^[9], to whom the authors express their gratitude.

The obtained pulse durations prior to passage through the amplifier varied from flash to flash in a range from 22 to 44 psec, with a mean value 36 psec. This agrees well with the value measured with the aid of an electron-optical converter,^[7] 35 psec, thus proving the reliability of the employed procedure. After passing through the amplifier, the pulse durations ranged from 14 to 22 psec, with an average 18 psec. In our opinion, the results show quite convincingly that pulse durations less than the reciprocal luminescence length of the ruby (approximately 20 psec) were attained in the employed setup.

The authors thank N. D. Galanin for interest in the work.

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