

Effect of self-induced transparency in ruby at 105°K

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We investigated experimentally the effect of self-induced transparency in ruby at a temperature 105°K following excitation with picosecond pulses.

Self-transparency in ruby at a temperature near 4°K was experimentally investigated in^[1,2], where the sample was excited by a Q-switched ruby laser generating pulses of 10–100 nsec duration. We report here the results of experiments on self-induced transparency in ruby at 105°K following excitation by picosecond pulses. The radiation source was a ruby laser operating at low temperature (about 90°K), the construction and output parameters of which are described in^[3-5]. The laser radiation constituted practically a single pulse with approximate output energy 0.02J, with a transverse beam dimension about 2 mm, and a duration 35 psec. This duration turned out to be less than the transverse relaxation time T_2 in ruby (on the order of 100 psec),^[6] and the interaction of the radiation with matter was coherent in this case. At these pulse parameters, the quantity $\theta = (d/\hbar) \int_{-\infty}^{\infty} E dt$ (it can be called the integral angle of the field), which determines the character of the passage of the coherent pulse through the medium^[1] (E is the amplitude of the light field, d is the matrix element of the transition, $d = 2 \times 10^{-20}$ cgs esu for Cr^{3+}), turns out to be on the order of π , i.e., a π pulse is generated. At the same time, the 2π pulse, which passes through a resonantly absorbing medium without energy dissipation, differs from the π pulse in that the field intensity is twice as large at the same waveform.^[1] This circumstance makes it possible to use this type of laser to investigate the self-induced transparency in ruby, and the 2π pulse can be obtained by simply narrowing the laser beam in the transverse direction with a telescope system.

The experimental setup is shown in Fig. 1. The beam from the ruby laser L was focused by telescope T on the investigated sample R , which was a ruby crystal 11 cm long with Brewster end faces. The radiation passing through the ruby was directed by mirror M_1 onto a coaxial photocell FEK-15, the signal from which was fed to an I2-7 oscilloscope. Part of the radiation was diverted by a glass plate P prior to entering the ruby, and was also directed to the photocell. Neutral filters F_1 and F_2 were used to equalize the amplitudes of the two signals. The ratio of the energies of the incident

and transmitted signals was determined from the transmissions of the filters F_1 and F_2 , with the reflection from the plate P and from the telescope lenses taken into account. It was also possible to determine from the oscillograms the slowing down of the propagation of the 2π -pulse envelope, which is a characteristic of the self-transparency phenomenon.^[1]

Since the laser crystal was excited with xenon lamps, which heat the active element, the initial temperature of the laser crystal was lower than the temperature of the investigated sample (90 and 105°K, respectively). The temperature difference was chosen to agree with minimal transmission of the weak signal, which was of the order of 10^{-6} .

Figure 2 shows one of the oscillograms obtained by narrowing the beam by a factor of four. At an exit mirror reflection coefficient 70%, this corresponded to production of a 2π pulse. The distance between the pulses of the reference train was 3.6 nsec, and the geometric delay of the reference train relative to the pulse passing through the ruby was 2.0 nsec.

The experimental results on the transmission of the sample as a function of θ are shown in Fig. 3. The black square on the diagram marks the transmission of the sample in the case when the laser operated in the smooth giant pulse regime (approximate duration 3 nsec). The radiation energy and the transverse dimension of the beam were the same as in the mode-locking regime.

The maximum transmission of the sample was about 10%. The presence of losses was due apparently to the finite divergence of the laser beam, which furthermore increased as a result of the scattering in the sample, and also to the influence of the finite relaxation time T_2 .^[7] In addition, a decisive role could be played by the level degeneracy in the ruby, which, while not changing in principle the character of the self-transparency

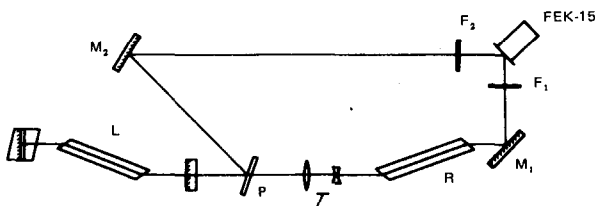


FIG. 1. Diagram of experimental setup.

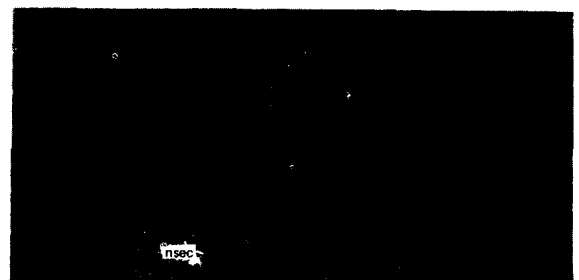


FIG. 2. Oscillogram of the radiation. The circles mark the pulses of the reference train, and the cross marks the pulse passing through the sample.

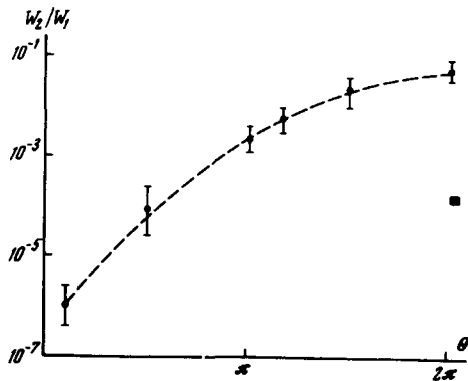


FIG. 3. Dependence of the sample transmission W_2/W_1 on the quantity $\theta = (d/k) \int_{-\infty}^{\infty} E dt$.

phenomenon, did complicate it somewhat (see, e.g., ^[6]).

The delay of the 2π pulse in the sample, determined from the oscillograms, varied from flash to flash in a range from 0.2 to 0.6 nsec (average value 0.4 nsec). The main cause of the scatter of the experimental values were apparently the experimental errors. A rigorous quantitative comparison of the results with the theory is difficult in this case, since the formula for the calculation of the velocity V of the propagation of the 2π pulse

$$\frac{1}{V} = \frac{1}{c} + \frac{\alpha\tau}{2}, \quad (1)$$

(α is the linear absorption coefficient), contains the value of the pulse duration τ , which is not constant during the course of propagation in the presence of losses, inasmuch as in the case of a 2π pulse it is necessary that the relation $E\tau = \text{const}$ be satisfied.^[7] In addition, τ also varies from flash to flash (in our case the rela-

tive changes of τ reached 40%). Nonetheless, an estimate of the delay from (1) yields a value 0.25–0.5 nsec, which is in good agreement with the experimental results.

As shown in^[7], the propagation of a 2π pulse in the presence of losses is accompanied by an increase in its duration. To estimate this phenomenon, we measured simultaneously the width of the spectrum of the pulse passing through the sample and the initial width of the spectrum, using IT-51-30 Fabry-Perot interferometers. Within the limits of the experimental errors, the width of the spectrum of the pulse passing through the sample did not depend on the initial width of the spectrum. Its value was on the average smaller by a factor 1.4 than the initial width. Since the average initial width of the spectrum, 0.9 cm^{-1} , corresponded to the value calculated from the uncertainty relation, this indicates that the duration of a 2π pulse increases by at least 1.4 times during the course of its propagation.

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