Effect of self-induced transparency in two-photon resonant absorption in neodymium glass

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We registered the delay and the breakup of a single ultrashort neodymium-laser pulse passing through neodymium glass cooled to 4.6 K.

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The effect of self-induced transparency (SIT) under conditions of two-photon resonant (TPR) interaction with a two-level medium consists in the fact that the light pulse passes through the medium without undergoing resonant absorption.[1] This calls for

$$\tau < T_2', \qquad \theta_0 \equiv \frac{|r|}{2\hbar} \int_{-\infty}^{+\infty} E^2(t)\,dt \gtrsim 2\pi ,$$

where τ and $E(t)$ are respectively the duration and amplitude of the electric field of the light pulse, T_2' is the time of the irreversible transverse relaxation, and r is the matrix element of the TPR transition. Owing to the continuous interchange of energy between the medium and the pulse (caused by induced reradiation), the velocity of pulse propagation in the medium decreases; the pulse leaves the medium with a certain delay. If $\theta_0 \geqslant 2\pi n$ $(n>1)$, then the pulse can break up into n 2π pulses.[2]

SIT was investigated experimentally in TPR in semiconductors, where anomalously weak absorption and delay of the pulse were observed.[3,4]

It should be noted that in the theoretical calculation[1,2] they neglected the inhomogeneous broadening of the upper level of the two-level system.

The levels $^4I_{9/2}$ and $^4G_{7/2}$ of the Nd^{3+} ion in glass (Fig. 1) comprise a two-level system whose upper level $^4G_{7/2}$ is inhomogeneously broadened.[5] From the results of the same reference it can be concluded that the time T_2' for the indicated level system does not exceed 10^{-11} sec at a sample temperature 80 K. It follows that the condition $\tau < T_2'$ can be realized only at lower temperatures of the sample and at ultrashort durations of the laser pulse.

To observe the SIT under TPR conditions we used the irradiation of a mode-locked neodymium laser. A single ultrashort pulse separated from the train was split by a glass dividing plate into two parts: one part (control pulse) was fed directly to the photoelectronic recorder, and the other passed first through a neodymium-glass sample. The sample was in a helium cryostat. To increase the laser-pulse intensity the cryostat with the sample was placed at the center of a telescope made up of two lenses with focal lengths $f_1 = f_2 = 1333$ mm. The optical system was adjusted in such a way that at room temperature both the pulse passing throught the sample and the control pulse reached the recorder simultaneously.

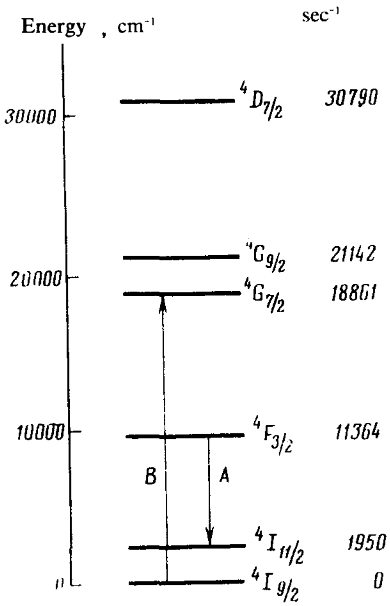

FIG. 1. Energy level scheme of Nd^{3+} in glass: A—laser transition, B—investigated two-photon transition.

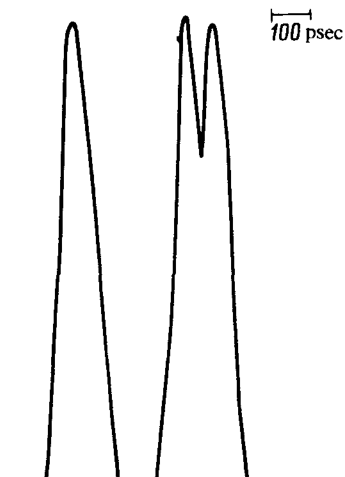

FIG. 2. Waveform of control pulse (a) and of the pulse passing through the cooled sample (b).

At a sample temperature 4.6 K, the registered delay of the pulse passing through the sample was $\Delta t = 150$ psec. The measured delay makes it possible to calculate the propagation velocity of the pulse in the medium

$$v = \left(1 + \frac{c\,\Delta t}{n' L}\right)^{-1} \frac{c}{n} \approx 0.9\frac{c}{n} \quad ,$$

where c is the speed of light in vacuum, $n = 1.52$ is the refractive index of the sample, and $L = 300$ mm is the length of the sample.

At helium temperatures we observed, besides the delay, a breakup of the pulse passing through the sample into two subpulses. Figure 2 shows the results of the photometry of the streak photographs of the incident pulse and of the pulse that passed through the cooled sample. From the coefficient of the TPR absorption measured in Ref. 5 and from its connection with the value of $|r|$ (Ref. 1) we can estimate θ_0. An estimate shows that $\theta_0 \approx 10 \approx 4\pi$, i.e., it can be stated that breakup of a 4π pulse into two 2π pulses has been observed in experiment.

The registered delay and breakup of a pulse passing through a sample cooled to 4.6 K indicate unequivocally that coherent interaction of laser radiation with matter, meaning SIT under TPR absorption conditions, has been observed.

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