

Grating induces in ruby by interference of atomic states

E. I. Shtyrkov, V. S. Lobkov, and N. G. Yarmukhametov

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We have observed experimentally the predicted (E. I. Shtyrkov, *Opt. Spectrosc. USSR*, in press) formation of a dynamic three-dimensional grating in a resonant medium coherently excited by light pulses that cannot interfere directly with one another.

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Optical quantum phenomena based on interference of atomic states are attracting ever increasing attention of late.^[2] All these phenomena (photon echo, quantum beats, self-induced transparency, etc.) can be observed when the particles are resonantly excited during a stage before coherence is lost in the system, i.e., prior to the time T_2 of termination of the transverse relaxation. During this stage, while the system has phase memory, i.e., it is in a coherent state of superposition of the basis vectors, it can memorize that phase characteristics of the exciting external fields. This is particularly clearly manifest by the possibility of obtaining an interference pattern in a medium even in the case when the optical pulse fields cannot interfere with one another directly, for example they are applied to the medium at different times. The possibilities and conditions for the formation of optically induced gratings by such an excitation were discussed in^[1]. In the present communication we present the results of an experimental verification of this possibility. The experimental setup is shown in Fig. 1. The pulsed coherent-light beams I and II used to obtain the optically induced grating in sample 1

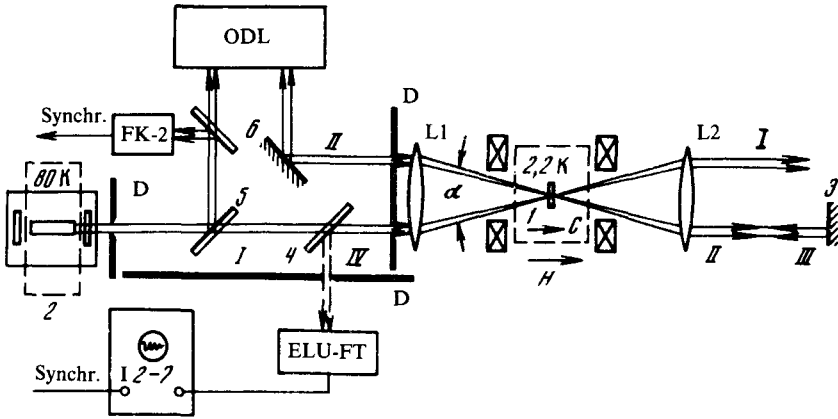


FIG. 1. Experimental setup.

have wave vectors \mathbf{k}_1 and \mathbf{k}_2 and are delayed relative to each other by an interval τ that exceeds the duration Δt of these pulses. This excludes a direct interference of the beams I and II. However, when the condition

$$\Delta t < \tau < T_2 \quad (1)$$

is satisfied, the interference of the atomic states of the system should lead to formation in the sample of a grating with a spacing $2\pi/|\Delta\mathbf{k}|$, where the grating vector $\Delta\mathbf{k} = \mathbf{k}_1 - \mathbf{k}_2$ is determined by the geometry of the experiment.⁽¹⁾ This grating can be revealed by its diffraction of some third beam having the same frequency. The phase synchronism condition for the diffracted wave, as in ordinary holograms,⁽²⁾ is of the form $\mathbf{k}_4 = \mathbf{k}_2 + \mathbf{k}_3 - \mathbf{k}_1$, and $\omega_4 = \omega_{1,2,3}$, where \mathbf{k}_3 and \mathbf{k}_4 are respectively the wave vectors of the reading (third) beam and the beam diffracted by the grating, while $\omega_4, \omega_{1,2,3}$ are the radiation frequencies of the corresponding beams. To satisfy the synchronism condition in one of the Bragg directions, in our experiment the beam III is formed simply by reflecting beam II from mirror 3. In such a scheme ($\mathbf{k}_3 = -\mathbf{k}_2$) the beam III is diffracted along the return path of beam I ($\mathbf{k}_4 = -\mathbf{k}_1$). After deflecting the diffracted beam with semi-transparent mirror 4, the signal in the direction IV is registered on the screen of the time meter I 2-7 with the aid of an ÉLU-FT photomultiplier. To prevent divergence of beam II, the optical delay line ODL which serves to shape this beam is assembled in accordance with a confocal scheme with a base 4 m. The employed sample 1 is cut perpendicular to the optical C axis of a ruby with a trivalent chromium ion concentration $\sim 0.05\%$, in the form of a plate 1.5 mm thick. To facilitate satisfaction of condition (1), the sample is cooled in an optical cryostat to 2.2 K. This increases the transverse relaxation time T_2 in the ruby to 10^{-7} sec, so that we can use as a pump the single-pulse ruby laser 2 with pulse duration 10 nsec and power 1 MW. The need for cooling the active rod of this laser to ~ 80 K is due to the shift, which violates the resonance condition, of the absorption line of the transition ${}^4A_2 \rightarrow {}^2E(\bar{E})$ of the ruby sample 1 when it is cooled to 2.2 K. As shown in an investigation of photon echo in

ruby,^[4] when the laser is so cooled, resonance takes place for the 6933.97 Å laser line [the transition ${}^4A_2(M_s = \pm 3/2) \rightarrow {}^2E(\bar{E})$ at 77 K] and for the 6934 Å absorption line [transition ${}^4A_2(M_s = \pm 1/2) \rightarrow {}^2E(\bar{E})$ at 2.2 K]. All the beams in our experiment were polarized perpendicular to the plane of Fig. 1, and Helmholtz coils are used to produce a weak longitudinal magnetic field ($H \parallel C$, 0–250 G). Figure 2 shows oscillograms of

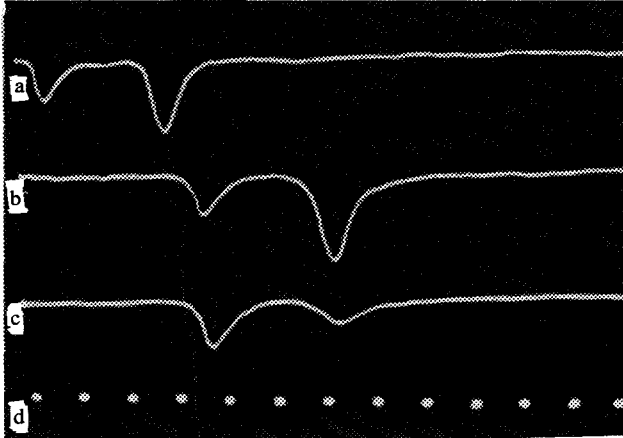


FIG. 2. Pump-pulse, diffraction, and backward stimulated photon-echo signals in ruby at $\alpha = 1^\circ$, $\tau = 50$ nsec (d—20-nsec markers).

the signals corresponding to exciting pulse I and II (a) and to the coherent responses of the system (b,c) in the direction of IV. The first pulse on the lower oscillograms (b,c) corresponds to diffraction of the beam III, which is delayed relative to beam II by approximately 10 nsec, by the grating induced in the sample by pulses I and II. The second pulse on the same oscillograms is a stimulated photon-echo signal, which, as is well known, is formed when a third pulse is applied after a time equal to the interval between pulses I and II. The appearance of both responses of the system in the same direction is due to the fact that these phenomena are subject to one and the same vector-synchronism condition. We have verified carefully that neither pulse is a consequence of any reflection of beams I, II, and III from different parts of the apparatus. To suppress false reflections we used a system of screens with diaphragms *D*. Neither signal (b,c) is observed in the case when at least one of the beams I, II, and III is blocked, and also when the resonance condition is violated (for example, when the active rod of the laser is heated). Turning off the magnetic field greatly weakens these signals, and a change in the field direction affects them to unequal degrees. An example of this is shown in Fig. 2, where the oscillograms of the signals were obtained at different angles between the field and the crystal axis: (b) $\rightarrow +12^\circ$, (c) $\rightarrow -15^\circ$. Thus, interference of the atomic states of a coherent system induces a three-dimensional grating. It appears that the formation of such a grating is the basis of a possibility of recording and reconstructing wavefronts of light in dynamic echo holograms,^[5] and determines also other features of the formation of coherent responses of an atomic system after it is brought to a coherent superposition state.

¹E.I. Shtyrkov, *Opt. Spektr*, in press.

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⁴J.D. Abella, N.A. Kurnit, and S.R. Hartmann, *Phys. Rev.* **141**, 391 (1966).

⁵E.J. Shtyrkov and V.V. Samartsev, *Phys. Stat. Sol. (a)* **45**, 647 (1978).