Discrete self-returning of the output line of a pulsed dye laser with a photorefractive crystal

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A discrete self-retuning of the output line of a pulsed dye laser has been observed when a photorefractive crystal was placed in the laser cavity. The effect stems from an interaction of variously polarized waves with gratings written in the birefringent crystal.

In the mid-1980s, several groups reported a sweep of the output wavelength of a dye laser in which a photorefractive crystal was used to create a positive feedback in the cavity.[1-5] The effect was explained in terms of a spatial mismatch of the refractive-index grating with respect to its steady-state position, with the effect that the grating went into motion and caused a sweep of the output frequency by virtue of a Doppler effect amplified by multiple reflections.

In the present letter we are reporting a discrete self-retuning of the output frequency of a pulsed dye laser with a photorefractive crystal in its cavity. The mechanism for this effect is fundamentally different from the sweep of the output frequency mentioned above; it stems from an interaction of gratings written in the crystal with waves of different polarizations which are diffracted by these gratings.

Figure 1 shows the experimental layout. We used a short-pulse dye laser with a switchable cavity consisting of two arms. The selective arm contained a total-reflection mirror *7*, positioned in the first order of diffraction of cut diffraction grating *4* (1200 mm^{-1}), while the nonselective arm contained a mirror *6* in zeroth order. The common part of the cavity contained a cell (*3*) holding an alcohol solution of the dye rhodamine-6G and a photorefractive $\mathrm{LiNbO_3}$: Fe crystal *2* (0.03% iron by weight), 5 mm thick. The optic axis of this crystal ran perpendicular to the faces and was directed into the cavity. The crystal was rotated in the plane of the figure through an angle α with respect to the cavity axis. The dye was excited by light in the second harmonic

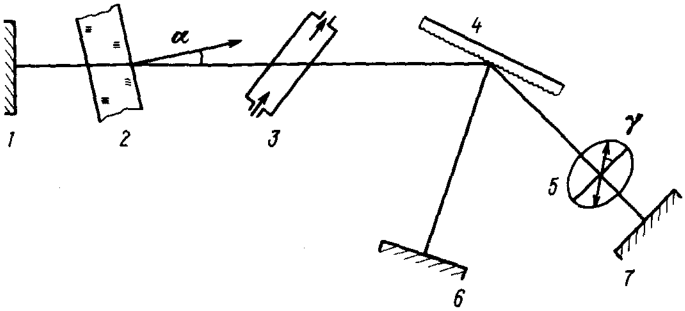

FIG. 1. Experimental layout.

from an yttrium aluminum garnet laser with a pulse length of 20 ns, an output energy of 7 mJ, and a pulse repetition frequency of 10 Hz. The output spectra were recorded on photographic film by a DFS-8 spectrograph; a television camera was used for visual observation of the spectrum.

The selective arm of the cavity operated first. It formed a narrow outline (≈ 15 pm wide), which wrote a thick holographic grating of the reflection type, with a diffraction efficiency of 40–50%, in the photorefractive crystal. The selective arm was then blocked, and the nonselective arm was connected. It was found that the output spectrum consisted of two lines of perpendicular polarizations. One of them had the same wavelength as the writing light. The distance between them depended on the angle α. The reason is that the $LiNbO_3$ crystal is birefringent, and the refractive indices for the ordinary wave (n_0) and the extraordinary wave $[n_e(\alpha)]$ are different. The light with the *e* polarization was more efficient in writing a grating in the photorefractive crystal. This light (we denote its wavelength by λ_0) was generated in the given geometry of the cavity, during the writing of a grating with a period $d_0 = \lambda_0/[2n_o(\alpha)]$. In the nonselective cavity, the losses for the two polarizations were approximately equal, and not only the *e* component but also the *o* component was generated at the grating in the photorefractive crystal. The *o* component was generated at a different wavelength, because of the difference between the refractive indices: $\lambda\alpha_1 = 2n_o d_0 = \lambda_0 n_o/n_e(\alpha)$. Since $n_o - n_e(\alpha) \sim (\alpha)^2$, the distance between the components is $\lambda_1 - \lambda_0 \sim \alpha^2$, as was confirmed experimentally.

A polarizer *5* was then inserted in the nonselective arm of the cavity. After the incident wave passed through this polarizer and was reflected from a mirror, only its component in the transmission direction of the polarizer was returned to the cavity. If this was the *o* wave, then a wave having both *o* and *e* components with respect to the crystal returned. Since the *e* component of the wave λ_1 in the photorefractive crystal corresponds to a grating with a period $d_1 = \lambda_1/2n_e(\alpha) = d_0 n_o/n_e(\alpha)$, generation of an *o* wave with $\lambda_2 = \lambda_1 n_o/n_e(\alpha)$, etc., can arise at this grating after it is written. Since the relation $n_o > n_e$ holds for the lithium niobate crystal, we have $\lambda_2 > \lambda_1$; i.e., the output line is shifted in the long-wavelength direction.

Figure 2 shows the experimental results. On the spectrograms recorded at 30-s intervals we clearly see that no more than two gratings (Fig. 2a) or no more than three (Fig. 2b) can exist at the same time. The actual number depends on the polarizer

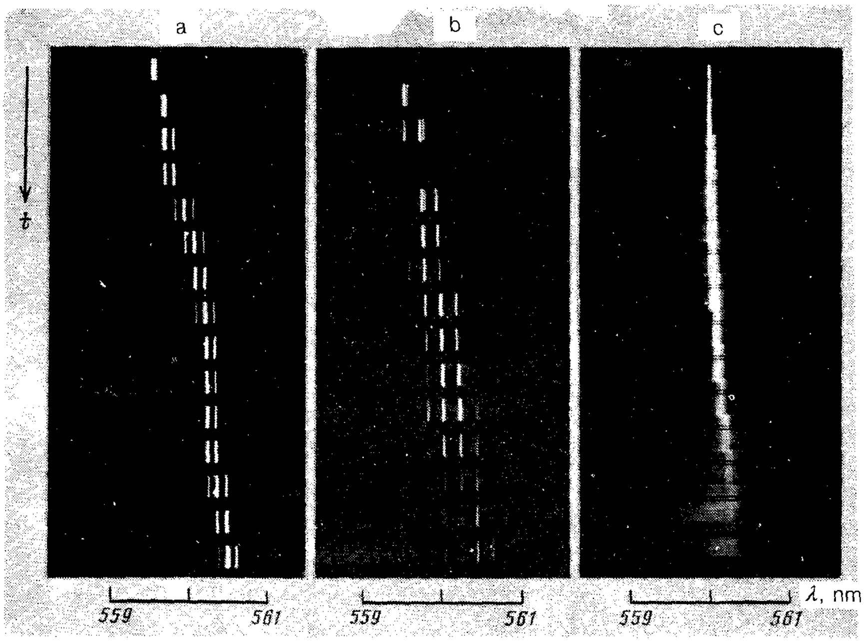

FIG. 2. Output spectra of a laser with a photorefractive crystal recorded at 30-s intervals with a polarizer rotated at angles of (a) 45° and (b) 60°. c—With rotation of the polarization plane as a result of reflection from tilted surfaces. The photorefractive crystal is tilted with respect to the cavity axis by angles of (a) 10°, (b) 13°, and (c) 6°.

rotation angle γ, i.e., on the relative intensities of the *o* and *e* components. At small rotation angles of the polarizer, the self-retuning is not observed. As γ is increased, no more than two gratings exist at any instant in the photorefractive crystal; then their number increases to three. At $\gamma \geqslant 60°$, the lines decay rapidly, and a continuum arises. Visual observations revealed 15 or more retuning steps; their number was limited by the field of view of the television camera. The rate of the tuning reached a maximum at $\gamma \approx 45°$.

An explicit polarization filter is not mandatory for rotating the polarization plane. The role of this filter can be played successfully by (for example) the faces of the photorefractive crystal itself, if the crystal is tilted simultaneously along two axes. The small difference between the reflection coefficients, amplified by repeated passage of the light through the cavity during the generation pulse, leads to a substantial rotation of the polarization plane (Fig. 2c). This effect is one reason for the multiplication and shift of the output line which were found in Ref. 6.

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