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Jumps in the phase difference of counterpropagating waves in a ring solid-state laser operating in the generalised synchronisation mode

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***Abstract*.** **The successive switching of the phase difference of counterpropagating waves is found in a ring solid-state laser operating in the generalised synchronisation mode in opposite directions.**

Keywords: *dynamic chaos, phase dynamics, ring solid-state laser.*

The studies of dynamic chaos in laser physics are both of fundamental and applied importance. Such studies can be used, for example, to analyse the synchronisation of chaotic oscillations in coupled systems. Recently, several different modes of synchronisation of chaotic oscillations were discovered in solid-state lasers: complete synchronisation, phase matching, generalised synchronisation, etc. (see, for example, [1 – 5]).

Note that, as a rule, only the amplitude and spectral characteristics of chaotic radiation of lasers have been investigated so far. However, it is obvious that a complete information on the nonlinear dynamics of two-directional and coupled lasers can be obtained only by taking their phase dynamics into account. From this point of view, of interest is paper [6] in which, based on numerical simulations, the possibility is predicted of the appearance of regular jumps in the optical phase difference by π in the interval between adjacent chaotic pulses in a two-directional ring solid-state laser pumped by periodically modulated radiation.

In this paper, we observed, probably for the first time, such regular jumps in the phase difference for counterpropagating waves between adjacent radiation pulses in a ring solid-state laser operating in the generalised synchronisation mode. We used an optical mixing signal for studying the phase dynamics of the counterpropagating waves. To obtain this signal, the counterpropagating waves $E_{1,2}$ were made coincident at the output of the ring laser with the help of a system of mirrors and were directed to a quadratic photodetector. The intensity of this signal is

$$I_{\text{pm}} \sim \langle (E_1 + E_2)^2 \rangle. \tag{1}$$

Here, the angle brackets mean averaging over rapid optical oscillations for waves with identical polarisations.

We obtain from (1)

$$I_{\text{pm}} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\varphi, \tag{2}$$

where $I_{1,2}$ are the intensities of the interfering waves and φ is the phase difference between these waves.

A chip laser under study represents a monoblock with a spherical input face and three total internal reflection faces. The geometrical perimeter of the resonator was 2.6 cm and the nonplanarity angle of the resonator was 80°. The laser design is described in detail in paper [7]. The laser was excited by a semiconductor laser. The pump radiation was modulated at frequencies $f_{\text{m}} = 18 - 180$ kHz with the degree of modulation up to 100 %.

In the absence of modulation ($f_{\text{m}} = 0$), the laser operated in the self-modulation mode of the first kind (the self-modulation frequency was $f_{\text{a}} = 230$ kHz). The frequency of relaxation oscillations was 75 kHz for the relative excess over the threshold pump power $\eta = 0.18$. For $f_{\text{m}} = 28.5$ kHz, the generalised synchronisation mode appeared in the laser. Polarisations of radiation in counterpropagating waves were elliptical and had somewhat different polarisation azimuths. For this reason, an optical mixing signal was detected by directing the interfering waves through identically oriented linear polarisers.

Fig. 1 shows the oscillograms of intensities $I_{1,2}$ of the linearly polarised components of the counterpropagating waves and of the optical mixing signal (I_{pm}) recorded in the generalised synchronisation mode. One can see that the laser radiation contains pulses of two types: inphase pulses, for

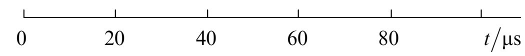

Figure 1. Oscillograms of the intensities I_1 and I_2 of counterpropagating waves and of the optical mixing signal (I_{pm}).

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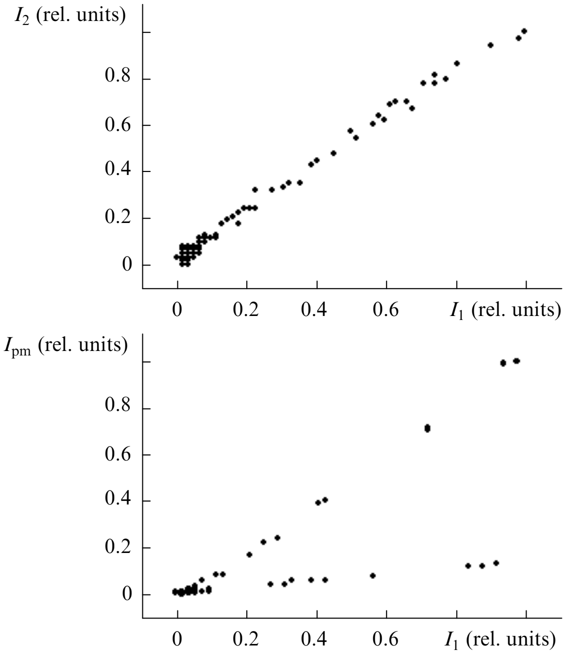

Figure 2. Projections of the phase portrait on the planes I_1, I_2 and I_1, I_{pm} for $f_{\mathrm{m}} = 28.5$ kHz and $\eta = 0.18$.

which the intensity of the optical mixing signal is approximately four times greater than the intensity of each of the interfering waves, and antiphase pulses, for which the amplitude of the optical mixing signal is rather small. The inphase and antiphase pulses are regularly alternated. Fig. 2 shows the projections of the phase portrait on the planes I_1, I_2 and I_2, I_{pm}. The projection of the phase portrait on the I_1, I_{pm} plane also confirms the existence of pulses of two types.

The oscillograms and phase portraits presented above confirm the existence of the generalised synchronisation mode in a ring solid-state laser when successive jumps of the optical phases of counterpropagating waves are observed. The observed phase dynamics of radiation agrees qualitatively with predictions of paper [6]. Note that in paper [6] the spontaneous radiation noise was neglected, whereas this noise can affect in principle the phase dynamics of radiation [8]. It follows from the results obtained that spontaneous radiation in the active medium does not prevent the appearance of regular jumps in the phase difference of the counterpropagating waves.

Therefore, we have found the regular jumps in the phase difference of the counterpropagating wave in the ring solid-state laser operating in the generalised synchronisation mode. Our study has confirmed the applicability of the interference method for observing this effect.

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