octahedral voids, is larger than for the lattice atoms. The relation between the indicated half-widths for the 110 and 122 planes serves as an additional confirmation of the hypothesis that the oxygen is located in octahedral voids.

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DYNAMICS OF ACTIVE MODE PHASING IN A PULSED LASER WITH PERIODIC LOSS MODULATION

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Ultrashort pulses with energy on the order of the gain saturation energy (6 J/cm^2) were obtained directly in a laser for the first time; this is important when it comes to effective amplification of the pulse energy. It is demonstrated that in the giant-pulse regime it is possible in principle to phase the spectral components of the emission within the limits of the generation spectrum. This spectrum contains frequencies that differ strongly from the resonator modes.

It is well known that the energy of single pulses in the mode self-locking regime does not exceed 10^{-3} - 10^{-2} J. This is why multistage amplification could not yield ultrashort pulses with energy exceeding 10^2 J [1]. At the same time, the time of active phasing of the modes [2 ÷ 4] differs in that the phasing regime is stable against an increase of the pumping, and the output energy is limited only by the optical strength of the laser components. It is shown in the present paper that by using this method one can focus in a laser pulses that come close in duration to the pulses obtained in the self-locking method, but their energy is larger by two or three orders of magnitude.

At the instant when the Q is switched on, the spontaneous-noise field has uniform frequency and phase distributions. Owing to the dependence of the loss in the resonator on the frequency, the lasing develops in a manner such that the frequency spectrum becomes narrower. A similar narrowing should be observed also in the phase spectrum. When the Q-switching frequency Ω coincides with the intermode frequency c/2L, the loss has a minimum at a field combination in which these frequencies are spaced $n\Omega$ apart, and the phases coincide with the Q-switching phase. This is an obvious fact, from which it follows that after the Q is turned on there should take place a predominant development of fields with a definite phase, i.e., they should acquire a distribution $P(\phi, t)$ with a maximum at the Q-switching phase. For a field of frequency ω we have

$$\tilde{a}(\omega, t) = \int_{-\pi}^{\pi} a(\omega, t)\cos\phi\, P(\phi, t)\,d\phi = a(\omega, t)\overline{\cos\phi(t)},$$

$$a(\omega, t) = \mathrm{E}(\omega, t)\exp(i\omega t). \tag{1}$$

In analogy with [5], the field intensity in the resonator is

$$I(t) = \sum_{m,n} a_m a_n \overline{\cos\phi_m}\,\overline{\cos\phi_n}\exp\{i\Omega t(m-n)\} + \sum_n a_n^2(1-\overline{\cos^2\phi_n}) = I_{\mathrm{pul}}(t) + I_{\mathrm{backg}} \tag{2}$$

where

$$a_{m,n} = \int_{\omega_{m,n}-\pi/2}^{\omega_{m,n}+\pi/2} a(\omega)\,d\omega,$$

and $\omega_{m,n}$ are the natural frequencies of the resonator. The interference of a large number of modes in the first sum forms a purely pulsed field $I_{\mathrm{pul}}(t)$. This field energy is dissipated as a result of the losses experienced by the remainder of the radiation contained in I_{backgr}. This shows that at certain frequencies of the loss oscillations in the laser, the latter exhibits selectivity to the phases of its modes. The phase selectivity depends on the losses introduced by the Q-switch for the part of the radiation included in the background, and the time dependence of the field amplitudes $a_{m,n}$ determines the dynamics of the development of the components I(t) during the entire lasing process. It follows from (2) that at the initial period of the generation it is possible to effect phasing in a spectral band comparable in width with the generation spectrum.

This result contradicts the results of the theoretical paper [4], which is based on an amplitude-time approach to the description of the dynamics of a laser with mode phasing. To choose between these two descriptions, the experiment was performed in a way that permitted comparison of its results with [4]1). For the Q switch used in our experiment we have

$$\eta(t) \approx 1 - \sin^4(\Gamma_0 \cos\Omega t/2), \qquad (3)$$

where Γ_0 is proportional to the amplitude of the electric oscillations at the shutter (at a half-wave voltage $\Gamma_0 = \pi/2$). In accordance with [4] we have for the pulse duration after the k-th pass

$$\tau_k = \left(-\frac{k}{384}\frac{d^4\eta}{dt^4}\right)^{-1/4} = \frac{2}{\pi\Omega}\left(\frac{282}{k}\right)^{1/4}. \qquad (4)$$

If we specify k = 20 and $\Omega = 5.5\times10^8$ rad/sec, then $\tau_{20} > 2\times11$ nsec2).

The experiment was performed with a ruby laser with an RL2B14-240/310 rod and has shown that this estimate does not agree with the experimental data. The laser resonator consisted of a wedge-shaped substrate with 10% reflection and a total-reflection prism in the shutter. The working surfaces of all the optical parts in the resonator were inclined at the Brewster angle. The Q-switch transmission $\eta(t)$ was varied in the manner shown in Fig. 1. An FK-3 photocell matched with an I2-7 meter was used to record radiation pulses of duration not larger than 6×10^{-10} sec, which is much less than the estimate of formula (4). An even greater deviation from (4) results if it is recognized that to obtain the pulses illustrated in Fig. 2 in the amplitudetime approach it is necessary that the modulation be applied during 4×10^3 passes as against the 20 in our experiment. Such discrepancies favor the conclusion drawn from formula (2) and show that the formation of ultrashort pulses occurs already directly before the Q-switching. The fact that the minimal duration corresponding to the total width of the spectrum (0.8 cm^{-1}) was not reached in our experiment is attributed to the low stability of the Q-switching frequency Ω, which was not less than 5×10^{-3}.

Interest attaches also the character of the dependence of the puse repetition frequency on the resonator length. As seen from Fig. 3, the pulse repetition frequency remains constant in

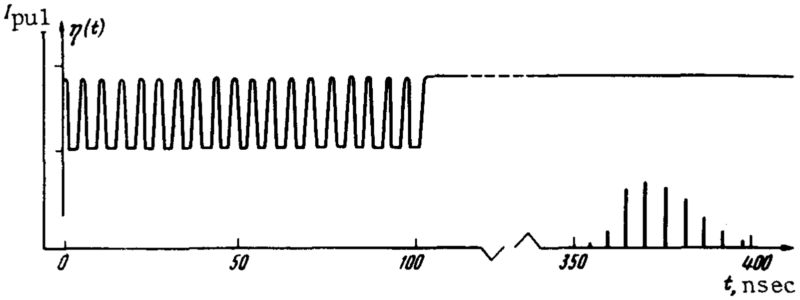

Fig. 1. Relative time sequence of the oscillations of the Q-switch transmission $\eta(t)$ and of the laser generation pulses I_{pul}.

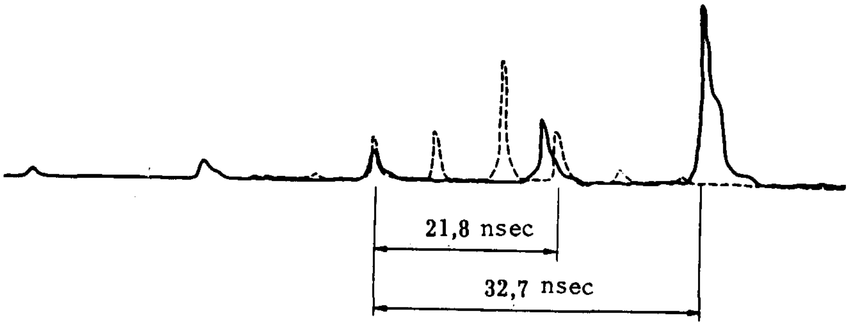

Fig. 2. Waveform of emission pulses. The solid line shows a fraction of a generation pulse train obtained with the pump 10 — 30% above threshold. The dotted line shows the profile of the train at a pump 70% above threshold. The individual pulses attain in this case an energy $6\ \text{J/cm}^2$ at a beam aperture 0.8 cm.

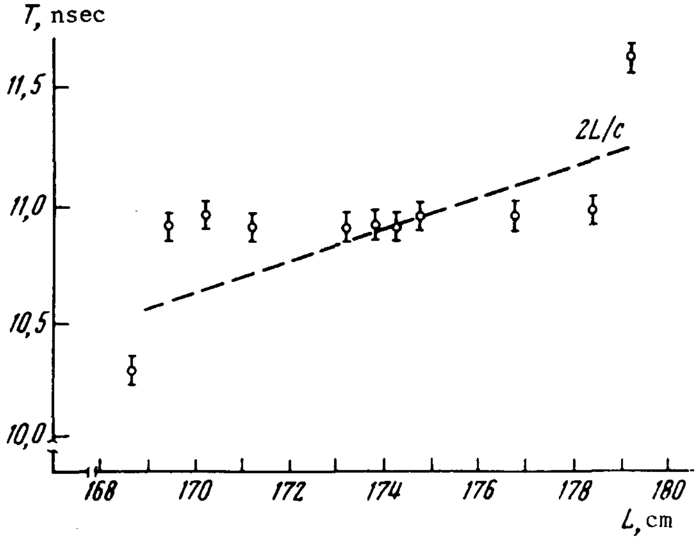

Fig. 3. Measured pulse repetition period T as a function of the variation of the resonator length L. At the center of the tuning range L, the frequencies c/2L and Ω coincide. The observed variation was obtained for the Q-switching schedule illustrated in Fig. 1.

the tuning interval and coincides with Ω. The total time of lasing development is several times longer than the development section during which the Q-switch acts (Fig. 1). Taking this into account, we can state that the disparity between the pulse repetition frequency and the intermode frequency proves that the lasing spectrum has "inertia." Frequencies that differ from the natural resonator frequencies by 12 — 25% develop. At the end points of the tuning band, the period exhibits a jumplike change symmetric about the line 2L/c. With further increase of detuning, the mode phasing disappears. At 70% pump over threshold (Fig. 2), the intensity is concentrated in three or four pulses, whose energy reaches $6\ \text{J/cm}^2$ at a beam aperture 0.8 cm on leaving the laser.

We have demonstrated in this investigation, for the first time, the feasibility of obtaining in a pulsed laser with mode locking ultrashort pulses with energies equal to the gain saturation energy. A laser similar to that investigated here can be useful as a driving laser in high-power amplification systems of the type described in [6], since the high energy of the input pulse makes it possible to amplify it efficiently in the subnanosecond and picosecond bands.

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[1] According to [4], the formation of ultrashort pulses is a monotonic and prolonged (relative to the axial period 2L/c) process of narrowing the pulses to the limiting value (determined by the dispersion phase shift of the spectral components of the emission), and does not represent formation of pulses immediately after the instant of Q switching as a result of the phase selectivity of the resonator.

[2] Larger, since the experimental $\eta(t)$ has a maximum that is steeper than in (3).

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HIGHLY EFFECTIVE GENERATION OF THE SECOND AND FOURTH HARMONICS OF HIGH-POWER PICOSECOND PULSES

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We report experimental realization of the theoretically maximal coefficient for the conversion of laser emission into the second harmonic, and also high-efficiency generation of the fourth harmonic of picosecond pulses (efficiencies 80 and 30%, respectively).

Much attention has been paid of late to high-efficiency generation of higher harmonics of ultrashort light pulses, in view of the definite promises offered by powerful sources of ultraviolet radiation for the solution of the problem of controlled thermonuclear fusion.

Although it has been theoretically demonstrated that almost all the fundamental-frequency radiation can be converted into the second harmonic [1], this possibility has not been realized experimentally even in high-power laser beams. To effect such a conversion it is necessary to satisfy a large aggregate and requirements with respect to the beam and crystal parameters. In powerful picosecond lasers, the principal limitation are effects of group delay of the fundamental-frequency and harmonic waves, so that the efficiencies attained to date do not exceed 50% [2].

We note that the optimal pulses for the initiation of a thermonuclear fusion reaction are of subnanosecond duration [3]. In addition, at durations exceeding several dozen picoseconds, the harmonic-generation is a quasistatic process, i.e., without a group delay, since real nonlinear crystals are much shorter than the quasistatic length L_τ at which delay effects become significant ($\ell_{cryst} << L_\tau = \tau_u(u_2^{-1} - u_1^{-1})^{-1}$, where τ_u is the pulse duration, and $u_{1,2}$ are the group velocities of the fundamental and of the harmonic). Obviously, the subnanosecond range is the most favorable for attaining maximum efficiency in the generation of optical harmonics.

A block diagram of our setup is shown in Fig. 1. Here I is a master laser operating in the nano- and picosecond pulse regime, II is a preamplifier with a circuit that shapes a single pulse (∿200 psec) from a light train or of 10 psec duration from a smooth pulse [4], III is a chain of amplifiers, and IV is the frequency converter.

The resonator of the master laser, with a base 1850 mm, had a near-semiconfocal configuration. The exit mirror was a plane-parallel plate 0.7 mm thick. To increase the reproducibility of the generated pulses [5], and also to lengthen them to ∿ 200 psec, we placed two thin selector plates inside the resonator. The Q-switch was a cell with polymethine dye No. 3955 in nitrobenzene.

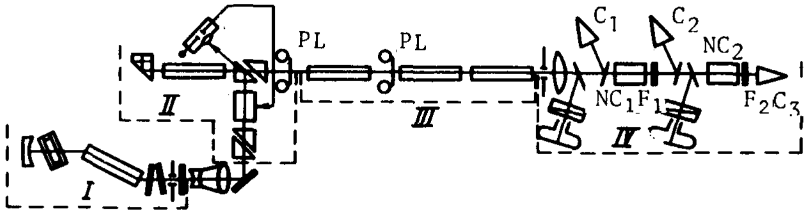

Fig. 1. Block diagram of experimental setup.