KINEMATIC MODE SYNCHRONIZATION IN A YAG:Nd^{3+} PULSED LASER

N. V. Kravtsov, V. A. Sidorov, and A. M. Susov

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Results are reported for a pulsed laser employing yttrium-aluminum garnet in a nonstationary cavity. Kinetic synchronization of the axial modes occurs in such a laser when the rate of change of cavity length exceeds 2 cm/sec; the establishment of kinematic synchronization is examined. It is found that the ultrashort pulses arising in such a laser have parameters closely reproducible from burst to burst. The length of the ultrashort pulses and the shift in the center of the lasing spectrum are examined in relation to the rate of change of cavity length.

There are fairly many papers on the experimental and theoretical aspects of nonstationary-cavity lasers.

Here we examine some aspects of the axial-mode synchronization in a pulsed solid-state laser with a nonstationary cavity.

The system is analogous to that described in [1].

The beam was passed to a broad-band detector and then to S7-10A and S1-31 oscilloscopes. The length of the ultrashort pulses arising by synchronization were examined with a photoelectric recorder. The dynamics of the emission spectrum were examined with a Fabry-Perot interferometer having a separation of 1.2 cm and a high-speed slot-scan camera.

Figure 1a shows a characteristic oscillogram for the laser with the mirror immobile. Figure 1b shows the corresponding spectrogram. Here there is characteristic time instability in the spectrum, as is found with solid-state lasers in which the luminescence line is homogeneously broadened [2]. The general tendency for the emission to shift to the long-wave region, which is due to thermal effects, is accompanied by a typical ladder structure.

When a nonstationary cavity is used, there are substantial changes in the lasing kinetics and spectrum dynamics. At mirror speeds above v = 2 cm/sec (with a stop of 1.5 mm), the modulation depth at the intermode frequency becomes stable at a certain time t_1 after the start of lasing and remains so throughout the pulse. The radiation takes the form of a quasiperiodic sequence of short (2-5 nsec) pulses. The speed at which this occurs increases with the excess of the pumping power over the threshold η. The spectrum becomes more regular in time but still remains split up into separate regions.

The pulses become much shorter as the rate of change of length increases, and the lasing spectrum broadens (the spectrum then becomes smooth). The pulse length becomes of the order of hundreds of picoseconds when the mirror speed

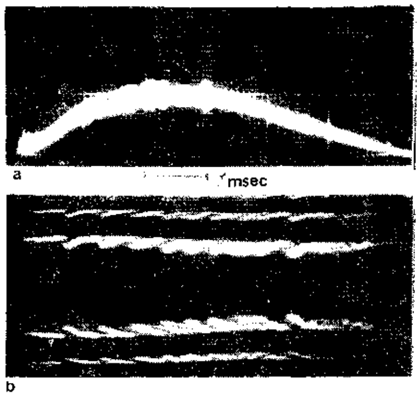

Fig. 1

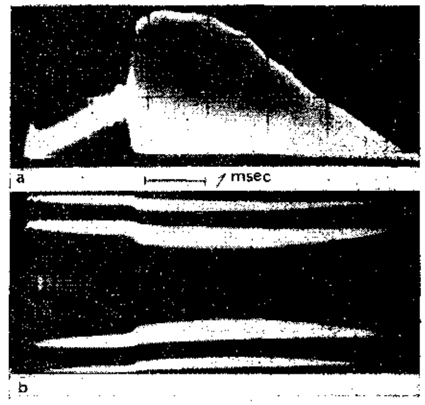

Fig. 2

Fig. 1. Characteristics of the emission pulse for v = 0 (1 msec/division, η = 5.4): a) lasing pulse; b) spectrum scan (Fabry-Perot interferometer, separation 1.2 cm).

Fig. 2. Characteristics of the emission pulse for v = 50 cm/sec (1 msec/division, $\eta \doteq 5.4$): a) lasing pulse; b) spectrum scan.

exceeds 10 cm/sec.

Figure 2 shows characteristic time and spectral characteristics for v = 50 cm/sec; after some delay t_1 from the start of lasing, the sequence of ultrashort pulses arises in a time t_2 and persists until the end of the pulse, i.e., one gets kinematic mode synchronization. The time for the synchronization to set in may be reckoned from the end of the delay to the instant when the quasi-stationary amplitude is reached, and this is highly reproducible, but the delay varies from flash to flash within wide limits (hundreds of μsec) and is dependent on the adjustment of the cavity. The minimum value of t_1 was about 1 msec in our experiments. Also, t_2 varies from 0.2 msec at high mirror speeds to t_2 = 0.5 msec at speeds of a few cm/sec, which agrees with the results obtained with a continuous-wave laser [1].

Figure 2b shows a time scan of the spectrum; comparison with the lasing curve of Fig. 2a shows that during the delay, which is here 1.7 msec, the spectrum oscillates with a period T_1 about 0.15 msec, with gradual increase in the number of spectral components. During t_2, the center of the emission spectrum shifts towards the center of the gain line, after which a quasi-stationary state sets in.

For speeds between 25 and 50 cm/sec, the spectrum width and time characteristics are only slightly dependent on the rate of change of length; the shape and length of the ultrashort pulses were measured at high speeds (some tens of cm/sec) and gave the length of the pulses at the middle of the bursts as $\tau \sim 160$ psec at half-height. Figure 3 shows the form of an individual pulse, as well as the form of the spectrum derived from photometry of the frame in Fig. 2b. The spectrum width at half-height is $\Delta\nu \approx 0{,}145\ cm^{-1}$. The product of the pulse length by the spectrum width is $\tau\Delta\tilde{\nu}c \sim 0{,}67$, which indicates a high degree of synchronization in the modes. This product is 0.44 for a gaussian pulse without frequency modu-

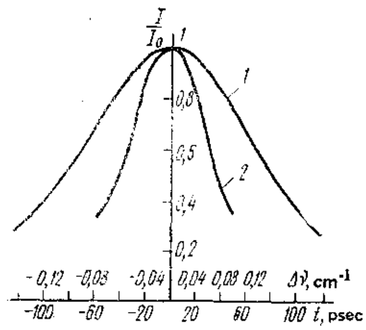

Fig. 3. Characteristics of ultrashort pulses: 1) shape of ultrashort pulse; 2) spectrum.

lation. The high degree of mode synchronization should correspond to high contrast in the radiation, i.e., high value of the ratio of the peak power in the ultrashort pulses to the power in the maximal fluctuation excursions in the axial period.

We have therefore shown that a stable state of kinematic synchronization can arise above a certain minimum rate of change in length. These minimal speeds may be compared for this pulse laser employing $YAG:Nd^{3+}$ and for a continuous-wave laser [1]; the values for the first ($v_{min}=2-8$ cm/sec), are much higher than those for the second ($v_{min}=0,05-0,2$ cm/sec).

The reason for this is that η is higher in the pulsed laser. In our experiments, η was 4-10, the exact value being dependent on the reflectivity of the exit mirror (R = 50-93%).

We consider briefly some spectral features of the kinematic synchronization state. Comparison and processing of the spectra showed that the position of the center (averaged over the length of the step) for v = 0 differed from that when the mirror was moving. As in [3], the spectrum was shifted in the sense determined by the Doppler frequency shift at the moving mirror, and so the shift was dependent on the speed. Also, the spectrum position for $v \neq 0$ is dependent on whether there is kinetic mode synchronization or not. For example, during t_1 = = 1.7 msec, when there is no kinetic mode synchronization, the shifts in the spectrum for $v \neq 0$ and for v = 0 occur at the same rate (which is determined by the temperature drift in the luminescence line). During the establishment of the kinetic synchronization state during t_2, the spectrum shifts towards the center of the gain line, and the subsequent position is determined by the width of the spectrum during kinetic mode synchronization (or by the length of the ultrashort pulses), and this varies during the lasing (Fig. 2b) in accordance with the variation in the pumping power. Therefore, the center of the spectrum in the kinetic synchronization mode is determined not only by the speed of the morror [3] but also by the width of the spectrum, which is dependent on the pumping power in the quasi-stationary state.

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