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SELF-LOCKING OF AXIAL EMISSION MODES OF A RUBY LASER IN THE FREE GENERATION REGIME

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Self-locking of axial emission modes of a ruby laser is described. It was observed on basis of the variation of the beats between the modes. On simultaneous excitation of several modes, the duration of a separate beat pulse decreased. Self-locking is compared with the spectral composition of the laser radiation.

MUCH attention has recently been paid in the literature to the synchronization of axial modes of different lasers. The great interest in this problem is understandable, for synchronization of axial modes makes it possible to obtain extremely short light pulses. There are published reports of mode synchronization by Q switching or by modulating the dielectric of the resonator at a frequency $f_0 = c/2L_{\text{opt}}$ (L_{opt} is the optical length of the resonator[1-3] and self-synchronization (self-locking) of modes by using saturable filters[4-7]. Self-synchronization can also be due to nonlinear mode interaction in the active medium.

We have investigated experimentally the dependence of mode self-locking on the spectrum of the excited modes and on the position of the active medium inside the resonator. We used in the experiment a ruby laser with semiconfocal resonator, operating in the usual spike regime. The resonator length was 52 cm, the ruby crystal length was 5 cm, and the curvature radius of the spherical mirror was I = 100 cm. A round diaphragm of 1 mm diameter, placed inside the resonator ahead of the flat mirror, was used to separate only the TEM_{00} modes. Measures were adopted to eliminate the Q-discrimination of the axial modes due to reflection from the ends of the ruby crystal and from the mirror surfaces that were external with respect to the resonator. To this end, the ruby crystal was tilted 2° relative to the resonator axis, the flat mirror had a 30′ wedge between surfaces, and the operating point on the spherical mirror was shifted 15 mm off center. The radiation receivers were electron-optical converters (EOC).

We investigated the spectrum and the beats between modes only in the first generations spike. The first EOC registering the beat operated in the linear-sweep mode. The second EOC, which registered the emission spectrum with the aid of a Fabry-Perot interferometer, operated in a framing mode, and the frame exposure time coincided with the duration of the linear sweep. The employed Fabry-Perot interferometers had dispersion regions 1.67, 0.5, and 0.1 cm^{-1}.

When the pump energy was very slightly in excess of threshold, and only two neighboring modes were excited, the beat had a clearly pronounced sinusoidal character (Fig. 1a). (In our experiment the beat period was $\tau = 1/f_0 = 3.7$ nsec.) When the pump was increased, and several axial modes were excited simultaneously, the duration of the spike in the beat turned out to be much smaller than the distance between the spikes (Fig. 1b). The shortening of the spike duration shows that the excited modes are in phase.

The experiments revealed that, as a rule, the reduction in the spike duration is proportional to the number of the excited modes. Such a dependence could be traced by exciting simultaneously up to eight modes, this being governed by the resolution of the EOC (0.5 nsec). We can therefore conclude that self-locking takes place at least in an interval 0.08 cm^{-1}. However, in approximately four out of ten observed cases the region in which self-locking took place was smaller than 0.08 cm^{-1}, whereas the width of the generation spectrum was larger than 0.08^{-1}. The maximum number of simultaneously excited modes at a large excess of pump over threshold reached 25, corresponding to a spectral interval ~ 0.25 cm^{-1}.

It follows from the results of[10] that self-locking should depend strongly on the position of the ruby crystal relative to the center of the resonator, namely, self-locking at a frequency f_0 should occur only when the crystal is shifted towards the edge of the resonator. In our experiments we observed no explicit relation between the self-locking and the position of the crystal in

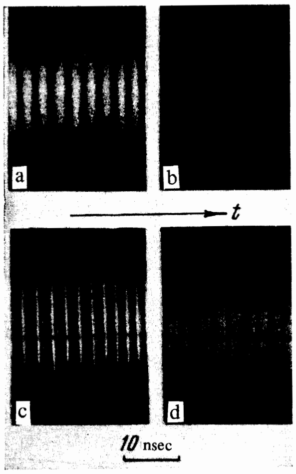

FIG. 1. Linear sweep of laser generation: a – sinusoidal beats of two modes; b – self-locking of five modes; c, d – more complicated cases of self-locking.

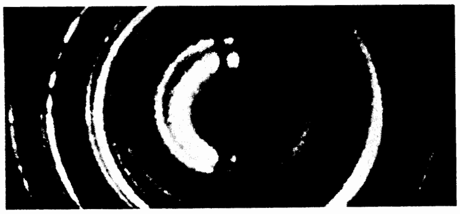

FIG. 2. Typical generation spectrum. The dispersion region of the left-hand interferometer is 0.1 cm^{-1}, that of the right-hand interferometer is 1.67 cm^{-1}.

the resonator. Thus, when the crystal was shifted 18 cm off the resonator center (the total resonator length was 52 cm) no changes were observed at all in the character of the self-locking.

The fact that not all the excited modes are self-locking, and that the position of the ruby crystal in the resonator has no significant effect on the character of the self-locking, can be attributed apparently to the fact that the excited modes do not have equal amplitudes (Fig. 2). This is due to the differences between the Q's of the modes, owing to longitudinal inhomogeneity of the ruby crystal. A certain role can also be played by the residual discrimination on end surfaces of the ruby and on the resonator-mirror surfaces. In such a case, the theory developed in[10] does not hold, and self-locking will occur at the frequency f_0.

It should be noted that the self-locking observed in our experiments was not sufficiently well reproducible. In addition to the reduction in the length of the spike in the beats, we sometimes observed also more complicated self-locking cases. Thus, for example, in Fig. 1c each spike has an asymmetrical form. A weaker satellite is observed somewhat later than the main spike. Figure 1d shows even a certain increase in the duration of individual spikes in the beat. This is apparently also connected with the fact that the amplitudes of the excited modes are not equal.

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