Spectral and picosecond temporal properties of flared guide Y-coupled phase-locked laser arrays

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Spatio-spectral and spatio-temporal properties of flared waveguide "Y"-coupled laser arrays are investigated in both cw and pulsed operation. In each case, regular sustained self-pulsations are exhibited. Destabilization of phase locking, caused by amplitude phase coupling, is thought to be the origin of the pulsations.

There has been considerable recent interest in flared waveguide "Y"-coupled laser (FYCL) arrays because they have been shown[1] to be capable of high-power (150 mW) cw operation with 70% of the total optical power concentrated in a single, stable, central far-field lobe. Interest in these devices has also been spurred by the observation that they exhibit quasi-instantaneous (<20 ps) phase locking[2] upon the initiation of lasing action. Recent experiments have also shown that FYCL arrays exhibit far-field beam steering[2] during pulsed operation, regular sustained self-pulsations during both pulsed and cw[3] operation, and near-diffraction-limited output in an external cavity.[4]

A recent theory predicts[5,6] that the individual emitters of phase-locked laser arrays should exhibit undamped sustained oscillations due to supermode competition and the presence of amplitude phase coupling. Indeed, both the theory[5] and an earlier experimental study[7] of gain-guided lasers indicate that these laser arrays can be intrinsically unstable and offer the possibility for direct observation of spatio-temporal chaos. In this letter we report on the spatio-spectral and picosecond spatio-temporal properties of FYCL arrays. We find that the FYCL arrays exhibit sustained multigigahertz self-pulsation during both cw and pulsed (from zero bias) operation. The structure of the FYCL arrays used in our experiments has been described elsewhere[1] and the devices are the same ones used in our earlier reports.[2,3]

The average spectral properties of the FYCL arrays were measured during cw operation with a 600 line/mm grating SPEX 1269 spectrometer used in the first through third diffraction orders. Figure 1 shows the low-resolution spatio-spectral properties of one such device during cw operation at 1.6 times threshold. The spectral properties shown in the figure are qualitatively similar to those in Ref. 4 and typical of others we have measured. From the figure it may be seen that the FYCL array exhibits multiple longitudinal mode operation with an average mode separation of approximately 2.6 Å. While each of the emitters has approximately the same total optical output, emitters 1, 2, and 3 show nearly single longitudinal mode operation while 4 through 10 have decidedly multimode operation. The low-resolution results depicted in Fig. 1 do not show transverse mode splitting in the wavelength domain. This is to be expected for ideal Y-guide arrays of identical emitters since transverse modes of such an array are known[8] to be energy degenerate. However, since actual Y-coupled laser (YCL) array guides are only nearly identical, some broadening of the longitudinal mode is to be expected.

It is evident from Fig. 2 that this is indeed the case. The figure shows a high-resolution spectral measurement of the dominant mode of emitter 1 at the same drive level above threshold as in Fig. 1. The line has a width of about 0.6 Å and exhibits strong sidebands and a pronounced dip at the center. The substantial linewidth and the asymmetric sidebands are suggestive of the presence of considerable amplitude and phase modulation. To confirm the presence of amplitude modulation, direct measurements of the temporal evolution of the array output were undertaken under both pulsed and cw conditions.

The experimental arrangement consisted of imaging the near field of the FYCL array on the streak camera optical

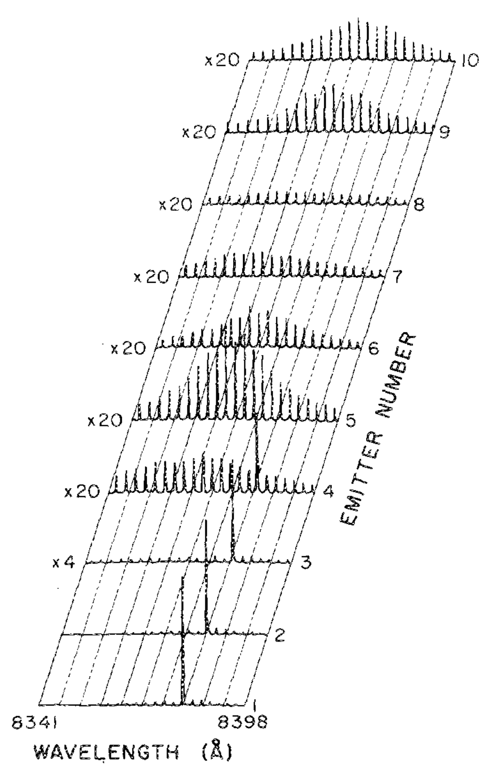

FIG. 1. Low-resolution spatio-spectral properties of a FYCL array during cw operation at 1.6 times threshold.

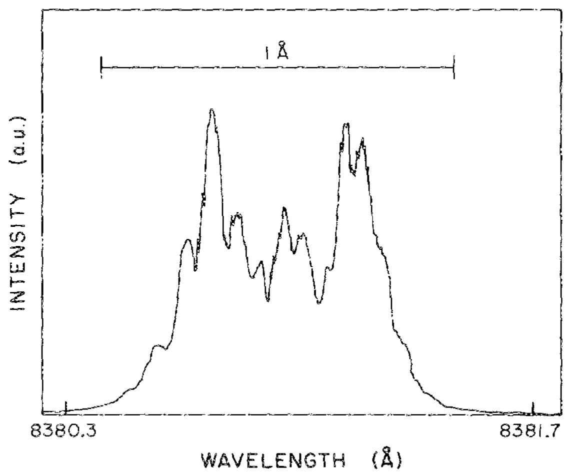

FIG. 2. High-resolution spectral properties of the dominant mode of emitter 1 shown in Fig. 1.

input plane while operating the array at various drive currents above lasing threshold. The time evolution of the pulsed light intensity from the FYCL arrays was measured with a Hamamatsu C979 streak camera in a manner similar to that reported previously.[2] The time evolution of the cw light intensity was measured with a Hamamatsu C1587 streak camera equipped with a M1952 high-speed streak unit also in a manner previously described.[3]

Figure 3 shows the time evolution for the same array during 500 mA cw operation. The figure has 210 vertical time pixels of 24 ps duration each. The sustained self-pulsation of the array is clearly visible from the figure. A curious feature of the spatio-temporal self-organization of the array output under cw operation is the "temporal curvature" in which the inner emitters lag the outer ones in the phasing of

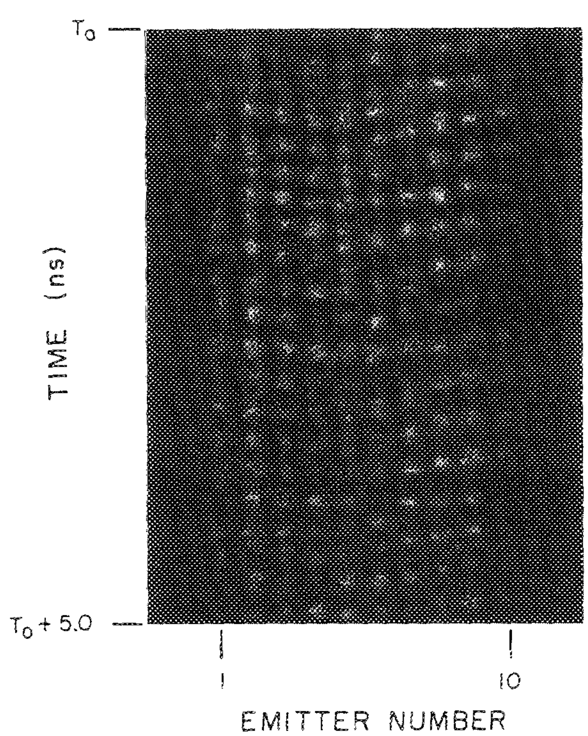

FIG. 3. Time evolution of the near field during cw operation at 500 mA. T_0 represents an arbitrary time (several minutes) after the initiation of lasing action.

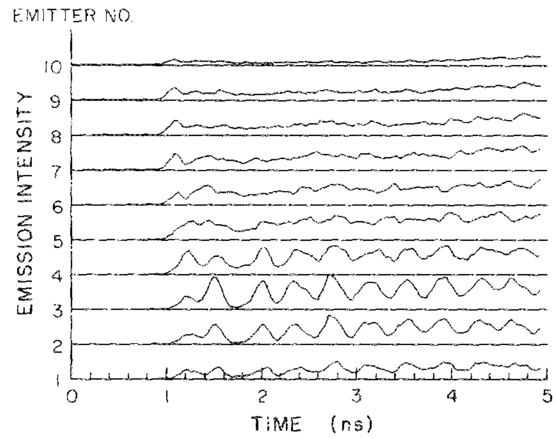

FIG. 4. Average temporal evolution of the FYCL near field averaged over 20 events. The FYCL array was pulsed from zero bias with a 500 mA current pulse.

the pulsations. There is an interesting analogy here to the behavior of diffusively coupled chemical oscillators in which diffusion of phase information to nearest neighbors results in the formation of moving fronts.[9] It may be noted that during high-resolution spectral studies of this array, to be reported elsewhere, we have observed an accompanying "spectral curvature" in which the inner emitters possess a longer wavelength ($\approx$Å) than the outer emitters. We have observed similar spectral and temporal chirping in other YCL arrays we have studied. A more detailed study of this self-organization process is in progress.

Figure 4 shows the time evolution of the near-field pattern during pulsed operation and averaged over 20 pulses. For the figure the FYCL array was pulsed from zero bias with a 500 mA current pulse. It is interesting to note the spiking has a fixed phase relationship from pulse to pulse relative to the initiation of lasing action as evidenced by the fact that it constructively adds over the 20 pulse averaging process which is particularly evident for emitters one through four in the figure. This pulsed behavior may be compared to that of gain-guided arrays where pulses with random phase relative to the initiation of lasing were observed.[7]

Figure 5 shows the discrete Fourier transform modulus (DFTM) of the FYCL array calculated emitter by emitter within each of 20 frames and then averaged and normalized

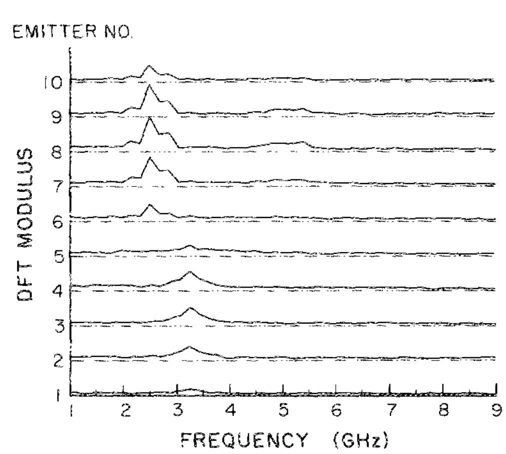

FIG. 5. Average DFTM for a FYCL array operated at a 400 mA cw drive current.

for graphical presentation. At a 400 mA cw drive current or approximately 1.6 times threshold, the average DFTM peaks at 3.3 and 2.6 GHz for emitters 1 through 5 and 6 through 10, respectively. At 500 mA, it peaks at 4.1 and 3.07 GHz for the same stripes. The 0.072 Å average spacing between the spectral peaks observed for emitter 1 of this device at 1.6 times threshold (Fig. 2) predicts a beat frequency which corresponds well with the observed regular spiking frequency of 3.3 GHz. While we have previously noted[3] that these frequencies, when ratioed, fit the known relationship between the semiconductor laser relaxation oscillation frequency and the current overdrive well, it should be noted that the spacing of the spectral peaks shown in Fig. 2 varies less rapidly with current overdrive.

In summary, the spatio-spectral and picosecond spatiotemporal properties of FYCL arrays have been recorded during both pulsed and cw operation. The spectral measurements reveal multilongitudinal mode behavior and the presence of amplitude and phase modulation. Streak camera measurements reveal regular sustained self-pulsations for the FYCL array during both pulsed and cw operation.

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