Temporal behavior of resonant-optical-waveguide phase-locked diode laser arrays

Sujatha Ramanujan and Herbert G. Winful
Department of Electrical Engineering and Computer Science and Center for Ultrafast Optical Science, University of Michigan, 1301 Beal Avenue, Ann Arbor, Michigan 48109

Marc Felisky and Richard K. DeFreez[a)]
Department of Applied Physics and Electrical Engineering, Oregon Graduate Institute of Science and Technology, Beaverton, Oregon 97006

Dan Botez,[b)] Michael Jansen, and Phil Wisseman
TRW Research Center, One Space Park, D1/1024, Redondo Beach, California 90278

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Measurements of the temporal and spatial behavior of resonant optical waveguide (ROW) laser arrays with significant interelement loss reveal the presence of sustained self-pulsations in the output intensity of the laser. The mechanism responsible for pulsations is believed to be saturable absorption arising from the presence of absorbers in the interelement regions. This is experimentally confirmed in that reduction or elimination of the interelement loss suppresses the pulsations. Quiescent behavior is obtained to at least 0.45 W continuous wave power and 3.4 times threshold in near-diffraction-limited beams from devices with negligible interelement loss.

Compact sources consisting of phase-locked arrays of antiguided semiconductor lasers have sparked considerable interest.[1] This is due to their ability to produce high output power (~0.5 W cw and 2.1 W pulsed) in a diffraction limited beam.[1,2] While the array is potentially capable of operating in several lateral modes, there are a number of discrimination mechanisms that encourage lasing in a single lateral mode. These mechanisms include[1,3] (i) lateral radiation loss, (ii) differences in optical mode confinement factors, (iii) diffraction losses in Talbot-type spatial filters, and (iv) the presence of absorbing regions between the lasing antiguides.[3] All these effects are highly mode dependent and result in considerable mode selectivity. In a recent letter we presented numerical simulations which suggested that the presence of interelement absorption can lead to sustained self-pulsations in the output power of the array.[4] We now confirm the existence of these pulsations with streak camera measurements on antiguided arrays with significant interelement loss. These pulsations occur at gigahertz frequencies and may be useful in such applications as all-optical clock recovery, optoelectronic sampling, and in video disk players.[5] Conversely, if interelement absorption is not present, theory predicts quiescent behavior. This is also confirmed experimentally in that arrays with little or no interelement loss are found to be stable.

The arrays studied here are of the resonant-optical-waveguide (ROW) variety.[1] A ROW array consists of a number of low index regions (element regions or antiguides), separated by high index regions (interelement regions). The interelement regions have low modal gain, while the low index regions have high modal gain. The structure supports laterally propagating waves. If the interelement spacing is an integral number of (lateral) half-wavelengths, the resulting behavior is similar to that of a Fabry–Perot etalon in the "on" or resonant state. The laterally propagating wave sees a transparent boundary at the interelement region-antiguide boundary. Laterally propagating waves emanating from each antiguide resonantly couple to each other and determine the lasing mode. When the interelement spacing is an odd number of half-wavelengths, the resonant mode is known as the in-phase mode. When there are an even number of half-wavelengths in the interelement region, the resonant mode is out-of-phase. At resonance the in-phase mode has a uniform near-field pattern and there is very little field in the interelement regions. Under that condition the out-of-phase mode is antiresonant and has substantial field in the interelement regions. Placing absorbers in the interelement regions can thus suppress the out-of-phase mode.[3,6]

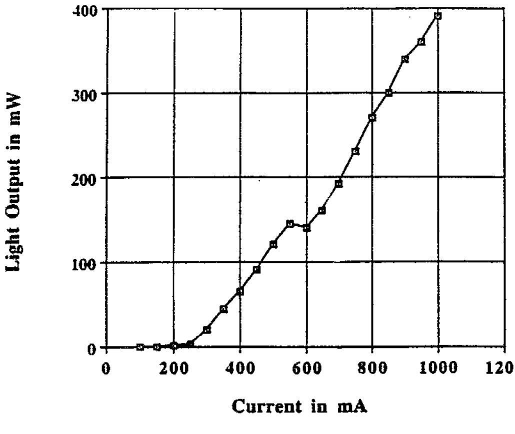

FIG. 1. Light-current characteristics for a 20-element ROW laser array with large interelement loss.

[a)] Present address: Linfield Research Institute, 900 S. Baker St., McMinnville, OR 97128.

[b)] Present address: Department of Electrical Engineering, University of Wisconsin, 1415 Johnson Drive, Madison, WI 53706.

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We have examined the temporal behavior of arrays with and without interelement absorbers. The first laser we studied was a 20-element ROW device, 1000 μm in length with a 3 μm element width and 1 μm spacing. The array was fabricated using the complimentary self-aligned (CSA) process described previously.[2] It had an emission wavelength of 850 nm. This device had significant interelement absorption ($\sim$75–100 cm^{-1}) to suppress nonresonant modes. The absorption was due to a GaAs cap layer grown near the active region. The L-I characteristics are presented in Fig. 1. Lasing begins at 250 mA and stable operation continues for pump currents up to 500 mA, which corresponds to the region before the kink in the L-I characteristic of Fig. 1. As the pump current crosses the kink which occurs at twice threshold, the laser begins self-pulsing and asymmetries develop in the near-and far-field profiles. The pulsation frequency is about 1.6 GHz as is seen in Fig. 2(a). Similar pulsations have been observed by Bossert in antiguide arrays fabricated with significant interelement loss.[7] The peak power of the pulsations in Fig. 2(a) is 290 mW and the power at the null is 50 mW. This sustained self-pulsation occurs with all the elements in synchronism and is quite regular. At three times threshold the temporal oscillations become more erratic as seen in Fig. 2(b). The peak power of the pulsations is 390 mW and the null is 90 mW. The near-field pattern is more asymmetric, and the asymmetry increases with pump current. At higher pump currents there is significant field buildup in the interelement regions. A typical rf power spectrum of a self-pulsing laser at twice threshold is shown in Fig. 3. For this device the pulsation frequency is also 1.6 GHz. At higher pump currents a rich spectrum of harmonics develops.

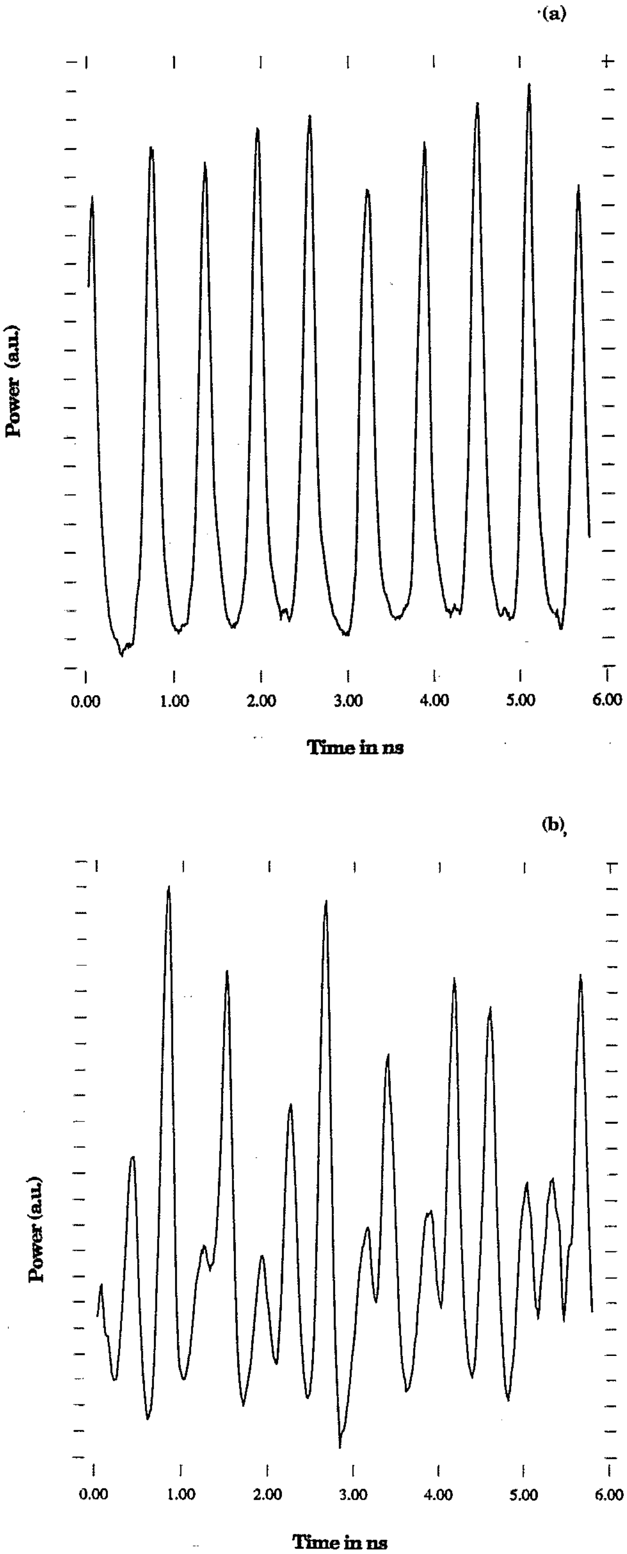

FIG. 2. (a)Output intensity vs time for the 20-element ROW laser array of Fig. 1, at twice threshold. (b) Output intensity vs time for the 20-element ROW laser array of Fig. 1, at thrice threshold.

The occurrence of the kink in the L-I characteristic suggests that saturable absorption may be responsible for the self-pulsations. Indeed, similar behavior has been seen in loss-coupled DFB lasers and has been attributed to the saturable nature of the GaAs loss grating.[8] Our numerical simulations based on a time dependent beam propagation model for the array shows that the saturable absorption can lead to repetitive Q switching at the frequencies observed in experiments.[4] The simulations also suggest that the asymmetries observed in the field profiles may be intrinsic to the unstable laser.

To confirm the role of interelement loss in inducing self-pulsations, we then studied a number of ROW arrays of different geometries. Devices with no interelement loss [e.g., CSA-type devices operating at λ=0.98 μm;[9] self-aligned stripe (SAS)-type devices[10]], and negligible interelement loss, (e.g., CSA-type devices of 5/1 element/interelement

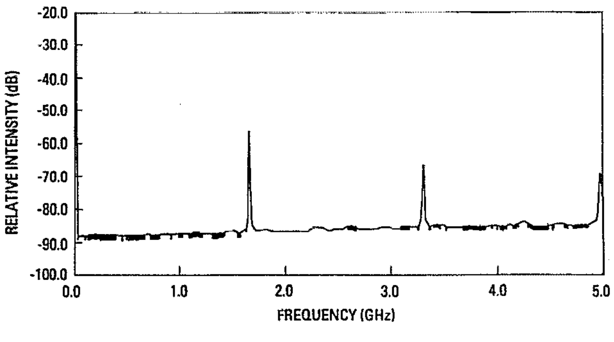

FIG. 3. rf power spectrum corresponding to ROW-device operation while self-pulsing at twice threshold.

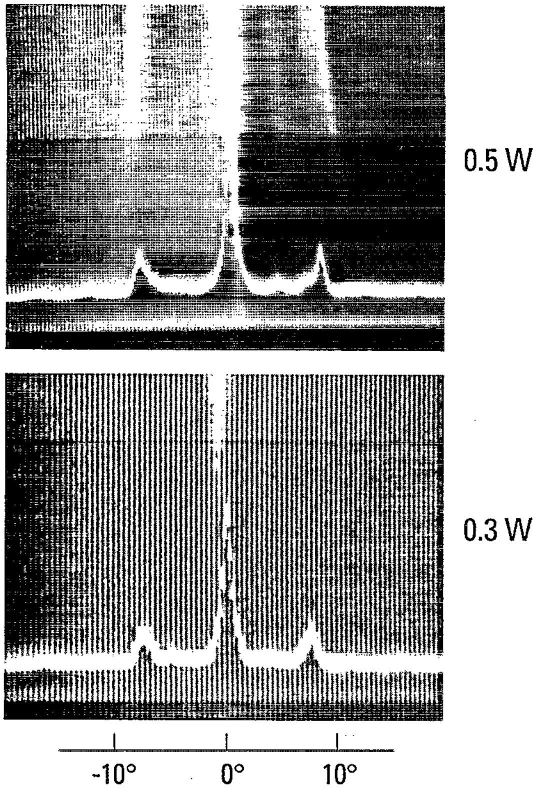

FIG. 4. Far-field patterns under cw operation for a 5/1-geometry ROW device with negligible interelement loss at 0.3 and 0.5 W output power levels. The lobewidth is 0.8°; that is, 1.6× diffraction limit.

width ratio),[11] were studied. In all cases reduction or elimination of interelement loss resulted in no self-pulsations.

Some relevant results are shown in Figs. 4 and 5. These are from 20-element ROW arrays with 5-μm-wide element regions and 1-μm-wide interelement regions. Since, at resonance, the ratio of element to interelement energy is proportional to the cube of the element/interelement ratio,[12] the 5/1-geometry devices have 4.6 times less interelement field than the previously studied 3/1 devices. In turn, 5/1 geometry devices should have negligible interelement loss and thus display no self-pulsations.

Figure 4 shows the cw far-field patterns at 0.3 and 0.5 W. The patterns are symmetrical, contain a significant amount of energy (~70%) in the main lobe as expected for 5/1-geometry devices,[11] and have a lobewidth of 0.8°, which is 1.6×diffraction limit. Figure 5 shows the rf spectra for two different 5/1-geometry devices. For the device whose beam patterns are shown in Fig. 4, there are no self-pulsations up to the maximum drive of the rf spectrum analyzer (950 mA), which corresponds to 0.3 W [Fig. 5(a)]. Another device of similar beam quality, but more efficient, shows quiescent rf spectra to 0.45 W at 3.4× threshold [Fig. 5(b)].

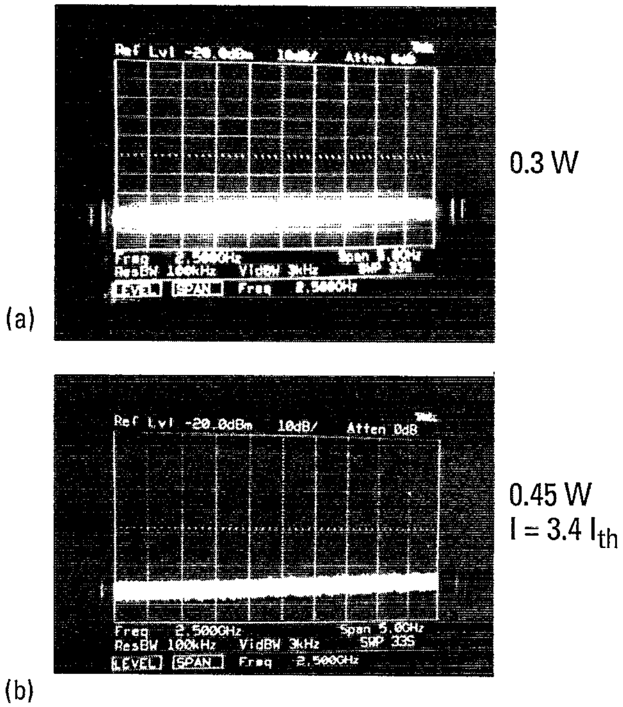

FIG. 5. rf spectra at maximum drive of the spectrum analyzer for (a) the device shown in Fig. 4. (b) another 5/1-geometry device. I_{th} is the threshold current.

In conclusion, we find the presence of interelement loss can lead to sustained self-pulsations in ROW arrays at pump currents as low as twice threshold. However, with proper design these self-pulsations can be eliminated.

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