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Invited

High Power Semiconductor Lasers

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Semiconductor lasers continue to increase in optical power and as importantly reliability at high power. Single mode lasers at both 830nm and 980nm have demonstrated damage levels above 400 mW with high reliability at 100 mW as demonstrated by 10,000 hour accelerated tests. Multimode lasers with power as high as 100 W are presented. Large aperture coherent structures with near diffraction limited powers of 0.5 W have also been demonstrated.

1. SINGLE STRIPE LASERS

Improvements in material quality and facet passivation techniques has led to semiconductor lasers with damage limited CW optical powers from single stripe lasers in excess of 400 mW as shown in Figure 1. Results have been similar for lasers with both AlGaAs active regions which emit between 780 nm and 860 nm and InGaAs active regions which emit between 900 nm and 1020 nm. These devices are single quantum well separate confinement heterostructure designs grown typically by organo-metallic vapor phase epitaxy. The limit for single mode behavior, both spectral and spatial is approximately half the damage limit or 250 mW [1)].

The highest optical powers have been obtained by Fabry-Perot cavities which exhibit single spatial and spectral behavior when operated CW. Under deep modulation these lasers maintain a stable spatial mode but most typically operate in multiple spectral modes. For dynamic spectral mode stability DFB or DBR designs are required. The inherent additional losses of such structures have kept the optical power below half that of the Fabry-Perot designs.

Recent emphasis for these single mode lasers has been on the optical power limits for reliable long life applications as demanded by satellite communications or telecommunications. Ten thousand hour tests at 100 mW of optical power and accelerated temperature (50C) for both 830 nm AlGaAs lasers and 980 nm InGaAs lasers have shown bulk degradation rates below 1 mA/khr with a small probability of sudden failure as shown in Figure 2. Estimated room temperature MTTF for these lasers is in excess of 100,000 hours. More recent results at 150 mW and 50 C have also demonstrated excellent life with bulk degradation rates only slightly higher in the range of 1.0 to 1.5 mA/khr.

2. HIGH POWER MULTI-MODE LASERS

As the emission aperture of the laser is expanded beyond the 3-4 microns typical of single modes much higher powers can be obtained at the expense of multiple spatial mode operation. These multimode beams are still very attractive for optical pumping of solid state material and other material processing and printing applications.

For continuous wave operation, or pulses much longer than 1 mS, both the damage limit and reliable power scale sublinearly with aperture width. Table 1 summarizes both peak and reliable power levels for various apertures. Reliable facet loading as high as 37 mW/um are obtained from the single mode laser while this number drops to 4 mW/um for very large 20 W bars. This decrease in reliable fact loading is due to both the statistical fluctuations in the damage level and field loading in a large area laser and the increased total thermal loading.

Many solid state laser pumping applications require pulsed operation at relatively low duty cycles with much mode modest life requirements. In these cases the thermal limits which force a spatial duty factor on centimeter bars no longer apply and the whole aperture can be used. Laser bars with just under one centimeter of emission aperture have been demonstrated at 300 W peak power (Figure 3) and operated reliably to 100 W peak power when operated with 200 usec pulses at 4% duty cycle[2].

For large solid state laser systems water cooled stacks of similar bars which emit at 808 nm with a 1 cm by 3 cm emission area have been made with peak optical power as high as 2.4 kW and average optical power of 105 W.

3. LARGE APERTURE COHERENT LASERS

The key to higher coherent optical power is to broaden the emission aperture while maintaining single mode operation. The most common approach has been to fabricate arrays of single mode emitters that are coupled by overlapping the optical fields. In these lasers the modal selectivity has been insufficient to discriminate against multimode operation at high optical powers. Recent progress has been made by forming the array from anti-guided sources which enhance optical coupling [3]. Near diffraction limited continuous wave optical powers of 0.5W have been obtained from these designs.

Another successful technique has been to use the lower power single mode laser as an injection source to a traveling wave amplifier. In this geometry MOPA the spatial and spectral properties of the beam are dictated by the master oscillator (MO) while the power amplifier (PA) provides increased power. This approach has been most successful in a discrete geometry where the oscillator can be optically isolated from the amplifier. Diffraction limited pulsed powers as high as 21 W have been obtained[4] while CW diffraction limited power has been limited to 3 W due to thermal lensing in the amplifiers.

A technique to fabricate a MOPA which integrates the oscillator and amplifier on a single chip is to outcouple the amplifier with a detuned surface emitting grating. This design combines a DBR single mode oscillator with a long amplifier that is outcoupled through the substrate with a second order grating that is tuned off resonance to prevent feedback to the oscillator. These lasers have shown near diffraction limited continuous wave powers of 0.5W as shown in Figure 4.

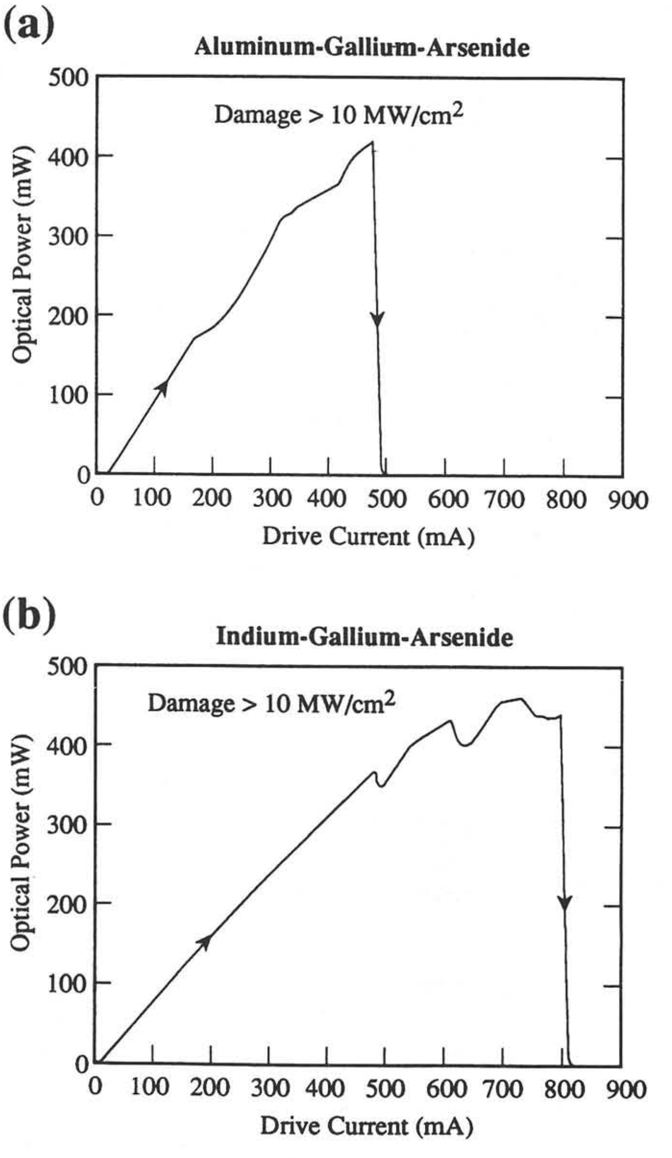

Fig. 1 Damage limit for either (a) aluminum gallium arsenide or (b) indium gallium arsenide single mode lasers is in excess of 400 mW of continuous optical power.

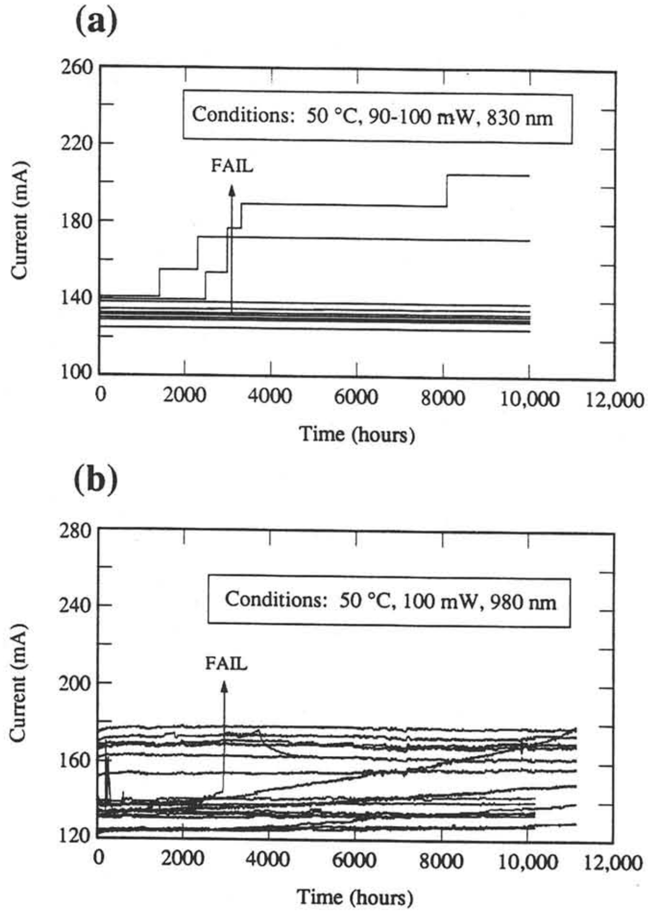

Fig. 2 Accelerated life tests for either (a) aluminum gallium arsenide or (b) indium gallium arsenide show little bulk degradation in 10,000 hours and a finite probability of sudden failure.

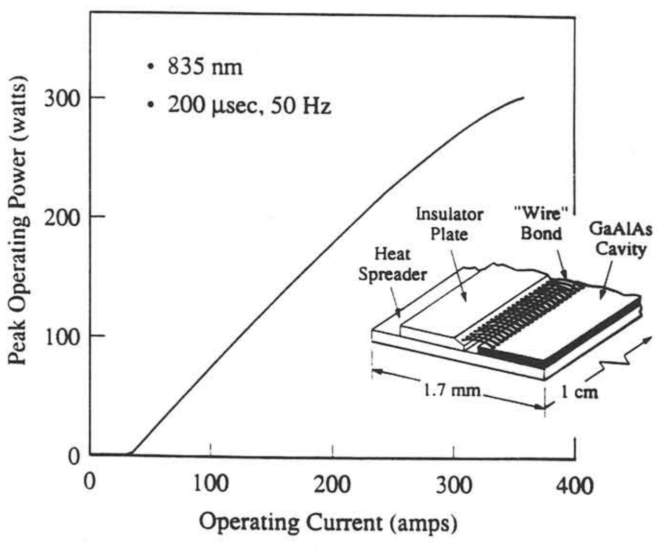

Fig. 3 Aluminum gallium arsenide lasers operated in pulsed operation have shown peak optical powers as high as 300 W.

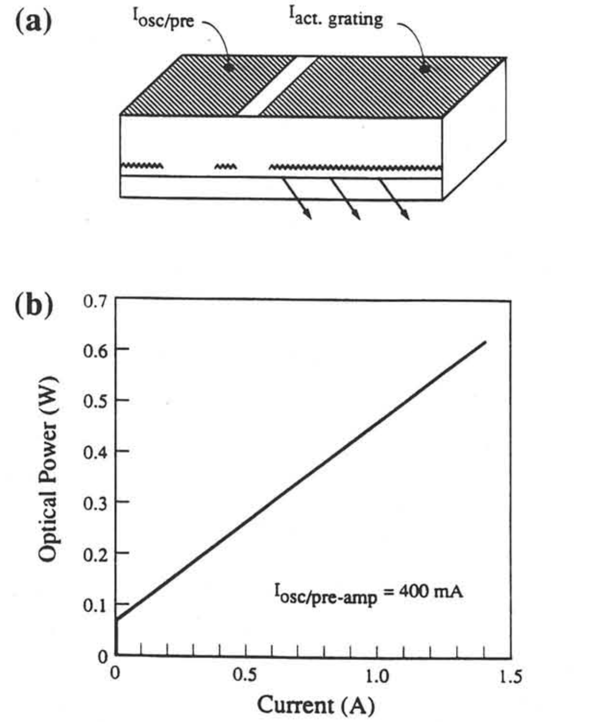

Fig. 4 An integrated master oscillator power amplifier (MOPA) laser has separate contacts for the oscillator (a) and amplifier. The power as a function of amplifier current (b) shows linear continuous wave behavior to in excess of 0.5

CW OPTICAL POWER FROM EDGE EMITTING LASERS

	OPTICAL POWER		OPTICAL POWER/APERTURE	
EMISSION APERTURE	PEAK (W)	RELIABLE POWER (W)	PEAK (mW/µm)	RELIABLE POWER (mW/µm)
4 µm	0.5	0.15	125	37
100 µm	7	1.2	70	12
200 µm	10	2	50	10
4800 µm	10	20	16	4
7200 µm	120	--	16	--

Table 1 Continuous wave peak and reliable optical power for various aperture widths.

1) J.S. Major et al, Elect. Lett. 27, (1991) 539.

2) D.R. Scifres et al, SPIE 1634, (1992)

3) J.S. Major et al, Appl. Phys. Lett. 59, (1991) 2210.

4) L. Goldberg et al, Elect. Lett. 28, (1992) 1082.

5) M. Sakamoto et al, Elect. Lett. 28, (1992) 197.