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# 20000h InGaAs QUANTUM WELL LASERS

*Indexing terms: Lasers, Semiconductor lasers*

Strained-layer GRINSCH-SQW InGaAs lasers operating CW at 1·01 μm have been CW life tested to over 20000h while exhibiting an average degradation rate of 1·3% per kh. These uncoated lasers were life tested at 70mW (per facet) in constant power mode at a heatsink temperature of 30°C. In addition to their longevity, these lasers exhibited a resistance to sudden failure with an unscreened sample of fifteen lasers experiencing total survival to 10000h.

InGaAs strained layer lasers have received considerable attention because of their extended wavelength range[1–5] and enhanced reliability.[6–8] New solid state materials (such as $Er^{3+}$-doped fibres) require pump sources in the previously inaccessible wavelength range of 0·9–1·1 μm, and transparent substrate architectures require wavelengths greater than 0·88 μm. With InGaAs technology these wavelengths can be achieved. Some space communication applications, which require increased laser lifetimes, can be operated at the shorter end of the InGaAs spectral window. With increased reliability already demonstrated at these wavelengths, InGaAs lasers are being investigated in a variety of these applications. Further, the apparent damage resistance and consequent elimination of a screening and/or burn-in procedure, offer the potential for greater yields and lower costs, which are enormous advantages in any application.

The increased reliability of InGaAs lasers has been attributed to both lattice hardening[9] and strain accommodation[10] in this strained layer material system. $In_xGa_{1-x}As$ quantum wells in an AlGaAs/GaAs material system experience mismatch strain which increases with higher indium composition. Although this initially led to expectations of inferior reliability (as compared to GaAs quantum well lasers), this has not been the case. As long as $In_xGa_{1-x}As$ layers are kept below some compositionally dependent critical thickness[11] the strain can be accommodated elastically. Although superior reliability has been routinely demonstrated for shorter wavelength InGaAs lasers,[6,7] increased reliability at wavelengths beyond 1·0 μm is not a forgone conclusion in view of the high strains. In this letter we report strained layer $In_{0.37}Ga_{0.63}As$ quantum well lasers at 1·01 μm with over 20000h CW operation and total survival to 10000h of a thirty laser sample.

The laser structure, a graded index separate confinement heterostructure single quantum well (GRINSCH-SQW), was grown by metalorganic chemical vapor deposition (MOCVD) at low pressure (76 Torr) in a horizontal geometry reactor. The laser structure, grown on an $n^+$-GaAs substrate, consists of a 0·5 μm n-GaAs buffer layer, a 0·1 μm n-$Al_xGa_{1-x}Ga_{1-x}As$ ($x$: 0·0 → 0·4) graded layer, a 1·5 μm n-$Al_{0.40}Ga_{0.60}As$ cladding layer, an undoped active region, a 1·5 μm p-$Al_{0.40}Ga_{0.60}As$ cladding layer, a 0·1 μm p-$Al_xGa_{1-x}As$ ($x$: 0·4 → 0·0) graded layer, and a 0·1 μm p-GaAs contact layer. The n- and p-type dopants were tellurium ($N_D = 2 \times 10^{18}$) and zinc ($N_A = 5 \times 10^{18}$), respectively. The undoped active region is a single 40 Å $In_{0.37}Ga_{0.63}As$ strained-layer quantum well centred between 100 Å GaAs layers. This active region is bordered by 0·2 μm $Al_xGa_{1-x}As$ ($x$: 0·0 → 0·4) graded layers. This GRINSCH-SQW structure is shown in Fig. 1. The growth temperatures were 650°C for the quantum well, 800°C for the n-$Al_{0.40}Ga_{0.60}As$ cladding layer, and 750°C for the p-$Al_{0.40}Ga_{0.60}As$ cladding layer. The growth rate was 240 Å/minute for the quantum well, 400 Å/minute for the graded region, and 1000 Å/minute for the rest of the structure.

The devices fabricated were 60 μm-wide oxide stripe, 600 μm cavity length, uncoated lasers. The n- and p-contacts were Ge/Au/Ni/Au and Ti/Pt/Au, respectively. The 400 μm chip-width lasers were indium-soldered using a flux-free process, epi-side down to a copper heatsink. The resulting lasers operated CW at 1·01 μm with a threshold current (threshold current density) of 128 mA (356 A/cm²) and a slope efficiency of 0·25 W/A per facet. The external efficiency of these lasers was 44·3%, and the characteristic temperature ($T_0$) was 147 K. These lasers were thermally limited at a maximum output power of approximately 400 mW.

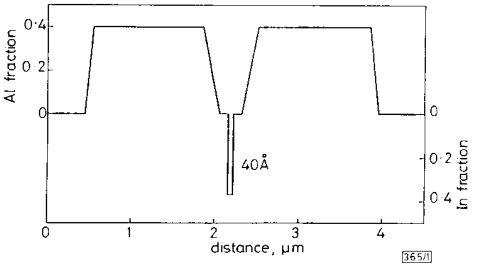

**Fig. 1** *$In_{0.37}Ga_{0.63}As$ GRINSCH-SQW laser structure*

The lasers were CW life tested at 70mW (per facet) in constant power mode at a heatsink temperature of 30°C. In this mode, feedback circuitry automatically controls both the drive current and heatsink temperature to maintain these conditions. Thirty lasers were originally placed on our life test system. No burn-in or screening was done on these lasers. Up to 1000h, the sample exhibited total survival. At that point half of the sample was removed from our life test system due to equipment capacity limitations. These fifteen lasers were arbitrarily chosen and were virtually identical to those left on. The remaining fifteen lasers, shown in Fig. 2, were life tested up to 10000h. This reduced sample continued exhibiting total survival over the additional 9000h. At this time six (arbitrary) lasers were removed from the life test system. Again the consideration here was an equipment capacity limitation. The remaining four lasers are still on life test and have logged over 20000h of CW operation.

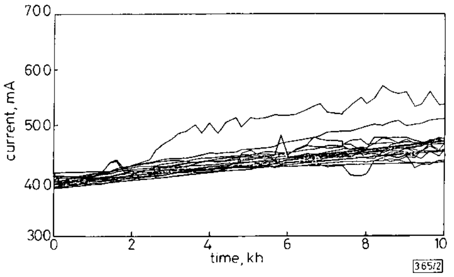

**Fig. 2** *Constant power (70mW per facet) CW life test for fifteen unscreened $In_{0.37}Ga_{0.63}As$ GRINSCH-SQW lasers operating at 30°C*

This laser material has exhibited extraordinary reliability both in yield and longevity. In the power density regime these lasers are operating (~0·1 MW/cm²), two lifetime limitations exist, sudden (or 'freak') failure and gradual (or bulk) degradation. Sudden failures account for 25%–75% of total failures in AlGaAs/GaAs quantum well lasers in our laboratory. These failures usually occur during the first 2000h of operation for our device configuration and are usually associated with dark-line defects (DLDs). DLDs are dislocation networks driven by nonradiative recombination and propagate in the ⟨100⟩ crystal direction.[12,13] The DLDs are initiated from material defects, handling damage, and predominantly scribe-induced damage to the chip side walls incurred during assembly. Once induced these DLDs propagate towards the stripe and cause device failure on entering the stripe region. Currently, a screening process or burn-in (or both) is needed to reduce the incidence of GDLD-related failures in AlGaAs/GaAs lasers and in most cases is not totally effective. The elimination of this failure mechanism without the need for a screening or burn-in has significant implications in time and cost savings. These InGaAs lasers, which experienced 100% survival (for a sample size of thirty lasers), exhibit this desired characteristic. The total survival of this unscreened sample (which is very large relative to our standard sample size) is dramatic. In our experience with AlGaAs/GaAs lasers, total survival of a sample of six unscreened lasers to 2000 h is rare. Thus the statistical significance of this large sample must be acknowledged. This result is consistent with other work on InGaAs reliability and further corroborates the resistance of InGaAs to sudden (or early failures).[7]

Lasers that do not experience sudden failure are limited by gradual degradation. Gradual degradation results from nonradiative effects in the bulk and accelerates with increasing current (density) and temperature. In our laboratory this gradual degradation limits typical AlGaAs/GaAs laser lifetimes to 5000–12 000 h; the laser lifetime being defined as the time to current doubling. The $In_{0.37}Ga_{0.63}As$ lasers remaining on life test, shown in Fig. 3, are presently at 22 000 h with an average degradation rate of 1·3% per kh. This is superior to the best AlGaAs/GaAs lasers with degradation rates of ~2% per kh,[14,15] and is a vast improvement on typical AlGaAs/GaAs lasers with degradation rates of 7–12% per kh.[15] The extrapolated lifetime (to current doubling) of these $In_{0.37}Ga_{0.63}As$ lasers is over 50 000 h. The degradation rate and consequent extrapolated lifetime are especially significant in view of the low efficiency of these lasers. Lasers with low efficiency and consequently below average thermal characteristics are more susceptible to increased degradation resulting from increases in thermal resistance during life testing.

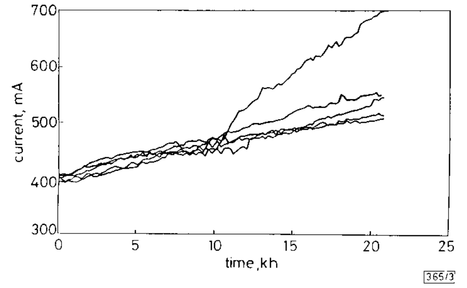

**Fig. 3** *Constant power (70 mW per facet) CW life test for remaining four $In_{0.37}Ga_{0.63}As$ GRINSCH-SQW lasers operating at 30°C*

In summary, 22 000 h CW operation of 1·01 μm InGaAs quantum well lasers operating at 70 mW (per facet) has been demonstrated. A degradation rate of 1·3% per kh has been measured and an extrapolated lifetime (to current doubling) of over 50 000 h is predicted. In addition, a statistically significant sample of fifteen unscreened lasers were life tested to 10 000 h with 100% survival.

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# HIGH-BANDWIDTH CMOS TEST BUFFER WITH VERY SMALL INPUT CAPACITANCE

*Indexing term: Amplifiers*

An analogue CMOS buffer configuration, which eliminates the tradeoff between high bandwidth and very low input capacitance, has been designed and simulated in a standard 2 μm process. The circuit shows a total input capacitance less than 50 fF up to 12 MHz and less than 110 fF overall with a 3 dB bandwidth of 20 MHz when driving a 15 pF and 100 kΩ load. The very small input capacitance and high bandwidth make the circuit very suitable for testing internal sensitive nodes in CMOS analog or mixed-mode circuits.

*Introduction:* Although testability of integrated circuits is fairly mature in the digital domain, the testability of the analogue portion of a mixed-mode integrated circuit is currently a major design problem. To completely evaluate performance of these circuits, several test blocks must be added to monitor internal nodes. Among these, the most important and critical