Long-lived InGaAs quantum well lasers

S. E. Fischer,[a] R. G. Waters,[b] D. Fekete,[c] and J. M. Ballantyne
School of Electrical Engineering and Field of Applied Physics, Phillips Hall, Cornell University, Ithaca, New York 14853

Y. C. Chen[d] and B. A. Soltz
McDonnell Douglas Astronautics Company, Opto-Electronics Center, 350 Executive Boulevard, Elmsford, New York 10523

(Received 28 December 1988; accepted for publication 27 February 1989)

Pseudomorphic InGaAs lasers with cw operating lifetimes exceeding 5000 h are reported for the first time. The device structure, grown by low-pressure metalorganic chemical vapor deposition, incorporates a single $In_{0.37}Ga_{0.63}As$ strained-layer quantum well in a GaAs/AlGaAs graded-index separate confinement heterostructure. These devices are remarkable for their immunity to sudden failure and for their (gradual) degradation rates which are comparable to the best GaAs lasers.

Strained-layer $In_xGa_{1-x}As$ quantum well lasers have attracted considerable attention of late due to the materials configurations made possible. Interest in the semiconductor laser community stems in part from the prospect of accessing the spectral window near 1 μm for pumping new solid-state hosts with quantum well lasers, and in part for space communications, if an advantage can be demonstrated. Since reliability is an issue for both applications, technologists have fostered the hope that strain accommodation[1] and perhaps lattice hardening[2-4] by In can enable viable long-lived devices. Steady progress in the development of high performance $In_xGa_{1-x}As$ lasers[5-11] has been encouraging with the first cw life-test reports coming quite recently.[11] In this letter we report 5000 h cw operation of strained-layer InGaAs lasers with degradation rates of 1.8% per kh and 100% survival.

The device structure, grown by low-pressure metalorganic vapor deposition, incorporates a single $In_{0.37}Ga_{0.63}As$ strained-layer quantum well ($L_z = 40$ Å) in a GaAs/AlGaAs graded-index separate confinement heterostructure (GRIN SCH) and a full description is given elsewhere.[7] Oxide-defined, 60-μm-wide stripes were formed using standard processing.[12] Facets were formed by cleaving and 600-μm-long uncoated devices were mounted junction down to a copper heat sink. The resulting devices operated cw at 1010 nm with a threshold current (density) of 128 mA (356 Å/cm^2) and slope efficiency of 0.25 W/A per facet.

Life testing was carried out at a 30 °C heat sink temperature in a constant power mode on devices operating cw at 70 mW/facet. A total of 30 devices was placed on life test. They were not screened in any way. Device histories are shown in Fig. 1 for 15 devices. (Half of the population was removed at the 1000 h point due to equipment needs but said devices were virtually indistinguishable from those shown.) Lasers have surpassed the 5000 h mark with an average degradation rate of 1.8% per kh (fractional current increase). This is to be compared with degradation in GaAs quantum wells in which rates below 2% have been achieved,[13,14] although in our experience 7–12% is more typical[13] at these current densities.

The apparent immunity to sudden failure is striking and, we believe, significant since our statistical base is greater than the figure would indicate. Recall that 30 devices were operated to 1000 h. In addition an earlier population of eight devices was tested to current doubling ($>$4000 h in that case). In spite of the large population, we have yet to see a sudden failure. Put simply and conservatively, 38 devices have shown 100% survival to 1000 h. Such a large population may be necessary to be convincing since experience with GaAs quantum wells has taught us that the survival rate depends on handling artifacts as much as anything. Whatever the cause, total survival for GaAs oxide-stripe GRIN SCH devices has been seen in no more than 3% of the populations that we have investigated. In the present case, therefore, it is unlikely that we are being deceived by a fortuitous population of damage-free lasers.

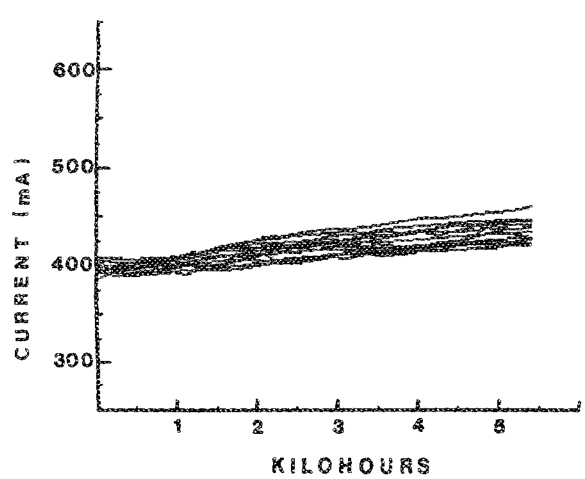

FIG. 1. Histories for $In_{0.37}Ga_{0.63}As$ lasers operating cw at 70 mW per facet and at 30 °C. Results for 15 devices are shown.

[a] Present address: IBM East Fishkill, Hopewell Junction, NY 12533.
[b] McDonnell Douglas Astronautics Company, Elmsford, NY 10523.
[c] Present address: Dept. of Physics and Solid State Institute, Technion, Haifa, Israel.
[d] Permanent address: Dept. of Physics, Hunter College, New York, NY 10021.

Downloaded 19 Sep 2003 to 146.95.52.13. Redistribution subject to AIP license or copyright, see http://ojps.aip.org/aplo/aplcr.jsp

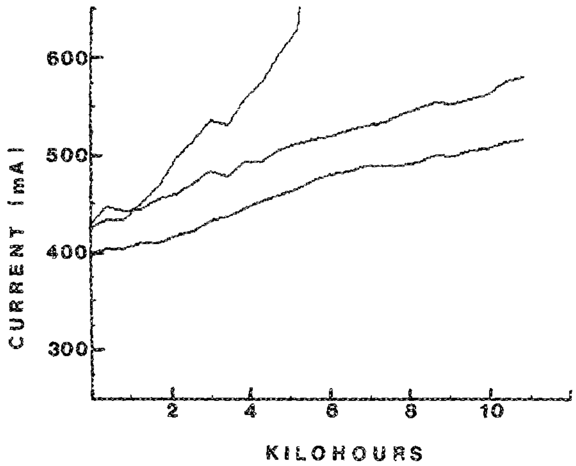

FIG. 2. Results for three lasers. These are nominally the same as Fig. 1 except that a different wafer section was used and testing was started earlier. Two devices continue to operate.

As mentioned, some other devices were placed on life test at an earlier date. The results for three lasers are shown in Fig. 2. While the statistics here are meager, the data do constitute an existence proof for lifetimes exceeding 10 000 h. In addition, five lasers operating at $\lambda = 967$ nm (from a separate growth run with a slightly thinner quantum well) were tested. Of these, two reached the current limit at 4000 and 7000 h, respectively, and three continue to operate beyond 10 000 h.

In summary, long-lived cw operation of strained-layer $In_xGa_{1-x}As$ quantum well lasers emitting 70 mW per facet at 1 μm has been demonstrated. Gradual degradation rates below 2% per kh have been measured and immunity to sudden failure has been documented.

The authors are grateful to K. Bystrom, T. Guido, S. Schultz, S. Yellen, and R. Soltz for valuable technical assistance.

[1] R. M. Kolbas, N. G. Anderson, W. D. Laidig, Y. Sin, Y. C. Lo, K. Y. Hsieh, and Y. J. Yang, IEEE J. Quantum Electron. **QE-24**, 1605 (1988).
[2] P. A. Kirkby, IEEE J. Quantum Electron. **QE-11**, 562 (1975).
[3] M. Ettenberg and C. J. Nuese, J. Appl. Phys. **46**, 2137 (1975).
[4] G. H. B. Thompson, *Physics of Semiconductor Laser Devices* (Wiley, New York, 1980).
[5] W. D. Laidig, P. J. Caldwell, Y. F. Lin, and C. K. Peng, Appl. Phys. Lett. **44**, 653 (1984).
[6] W. D. Laidig, Y. F. Lin, and P. J. Caldwell, J. Appl. Phys. **57**, 33 (1985).
[7] D. Fekete, K. T. Chan, J. M. Ballantyne, and L. F. Eastman, Appl. Phys. Lett. **49**, 1659 (1986).
[8] Y. J. Yang, K. Y. Hsieh, and R. M. Kolbas, Appl. Phys. Lett. **51**, 215 (1987).
[9] J. N. Baillargeon, P. K. York, C. A. Zmudzinski, G. E. Fernandez, K. J. Beernink, and J. J. Coleman, Appl. Phys. Lett. **53**, 457 (1988).
[10] S. E. Fischer, D. Fekete, G. B. Feak, and J. M. Ballantyne, Appl. Phys. Lett. **50**, 714 (1987).
[11] W. Stutius, P. Gavrilovic, J. E. Williams, K. Meehan, and J. H. Zarrabi, Electron. Lett. **24**, 1493 (1988).
[12] D. K. Wagner, R. G. Waters, P. L. Tihanyi, D. S. Hill, A. J. Roza, H. J. Vollmer, and M. M. Leopold, IEEE J. Quantum Electron. **QE-24**, 1258 (1988).
[13] G. L. Harnagel, T. L. Paoli, R. L. Thornton, R. D. Burnham, and D. L. Smith, Appl. Phys. Lett. **46**, 118 (1985).
[14] R. G. Waters and R. K. Bertaska, Appl. Phys. Lett. **52**, 179 (1988).

Downloaded 19 Sep 2003 to 146.95.52.13. Redistribution subject to AIP license or copyright, see http://ojps.aip.org/aplo/aplcr.jsp