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13. ABSTRACT (Maximum 200 words)

Broad stripe 1.5μm InGaAsP/InP MQW graded index SCH lasers with different waveguide widths and doping profiles were designed, fabricated and characterized. Studies of the characteristics of lasers with different p-doping profiles as well as modeling data show that the heterobarrier electron leakage is responsible for the effect of optical power saturation with current. Broadened waveguide devices containing higher Zn concentration in the vicinity of p-cladding/SCH interface yielded maximum output optical pulsed power density giving more than 16W from 100μm aperture. Direct measurements of optical loss for BW lasers with different doping profiles have shown that doping can increase the internal loss of the device by more than two times, which explains the reduction of the device slope efficiency with doping. We have found that the benefit associated with the suppression of heterobarrier electron leakage outweighs lower efficiency near threshold leading to improved linearity of the light-current characteristics and higher output optical power and brightness. Broadened waveguide lasers with doped p-cladding/SCH interface have twice as high output optical power density and brightness compared to undoped BW devices.

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Sincerely,

Gregory Belenky

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DAAD1999910122

List of manuscripts submitted or published under ARO sponsorship during reporting period.

1. L. Shterengas, R. Menna, W. Trussell, D. Donetsky, G. Belenky, J. Connolly, D. Garbuzov, "Effect of heterobarrier leakage on the performance of high-power 1.5μm InGaAsP multiple-quantum-well lasers", *J. Appl. Phys.* **88** (2000), p.
2. 2211R. Menna, L. Shterengas, G. Belenky, W. Trussell, D. Donetsky, M. Maiorov, J. Connolly, D. Garbuzov, " Effect of p-cladding layer doping on pulsed, high power 1.5 mm InGaAsP/InP MQW lasers ", International Conference on Indium Phosphide and Related Materials, (2000), Conference Proceedings, p. 274
3. G. Belenky, L. Shterengas, W. Trussell, R. Menna, D. Donetsky, J. Connolly, D. Garbuzov "Effect of heterobarrier leakage on the performance of high power 1.5μm InGaAsP multiple quantum well lasers", 13th Annual Meeting IEEE Lasers and Electro-Optics Society, (2000), Conference Proceedings Vol. 2, p. 872
4. G. Belenky, L. Shterengas, C.W. Trussell, C.L. Reynolds, Jr., M.S. Hybertsen, R. Menna, "Trends in semiconductor laser design: Balance between leakage, gain and loss in InGaAsP/InP MQW structures". Advanced Research Workshop on "Future Trends in Microelectronics: The Nano Millennium" (2001) Conference Proceedings, to be published (Wiley)

Scientific personal supported by this project

Dr. Gregory Belenky, Professor
Dmitry Donetsky – researcher
Leon Shterengas – graduate student

Scientific progress and accomplishments

In this work we carried out a comprehensive study of the nature of power saturation in 1.5-μm high power InGaAsP/InP MQW two step graded SCH lasers. We studied devices with different waveguide geometries and different p-doping (Zn) profiles in the upper cladding layer. The experimental data show that heterobarrier leakage is responsible for power saturation in 1.5-μm InGaAsP/InP lasers. Narrow waveguide lasers with a higher Zn concentration at the SCH/p-cladding interface exhibited increased output power. We used the PADRE modeling procedure to simulate the performance of devices with two doping profiles. Our simulation results support this conclusion. Direct measurements of the optical loss in device with narrow (260nm) and broadened (710nm) waveguide demonstrate significant optical loss reduction with waveguide broadening: narrow waveguide devices have internal optical loss of about 25cm^{-1} while broadened waveguide devices with low doped p-cladding/SCH interface have internal loss less than 4cm^{-1}. The broadened-waveguide design decreases the internal optical loss leading to improved slope efficiency at threshold.

Higher doping concentration at the p-cladding/SCH increases the barrier for electron thermoionic emission from the waveguide into p-cladding and improves the LI linearity at high injection currents. There is always a trade-off between the internal optical loss enhancement by doping and the effect of heterobarrier leakage suppression. This issue is especially important for broadened waveguide devices, which inherently have a very low internal optical loss (for undoped waveguide).

We have fabricated broadened waveguide lasers with three different doping profiles. The best linearity of LI and the highest output optical power density was obtained for lasers with doped p-cladding/SCH interface while undoped devices have displayed the largest slope efficiency at threshold. We measured directly the current dependence of the modal gain spectra of the lasers studied. A spatial filtering [1] selected on-axis optical mode of the multimode broad area lasers. Lasers with the lowest Zn concentration in the vicinity of the p-cladding/SCH interface have about $4cm^{-1}$ internal optical losses. As Zn propagates deeper into the waveguide, the internal loss goes up to $12cm^{-1}$.

At high injection levels when the barrier for electron thermoionic emission from SCH into p-cladding is suppressed by external voltage, heterobarrier leakage increases and LI saturates. Doping reduces part of the external voltage drop across the p-cladding/SCH interface. As a result highly doped lasers experience lower heterobarrier leakage at high injection currents and their LI's have better linearity compared to low doped devices [2]. Optimization of the device p-doping profile allowed us to obtain the same output optical power from 100μm BW doped lasers as from 200μm BW low doped ones. Far field emission patterns were almost independent of stripe width and doping profile with about 20^0x50^0 divergence for high output power levels. Due to better linearity of LI characteristics the BW doped lasers yielded twice the output optical power density and brightness as BW low doped devices at 60A giving more than 16W from 100μm aperture at room temperature.

References

1. Bossert D.J., Gallant D., "Improved method for gain/index measurements of semiconductor lasers." *Electron Lett*,, **32** (1996) 338-339.
2. Shterengas L, Menna R, Trussell W, Donetsky D, Belenky G, Connolly J, Garbuzov D, "Effect of heterobarrier leakage on the performance of high-power 1.5μm InGaAsP multiple-quantum-well lasers", *J. Appl. Phys.* **88** (2000) 2211-2214.