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Improved Lateral Mode Stability From Ridge Laser Using Self-Aligned Buried Heterostructure Defined By Defect Induced Quantum Well Intermixing

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***Abstract*—We demonstrate improved lateral mode stability and discrimination from a novel high brightness single-mode ridge laser using defect induced quantum well intermixing to form a self-aligned buried heterostructure.**

I. INTRODUCTION

High brightness semiconductor lasers operating in the fundamental lateral mode are required for applications including erbium doped fiber amplifier (EDFA) pumping, Raman amplification, free-space communications, printing, material processing, and optical disk storage. These lasers are often limited by lateral mode instability, caused by spatial hole burning and the excitation of higher order modes [1]. Lateral mode stabilization is typically achieved using a narrow laser waveguide of a few micron width, which does not support higher order lateral modes. Confining the optical mode using such a waveguide has the limitation that the output aperture is small, and consequently the optical intensity is high, resulting in mirror degradation and eventually catastrophic optical damage (COD). Ridge waveguide and buried heterostructure lasers are typically limited in that the optical and electrical confinement are interdependent; the optical waveguide width is approximately the same as the current aperture. The device requirements to give stable fundamental mode operation and avoid COD are disparate, limiting the power capability of such devices.

In this paper we propose a novel ridge laser structure using a buried heterostructure, which suppresses higher order lateral modes, and allows wider ridges to operate in the fundamental mode, increasing the lateral stability and power capability before COD. Optical confinement of the mode is defined by the ridge waveguide, and the electrical confinement by the buried heterostructure. Independent control of the optical and electrical confinement allows modification of the lateral gain profile, reducing the gain of higher order modes relative to the fundamental mode. Furthermore, the buried heterostructure should reduce carrier leakage, leading to reduced threshold currents and increased differential efficiencies. The buried heterostructure is created using a defect induced quantum well intermixing (QWI) technique described elsewhere [2]. Point defects are generated at the surface during sputter deposition of SiO_2; diffusion of these point defects at elevated temperatures results in the intermixing of the wells with the barriers, and a consequent increase in the band-gap energy.

Higher order lateral modes are less well confined by the waveguide than the zero order mode; as the order increases the mode overlaps less with the center of the waveguide. Narrowing the gain profile in the center of the waveguide can therefore reduce the gain of higher order modes relative to the fundamental. This suppression of higher order modes enhances single-mode operation and stability.

II. DEVICE DESIGN AND FABRICATION

Fig. 1 is a schematic diagram of the device. The double quantum well (DQW) separate confinement heterostructure (SCH) wafer was grown by metal-organic vapor phase epitaxy (MOVPE). Two 10 nm GaAs QWs were placed at the center of an $Al_{0.2}Ga_{0.8}As$ waveguide core, surrounded by two $Al_{0.4}Ga_{0.6}As$ cladding layers.

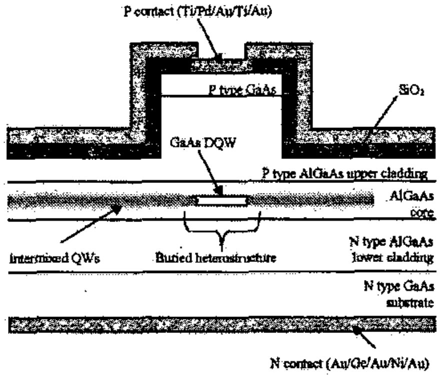

Fig. 1. Schematic of the ridge waveguide laser with a buried heterostructure defined by QWI.

Precise alignment of the ridge to the buried heterostructure is difficult with standard photolithography due to the lateral and rotational errors involved, hence a novel fabrication process was developed which self-aligned the ridge and heterostructure. First a 500 nm layer of plasma enhanced chemical vapor deposition (PECVD) SiO_2 was deposited. Photolithography and pattern transfer using CHF_3 reactive ion etching (RIE) were then used to form a stripe in the PECVD SiO_2; this stripe formed the intermixing suppressant cap and ridge etch mask. Deposition of 50 nm of sputtered SiO_2 was performed to create the point defects necessary for this intermixing process; intermixing takes place in regions where the semiconductor surface is exposed to this deposition, whereas the 500 nm PECVD SiO_2 is sufficiently thick to suppress intermixing under this cap. Annealing at 875 °C for 60 s was performed to diffuse the point defects and intermix the QWs. Some lateral diffusion of defects takes place, therefore the buried heterostructure is narrower than the ridge waveguide, and from previous experiments on this QWI process within the department [3], the buried heterostructure is believed to be around 2 μm wide. Fig. 2 shows the photoluminescence (PL) spectra from test samples annealed

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alongside the laser sample. Successful intermixing is demonstrated by the 48 nm differential blue-shift between the intermixed and suppressed peaks. The 50 nm sputtered SiO_2 layer was subsequently removed using CHF_3 RIE, leaving the stripe of 500 nm-PECVD SiO_2, which was used as the etch mask during $SiCl_4$ RIE of the semiconductor ridge. Following this, standard ridge laser processing was used to complete the devices. No facet coatings were used.

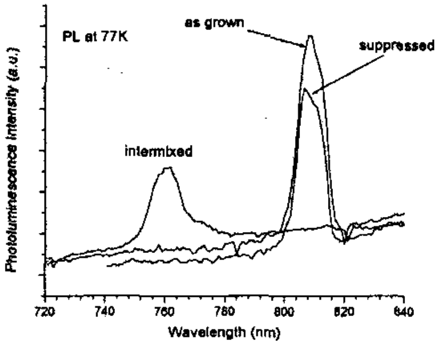

Fig. 2. Photoluminescence spectra showing differential blue shift achieved by intermixing. The as grown sample was not annealed.

III. DEVICE CHARACTERISTICS

Fig. 3 shows the light-current (L-I) and lateral far-field characteristics of a 5 μm wide standard ridge laser. The wafer design was not optimized for low threshold operation, and facet coatings were not deposited, hence the threshold current is 40 mA. Although the L-I characteristic is linear, the far-field beam profile is poor, indicating instability of the lateral mode. Clearly the 5 μm wide devices are too wide to operate in the fundamental mode; the waveguide supports higher order modes, the excitation of which causes lateral mode instability and far-field deterioration.

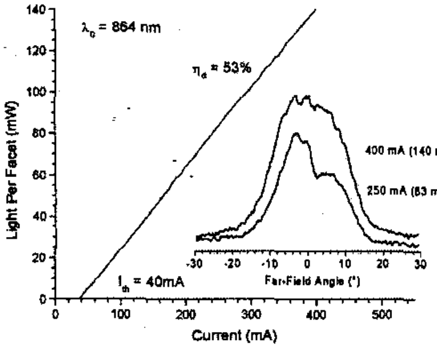

Fig. 3. Light-current (L-I) and lateral far-field characteristics of 5 μm wide standard ridge waveguide laser (600μm long).

L-I and far-field characteristics of the 5 μm wide ridge laser with buried heterostructure are shown in Fig. 4. The threshold current has increased and the differential efficiency reduced slightly. Since this QWI process has demonstrated very low losses [2], this increase in threshold current is likely to be due to a combination of a reduced lateral confinement factor, and losses related to the novel fabrication scheme. A slight non-linearity can be seen in the L-I characteristic, but this is not like the sharp kinks typical of mode instability. The far-field beam profile shows dominantly single mode operation, and although a slight deterioration can be seen at 500 mA the beam still has one dominant lobe; proof that the buried heterostructure helps reject higher order lateral modes.

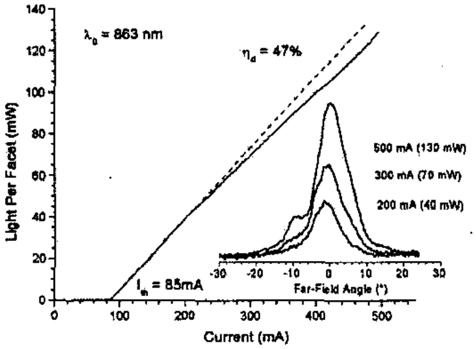

Fig. 4. L-I and lateral far-field characteristics of 5 μm wide ridge waveguide laser with buried heterostructure (600 μm long).

IV. CONCLUSION

We have successfully demonstrated improved lateral mode stability from a novel ridge waveguide laser benefiting from a self-aligned buried heterostructure engineered by QWI. The standard 5 μm wide ridge lasers are too wide to operate in the fundamental mode; higher order modes have sufficient gain to oscillate, causing lateral mode instability. Although the 5 μm wide ridge lasers with the buried heterostructure have similar optical confinement to the standard ridge lasers, they benefit from improved lateral mode discrimination due to the narrower gain profile; higher order modes have reduced modal gain relative to the fundamental, hence insufficient gain to oscillate and cause lateral mode instability. This clearly demonstrates the advantage of using the buried heterostructure; the ridge width can be increased and still maintain fundamental mode operation, a clear benefit for high brightness lasers prone to COD. Furthermore, it demonstrates the feasibility of the fabrication and QWI processes.

REFERENCES

[1] J. K. Lee, K. H. Park, D. H. Jang, H. S. Cho, E. S. Nam, K. E. Pyun, and J. Jeong, "Improvement of Kink and Beam Steering Characteristics of 0.98 μm GaInAs-GaInP High-Power Lasers Utilizing Channel Ion Implantation," *IEEE Photon. Technol. Lett.*, vol. 12, no. 2, pp. 140-142, Feb. 2000.

[2] S. D. McDougall, O. P. Kowalski, C. J. Hamilton, F. Camacho, B. Qiu, M. Ke, R. M. De La Rue, A. C. Bryce, and J. H. Marsh, "Monolithic Integration via a Universal Damage Enhanced Quantum-Well Intermixing Technique," *IEEE J. Selected Topics Quantum Electron.*, vol. 4, no. 4, pp. 636-646, Jul./Aug. 1998.

[3] A. Saher Helmy, A. C. Bryce, C. N. Ironside J.S. Aitchison, J.H. Marsh, S. G. Ayling "Optical Diagnostics Of Microstructures Fabricated Using Quantum Well Intermixing", MRS 1999 Fall Meeting, Boston., 29 November-3December 1999.