High power coupled ridge waveguide quantum cascade laser arrays

Jin-Chuan Zhang, Feng-Qi Liu, Jun-Qi Liu, Li-Jun Wang, and Zhan-Guo Wang

Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, P.O. Box 912, Beijing 100083, People's Republic of China

Abstract—The fifteen-unity coupled ridge waveguide quantum cascade laser (QCL) arrays integrated in parallel were present. In-Phase mode of operation is provided by both the index-guided nature and the strong coupling between lasers inherent in this structure. Single-lobe lateral far-field with a nearly diffraction limited beam pattern was obtained. The simplicity of this structure and fabrication process makes this approach attractive to many practical applications.

I. INTRODUCTION

Since their invention in 1994, quantum cascade lasers (QCLs) have undergone a rapid development and are now well established as reliable semiconductor coherent light sources in the mid-infrared spectral region.[1-2] For many applications such as remote sensing of chemicals, and free space communication, there is a need for high peak output power operation of QCL. For achieving high peak output power, the most straightforward approach is to increase ridge width of the laser. However, simply widening the ridge width above a certain value is not viable as it leads to poor beam quality. [3] As a result, some solutions have been proposed to maintain strong optical coherence for a large-area laser, such as photonic crystal DFB lasers, [4] master-oscillator power-amplifiers, [5] and angled cavity lasers.[6] Another elegant and simple method to obtain fundamental transverse mode far-field is coherent ridge waveguide or stripes laser arrays. In this work, we present the fifteen-unity coupled ridge waveguide DFB QCL arrays and demonstrate a single-lobe far-field pattern with a near diffraction limited beam quality. Compared with QCL micro-stripes in Ref. 7-8, ridge waveguide arrays are only etched in upper InP cladding. The optical field of coupled ridge waveguide structure is mainly confined in the ridge region while the coupling region has gain instead of loss, thus promoting in-phase operation when the gain in the interspaces between the waveguides exceeds that of the waveguides themselves.

Results

The wafer was etched into coupled ridge waveguide laser arrays structure with fifteen elements by standard photolithographic techniques and wet chemical etching. The average width of each ridge was about 7.5 μm and the center-to-center spacing was 10 μm. The etching depth was about 2.5 μm, which give enough index guidance. The fifteen-unity coupled ridge waveguide are chosen as elements of a laser array mainly because of their index-guided nature and simplicity in fabrication. Such a structure possesses two distinct features: i) both the waveguides and interspaces are laterally uniform and the width of each emitter is far larger than interspaces, ii) the optical field is mainly confined in the ridge region while the coupling region has gain instead of loss, thus promoting in-phase operation. Fig. 1 (b) shows the results of a numerical 2D simulation of the near-field patterns of fifteen-unit coupled ridge waveguide laser arrays with finite element method software [COMSOL]. The arrays were generated by the injected-carrier profile induced in the active region by a periodic upper InP cladding. The presence of near-field intensity favor in-phase supermode, where the signs of electric field distribution is consistent with a 0° phase shift between emitters. The radiation intensity is centrally peaked, indicating an oscillation in virtually the fundamental supermode.

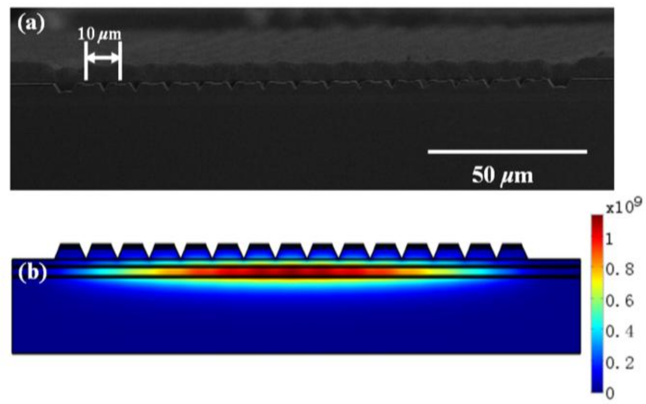

FIG 1. (a) Scanning electron microscopy images of the fifteen-unity coupled ridge waveguide QCL arrays (b) The calculated near-field profiles of the fifteen-unity coupled ridge waveguide structure taken with finite element method software [COMSOL].

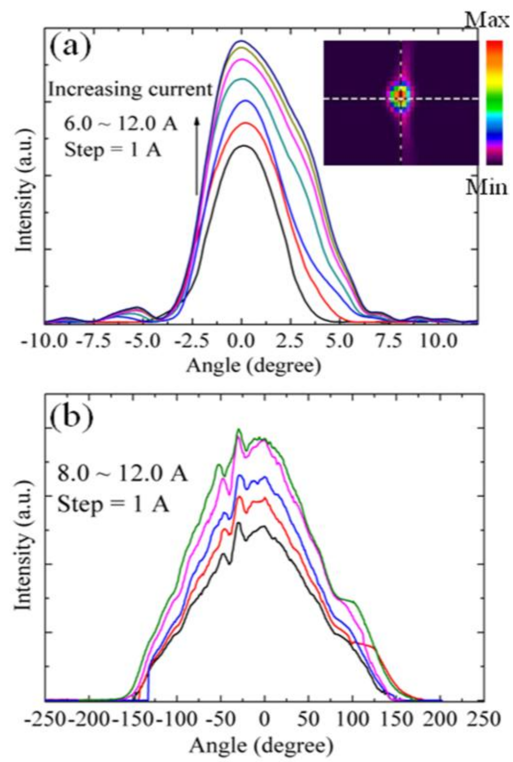

FIG 2. (a) Measured lateral far-field radiation patterns for the coupled ridge waveguide devices at different driving currents operated in pulsed mode. The inset of Fig 2(a) shows the image of a laser beam emitted from the coupled ridge waveguide devices after collimation by the aspheric lens. The result was taken with a calibrated thermopile Infrared camera (Pyrocam III). (b) Measured vertical far-fields of these lasers at different driving currents operated in pulsed mode.

Of particular interest is the lateral far-field radiation pattern of these lasers. In this lateral direction, the coherence between spaced emitting regions generates a single, well-collimated far-field radiation lobe at different driving currents. The emission direction is normal to the facet. The measured full width at half maximum (FWHM) of the far-field pattern is 3.9° at a driving current of 6 A at 20 ℃, which is nearly diffraction limited (i.e., 2.9 ° for an in-phase 150-um-wide array with amplitudes weighted as indicated by the near-field pattern in Fig. 1). This indicates a pure in-phase operation. The lobe FWHM increases gradually to 5.3° at a driving current of 9 A. Fig. 2 (b) shows the vertical far-fields of these lasers up to 12 A. Single lobe radiation with a symmetric far-field pattern is obtained.

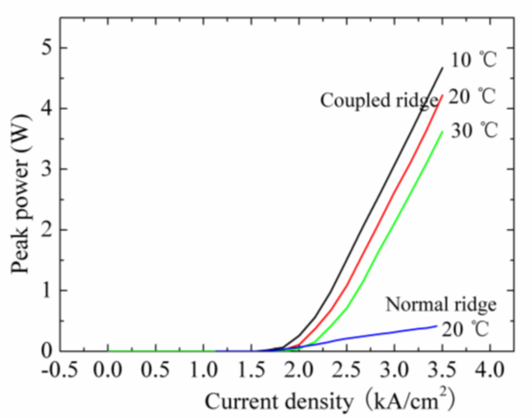

FIG 3. Light-current of a coupled ridge DFB QCL operated in pulsed mode at different heat sink temperatures between 10 and 30 ℃ along with a normal ridge waveguide laser at 20 ℃.

The light-current (*L-I*) characteristic for one of these devices under pulsed operation is shown in Fig. 3. Threshold currents densities are in the range of 1.83-2.33 kA/cm^2 (Threshold currents are in the range of 5.5-7 A) at different heat sink temperatures from 10 to 30 ℃. For temperature characteristics of the couple ridge QCL, the maximum peak output power was observed to decrease from 4.6 to 3.5 W (The maximum current is at 11 A), while the slope efficiency reduces from 1.15 to 0.96 W/A at heat sink temperatures of 10 to 30 ℃. We also give characteristics of a normal ridge waveguide laser in Fig. 4 for comparison (The ridge width is 13 μm and the grating structure is the same as coupled ridge waveguide arrays). The current density of normal ridge waveguide laser is lower than the coupled ridge waveguide arrays. The possible reason is that the coupled ridge waveguide laser suffers a higher interface scattering.

II. SUMMARY

We have described a fifteen-unity couple ridge waveguide DFB QCL arrays with coherent emission. Phase-locking and the fundamental supermode emission have been obtained leading to beam close to diffraction limited operation in lateral direction. these results are highly reproducible and it may also be possible to achieve even higher single longitudinal mode output power with good beam quality by adding more ridge waveguide to the arrays.

REFERENCES

[1]J. Faist, F. Capasso, D. L. Sivco, Sirtori C, A. L. Hutchinson, and A .Y. Cho, Science 264, 553 (1994).

[2]C. Gmachl, F. Capasso, D. L. Sivco, and A .Y. Cho, Rep. Prog. Phys. 64, 1533 (2001).

[3]Y. Bai, S. Slivken, S. R. Darvish, A. Haddadi, B. Gokden, and M. Razeghi, Appl. Phys. Lett. 95, 221104 (2009).

[4]I. Vurgaftman and J. R. Meyer, IEEE J. Quantum Electron. 38, 592 (2002).

5Q. Y. Lu, W. H. Guo, W. Zhang, L. J. Wang, J. Q. Liu, L. Li, F. Q. Liu, and Z. G. Wang, Appl. Phys. Lett. 96, 051112 (2010).

[6]S. Menzel, L. Diehl, C. Pflügl, A. Goyal, C. Wang, A. Sanchez, G. Turner, and F. Capasso, Opt. Express 19, 16229 (2011).

7G. M. de Naurois, M. Carras, B. Simozrag, O. Patard, F. Alexandre, and X. Marcadet, AIP dvances 1, 032165 (2011).

[8] G. M. de Naurois, M. Carras, G. Maisons, and X. Marcadet, Opt. Lett. 37, 425 (2012)