Design optimisation of high-brightness laser diodes for external cavity operation in the BRIDLE project.

E.C. Larkins[1*], S. Bull[1], S. Kaunga-Nyirenda[1], M. A. Helal[1], V. Vilokkinen[2], P. Uusimaa[2], P. Crump[3], G. Erbert[3]
[1] Electrical Systems and Optics Research Division, University of Nottingham, Nottingham, NG7 2RD, U.K. (*email: eric.larkins@nottingham.ac.uk)
[2] Modulight, Inc., Hermiankatu 22, 33720 Tampere, Finland
[3] Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

***Abstract* – We report on the design aspects of high performance diode lasers for application in high-brightness spectral beam combining and coherent beam combining modules. Key performance trade-offs are identified and potential solutions are explored.**

I. Introduction

The BRIDLE project aims to develop direct diode laser modules, whose performance, manufacturability and cost scaling are suitable for industrial applications [1]. Spectral beam combining (SBC) is being pursued using high-brightness emitters (7W, < 2mm.mrad) with internal spectral stabilization, including DBR tapered lasers and DFB narrow broad-area lasers. Coherent beam combining (CBC) work will use ridge waveguide lasers (1W) with external stabilisation.

II. Design Considerations

The use of a laser diode in an external cavity introduces new challenges with respect to both its operation and its performance and requires multi-parameter optimisation.

Firstly, efficient external cavity coupling requires a wide vertical mode width (near-field) for efficient coupling and reduced alignment tolerance. This is important for CBC applications, as this can simplify the alignment of the external optical cavity, increase the tolerance to "smile" across a laser array and allow the use of simpler optics.

Secondly, unintentional excitation of higher order vertical cavity modes by external feedback must be suppressed. The confinement factor of the higher order modes should also be much lower than that of the fundamental mode. Accordingly, we define the modal discrimination (MD) as a new figure of merit for how well the structure supports the fundamental mode and suppresses the gain of higher-order modes:

$$MD = \Gamma(1) / \Gamma(n),$$

where Γ is the optical confinement factor and n refers to the higher-order mode with the largest confinement factor.

Thirdly, optical damping of higher order modes is needed to suppress the total amplified spontaneous emission from the higher order modes. Even without lasing, the resulting amplified spontaneous emission represents a parallel path for current leakage, which will affect the efficiency.

Fourthly, the external optics require a narrow far-field divergence to minimise the impact of optical aberrations.

Finally, a high power conversion efficiency (PCE) is required to meet the efficiency targets for the *BRIDLE* laser systems (>40%). The PCE of the external cavity laser diodes must be higher (>50%) due to losses in the coupling and beam combining optics. A high PCE results in a lower thermal load, which will improve reliability and allow the use of smaller emitter pitches in the mini-bar arrays. Finally, greater efficiency and lower heat generation will reduce the impact of the thermal lensing and thermal dephasing processes, which affect the beam quality at high powers and contribute to beam dephasing in CBC arrays.

III. Epitaxial Design

We are pursuing two advanced waveguide concepts to achieve the best overall performance – the use of an optical trap (OT) to tailor the optical mode profiles [2, 3] and low-index quantum barriers (LIQB) to reduce the waveguiding by the MQW region [4]. Both approaches are based on InGaAs QW active regions for operation at ~ 975nm.

The CBC lasers employ a 2.4µm wide InGaP waveguide with an InGaAsP OT layer in the n-waveguide. Different values of the QW/p-cladding layer separation, OT/QW separation and OT width were investigated (see Fig. 1) to identify optimum designs with both a wide near-field and a large modal discrimination. The OT increases the far-field divergence, but increases MD by 38% - which is expected to be critical for the external cavity operation of the CBC lasers.

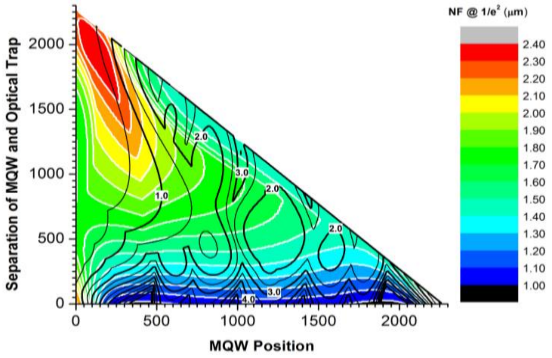

Fig. 1. NF width (black contour lines) and MD (colour contours) versus DQW/p-cladding layer and the DQW/ OT separations (OT = 27nm).

The SBC lasers employ an $Al_{0.15}Ga_{0.85}As$ waveguide and $GaAs_{0.55}P_{0.45}$ LIQB layers. As discussed in [4,5], by lowering the index of the MQW region, the LIQB layers facilitate a narrow FF divergence – at the cost of a small type II band offset with the waveguide layers. Fig. 2 shows how the MD and far field scale with waveguide thickness and MQW position for this design.

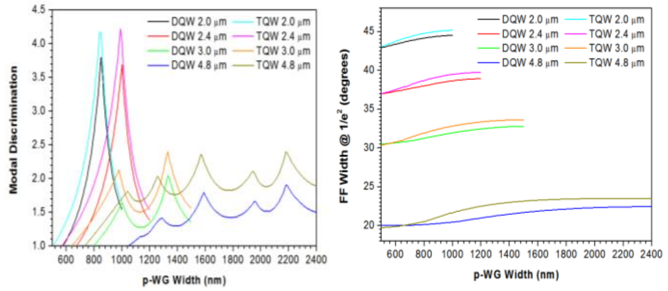

Fig. 2. Modal discrimination (left) and vertical far-field divergence (right) as a function of waveguide width and MQW to cladding separation.

When the SBC1 structure (ELoD2 [5], with 26° vertical far field at 95% power) was used to make high-brightness tapered lasers, a high lateral beam quality was observed, but the power conversion efficiency was < 50%. Increases to efficiency are most directly achievable by reducing the waveguide thickness, here from 4.8µm to 2.0µm (SBC2) – doubling the modal discrimination and increasing the achievable PCE at 7 W by 8%, as shown in Table 1 and Fig.3 for 100µm stripe width, 3mm long broad area (BA) lasers.

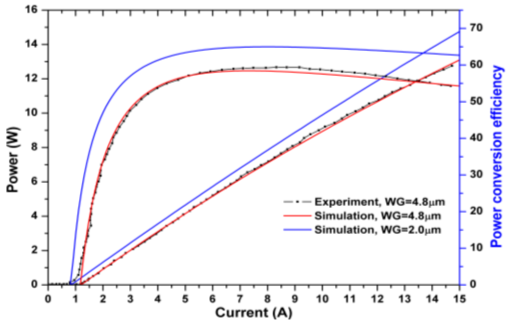

Fig. 3. Calculated power and PCE of the SBC1 and SBC2 BA lasers (W=100µm, L=3mm) as a function of current at room temperature.

Device	**CBC1**	**SBC1 (ELoD2)**	**SBC2**
Waveguide type	OT	LIQB	LIQB
Waveguide Thickness (µm)	2.4	4.8	2.0
InGaAs Active Region	SQW	TQW	DQW
Modal Discrimination	2.50	1.88	3.80
NF (µm) [FWHM/FW @ 1/e^2]	0.75 / 1.38	1.20 / 2.91	1.02 / 1.72
FF@95% power (°) [Sim/Exp]	59 / 60	25 / 26	43 / -

Table 1. Summary of the cavity performance of the investigated devices.

IV. Cavity Design

The performance and brightness of the laser sources also depends upon the lateral cavity design. For CBC applications, the single-mode ridge waveguide cavity ensures a high lateral beam quality for powers up to 1 W. However, the high emitter power required from the SBC application requires a wider cavity with a nearly diffraction limited beam, such as a tapered laser. At high output powers and/or in the presence of back reflections, Fig. 4 shows that even weak backward traveling waves degrade the beam quality by absorption bleaching outside the ridge waveguide, due to strong amplification in the taper). Together with gain saturation in the ridge waveguide, this reduces the spatial filtering performance of the ridge waveguide relative to the adjacent regions as the current increases from 2.5A to 10A (Fig. 5).

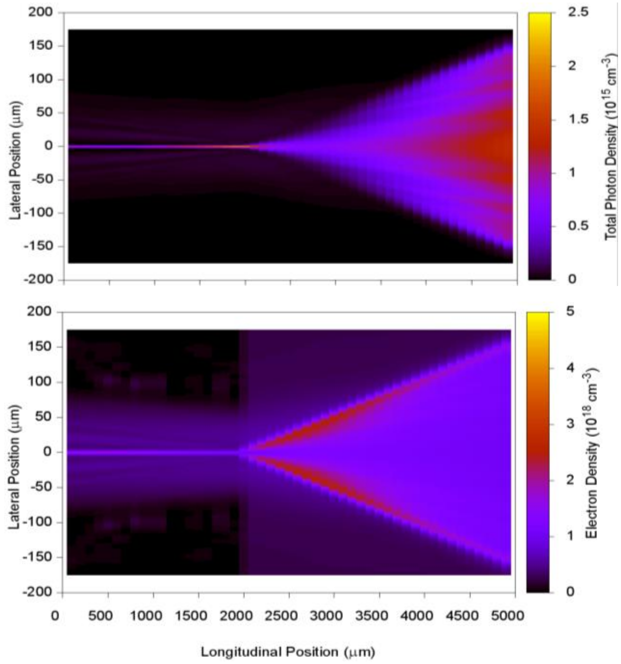

Fig. 4. Simulated photon (top) and QW electron distributions (bottom) in SBC1 tapered laser (L_{taper} = 3000µm, L_{RW} = 2000µm, L_{DBR} =1000µm, θ_{taper} = 6°) for I = 10A and T = 300K.

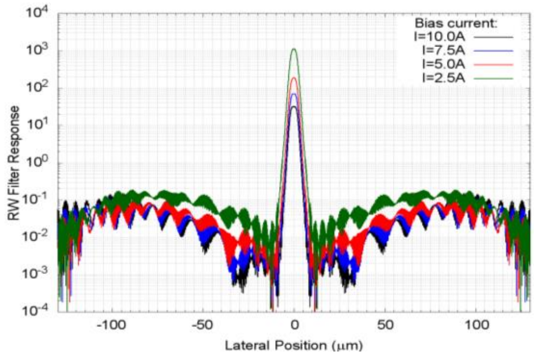

Fig. 5. Evolution of the spatial filter response of the ridge-waveguide section of the ELoD2 tapered laser as a function of bias current at T = 300K.

V. Conclusion

The design of high-brightness lasers for direct diode laser systems involves a complex multi-parameter optimisation process, which considers trade-offs between the power conversion efficiency, the near- and far-field beam patterns, modal discrimination and beam quality evolution with power.

References

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