Double-asymmetric-structure 1.5 μm high power laser diodes

Lauri Hallman[1], Boris S. Ryvkin[1,2], Eugene A. Avrutin[3*], Antti T. Aho[4], Jukka Viheriälä,[4]
Mircea Guina[4], and Juha T. Kostamovaara[1],
[1] Circuits and Systems Research Unit, University of Oulu, 90014, Finland,
[2] A.F. Ioffe Physico-Technical Institute, St. Petersburg 194021, Russia
[3] Dept of Electronic Engineering, University of York YO10 4LE, UK ([*]eugene.avrutin@york.ac.uk)
[4] Optoelectronics Research Centre, TUT, Tampere, Finland

***Abstract* —Design considerations for high pulsed power and brightness 1.5 μm laser emitters for laser radar applications, based on comprehensive semi-analytical theory, are presented. A strongly asymmetric waveguide design with a bulk active layer positioned very near the *p*-emitter interface is chosen to minimize the current-induced losses at high power while maintaining a single, broad transverse mode. Moderate to high doping of the *n*-side of the Optical Confinement Layer and high *p*-doping of the *p*-cladding layer are used to reduce the residual current-induced losses and the electric resistance of the structure. For pulsed room-temperature operation, short laser resonators are found to be advantageous. First experimental results are presented. An as-cleaved sample with a stripe width of 90 μm and a resonator 2 mm long exhibits an output power of about 18 W at a pumping current amplitude of 80 A, with 1 mm long resonators showing higher power output. Further improvements are predicted by structure optimization as well as increase in internal quantum efficiency and thermal performance.**

***Index Terms*—laser diodes, high power lasers, efficiency, modelling.**

I. INTRODUCTION

HIGH power broad area pulsed diode lasers operating in the eye-safe wavelength range (λ= 1.4-1.7 μm) are indispensable for applications including medical instrumentation and range finding / LIDAR systems. The main approach to long-wavelength high power design to date uses ultranarrow waveguides (see e.g. [1][2]). An alternative to this approach is the use of waveguide and active layer position asymmetries. The use of these asymmetries for high power λ~1.5 μm lasers was first investigated theoretically by some of the authors [3], in order to combine low penetration of the (single) transverse mode into the lossy *p*-claddings with suppressing carrier accumulation and hence free carrier absorption in the optical confinement layer (OCL) at high currents. It was shown theoretically [3] that spatially nonuniform OCL carrier accumulation is suppressed most efficiently when the active layer position is shifted strongly towards the *p*-cladding. Such *double-asymmetric structures* have subsequently been proven very successful at shorter wavelengths (λ≈1 μm) [4][5], particularly as they also decrease the series resistance and improve thermal properties of the lasers [4][5]. Here, we continue the previous work [3][6] and report the first experimental characterization of 1500 nm strongly double asymmetric cavity lasers.

II. LASER DESIGN

The design of the asymmetric single-mode InGaAsP waveguide structure is shown in Fig. 1. The structure retains the main advantages of those studied theoretically [3][6]. Low built-in optical losses are achieved by the weak penetration of the transverse mode into the *p*-cladding, while the very thin *p*-side of the OCL, with the active layer (AL) located very near the *p*-cladding, almost eliminates the hole accumulation in the OCL at high currents and any absorption it might cause. Following the approach proposed in [6], the *n*-side of the OCL is *n*-doped to suppress any residual high-current losses due to accumulation of holes in the *n*-OCL. As the current structure has a narrower OCL (1.8 μm thick) than that of [5], lower doping ($N_D^{(n-OCL)} \sim 10^{17}$ cm^{-3} as opposed to $N_D^{(n-OCL)} \sim 10^{18}$ cm^{-3} considered in [5]) can be used to achieve hole accumulation suppression in the same current density range.

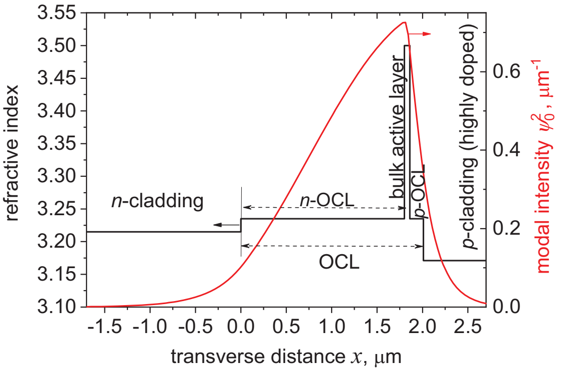

Fig. 1. Schematic of the laser structure and the waveguide mode intensity distribution.

III. FABRICATION AND CHARACTERISATION

The semiconductor structure [7] was grown by metalorganic vapor phase epitaxy. Current confining ridge waveguides

90 μm wide were etched by reactive ion etching using CH_4/H_2 plasma, followed by deposition of insulator (SiO_2), in which a 90 μm stripe was then opened by wet etching and photolithography, to form the *p*-side contact. The substrate was thinned down to ~110 μm, and its backside was metallized with a Ni/Au/Ge/Au layer stack subsequently annealed at 370 °C. The structure was then scribed and cleaved into chips of different lengths, which were mounted for characterization *p*-side up on ceramic substrate with silver epoxy glue. The as-cleaved lasers were driven with current pulses ~ 60 ns long, at a repetition frequency of ~100 Hz.

The measured results for a laser with a 2 mm long resonator are shown in Fig. 2. Also shown are the theoretical values of power $P(i)$ and total internal loss $\alpha_{in}(i,P(i))$, calculated using the transcendental equation

$$P(i)=\eta_i\frac{\hbar\omega}{e}\frac{\alpha_{out}}{\alpha_{out}+\alpha_{in}(i,P(i))}\left(i-i_{th}(i)\right)$$

with the different current- and power-dependent contributions to $\alpha_{in}(i,P(i))$ (current-induced absorption, direct and indirect two-photon absorption effect, absorption in the AL) calculated using the approach of [6] and similar values of material parameters (e.g. free carrier cross-sections and two-photon absorption coefficient). The injection efficiency η_i= 0.73 was used as the fitting parameter, giving good agreement between experiment and calculations. The combination of the AL location near the *p*-cladding and the doping of the *n*-OCL [6] ensures that the absorption due to current-induced carrier accumulation in the OCL is suppressed (~5 times smaller than in a similar structure with an undoped *n*-OCL, and tens of times smaller than in a laser with a symmetrically located AL), accounting for only ≈5% of the total $\alpha_{in}(i,P(i))$ at high currents.

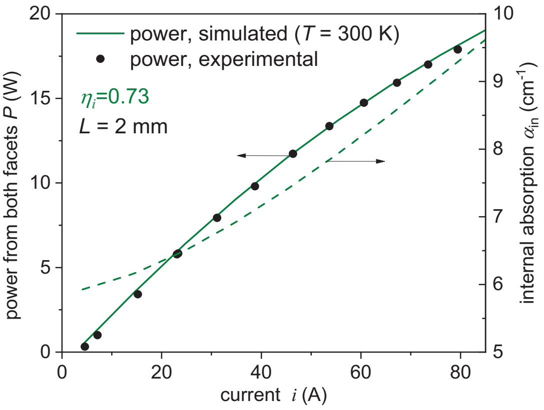

Fig.2. Experimental and simulated output power and simulated internal losses.

The laser design we use influences the optimal choice of the cavity length for high pulsed power emission. Indeed, in our structure, the current-induced absorption, governed by the *current density*, is suppressed. Thus a laser with a moderately short cavity (in which an increase in the output efficiency compared to a longer cavity due to a high outcoupling loss α_{out} is more significant than the increase in $\alpha_{in}(i_{th},P=0)$ caused by the higher threshold carrier density) is not only predicted to yield higher power than a long cavity laser at *moderate* currents, but also to retain this advantage at *high* currents, so long as the current-induced heating can be avoided. Experimentally, we see higher output from lasers with *L*=1 mm compared with those with *L*=2 mm at currents up to 80 A (Fig. 3). At currents over 30-50 A (depending on the η_i value used in simulations), the measured power output is smaller than simulated, which we attribute to the onset of current heating.

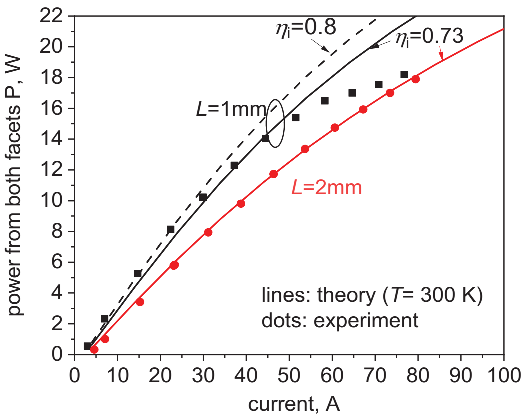

Fig.3. Simulated and experimental output curves for two cavity lengths.

The output data of Fig. 2-3 compare favourably with the state of the art results for similar wavelength, laser cavity parameters, and current range. The performance is expected to be improved further, by increasing η_i, improving the laser mounting hence thermal properties (e.g. by *p*-side down soldering), and optimizing length, waveguide structure and doping.

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