

High Power InP-based 1.55 Micron Laser Sources for Long-Range IR Illumination Applications

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Abstract

Novel semiconductor laser designs incorporating passive intra-cavity spatial mode filters are evaluated as a means of providing high output power from an InP-based laser element at 1.55 μm together with high transverse beam quality.

Keywords: InP, laser diode, laser array, segmented gain section laser (SGSL), extended cavity laser (ECL), all-active laser (AAL), quantum well intermixing (QWI)

Introduction

InP based laser diodes operating at the eye-safe wavelength of 1.55 μm have a range of potential applications in infra-red illumination and imaging, including burst-illumination and selected range-finding schemes. Such applications require a low-divergence, low coherence source capable of producing high output power.

For high power applications semiconductor lasers typically employ a broad area configuration because the reduced power density at the facet decreases the likelihood of catastrophic facet failure and because thermal effects which limit output power are diminished. Such configurations however, tend to exhibit a poor beam quality in the transverse plane due to the tendency for filamentation - a non-linear interaction between the oscillating optical field and the injected carrier density, which leads to spatially localised and time-varying fluctuations in refractive index and ultimately results in the fragmentation of the output beam into a number of 'beamlets'.

A number of approaches have been adopted to improve the beam quality of such

devices, including the use of tapered emitters or master-oscillator power amplifiers[i,ii], laterally profiled facets[iii,iv], patterned contacts[v], cavity spoiling features[i,ii] and unstable resonators[vi]. Although these approaches have demonstrated improvements in beam quality, they typically exhibit low design and processing tolerances, leading to low manufacturing yields.

Here a novel device concept is proposed and evaluated as a means of achieving high beam quality together with high output power. The concept employs a laser cavity configuration known as an extended cavity laser (ECL), in which passive diffractive regions within the laser cavity serve as spatial mode filters which effectively suppress filamentation and higher order modes.

Device Concept

The ECL concept is illustrated in Figure 1 which shows a schematic diagram of the device design. The device comprises a gain region which may be broad area or index guided in nature, together with an unguided, unpumped region in which the propagating optical field is free to diffract laterally.

Diffraction within this passive region is greater for smaller emission apertures and therefore higher order modes and/or filaments within the active region experience greater diffraction loss compared to the fundamental mode.

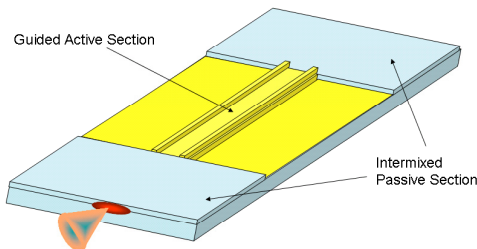


Figure 1. Schematic of ECL device design.

This is illustrated in Figure 2, which shows a theoretical simulation of the diffraction occurring for light incident from a 10 μ m wide waveguide after traversing an 80 μ m long passive region. This clearly illustrates a smaller degree of diffraction for the fundamental mode (a) compared to the first order mode (b) and a differential diffraction loss which is dependant upon the diffraction section length, as shown, and the width of the input emitter.

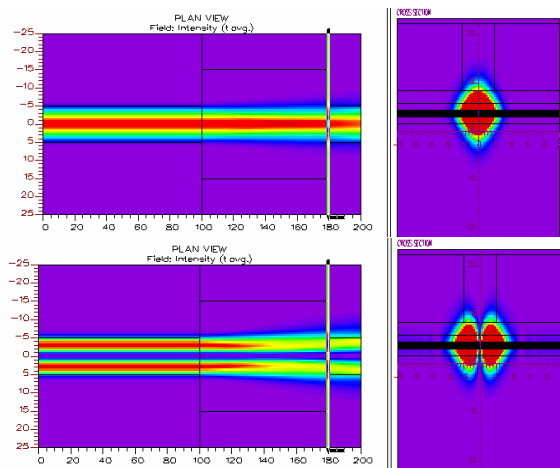


Figure 2. Simulated diffraction occurring within passive slab waveguides for the fundamental(a) and first order (b) modes.

For ECL devices the passive sections undergo a post-growth quantum well intermixing (QWI) process which increases

the effective band gap of the passive region, thereby reducing band-to-band absorption losses. The QWI process involves deposition of a thin sputtered SiO₂ layer which enhances the QWI rate during a subsequent high temperature anneal to temperatures of ~ 700 °C.

Previously, ECL devices incorporating a single gain section and intermixed passive sections have been demonstrated to provide significant improvements in beam quality[vii], as have devices with segmented gain sections[viii], in which the gain section is split into a number of smaller gain elements each separated by a diffractive region.

Experimental Results

Initially a series of device configurations were investigated, all employing an unetched gain-guiding oxide-stripe geometry. All devices studied possessed a total cavity length of 1.2 mm. An all active laser (AAL) in which the total cavity length was pumped served as an experimental control. The output power and far-field beam characteristics of this device were compared against two ECL configurations with active:passive section length ratios of 60:40 and 40:60. For each device configuration, three different stripe widths were investigated: 10 μ m, 40 μ m and 75 μ m, with the former expected to give greater diffraction discrimination at the possible expense of reduced output power performance.

Figure 3 shows typical light-current curves for each of the ECL devices outlined above with a stripe width of 75 μ m.

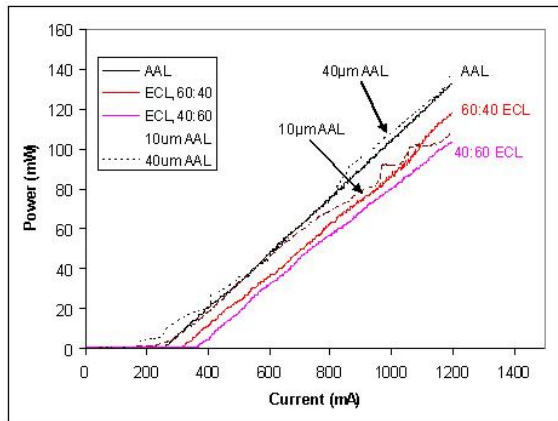


Figure 3. Light-current characteristics for 75µm wide AAL, ECL and SGSs, together with AAL data for 10 (dashed), 40 (dotted) and 75 µm (solid) stripes.

This illustrates that threshold currents of ~ 250 mA are obtained for AAL control devices, with a slope efficiency of 0.15 W/A per facet, comparable with state-of-the-art InP-based material.

The ECL devices exhibit an increased threshold current and slight reduction in slope which is dependant upon passive section length. The effect of residual absorption in the passive section has been successfully modelled using a 1-D laser model which accounts for all sources of gain and loss within the cavity to yield a prediction for the threshold current and slope efficiency. This enables the L-I characteristics of a particular configuration to be predicted.

For the 10 and 40 µm stripe emitters, the L-Is exhibit non-linear slopes with large discontinuities as also shown in the dashed and dotted curves respectively of Figure 3. It is believed that this is due to poor overlap between the optical mode and the carrier injection volume, such that large regions of the mode are not effectively pumped and are therefore highly absorbing. This is supported by near-field measurements on the optical output at the facet. These effects can be eliminated by improving the waveguiding for narrow stripe devices by employing etched ridge waveguide

geometry.

Despite a small degradation in output power characteristics, significant beam quality improvements are obtained for the ECL devices. Figure 4 compares typical far-field profiles obtained at an output power of 40 mW per facet for 40 µm wide stripes with the AAL configuration and both the 60:40 and 40:60 ECL configurations. The AAL produces a multi-lobed far-field in which the output appears to be distributed between a number of modes, with an overall envelope 16° wide, with ~ 30% of the total output power in the dominant, off-axis lobe. For the 60:40 ECL device, the far-field envelope remains relatively broad, 15° and multi-lobed, but the number of competing modes appears reduced, with ~ 65% of the total output power in the dominant lobe. However, for the 40:60 ECL the far-field appears further improved with most of the power (~ 90%) concentrated within a single central lobe with FWHM of 4°. Similar improvements are obtained in wider stripe (75 µm) devices, however the improvements are less marked due to the reduction in diffraction loss, and hence discrimination loss, for wide stripe elements.

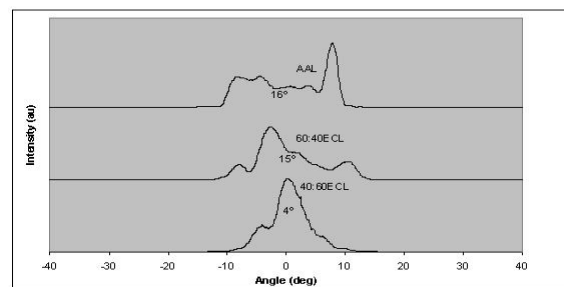


Figure 4. Far-field profiles obtained for ECL devices in which the active sections comprise 60% and 40% of the total cavity length compared to an AAL device of the same cavity length.

The experimentally observed improvements have been modelled using beam propagation methods and an in-house

filamentation model. The predicted discrimination loss between the fundamental and first order mode is shown in Figure 5 for a 1mm long passive section, and shows that for wide stripe devices, the loss between the fundamental and first order mode is small. This suggests that modal discrimination alone is insufficient to account for the observed reduction in far-field, which is therefore ascribed to the suppression of filamentation in these devices.

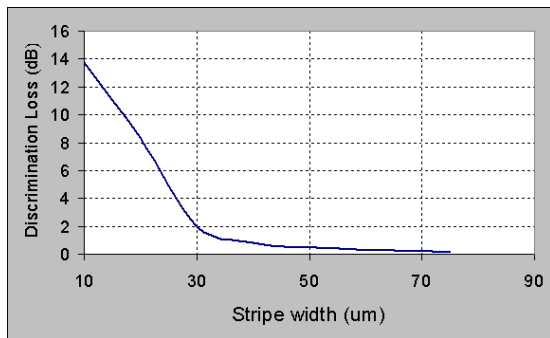


Figure 5. Modal discrimination loss between the fundamental and first order mode as a function of stripe width.

A self-consistent theoretical model has been developed to establish the dependence of filamentation suppression on device design parameters. Figure 6 shows the predicted filamentation loss for different filament sizes as a function of passive section length for both (a) 10 μm and (b) 75 μm stripe devices.

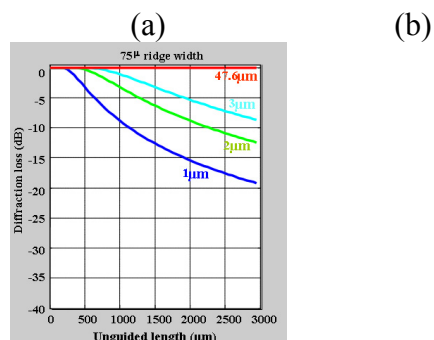


Figure 6. Predicted diffraction loss for (a) 10 μm and (b) 75 μm stripe devices.

This suggests that filamentation suppression is strongly dependant upon the stripe width and the passive section length, and although

suppression will be greater for narrow stripe devices, significant suppression can be attained with wide stripes. The model has been used to predict the filamentation suppression as a function of passive section length for 40 and 75 μm ECL devices and shows good agreement with the observed experimental trends in far-field reduction as shown in Figure 7, which plots the trend in measured far-field FWHM (solid curves) against passive section length and compares this to the theoretically predicted trend (dashed curves) in filamentation suppression for a 1 μm 'diameter' filament. This suggests that the model can be utilised to determine the optimum device geometry for high output power together with high beam quality.

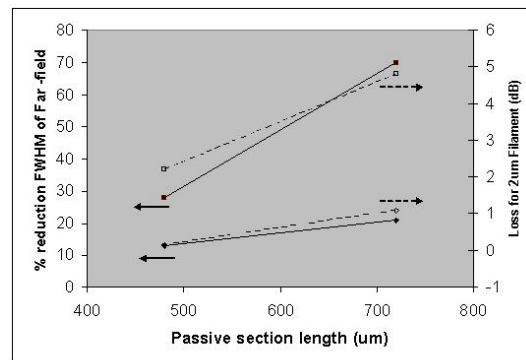


Figure 7. Comparison between trends in measured far-field FWHM and predicted trends in filamentation suppression.

The model implies that optimum performance can be achieved with a ridge waveguide configuration, which will simultaneously provide a high level of discrimination loss for small passive section lengths, thus reducing the loss accrued for the fundamental mode.

Subsequent to this initial investigation, narrow ($\leq 30 \mu\text{m}$) ridge based devices have been shown to yield significant improvements in beam quality due to filamentation suppression as shown in Figure 8.

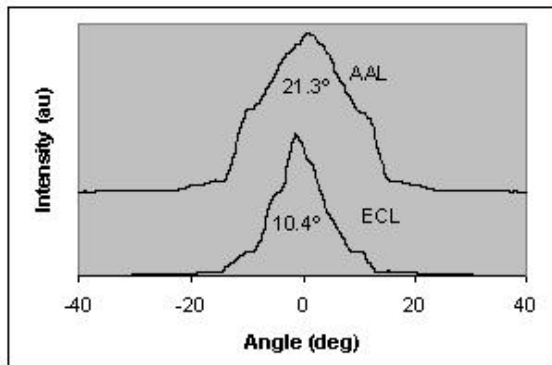


Figure 8. Far-field profiles for AAL and ECL devices with a deep-etched 30 μm wide ridge waveguide configuration.

This shows far-field profiles obtained at 75 mW output power per facet for 30 μm wide AAL and ECL devices. The former exhibits a highly broadened far-field profile characteristic of a device exhibiting significant filamentation, while the ECL device produces a significantly narrower angular divergence, due to suppression of filamentation. For narrower (10 and 20 μm) emitters, although evidence of filamentation suppression is again apparent, leading to an initial reduction in FWHM of the far-field, at higher output powers the devices exhibit a multiple-lobed far-field characteristic of higher order mode operation. This can be ascribed to an overetch of the ridge which enables the waveguide to support higher order modes which are not sufficiently suppressed in these ECL configurations. Despite this, it is strongly believed that with optimised etch depth, such devices will enable single transverse mode operation together with high efficiency.

In summary, a novel laser design concept has been demonstrated, in which passive waveguides are monolithically integrated with the laser active section resulting in significant improvements in beam quality, with minimal impact upon other optical characteristics.

Future Work

The research conducted thus far into ECL design optimisation suggests that the device concept can be utilised to yield significant improvements in beam quality. Although the extent of such improvements is not yet sufficient for deployment in applications, parallel investigations have yielded single transverse mode operation from narrow ridge waveguide devices, suggesting that this device configuration will satisfy the beam quality requirements of the application. For such devices, it is strongly believed that the ECL concept will greatly increase the output power range over which single mode operation can be sustained.

Initial modelling into the thermal properties of these devices has been completed and suggests that thermal effects will not adversely affect the ability of these devices to achieve the required output power characteristics. This has been supplemented by research into the type of optical system required for efficient delivery of the output power to a remote target.

The research completed thus far suggests that an array of narrow ridge waveguide ECLs, with the appropriate collimation optics should provide a high power, low coherence 1.55 μm laser diode sources for remote illumination applications.

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Acknowledgements

The authors would like to acknowledge support for this work by the Electro-Magnetic Remote Sensing (EMRS) Defence Technology Centre.