HIGH-SPEED DIRECT MODULATION OF 50Ω BIPOLAR CASCADE SEGMENTED LASERS

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Abstract *The high-speed direct modulation of segmented ridge lasers with 50Ω input impedance and CW differential quantum efficiency (DQE) >100% is reported. 2.5 Gbit/s operation is demonstrated with 7dB less drive power than conventional single-stage lasers.*

Introduction

Bipolar cascade lasers enhance differential efficiency by driving current, in series, through a number of diode stages, each of which can emit a photon for each electron. This can drive DQE well beyond 100%, allowing integrated, low-noise signal gain[1] without an amplifier. The input impedance of such a diode chain also increases with the number of stages, allowing a broadband match to 50Ω or to higher-impedance source (e.g. photodiode), and eliminating the need for hot, bulky on-chip resistors. Most of the work on bipolar cascade lasers to date has focused on vertical emitters with an alternating stack of active regions and tunnel junctions[2-4]. These lasers have demonstrated effective cascading up to 3-4 stages, but are limited by excess heating, epitaxial constraints, and excess impedance, and are difficult to integrate into photonic IC's.

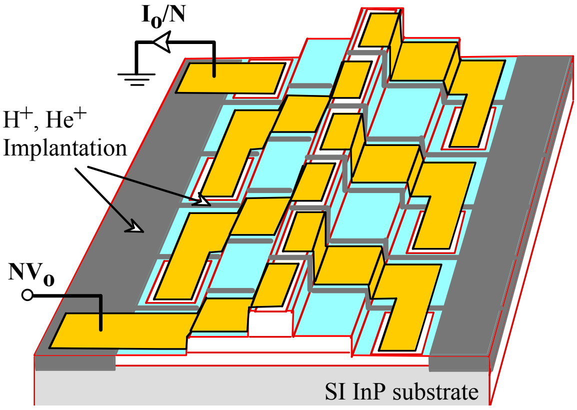

Fig. 1. 3-d schematic of bipolar cascade segmented ridge laser. The dark grey areas are ion-implated to force current, in series, through *N* diode stages

Series-connected, segmented lasers (Fig. 1) relieve these constraints by electrically segmenting a conventional Fabry-Perot ridge laser (though most types of lasers are compatible) with ion implantation, then series-connecting these *N* electrically separated sections across the same waveguide and active region. The same current density and optical power can then be developed by passing *N* times less current through the diode chain. This increases DQE and voltage by a factor of approximately *N*, and input impedance by N^2.

CW Performance

InP/InGaAsP QW segmented ridge lasers with 50μm, 100μm, and 200μm stages were fabricated alongside control lasers without segmentation, for ease of comparison. Please refer to our OFC abstract [5], for information on device geometry, epitaxial structure, and fabrication; the room-temperature, CW performance of the same 600μm lasers, soldered to an AlN submount, is shown in Fig. 2.

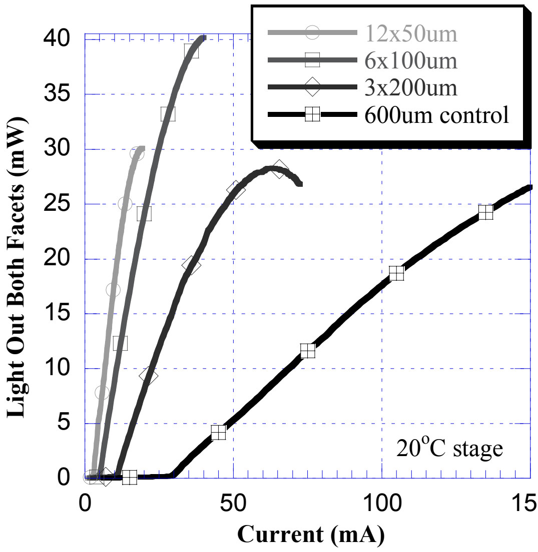

Fig. 2. L-I response of a 600μm laser, subdivided into 1, 3, 6, and 12 stages. DQE exceeds 100% in all but the control laser

Though the 12-stage laser achieved a CW DQE of 390%, its high input impedance prevents it from being as useful in a 50Ω direct-modulation scheme. Of much greater interest to this report is the 3-stage laser (divided into 200μm stages), which achieves a DQE of 118% with a threshold current below 10mA. The input impedance, while varying with bias and frequency, reaches 50Ω near the optimal bias for high-speed modulation. As shown in Fig. 3, the best electrical reflection coefficient S_{11} is better than -40dB from DC to beyond 6 GHz, and better than

-20dB to 10GHz, for all biases above threshold. This excellent broadband matching compares favorably to the single-stage control laser's reflection coefficient of -2dB.

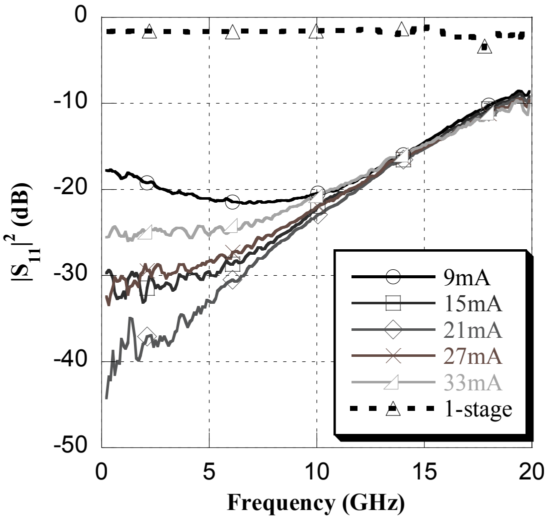

Fig. 3. Electrical reflectance of the three-stage segmented lasers as bias current is varied. The input impedance reaches 50Ω at 21mA; the single-stage control laser, shown at 60mA, has a 6Ω input impedance.

Modulated Performance

Of course, the high DQE and broadband matching of the segmented laser are useless if it cannot be cleanly modulated at high speed. Small-signal bandwidth, Relative Intensity Noise (RIN), and distortion were all examined for unsegmented control and 50Ω three-stage segmented lasers. In each case, it was found that the segmented laser equalled or exceeded the performance of the control laser, at a given current density. The improvement is likely due to improved gain uniformity where the current is distributed by interstage interconnects.

As a litmus test, both lasers were modulated with 2.5Gbit/s digital data. Bias and modulation were chosen to achieve an unfiltered, clear eye under back-to-back transmission, and 8dB extinction ratio at the lowest acceptable modulation power. For the control laser, this was achieved with a 2V peak-to-peak setting on the BERT's 50Ω RF source, and a 63mA (1.4V) DC bias. The segmented laser achieved the same bit rate and extinction ratio with a 0.9V modulation from the same RF source, and a 22.5mA (@3.4V) DC bias, producing the unfiltered eye diagram shown in Fig. 4. Thus, the segmented laser produced the same high-speed optical signal with 4.9 times (7dB) less RF power, and 16% less DC bias power than the conventional single-stage laser.

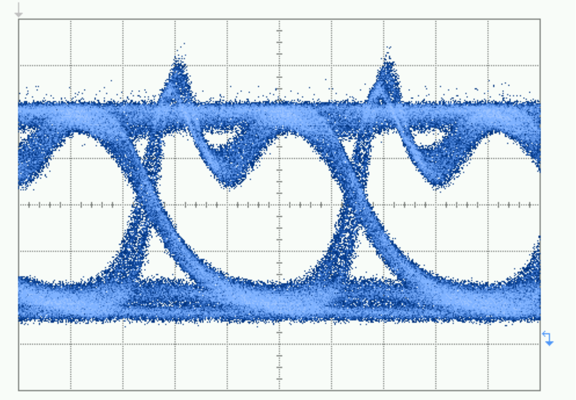

Fig. 4. Unfiltered 2.5Gbit/s eye diagram for a three-stage laser biased at 22.5mA with $0.9V_{p-p}$ modulation, resulting in an 8dB extinction ratio. The eye for the control laser is slightly inferior.

Conclusions

The segmented laser shows considerable promise in improving the efficiency of direct modulation, and we have demonstrated a 50W laser with over 100% differential efficiency. Both improved broadband matching and current recycling result in an enhanced modulation efficiency, which can be used to reduce drive power, or provide gain. By choosing the number and length of stages correctly, the segmented laser can be matched to nearly any source impedance, and can easily be integrated as an active region into more complex tunable lasers, or photonic IC's.

References

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