Material Characterization of Advanced III-V Semiconductors for Nanophotonic Integration

Brian T. Chung
Engineering Physics, University of Michigan – Ann Arbor

NNIN REU Site: Nanotech, University of California, Santa Barbara, CA
NNIN REU Principal Investigator(s): Professor Larry A. Coldren, Electrical and Computer Engineering, UC Santa Barbara
NNIN REU Mentor(s): Robert S. Guzzon, Erik J. Norberg, and John S. Parker, Electrical and Computer Engineering, UCSB
Contact: btchung@umich.edu, coldren@ece.ucsb.edu, guzzon@ece.ucsb.edu, norberg@ece.ucsb.edu, jparker@umail.ucsb.edu

Abstract:

New applications for integrated nanophotonic components and circuits typically found in telecommunication and internet data transfer will utilize tunable microwave filters for the pre-filtering and channelizing of information in the radio frequency (RF) domain. Such applications will require the use of high optical saturation power quantum well designs in order to reduce detrimental nonlinear phenomena. The goal of this project was to experimentally characterize novel quantum well designs and extract material parameters to guide future design work. By fabricating and testing broad area laser structures, the material loss and gain parameters were extracted. We fabricated broad area laser structures using a standard wet-etch process defining surface ridge waveguides. The P-metal pattern was first defined using contact lithography and then deposited by electron beam evaporation followed by metal liftoff. Material characterization was performed using a pulse setup and cleave-back approach to determine light-current-voltage characteristics and differential efficiencies. Net internal optical loss and characteristic gain values were then calculated. Internal optical loss values as low as 4.175 cm^{-1} and characteristic modal gain values as low as 15.152 cm^{-1} were recorded.

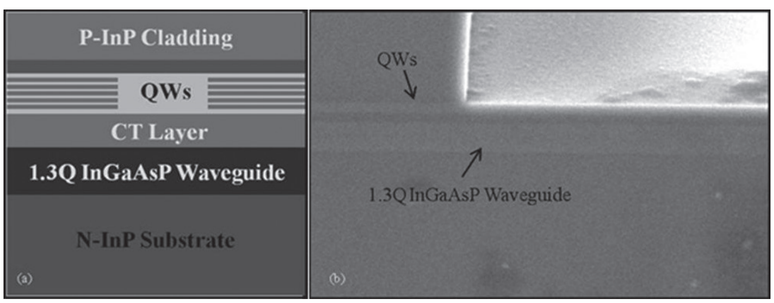

Figure 1: (a) Schematic of CTL epitaxial design, (b) SEM of fabricated 100 nm CTL design active region.

Introduction:

The active confinement factor Γ of a device is defined as the overlapping integral between the optical mode and the active quantum well (QW) region. The optical saturation power of an amplifier is inversely proportional to Γ, thus decreasing Γ becomes the strategy for increasing saturation power. By placing QWs outside the waveguide where the optical intensity is smaller, Γ is reduced. A confinement tuning layer (CTL) of passive material may also introduced between the QWs and waveguide of a structure. This further decreases Γ since the QWs are moved to the evanescent tail of the optical mode [1].

In this experiment, we have characterized the gain and loss parameters of two novel material designs employing five QWs and CTLs of 100 and 250 nm thicknesses. Figure 1 depicts (a) a schematic of a sample epitaxial design utilizing a CTL, and (b) a scanning electron microscopy (SEM) image of the active region of the 100 nm CTL design.

Procedure:

Growth and Fabrication. The novel material designs investigated in this work were designed at the University of California, Santa Barbara, (UCSB) and the actual growths and regrowths were prepared by Land Mark Optoelectronics Corporation, using the metal organic vapor phase epitaxy technique. The finished dyes were fabricated into 50 μm width broad area lasers at Nanotech at UCSB via a

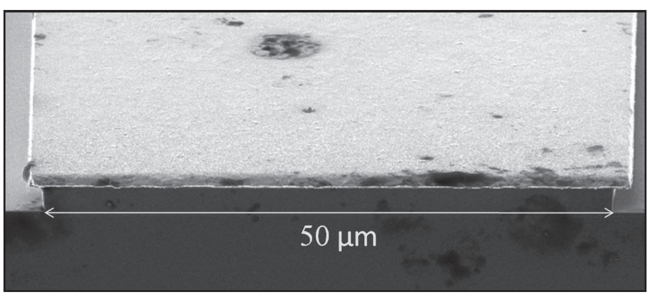

Figure 2: SEM image of 100 nm CTL design laser cross section.

single contact lithography process and a standard wet-etch for ridge definition. Ohmic contacts were established on the top and backside using electron beam metal deposition followed by metal liftoff. Figure 2 shows the cross section of a fully fabricated broad area laser.

Characterization Setup. To characterize the designs, we implemented the cleave-back method to extract the following loss and gain parameters: the internal quantum efficiency η_i, net internal optical loss $\langle\alpha_i\rangle$, transparent current density J_{tr}, and characteristic modal gain $\langle g_o\rangle$ [2]. In the measurement, we cleaved the ends of the lasers along crystal planes to ensure ideal mirrors.

Probes were attached to the contacts to facilitate the injection of a pulse current, and the light output power was measured using a photodiode. From the LIV curve obtained after a voltage sweep, we were able to determine the threshold current density J_{th} and the differential efficiency η_d of the device. We repeated this process and obtained values for lasers of differing lengths.

Plotting lengths versus the inverses of the recorded differential efficiencies yielded values for η_i and $\langle\alpha_i\rangle$. From these parameters, we calculated the threshold modal gains of the samples and plotted these versus J_{th} values. Similarly, these plots yielded values for J_{tr} and $\langle g_o\rangle$.

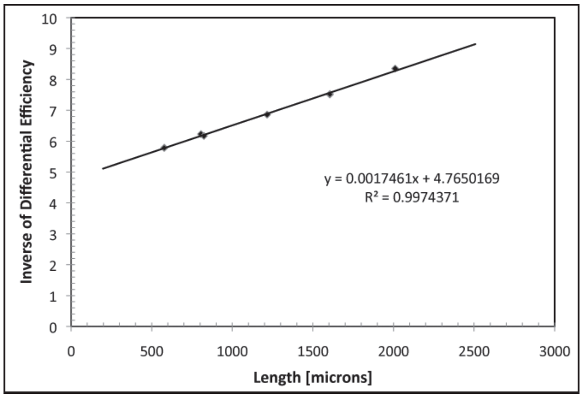

Figure 3: Internal loss of 250 nm CTL design.

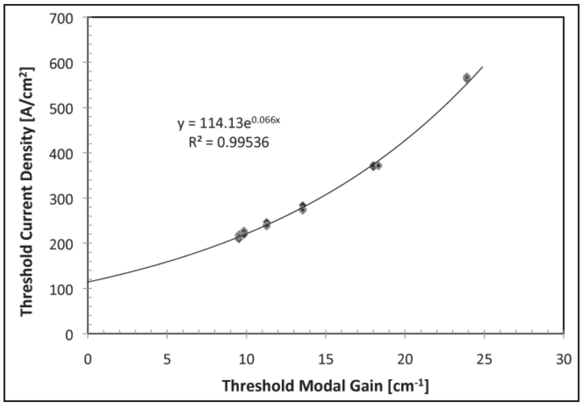

Figure 4: Characteristic gain of 250 nm CTL design.

Results:

Figures 3 and 4 delineate interpolations of the internal loss and gain data for the 250 nm CTL design. Similar plots for the 100 nm CTL design (not shown) were constructed. From these plots, we calculated η_i values of 0.262 for 100 nm and 0.21 for 250 nm; $\langle\alpha_i\rangle$ values of 5.882 cm^{-1} for 100 nm and 4.175 cm^{-1} for 250 nm; $\langle g_o\rangle$ values of 31.681 cm^{-1} for 100 nm and 15.152 cm^{-1} for 250 nm; and finally J_{th} values of 105.916 A/cm^2 for 100 nm and 114.13 A/cm^2 for 250 nm.

Results were largely consistent with anticipated values, however injection efficiencies were noticeably lower than anticipated. Possible explanations for this deficiency include the possibility of a leakage current through the device or an inconsistent material doping profile.

Conclusions and Future Work:

We have successfully demonstrated low loss and gain characteristics from far-offset QW and CTL designs. The 250 nm CTL design exhibited a low modal gain value of about one half that of the 100 nm design, making it preferential for applications that require a high saturation power.

Further characterization of the 250 nm CTL design will include fabricating and pulse testing ridge lasers and experimentally verifying the material's improved saturation power. Following these performance verifications, the design has the potential to be incorporated into a fully functional microwave photonic filter.

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References:

[1] J. Raring, E. Skogen, M. Masanovic, S. DenBaars, and L. Coldren, "Demonstration of high saturation power/high gain SOAs using quantum well intermixing and MOCVD regrowth," IET Electronics Letts. vol.41, pp. 1345-1346, Nov. 2005.

[2] L. Coldren and S. Corzine, Diode Lasers and Photonic Integrated Circuits, Wiley Series in Microwave and Optical Engineering, pp. 52-53, 1995.