# Design and Characterization of Multiple Quantum-Well Lasers

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## Abstract:

**With the exponential growth of internet users and data-hungry devices, the need for faster and more accessible communication has been on the rise. Unlike copper wires, the integration of light amplification by stimulated emission of radiation (LASER) components in optical fibers enables us to transmit data through photons with the speed of light without heating up. In this regard, vertical cavity surface emitting lasers (VCSELs) could be good candidates due to their easy manufacturing in optical applications. However, resistive losses slow down such lasers. By studying the structure of the lasers and comprehending the losses, lower resistive VCSELs can reach higher modulation speeds. In this process, different components of VCSELs, distributed Bragg reflectors, and separate confinement heterostructures were tested to characterize their properties and propose desirable designs. The new structures show great potential for lowering the resistance.**

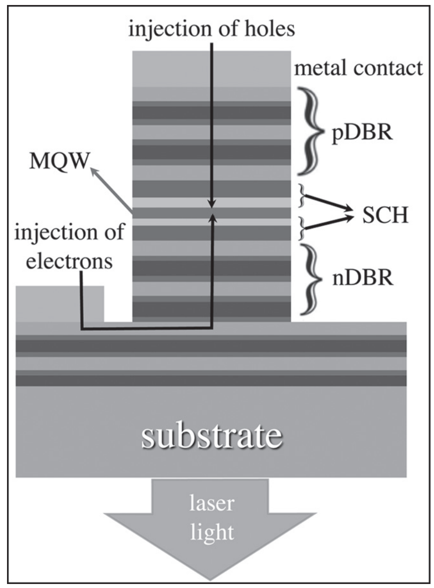


*Figure 1: Different components of a VCSEL relative to each other, but not to scale.*

## Introduction:

Similar to other lasers, VCSELs consist of an active medium, which creates photons, and two mirrors, known as distributed Bragg reflectors (DBRs). Electrical current is supplied to the laser through metal contacts. The injected carriers, electrons and holes, pass through the DBRs into the active region, but these mirror structures are resistive.

In the active medium, separate confinement heterostructures (SCH) funnel the carriers toward multiple quantum-wells (MQWs). In MQWs, electrons and holes become confined in energy wells, get stimulated by a photon, recombine with each other, and then create another photon coherent to the first photon. Afterward, these two photons get reflected between the two DBRs and stimulate other electron-hole pairs, amplifying the total photon density. At some point, a small portion of the light passes through the bottom DBR and leads to lasing phenomenon.

**Distributed Bragg Reflectors (DBRs).** DBRs are periodic layers of aluminum gallium arsenide (AlGaAs) with a transition layer from the same material between each two consecutive sheets to lower their resistance. Each layer has different aluminum (Al) concentration, which corresponds to different index of refraction; because of this difference in refractive indexes, photons become constrained between the two DBRs to increase stimulated recombination.

As mentioned, the resistivity of DBRs can be reduced by having an effective transition layer with the right aluminum concentration. This was achieved through a comparison between two different DBR structures by applying transmission line measurements (TLM). By this method, the resistivity of DBRs can be evaluated and compared with each other.

Two DBRs were grown on gallium arsenide (GaAs) substrates by molecular beam epitaxy with the following design rules. The first sample consisted of four periods of alternating layers of 0.050 $\mu$m GaAs with $8 \times 10^{18}$ *n*-type doping and 0.0448 $\mu$m AlGaAs with 90% Al concentration, and $8 \times 10^{18}$ *n*-type doping separated by 0.016 $\mu$m AlGaAs

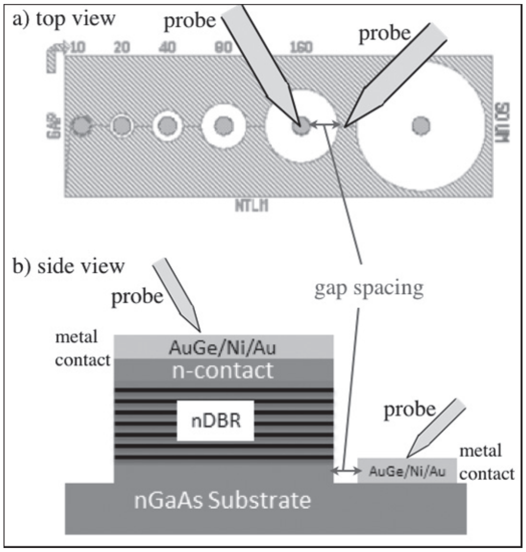


Figure 2: Transmission line measurement.

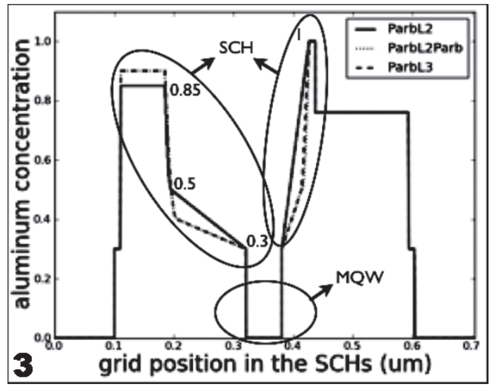


Figure 3: Al concentration in 3 different SCHs.

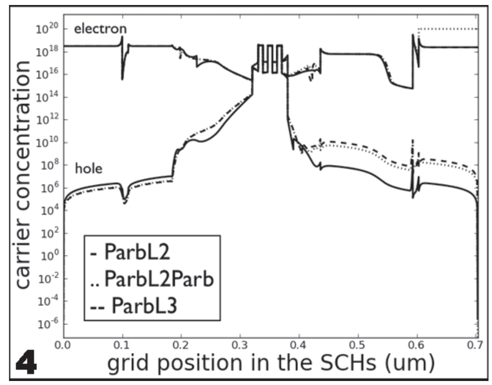


Figure 4: Carrier concentration in log scale.

with 30% Al concentration, and $8 \times 10^{18}$ *n*-type doping in the transition layer. For the second DBR, only the transition layer was changed to a linear grading of Al concentration from 0% to 90%. After the growth, the DBRs were fabricated, and metal contacts were deposited in circular patterns with different gap spacings.

By passing a current through the sample, shown in Figure 2(a), the total resistance was measured. With the use of known values for the specific contact resistivity between the metal and the semiconductor, 615.1396 $\Omega$-$\mu m^2$, the resistance of each DBR was extracted. According to the data, the second DBR with linear Al had a lower average resistance than the first DBR—2.93Ω compared to 5.62Ω. As a result, the linear grading of Al in the transition layer of our structure reduced the resistance of the *n*-type DBR.

**Separate Confinement Heterostructure (SCH).** The need for a structure to direct the carriers toward small layers of MQWs is significant in VCSELs. Aside from guiding the electrons and holes to MQWs, a SCH is required to have low resistivity and capacitance. Hence, the new design of SCH had to consider both factors, resistance and capacitance. Simulating different structures in SimWindows [1] was the approach taken to reach this goal.

A SCH was made from AlGaAs, and Figure 3 shows the Al concentration and the structure of three SCHs. As is evident in Figure 3, the new SCH, ParbL2, consists of a parabolic Al grading from 0.85 to 0.5, then a linear Al concentration to 0.3, and after MQWs, another linear Al from 0.3 to 1.

Using a simulation tool called SimWindows, all SCHs were simulated by applying voltages from 0.0 V to 3 V, and their currents were extracted. From the slope of the current vs. voltage graphs, the resistance of each SCH was determined. Based on the results, ParbL2 had the lowest resistance—6.52 $\Omega$-$cm^2$—than either ParbL3, with 6.95 $\Omega$-$cm^2$, or ParbL2Parb, with 6.73 $\Omega$-$cm^2$. Furthermore, Figure 4 demonstrates that ParbL2 fairly had the lowest carrier concentration compared to other designs. This low accumulation of carriers in SCH corresponds to lower capacitance. Therefore, the new model lowered the resistance and capacitance over the older versions.

## Conclusion:

This paper presented a comparison between two DBRs and a simulation analysis for different SCHs. According to the results, the proposed structures lowered the resistance in *n*-type DBR and reduced the resistivity and capacitance in the new SCH. Future work remains to be done to grow the simulated SCHs and determine their resistance and capacitance.

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## References:

[1] Winston, D; "Optoelectronic Device Simulation of Bragg Reflectors and Their Influence on Surface-Emitting Laser Characteristics"; IEEE Journal of Quantum Electronics, Vol. 34, No. 4, (1998).