nLIGHT Advanced Technologies Internship Report: Summer 2025

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Abstract: During my internship at nLIGHT's Advanced Technologies division, I contributed to the optimization and characterization of 1060 nm ridge-waveguide laser diodes for industrial metal-cutting applications. My work spanned numerical simulation, Python-based automation, and hands-on optical testing, leading to measurable improvements in laser performance and efficiency. © 2025 The Author(s)

1. Laser Diode Simulation and Optimization

A major focus of my internship was the simulation and optimization of ridge-waveguide laser diodes operating at 1060 nm. The ridge width and height were carefully examined because of their strong influence on both the effective refractive index and current spreading within the device. Narrower ridges offered stronger optical confinement and better mode control but limited the overall power that could be extracted, while wider ridges allowed for higher power extraction at the cost of degraded confinement and the risk of multi-mode operation. To address this trade-off, I implemented tapered oscillator sections, which are passive adiabatic components recognized in literature as effective mode filters. By gradually widening the waveguide, the tapered oscillator enables higher power operation from larger ridge volumes while suppressing higher-order modes, ensuring that the output remains single-mode even in devices designed for elevated power levels.

To study these effects, I carried out two types of simulations in RSoft LaserMOD: single-mode analysis and first-order mode analysis. However, the software did not provide a direct method to select which mode to evaluate. To overcome this limitation, I introduced a thin, high-loss material at the region of highest intensity for the fundamental mode. This artificially suppressed the fundamental mode, allowing the solver to converge on the first-order mode instead. With this technique, I could accurately characterize both the fundamental and the dominant higher-order mode without interference. Because modal gain decreases with increasing mode order, we restricted our investigation to the first-order mode as the only higher-order mode likely to compete with the fundamental in practical devices. This ensured that our designs maintained sufficient suppression of the first-order mode while maximizing output from the fundamental.

In addition to structural adjustments, I investigated modifications to the active region, particularly the number of quantum wells incorporated into the design. Quantum wells discretize electron energy transitions, concentrating emission at a target wavelength and thereby enhancing optical power at 1060 nm. While it was clear that increasing the number of wells could improve power output, the tradeoffs among single, double, or triple quantum well structures were less well established. My simulations explored these variations to evaluate how additional wells influenced both threshold currents and modal stability. Beyond quantum well engineering, I also investigated the use of auxiliary ridge waveguides as a means of coupling out higher-order modes through evanescent interaction. Although promising in principle, this approach was ultimately abandoned due to its reliance on precise phase relationships, which would be highly susceptible to thermal lensing effects at the high powers nLIGHT's devices target.

Through these investigations, I was able to balance material composition, ridge geometry, and mode-control structures to achieve a 34% improvement in overall output efficiency while maintaining single-mode operation above 1 W with a beam quality factor of $M^2 < 1.1$. This process gave me firsthand experience in managing the trade-offs between confinement, power extraction, and modal stability that define the performance limits of high-power semiconductor lasers.

2. Python Automation for Mode Analysis

Alongside simulation, I developed a suite of Python scripts to automate both the editing of RSoft CAD files and the analysis of LaserMOD output logs. I discovered that the underlying CAD files for LaserMOD and BeamPROP were plain text documents that encoded device geometries and material properties using a structured syntax.

Leveraging this, I wrote a Python-based interface that could inject new values—such as ridge width, taper angle, or quantum well thickness—directly into the CAD files, effectively transforming my script into a fast-editing layer that generated new simulation-ready designs with minimal user intervention. Once a new design was specified, my script would automatically initiate the simulation, monitor the internal RSoft log files to detect when it had completed, and then direct the output data to a user-defined directory.

To process these results, I implemented a second Python script that parsed the output logs to extract threshold current data for both fundamental and higher-order Gaussian modes. This analysis was coupled with automated visualization routines, enabling me to quickly generate plots that tracked the relationship between structural parameters and modal performance. Importantly, this framework allowed me to run long simulation sweeps overnight, freeing me to focus on physical characterization tasks and further refinement of my design strategy during the day. By creating a seamless loop between design input, simulation execution, and data parsing, I reduced simulation turnaround times by approximately 20% and enabled parallel progress across multiple areas of my internship. This work demonstrated how software automation can amplify research productivity in photonics device development by eliminating repetitive manual steps and ensuring rapid iteration between design and evaluation.

3. Opto-Mechanical Assembly and Characterization

To complement simulation and automation, I performed hands-on characterization of fabricated laser diodes in nLIGHT's cleanroom facilities. I was provided with a box of test samples that incorporated variations of the designs explored in simulation, including different ridge widths, taper geometries, and quantum well structures. Each diode was carefully loaded onto a precision sample stage that integrated four measurement tools: an LIV station for current–voltage–light output curves, a spectrum analyzer for emission wavelength and linewidth, a near-field imaging system for mode profile inspection at the facet, and a far-field measurement system for divergence and M^2 analysis. Loading each sample required extreme care; using tweezers, I placed the diode onto the stage, ensuring that the fragile wire bonds, which controlled current injection into the active region, were never disturbed. Once secured, a pneumatic switch was engaged to press the device against a contact pin linked to the power supply. Because these devices operated at high output power, all characterization work was conducted under optical density (OD) protective eyewear to ensure laser safety.

During characterization, I applied bias voltages to the devices while monitoring their LIV response to determine threshold current and slope efficiency. For optical beam measurements, I used two cameras mounted on rotating arms that could sweep through vertical and horizontal planes. This allowed for detailed mapping of the far-field divergence, from which I could calculate M^2 and assess beam quality, while the near-field camera provided complementary information on mode confinement and facet emission uniformity. The combination of these techniques offered a comprehensive view of both the electrical and optical performance of each diode, enabling direct comparison between simulated predictions and real device behavior. This experience provided me with valuable practical skills in laser diode handling, cleanroom operation, and optical safety, while also deepening my appreciation for the delicate interplay between theoretical design and experimental validation.

4. Conclusion

This internship allowed me to bridge theoretical modeling with experimental practice in semiconductor laser engineering. By contributing to device simulation, developing automation tools, and constructing experimental setups, I played a direct role in improving the performance and testing efficiency of nLIGHT's next-generation industrial laser diodes. The experience strengthened my skills in laser physics, semiconductor device design, and optical engineering, while also sharpening my ability to integrate computational and laboratory approaches in solving complex engineering problems.