# Power Saturation in Standard and Double-AR Unfolded Laser Diode Cavities

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***Abstract:*** *We report modeling and experimental results that demonstrate mechanisms limiting the output power of broad area semiconductor lasers. The modeling comprises numerical simulations of the laser cavity with evolution of non-uniform carrier density, photon density, temperature and index. We measure unfolded laser cavities to validate simulation methods and input parameters.*

***Keywords:*** *laser diode, high power, saturation, simulation, unfolded cavity*

## INTRODUCTION

Semiconductor lasers with highest output power are of interest to many applications including but not limited to optical pumping of solid state and fiber lasers, frequency doubling and material processing. For applications requiring orders of magnitude greater optical power, optical sources have been developed wherein beams from multiple high-power laser diodes are combined to reach kW-level industrial diode lasers [1]. These sources are on the way to replace industrial lasers due to their superior performance than $CO_2$ lasers [2].

Despite the ability to combine many laser diodes together as direct sources or for pumping solid state and fiber lasers there are two key driving factors for maximizing individual device power. First the highest reliable output power per each laser diode is critical to optimize system level characteristics such as cost, power consumption and size. Second the laser diode output is usually limited to a certain aperture, for example to match an optical fiber for coupling. Therefore there is a drive for highest reliable power density within that aperture which puts the laser in a regime closer to power saturation or even roll-over.

## DEVICE SIMULATION

Custom code was designed to simulate the performance of high power multi-mode laser diodes to self-consistently correlate the three key components: the carrier transport model, optical model and thermal model. In an example below we simulated a representative laser diode with 5.5mm cavity length, AR/HR 1%/99% facet coatings and an active stripe width of 100 µm as could be coupled directly into a 106 µm fiber core diameter. The simulation generates 2D maps of the optical power density (forward and backward traveling), carrier density, temperature and index at different drive currents. Most importantly the device is simulated up to 18A where the light-current begins to roll-over (see Figure 2) and thermal lensing begins to dominate the lateral mode profile. Figure 1 shows the carrier density profiles comparing relatively low 9A current and at the high 18A current at the onset of power saturation.

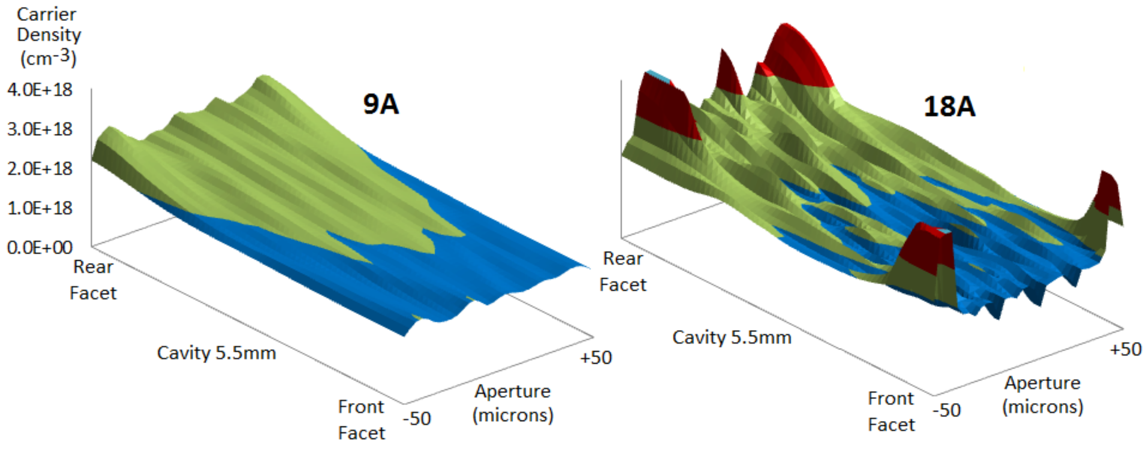

Fig.1. Simulated laser diode active region carrier densities in a 5.5x0.1mm optical cavity with 1%/99% facet coatings at 9A and 18A currents.

The low 9A current simulation in Figure 1 illustrates the first limiting factor which is the asymmetric photon density, low at the rear facet (RF) and high at the front facet (FF) leads to asymmetric carrier density along the cavity. At the current of 18A the asymmetry is even worse where at the FF the carrier density drops very low (spatial hole burning) while at the RF grows very high leading to excess waste resistive heating and optical loss. Also at 18A the impact of the thermal lens is seen as the optical mode pulls toward the center of the 100 µm width leaving excess carriers on the sides of the active region, especially at the RF and FF ends, also causing waste heating and loss. The goal of these simulations is to model modified structures to eliminate or compensate for non-uniform carrier density, photon density and heating to design a laser diode that operates to highest possible power and power density.

## UNFOLDED CAVITIES

In order to test the simulation and explore the limits of output power density we simulated and built symmetric devices with the same coating on both facets [3,4]. The advantage of this approach is most device parameters, like dimensions, thermal resistance and electrical resistance, are fixed compared to a normal 1%/99% device including the total output power coupling if one chooses 10% for both facets. The main difference is that the device is now symmetric front to back (hence the name unfolded) so the simulation and experimental performance are not dominated by asymmetry.

Figure 2 shows the modeled carrier density profile for a symmetric coated device. Comparing the 18A simulated carrier density profile in Figure 1 to the one in Figure 2 the extreme lows and highs of carrier density are gone. The right plot in Figure 2 shows experimental results for the standard asymmetric and two symmetric coated structures. The power from the symmetric structures is the sum from both facets. The peak power for the symmetric coated devices is significantly higher giving clues to the power saturation mechanisms of the standard device and possible improvements.

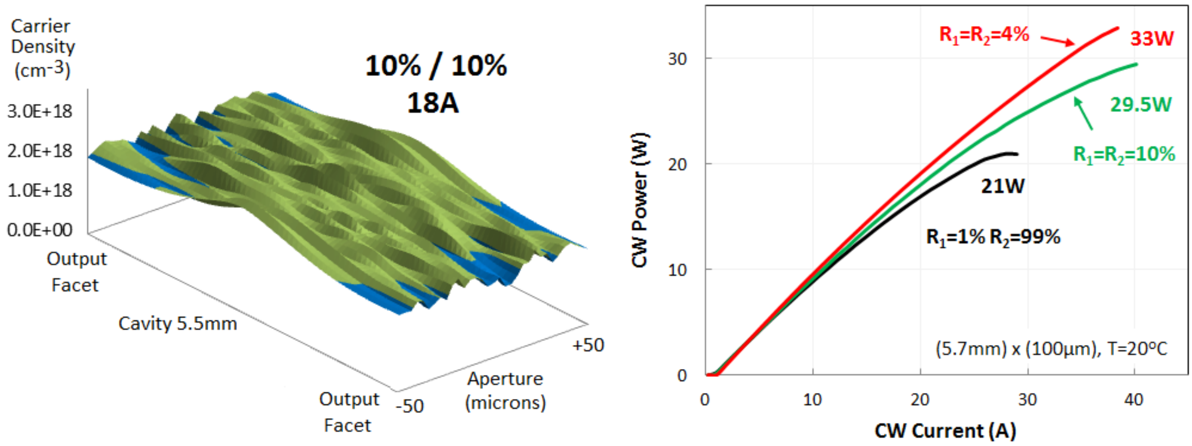

Fig.2.The left is simulated active region carrier densities in a 5.5x0.1mm optical cavity at 18A with symmetric 10%/10% coating. On the right are measured light-current data for a standard AR/HR 1%/99% structure and the light-current (sum from both facets) for symmetric coated structures

## CONCLUSION

Highest reliable total power and power density are critical for broad area laser diodes enabling best solid-state and fiber laser system performance. We have used 2D simulations to explore the limiting factors of power saturation and roll-over. We have built unfolded cavities to test these limiting mechanisms and seen significantly higher power from these devices due to more uniform carrier density and photon density.

## REFERENCES

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