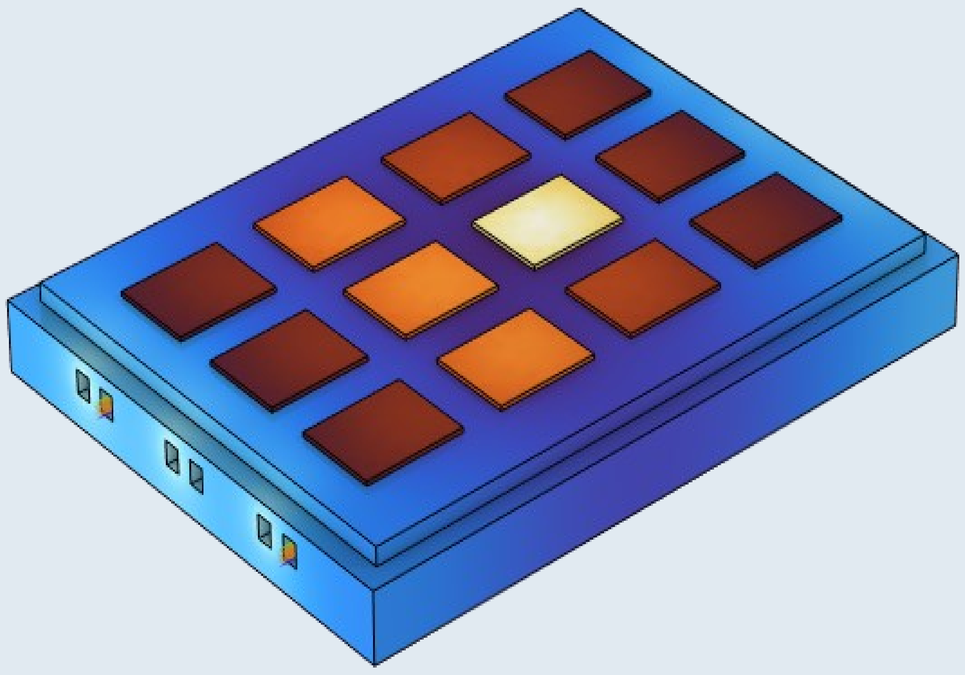


Thermal-Fluid Characteristics and Thermally Induced Wavelength Uniformity of a Microchannel-Cooled Semiconductor Laser Array

3D Conjugate Heat Transfer Analysis Based on COMSOL Multiphysics

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Introduction & Goals

High-power semiconductor laser arrays generate substantial waste heat, while nonuniform heat generation and local cooling degradation can increase device temperature and deteriorate temperature uniformity. Since the emission wavelength of semiconductor lasers is temperature dependent, thermal nonuniformity can further lead to wavelength mismatch among array elements. In this work, a 3D conjugate heat transfer model of a 4×3 GaAs laser array with microchannel liquid cooling is developed in COMSOL Multiphysics to:

- **characterize the coupled flow and temperature fields;**
- **investigate thermal responses to nonuniform heat loads and local channel blockage;**
- **evaluate thermally induced wavelength differences among laser elements.**

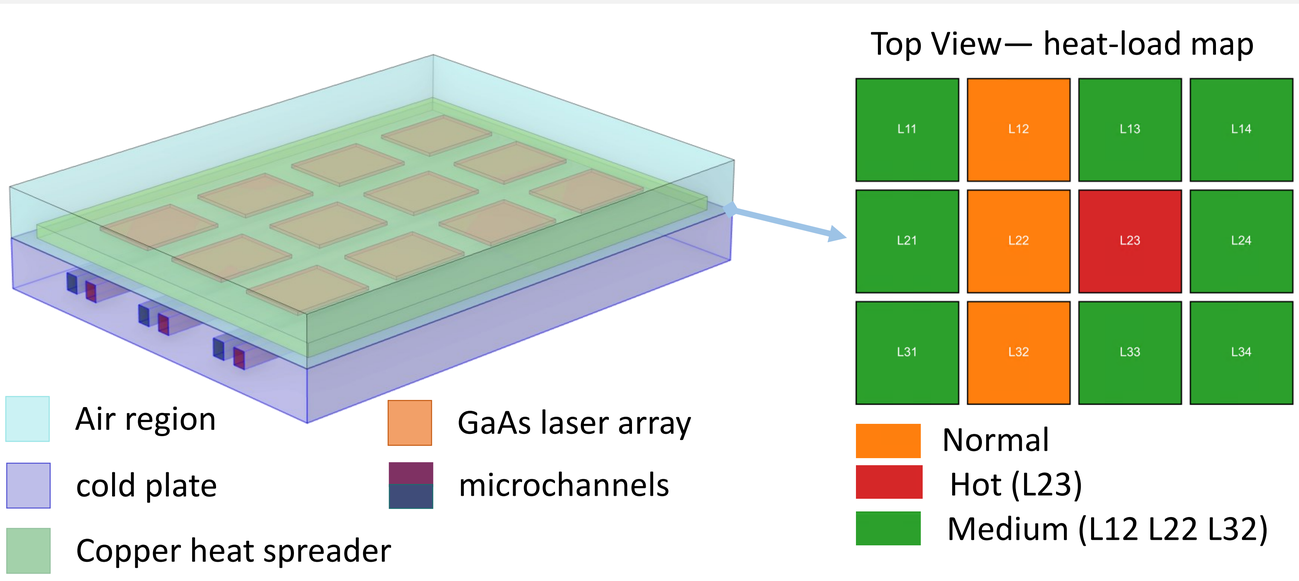


FIGURE 1. Model geometry.

Methodology

A 3D COMSOL model of a 4×3 GaAs laser array, copper heat spreader, and six-channel liquid-cooled plate was developed. Laminar Flow and Heat Transfer in Solids and Fluids were coupled for steady conjugate heat transfer with alternating channel directions. Flow-rate variation, fixed-total-power hotspot redistribution (54.8 W), and local blockage under a calibrated pressure drop were evaluated. Device temperatures were converted to estimated wavelength shifts using a representative wavelength-temperature coefficient [1].

Results

The baseline simulation resolves the coolant flow and three-dimensional temperature distribution of the laser array. Increasing the total flow rate reduces the maximum die temperature and thermal resistance, while requiring a higher pressure drop. Under a fixed total heat load, redistributing power toward local hotspot devices increases the die-to-die temperature spread and estimated wavelength spread.

Local microchannel blockage under a calibrated pressure-driven condition reduces the total coolant flow and modifies the local temperature field. Its effect on peak temperature is comparatively moderate, while device-level temperature differences translate into corresponding estimated center-wavelength differences. The simulations therefore connect **cooling conditions and heat-load nonuniformity → temperature nonuniformity → wavelength consistency**, providing a numerical framework for evaluating high-power laser-array thermal management.

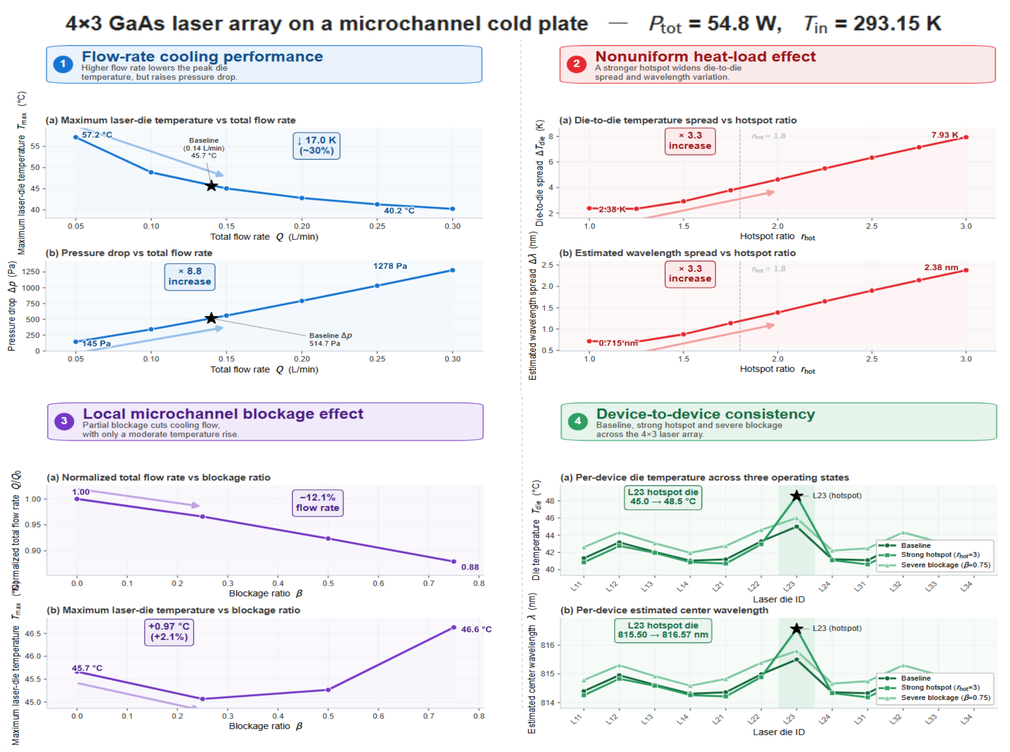


FIGURE 2. Thermal-fluid and wavelength-consistency results for flow-rate variation, fixed-power hotspot redistribution, local blockage, and device-to-device temperature and estimated center-wavelength distributions.

REFERENCES

1. Liu, J., Pan, W., Wu, X. et al. Electrically injected GaAsBi/GaAs single quantum well laser diodes. AIP Advances 7, 115006 (2017). doi: 10.1063/1.4985231.

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