Simulation of the Thermal Management of the Semiconductor Disk Laser

Yanrong Song, ZhenHua Yu, Peng Zhang and Zili Li
College of Applied Sciences, Beijing University of Technology, Beijing 100124, China

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Abstract: For the optically pumped semiconductor disk lasers, the thermal problem is the key to obtain the high out power. To solve this problem, we simulated the heat distribution of the gain chip by finite-element analysis method to discover the heat spread affected by the thickness of the substrate and found the outstanding heat spread result of the diamond chip.

1 INTRODUCTION

The semiconductor disk laser (SDL), which is also known as the Vertical external cavity surface emitting laser (VECSEL) (Kuznetsov, 1999), combining the advantages of compact, small size, low loss and good beam quality (Maclean, 2008), is an ideal candidate for applications such as biomedicine (Daukantas, 2007), high density optical data storage (Risk, 2003), chemical sensor (Garnache, 2005), and pump sources for other lasers (Richter, 2005).

In the past decade, output powers of SDL s have been upgraded significantly, but still not very high. Limitations to the output power of a V SDL come from the heat effects. With the deposited heat, thus increased temperature, the gain of quantum wells (QWs) will decrease sharply, and the laser wavelength will redshift so the periodic resonant gain structure will be detuned (Corzine,1989).What is more, the nonradiative recombination will become dominant and the temperature rise will be further accelerated. All of the above factors are compounded until finally the thermal rollover of the laser occurs.

Numerical analysis can give an overall pattern of the generation, deposition and dissipation of heat in a SDLs, and therefore bring forward advanced thermal management to improve the thermal properties and upgrade the output power of the laser. A finite element analysis was used by Kemp et al. to study the heatspreader approach; the required properties of a heatspreader were examined and the effect on heat flow and thermal lens effects were discussed.

Here we present a numerical analysis of thermal effect in InGaAs system SDL. We discovered the heat spread affected by the thickness of the substrate and found the outstanding heat spread result of the diamond chip.

2 NUMERICAL METHODS

2.1 Model for Thermal Simulation

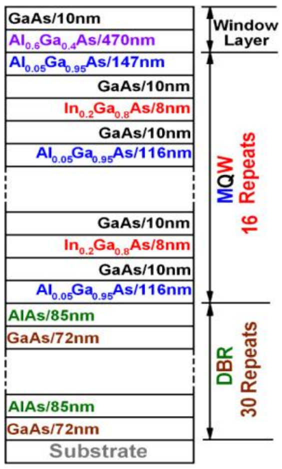

Figure 1: The epitaxial structure of the simulated semiconductor wafer.

The epitaxial structure of the simulated semiconductor wafer is shown in Fig. 1. We divide

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the whole structure into four parts: the window layer, the multiple QWs, the DBR and the substrate. The total thermal conductivity in axial and radial direction of each part including multiple layers can be written as

$$k = \frac{\sum k_i t_i}{\sum t_i} \qquad (1)$$

And the total absorption coefficient of each part is obtained by

$$\alpha = \frac{\sum \alpha_i t_i}{\sum t_i} \qquad (2)$$

where k_i and α_i are the thermal conductivity and absorption coefficient of the ith layer, and t_i is the thickness. In the computation, the wavelengths of pump and laser are 808 and 1040 nm; the value of 0.475μm^{-1} for the absorption coefficient of GaAs layer and 1μm^{-1} for the absorption coefficient of $In_{0.2}Ga_{0.8}As/Al_{0.05}Ga_{0.95}As$ QWs are used.

Then, the temperature, the heat flux and the gradient of temperature can be obtained by solving the standard heat equation (steady state):

$$-\nabla \cdot (k \nabla T) = Q \qquad (3)$$

where k is the thermal conductivity and T is the temperature.

The heat loading density Q is calculated by

$$Q_w = \frac{2\eta_w P \alpha_w}{\pi \omega^2} \cdot \exp\left(-\frac{2r^2}{\omega^2}\right) \cdot \exp\left(-\alpha_w (z_{0w} - z_w)\right) \qquad (4)$$

where w is the fraction of absorbed pump power that goes to heating, and $\eta = 1 - \lambda_{pump}/\lambda_{laser}$ in MQWs part and $\eta=1$ in other parts. α is the absorption coefficient of each part, r is the coordinate in radial direction and z is the coordinate in axial direction. The start position z_0 of each part is different and the start position of window layer is chosen to be zero. In this paper, the pump power and the pump spot radius are assumed to be 10W and 50 mm unless there is a special explanation.

Table 1: Parameters of some materials.

Material	k ($Wm^{-1}K^{-1}$)	α (μm^{-1})
GaAs	44	0.457
AlAs	91	0
$Al_{0.6}GaAs$	11	0
$Al_{0.05}GaAs$	27	1.000
$In_{0.2}GaAs$	7	1.000
Diamond	2000	0

2.2 Results of the Simulation

We used the finite-element analysis method to simulate the heat distribution of the semiconductor chip when the heat sink temperature was 300 k. The parameters used is in table 1. We could discovery the heat spread affected by the thickness of the substrate illustrated in Fig.2. and Fig.3. We also can find the outstanding heat spread result of the diamond chip from Fig.3. and Fig. 4.

The Fig.2 described the temperature variation when the thickness of the gain chip substrate is 0 μm, the maximum temperature rise is 30.05 K, compare to the 934.21 K of the max temperature rise represented in Fig.3. when the thickness of the gain chip is 350 μm. So the substrate removal is an effective method to improve the heat spread of gain chip.

At the same time, a 300μm-thick diamond chip was bonded on the gain chip with 350 μm substrate, as shown in Fig. 4. The maximum temperature rise is 56.79 K, which is much lower than the 934.21 K shown in Fig.3. Therefore, the diamond has outstanding heat spread results. Whilst using heatspreader has superior heat spread effect, and we'll try to bonding the diamond on the gain chip to obtain higher fundamental power so as to get higher harmonic power in our next work.

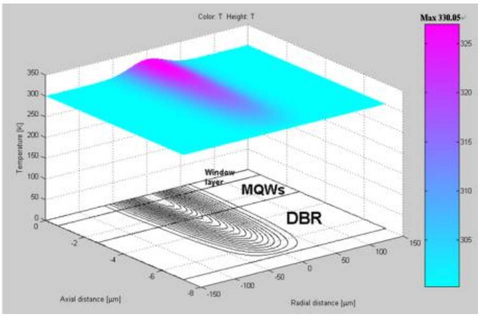

Figure 2: Heat distribution of the semiconductor chip without substrate.

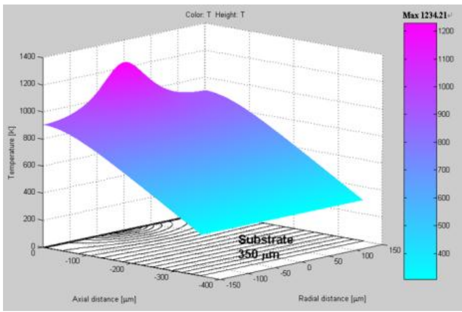

Figure 3: Heat distribution of the semiconductor chip when its substrate is 350 μm-thick.

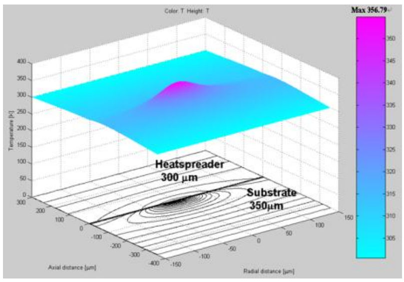

Figure 4: Heat distribution of the semiconductor chip with its 350 µm-thick substrate which is bonded a 300μm-thick diamond heatspreader.

3 CONCLUSIONS

In this papser, the thermal distribution has been discussed and the simulation results has been demonstrated by finite-element analysis method. Using the model, we could optimize the SDL and obtain higher output power.

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