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Self-Consistent Electro-Thermal-Optical Simulation of Thermal Blooming in Broad-Area Lasers

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Abstract – **High-power broad-area laser diodes often suffer from a widening of the lateral far-field with increasing current, called thermal blooming. This effect is mainly caused by the non-uniform self-heating of the laser and it has been studied for several decades. For the first time, this paper presents a self-consistent electro-thermal-optical simulation of thermal blooming, including all relevant physical mechanisms. The results are in good agreement with previous measurements and reveal the blooming mechanism in detail. Common mistakes in the experimental determination of the internal temperature rise are also discussed.**

I. INTRODUCTION

High-power broad-area laser diodes often suffer from a widening of the lateral far-field with increasing current.[1,2] This effect is also referred to as thermal blooming, since self-heating is considered the main cause. The non-uniform temperature profile inside the waveguide leads to a lateral refractive index profile that enhances the index guiding of laser modes (thermal lens). Numerical simulation is a valuable tool in investigating this interaction of electronic, thermal, and optical processes, however, a comprehensive numerical analysis has not been published yet. Recent simulations combine optical mode guiding with the internal heat flux,[2] but without accurate calculation of the internal heat power distribution.

This paper present the first self-consistent electro-thermal-optical simulation of the thermal blooming effect, including the highly non-uniform heat power distribution inside the laser. A previously investigated GaAs-based broad-area quantum well (QW) laser structure with an emission wavelength near 975nm is used as an example.[2]

II. MODELS AND PARAMETERS

A customized version of the LASTIP laser simulation software is employed here,[3] which allows for the self-consistent combination of multi-mode wave guiding, drift-diffusion of electrons and holes, and heat flow in the transverse plane. The heat power distribution is calculated using the local densities of carriers and current, including Joule heat, non-radiative recombination heat, heat caused by modal absorption, as well as the Peltier/Thomson effect. Index guiding by etched trenches is considered as well as anti-index guiding by carrier-induced index changes in the quantum well. The local refractive index N(T) is calculated from the temperature distribution T(x,y) using published material parameters.[4]

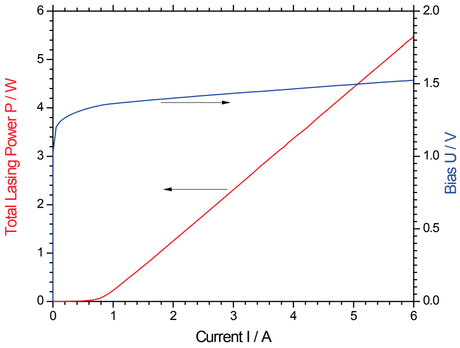

Fig. 1: Simulated laser characteristics.

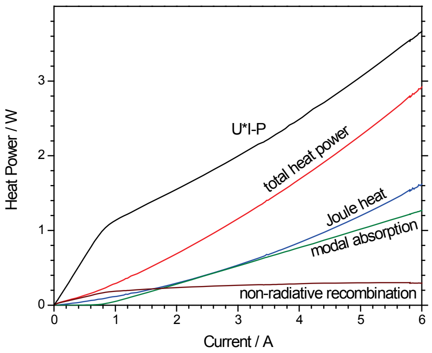

Fig. 2: Comparison of different heat sources. U*I-P gives the heat power estimated from the laser characteristics in Fig. 1.

III. SIMULATION RESULTS

The simulated light-current and current-voltage characteristics are shown in Fig. 1 and they are in excellent agreement with measurements.[2] Different heat generation mechanisms are distinguished in Fig. 2. Joule heating and modal absorption cause a similarly high contribution. Heating from non-radiative recombination hardly changes above threshold, due to the almost constant QW carrier densities. Also shown in Fig. 2 is the heat power U*I-P commonly extracted from the laser characteristics in Fig. 1,[2] which is substantially

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larger than the numerically calculated heat power. The main reason is the inclusion of the spontaneous photon emission as heat source in the formula U*I-P. An unknown fraction of these photons is internally absorbed and eventually generates heat, but that heat generation mainly happens far away from the active region and without much influence on its temperature. Therefore, the absorption of spontaneously emitted photons is neglected in this paper.

Since the spontaneous emission power is hard to measure, the accurate determination of the QW temperature seems to be an open problem which should be discussed at the conference. Another inaccuracy is related to the employment of a thermal resistance,[1] since this concept puts the entire heat power into the active layer, which is not correct for distributed heat sources.[5]

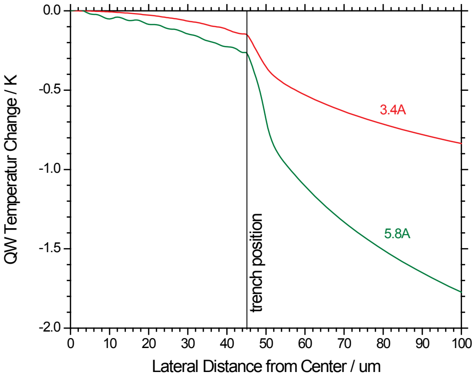

Fig. 3: Lateral QW temperature profiles relative to their peak value at two different bias points. Assuming perfect symmetry, only half the laser is considered.

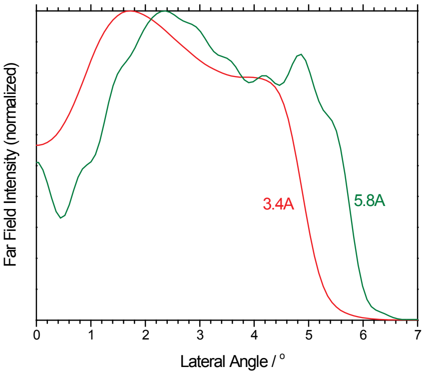

Fig. 4: Lateral far field profiles calculated at two bias points.

However, the thermal lens near the active region is not dominated by the absolute temperature but by local temperature differences. Figure 3 shows the calculated temperature profiles at two bias points. Obviously, a higher current induces a stronger temperature drop in lateral direction.

The calculated far-field profile is shown in Fig. 4 for the same bias points, clearly demonstrating the thermal blooming effect. At 3.4A current, a total of 17 lateral modes contribute to lasing. This mode number increases to 19 at 5.8A. Higher-order modes are known to generate wider far fields. Figure 5 compares the far field of the 17th and the 18th mode. Thus, the widening of the far field can be attributed to a rising maximum mode order. The simulated near field is shown in Fig. 6. The width of the near field remains nearly constant.

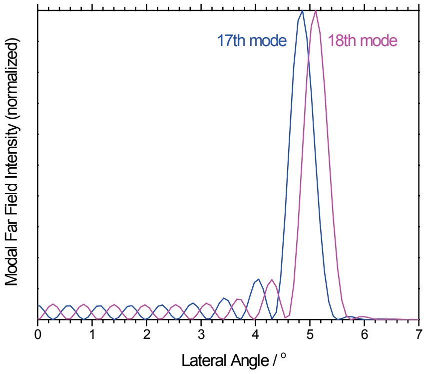

Fig. 5: Far fields of modes 17and 18. The mode order corresponds to the total number of peaks.

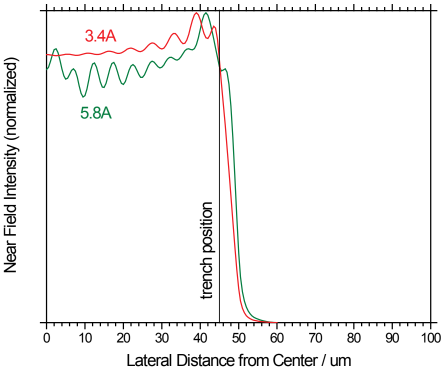

Fig. 6: Lateral near field profiles calculated at two bias points.

In summary, using self-consistent electro-thermal-optical simulation, the thermal blooming effect in high-power lasers is linked to the rising order of lateral modes due to thermal lens enhancements with higher current. This enables future laser design optimization towards smaller and more stable far fields.

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