Thermal Management of GaInNAs/GaAs Disk Lasers

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Abstract **–Methods used to reduce thermal resistance of GaInNAs/GaAs disk lasers are described and compared with the aid of the self-consistent thermal-electrical finite-element model.**

I. INTRODUCTION

Currently there are two distinctly different classes of semiconductor lasers: edge-emitting lasers (EELs) and vertical-cavity surface-emitting lasers (VCSELs). EELs may emit very intense high-power radiation of the order of many watts, but their output beams contain many longitudinal modes and are very divergent, with astigmatism effects. VCSELs, on the other hand, emit low-divergent, single-mode, circularly symmetric output beams without astigmatism but of relatively low output of the order of few milliwatts. New optically pumped semiconductor disk lasers [1], known also as vertical external-cavity surface-emitting lasers (VECSELs), have been proposed to combine simultaneously virtues of both the above laser types. They are compact laser devices emitting a single-mode high-quality laser beam of relatively high output. Currently, as practically in all high-power devices, especially during their infant period, thermal problems are the most important ones limiting possible applications of disk lasers. Their poor thermal behavior results from both a very intense heat generation within their volumes and ineffective heat-flux extraction from these volumes. Therefore the main aim of this paper is to propose a detailed self-consistent finite-element model of thermal properties of semiconductor disk lasers emitting the 1.3-µm radiation for the second-generation optical-fiber communication, which may enable their thermal optimization, i.e. an improvement of an efficiency of a heat-flux extraction from their cavities.

II. THE LASER STRUCTURE

Structure of a typical disk laser [1] is schematically shown in Fig. 1. The laser cavity is extended between a distributed Bragg reflector (DBR) mirror and an external spherical mirror. For an emission of the 1315-nm radiation, the laser active region is in a form of five pairs of 7-nm $Ga_{0.63}In_{0.37}N_{0.012}As_{0.988}$ quantum wells separated in each pair by 13-nm and between pairs by 158-nm GaAs barriers to form the resonant-periodic-gain (RPG) structure. The laser is pumped by an external diode laser emitting the 810-nm radiation. The laser was grown on the 300-µm GaAs substrate. The DBR mirror is composed of 25.5 periods of the quarter-wave GaAs/AlAs layers. The laser chip is soldered with indium to the 15 mm copper heat sink. The upper 282-nm window $Al_{0.3}Ga_{0.7}As$ layer is located over the active region.

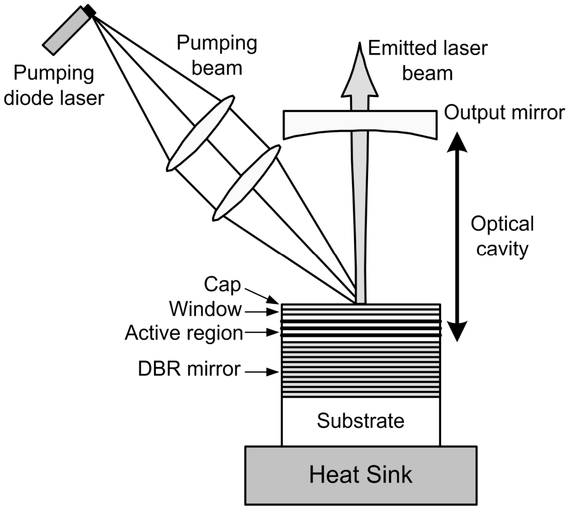

Fig. 1. Structure of a semiconductor disk laser.

Heat generation within the disk laser is a result of a not perfect transfer of the pumping radiation into the active-region optical gain. In the disk laser under consideration, it is improved by the RPG active-region structure. Let us consider now efficiency of heat-flux extraction from the disk laser.

In a simple 'as-grown' disk laser directly attached to its heat-sink, its high thermal resistance R_{TH} follows mostly from a heat-flux flow through its DBR mirror and a thick substrate. Therefore, to reduce R_{TH}, two methods are used to improve efficiency of a heat-flux extraction [2]: substrate removal or an application of a heat spreader [3]. The first approach [1] leads to a 'thin' (~ 6 µm) device soldered directly to a heat sink whereas, in the second one, the heat spreader of high thermal conductivity is applied on the top of the laser chip. In the first solution, for an approximately one-dimensional heat flow from the active region towards the heat sink, the laser thermal resistance is practically equal to that of the DBR mirror. Configuration of the second disk laser is schematically shown in Fig. 2. The 270-μm diamond heat spreader is bonded directly on the laser chip with the aid of liquid capillarity. Besides, the laser chip is clamped in a heat-sink mount using an indium foil. Then the heat spreader enhances unconstrained radial heat-flux spreading, so the cross-section of the heat flow towards the laser heat sink is considerably increased leading to lower thermal resistance. Moreover, heat is also removed by the ring contact on the top of the heat spreader and the upper part of the laser submount.

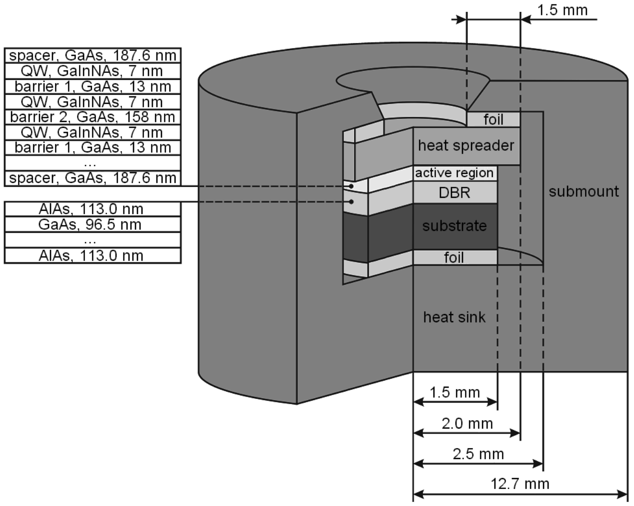

Fig. 2. Configuration of the disk laser with a heat spreader. Not to scale.

III. RESULTS

The thermal radiation and the acceptance of thermal energy by air particles from laser external and top walls are assumed to be negligible as compared with an intense heat-flux removing by the laser copper heat sink. Therefore top and side walls of the semiconductor chip are regarded as thermally isolated ones. The external surface of the heat sink is assumed to be kept at the room ambient temperature. In the calculations, the gaussian radial distribution of the pumping beam is assumed, which leads to analogous form of heat generation in successive structure layers. Steadily reduced intensity of the pumping beam in the above layers is determined. Temperature dependence [4] of thermal conductivities [5] is taken into account. The heat spreader is regarded as perfectly transparent for the pumping beam but its reflection from both heat-spreader sides is included: about 80% of the pumping-beam power has been determined to reach the laser chip. The absorption coefficients has been found in [6].

Main simulation results are presented in Fig. 3, where a dependence of the laser thermal resistance (defined as the ratio of the maximal temperature increase within the laser volume to the power of heat sources) on the pumping-beam diameter is plotted for the typical pumping power of 8.62 W. As one can see, the pumping-beam diameter ϕ has been found to have a significant impact on temperature increases, its reduction leads to a considerable temperature increases. In the case of the ‘as grown’ disk laser, an enormous temperature increase even over melting temperatures of used materials should be expected. A complete removing of the VECSEL substrate leads to a dramatic reduction of temperature increases and the lasers could operate at room temperature. But these increases have been still too high to reach expected high power of an emitted beam. Finally an application of both the above substrate removing and the diamond heat spreader was found to enable an efficient VECSEL operation.

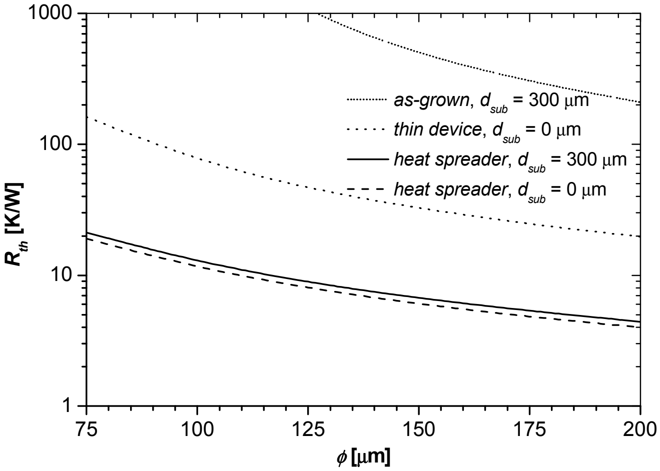

Fig. 3. Laser thermal resistance R_{TH} versus a diameter ϕ of the pumping beam of power P_p = 8.62 W.

In conclusion, it has been found in our simulations, that, for a proper work of a disk laser, both removing of its substrate and a diamond heat spreader should be applied.

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