

Thermo-Electrical Modelling of Nitride Mini-Arrays Based on the Single Edge-Emitting Laser Diode

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Abstract – This paper shows results obtained by thermo-electrical modelling of nitride laser mini-arrays based on a single emitter. An influence of the array attachment, emitter number and their mutual distance on thermal and electrical properties as well as on operation parameters has been determined.

I. INTRODUCTION

Blue optoelectronics relates to semiconductor emitters based on wide-bandgap nitride compounds. Since the first blue laser diode (LD) was made, broad market commercialization of these devices and an output power increasing have become of paramount importance. In order to obtain more power, the first nitride mini-arrays were made [1]. Blue emitters suffer from self-heating because of very intense heat generation within their volumes and poor thermal properties of ternary nitride layers. In these devices the nitride materials are used in several structural forms – bulk GaN crystal as substrate, mixed crystal (alloy) thin films and short-period superlattices (SLs) as device areas including active region. Thermal conductivities of thin ternary films and SLs are much lower than those of bulk GaN crystals. Because the heat dissipation in these devices increases with an increase in electric power, the low thermal conductivity of high-doped thin films and SLs becomes the cause of the thermal problems. Because of a considerable thermal crosstalk between array emitters the thermal properties of these devices are more crucial than in single emitter. The main goal of this paper is to present thermo-electrical models of multi-quantum-well (MQW) nitride laser mini-arrays based on the edge-emitting (EE) LD [2]. An influence of the array attachment, emitter number and mutual distance (pitch) to the thermal properties and operation parameters has been shown.

II. SINGLE BLUE EMITTER

A thermo-electrical model has been applied to simulate a room-temperature (RT) continuous-wave (CW) operation of the nitride EE LD reported by Kauer et al. [2]. It is the MQW EE ridge-waveguide (RW) LD emitting 405 nm radiation, grown by molecular beam epitaxy. Its low RT CW threshold current of 110 mA and voltage of 7 V correspond to a threshold current density of 5.5 kA/cm². The CW output power was 14 mW and a CW characteristic temperature $T_0 = 123$ K. The 2 μm wide and 1000 μm long stripes were used for the laser resonator. The LD has been attached *p-up* to a copper heat-sink with silver paste solder as in [3].

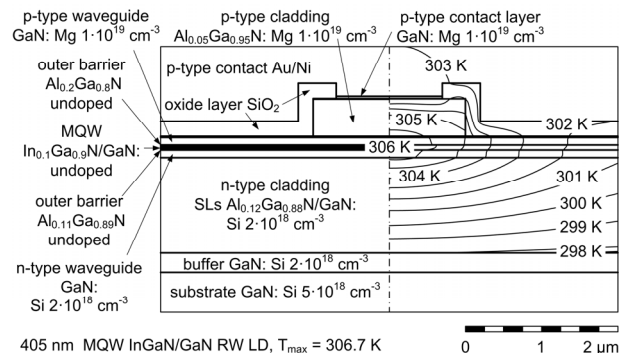


Fig. 1. The analyzed LD structure and RT CW isotherms (LD width = 300 μm).

Temperature dependence of semiconductor lasers is usually described by the phenomenological parameter T_0 defined in the expression (1), where T and j_{th} are the absolute temperature and threshold current density, respectively [4].

$$j_{th}(T+\Delta T) = j_{th}(T)\exp(\Delta T/T_0) \quad (1)$$

Three-dimensional finite-element models have been used to determine temperature and current density distributions in the single nitride emitter and laser mini-arrays. Furthermore, it was possible to determine threshold conditions for the single emitter with changed mounting side as well as for emitter arrays thanks to the knowledge of characteristic temperature and calculated values of active region threshold current density and temperature of the single LD. Calculated threshold current density and maximal temperature increase in single emitter active region are 6.00 kA/cm² and 18.7 K, accordingly. After reversing the single emitter *p-down* to the copper heat-sink) the threshold voltage dropped to 6.89 V and the values of threshold current density and maximal temperature increase dropped to 5.53 kA/cm² and 8.2 K, correspondingly.

III. NITRIDE LASER MINI-ARRAYS

The nitride laser mini-arrays were designed by multiplying the single emitter and mounting it *p-up* and *p-down* to the copper heat-sink with silver paste solder. The sizes of single laser stripe and the substrate were fixed to 2x1000 μm and 300x1000 μm, accordingly. Thermo-electrical calculations have been made using mini-arrays with 2–5 emitters and pitch ranging 10–40 μm.

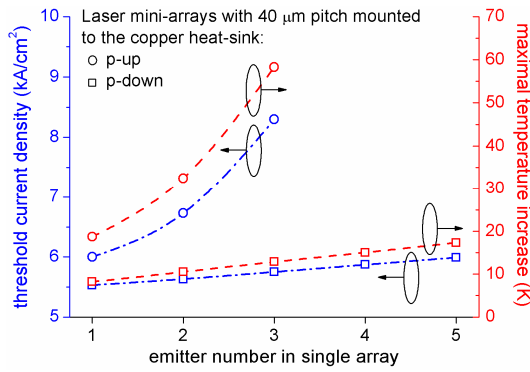


Fig. 2. Threshold current density and maximal temperature increase in the active region as a function of number of emitter placed with 40 μm pitch in each mini-array mounted *p-up* and *p-down* to the copper heat-sink.

A significant drop of the active region maximal temperature in the single emitter mounted *p-down* to the copper heat-sink (of over 50%) results in a low thermal crosstalk of corresponding *p-down* laser mini-arrays (Fig. 2.). In contrast to the *p-up* attachment, an increase of emitter number in a single mini-array causes much lower increase of the active region maximal temperature and threshold current density. Moreover, the pitch changing in the range of 10–40 μm doesn't influence much the thermal crosstalk in *p-down* mounted mini-arrays. For *p-down* 5-emitter mini-array the pitch decrease from 40 to 10 μm gives relative temperature increase of 20%. On the contrary, the *p-up* mini-arrays are more sensitive to the emitter number and pitch changes than corresponding *p-down* mini-arrays. Nearly the same relative temperature increase of 20% with increasing the pitch has been observed in the *p-down* 5-emitter mini-array and *p-up* 2-emitter mini-array. The maximal temperature increase in the active region of *p-up* 3-emitter mini-array is nearly twice as big as the corresponding temperature increase in *p-up* 2-emitter mini-array. A strong thermal crosstalk determined in *p-up* mini-arrays prevents a 4-emitter mini-array from lasing. Calculated from (1) threshold current density is too high to be achieved by each emitter of this mini-array (Fig. 3). The difference in threshold current of mini-array emitter was clearly observed in *p-up* 3-emitter mini-array. A side-emitter threshold current of 453 mA was lower than that of 462 mA for

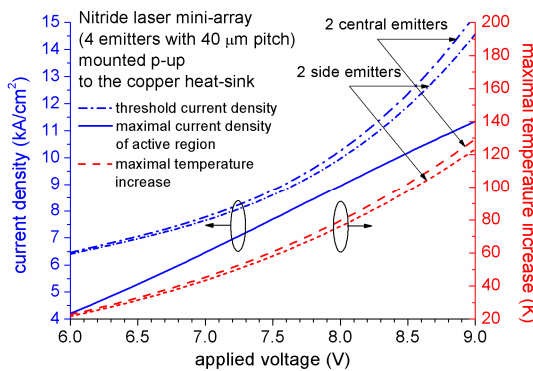


Fig. 3. Maximal temperature increase, maximal current density of active region and corresponding threshold current density calculated from (1) as a function of applied voltage to the laser mini-array consists of 4 emitters with 40 μm pitch mounted *p-up* to the copper heat-sink.

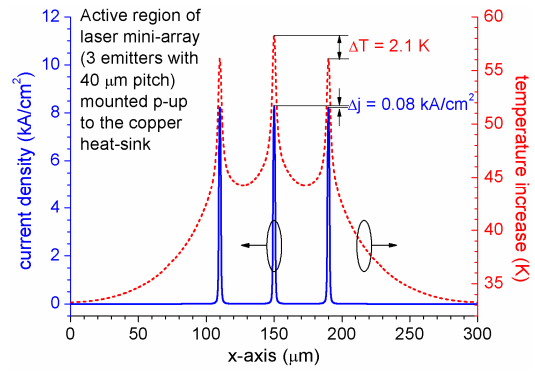


Fig. 4. Current density and temperature increase distributions in active region of the nitride 3 emitters and 40 μm pitch mini-array as a function of x-axis i.e. the distance from the edge of semiconductor structure.

a central-one. The difference of 2.1 K (Fig. 4) in maximal active region temperature of the central- and side-emitter corresponds to the difference of 0.08 kA/cm² in the current density. The temperature increase of 45 K remains in the active region area between side-emitters and drops to 33 K at structure edge. The pitch decrease to 20 μm prevents this mini-array from lasing by increasing the thermal crosstalk.

IV. RESUME

Nitride laser mini-array is a promising novel system in wide-bandgap devices as the blue-light high-power source. However, since the single high-power nitride lasers suffer from poor thermal properties, their multiplying to mini-arrays results in considerable thermal crosstalk. Thermal and electrical properties of the nitride mini-array depend strongly on the mounting side (*p-up*, *p-down*) of these devices. The influence of emitter number and pitch has been determined and discussed in details. High efficiency of *p-down* attachment allows multi-emitter mini-array to achieve RT CW threshold operation without strong thermal crosstalk. *P-up* mini-array is far more sensitive to change of emitter number and the pitch. The maximal number of emitters of *p-up* mini-array has been determined to be 3 with 40 μm pitch. Its emitters have been characterized by different threshold current.

ACKNOWLEDGMENT

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