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Method of low-temperature rise of laser diode quality

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Abstract. In 1987 the authors of this article discovered the effect of irreversible gigantic modification (IGM) of semiconductors. Basing on the IGM phenomenon the authors have developed technological method that enables to considerably improve performances of laser diodes after their manufacturing by increasing power, slope efficiency, and decreasing threshold current. The technology has been tested on the laser diodes of several US companies. We obtained the same results in improvement of all the diodes from these companies. Performances of the laser diodes with small slope efficiency and high threshold current were improved using this modification. Slope efficiency of laser diodes was increased by 2.3 or 3.7 times and the threshold current was decreased from 15 % up to 29 %. It is shown that modification depth of the semiconductor chip for these laser diodes exceeds 50 microns. Shown is that a beam divergence of laser diode can be decreased using the irreversible gigantic modification.

Keywords: laser diode, semiconductor modification, irreversible gigantic modification.

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1. Introduction

Laser diodes compact and convenient in operation are now widely used in various areas of technology, technique, medicine, transfer, and processing of information, communication, *etc*. Annually about 100 million laser diodes (LDs) on the sum over 2 billion US dollars are produced in the world.

The basic working parameters of typical laser diodes are determined by technology of growing of laser plates. During growing of laser plates it is necessary to observe very precisely a technological mode and even small very often not controllable deviations from it is resulting in appreciable deterioration of such the laser diode parameters as threshold current and slope efficiency. Therefore, only a very small amount from all made LDs (about 10–30 %) have high parameter values, while those for another LDs are considerably lower.

On magnitude of a threshold current and a slope efficiency of LDs of the same series and were made in the same firm, it is possible to divide onto the first and second categories (Figs 1, 2) conditionally. LDs of the first category have the smallest threshold current and the greatest slope efficiency; LDs of the second category have the greatest threshold current and the smallest slope efficiency (Figs 1, 2). From Figs 1, 2 one can see that magnitudes of threshold currents of LDs differ by 15–20 %, and magnitudes of slope efficiency do more than twice.

It was experimentally shown that for decreasing of a threshold current and increasing of slope efficiency LDs it is necessary to decrease internal optical losses and a non-radiating recombination in laser plates out of which the chips of laser diodes make. The dot defects of the active area of LDs make the significant contribution to optical losses and a non-radiating recombination.

The quantity of diodes of the second category is much more than of diodes of the first category. Therefore, today development of new technological methods of dot defects removal out of active areas of diodes has a great practical significance.

Creation of a low-temperature correction method of the parameters of LDs after their fabrication is our basic purpose in this work. In this article offered is the new approach to improve (correct) key parameters of LDs, which allows to reach that for all key parameters (the threshold current, slope efficiency, and others) simultaneously. Our approach to improvement of parameters of LDs is based on the new physical phenomenon - irreversible gigantic modification of properties of semiconductors (IGM) [1,2,3].

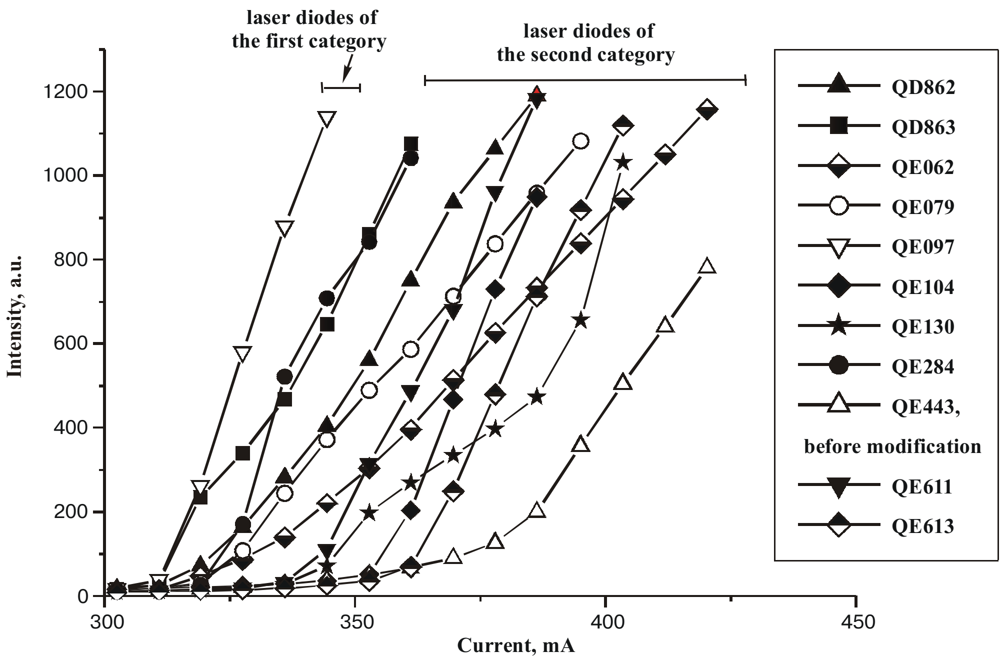

Fig. 1. Dispersion of L-I characteristics of the one laser diodes type of firm OPTO POWER Corporatin, USA.

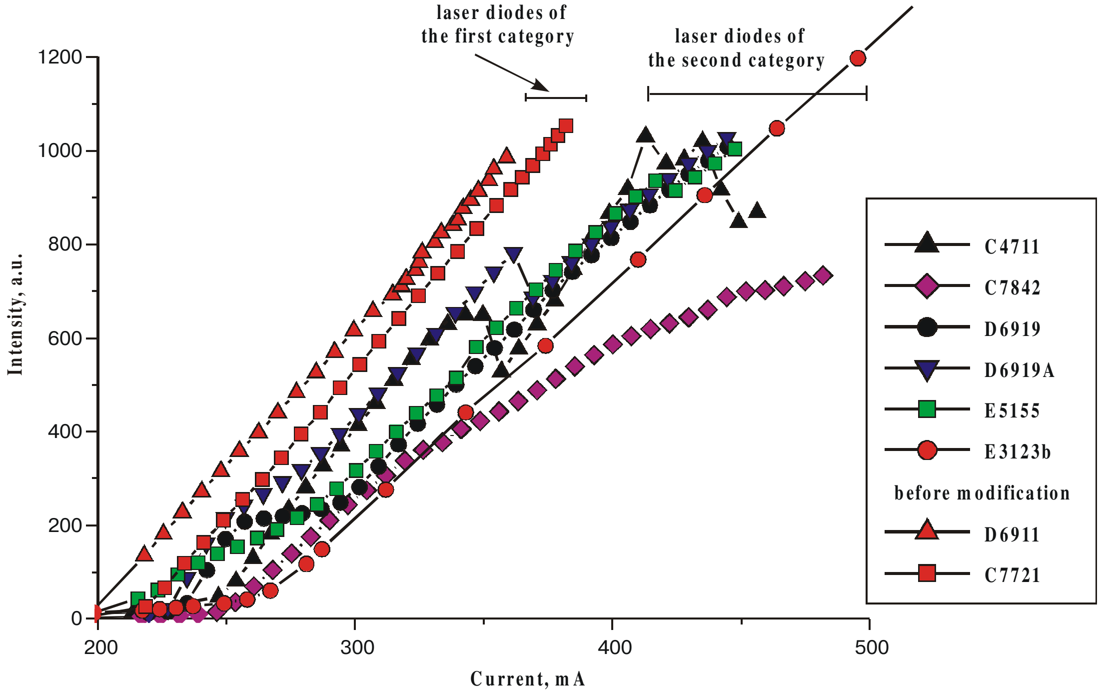

Fig. 2. Dispersion of L-I characteristics of the one laser diodes type of firm Polaroid, USA.

2. Experimental samples and scheme of modification

We have shown [1,2,3] earlier that in process of modification of semiconductors at room temperature the dot defects are moved from volume of a sample into its subsurface area. Concentration of dot defects in volume of a sample goes down (a clearing of volume of a sample from the dot defects is occurred), and in its subsurface area arise quantum points and a wires, which strongly change its optical properties. Experimentally, we registered a decreasing of the real part of a complex refractive index of subsurface area of a semiconductor samples on 0.8.

We used process of formation of quantum dots in subsurface area of a semi-conductor material and change a refractive index for improvement of characteristics of laser diodes.

Formation of quantum points and wires in area of mirrors of the laser diode and decrease of internal optical losses in active area of the resonator induces to increase of its power, increase of its slope efficiency and decrease of its threshold current.

IGM occurs at simultaneous action onto the semiconductor of high polar liquids, the acceptors that dissolve in them and optical radiation from area of own absorption. Atoms of salt, which were superficial acceptors to semiconductor material of diode, was dissolved in a liquid.

In our experiments LD of firm OPTO POWER Corporation (USA) and of firm Polaroid (USA) were used for modification. Designs of all LDs were such as C-Mount. Diodes were joined mechanically and electrically to a copper plate (S = 21 cm^2) and then were immersed in the cell with high polar liquid (bi-distilled water) (Fig. 3).

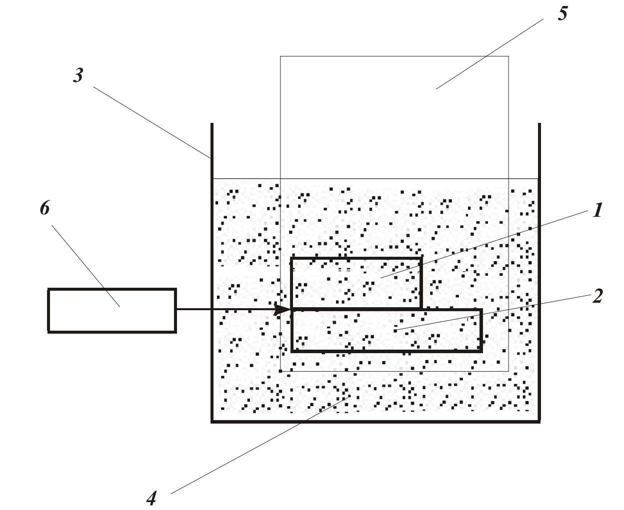

Fig. 3. The scheme of modification of laser diodes. *1* – laser diode, *2* – heat sink, *3* – quartz cell, *4* – water with acceptors, *5* – copper plate, *6* – gas laser.

The surface of a laser mirror was shined by normally light of He-Ne of the laser (0.6328 microns) with a density of power 5–10 mW/cm^2 during several minutes. After modification the diodes were dried under a stream of air at the room temperature.

Structures of LDs of firm OPTO POWER Corporation (Fig. 4a) and firm Polaroid (Fig. 4b) are schematically shown in Fig. 4. It is seen that they differ only by structures of heat sink. A heat sink is located densely to a back end-wall in diodes of firm OPTO POWER Corporation. Therefore, at immersing of the laser diode into liquid, its chip contacts with liquid only via lateral sides and a forward mirror (through a thin dielectric film). At immersing the laser diode of firm Polaroid in modifying liquid, its chip contacts with liquid by both lateral sides and both back end-walls.

That is, the total square of the chip surfaces, that contact with liquid for the chip of the firm OPTO POWER Corporation is more than that of the of firm Polaroid chip.

3. The received results and their discussion

The L-I characteristics of the laser diode of the second category before and after modification (firm OPTO POWER Corporation, USA) are shown in Fig. 5. The L-I characteristics of the laser diode of the second category before and after modification (firm Polaroid, USA) are shown in Fig. 6. From fig. 5 one can see that after modification the L-I characteristic of diode has very strongly changed: the threshold current has decreased with 375 mA up to 318 mA, and slope efficiency has increased into 2.33 times. From Fig. 6 one can see that after modification the L-I characteristic of diode has very strongly changed: the threshold current has decreased with 258 mA up to 183 mA, and slope efficiency has increased into 3.74 times.

In Fig. 7 (firm OPTO POWER Corporation) and Fig. 8 (firm Polaroid) L-I characteristics of laser diodes of the

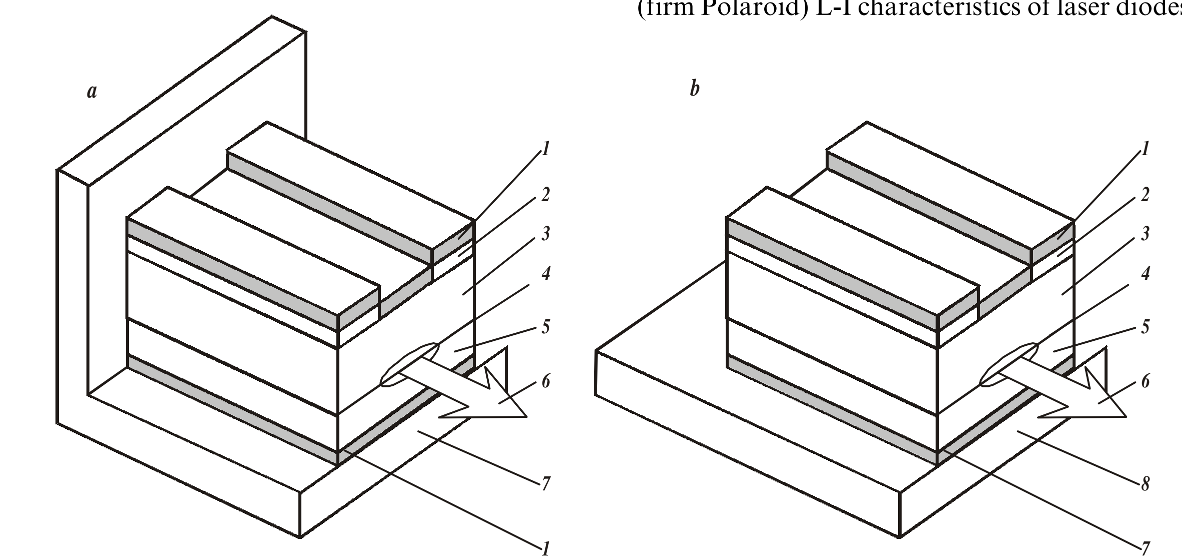

Fig. 4. *a* – design of LD of OPTO POWER Corporatin firm; *b* – design of LD of Polaroid firm. *1* – electric contact, *2* – a layer of insulator, *3* – a layer of *n*-type, *4* – *p-n* junction, *5* – a layer of *p*-type, *6* – the light emitting by laser diode, *7*, *8* – a heat sink.

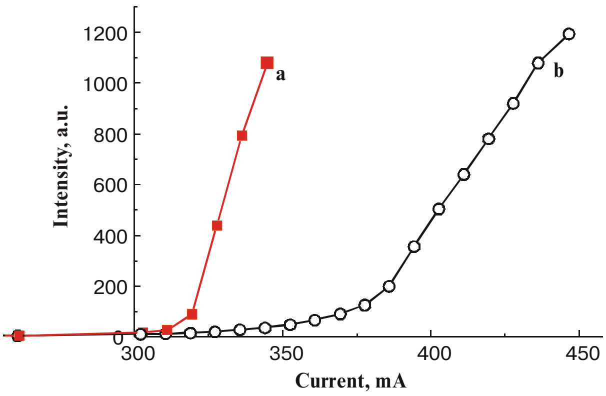

Fig. 5. The L-I characteristic of laser diode QE-443 of firm OPTO POWER Corporation, USA before (*b*) and after (*a*) modification. The threshold current of laser diode before modification is 375 mA; the threshold current of laser diode after modification is 318 mA. The decreasing of a threshold current of laser diode is 57 mA, the slope efficiency has increased into 2.33 times.

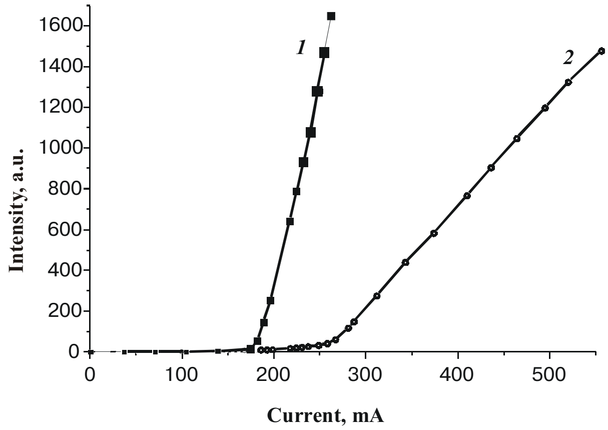

Fig. 6. The L-I characteristic of laser diode QE-443 of firm Polaroid, USA before (b) and after (a) modification. The threshold current of laser diode before modification is 258 mA; the threshold current of laser diode after modification is 163 mA. The decreasing of a threshold current of laser diode is 75 mA, the slope efficiency has increased into 3.74 times.

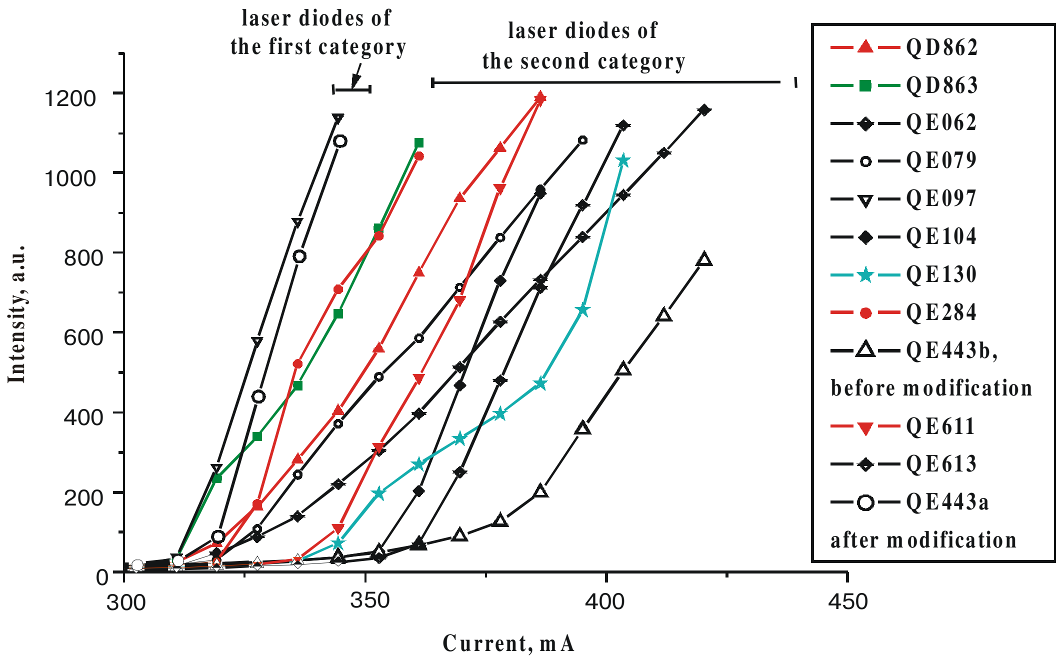

Fig. 7. The L-I characteristics of laser diodes of the first and second category of OPTO POWER Corporation firm and also the L-I the characteristic of laser diode QE-443 after its modification.

first and second category together with L-I characteristics of diodes after their modification are given. From figures it is clearly seen that lasers diodes of the second category using our method of modification are converted into laser diodes of the first category.

From Fig. 8 one can see also that parameters of laser diodes of the second category of the firm Polaroid after modification became better than those of laser diodes of the first category of this firm. Apparently, it is caused by the fact that the total area of surface of contact with a liquid of the chip of the laser diode of firm Polaroid is more than the analogous surface of the chip of the laser diode of firm OPTO POWER Corporation.

It follows from this, that using our modification it is possible to improve parameters of laser diodes not only of the second category but of laser diodes of the first category, too.

After a modification the beam divergence ($\theta_{\perp}$) of laser diodes has decreased ($\theta_{\perp}$ is the full angle at the point which is S of peak intensity). The beam divergence ($\theta_{\perp}$) of laser diodes of firm OPTO POWER Corporation has decreased from 32° up to 30°, and the beam divergence ($\theta_{\perp}$)

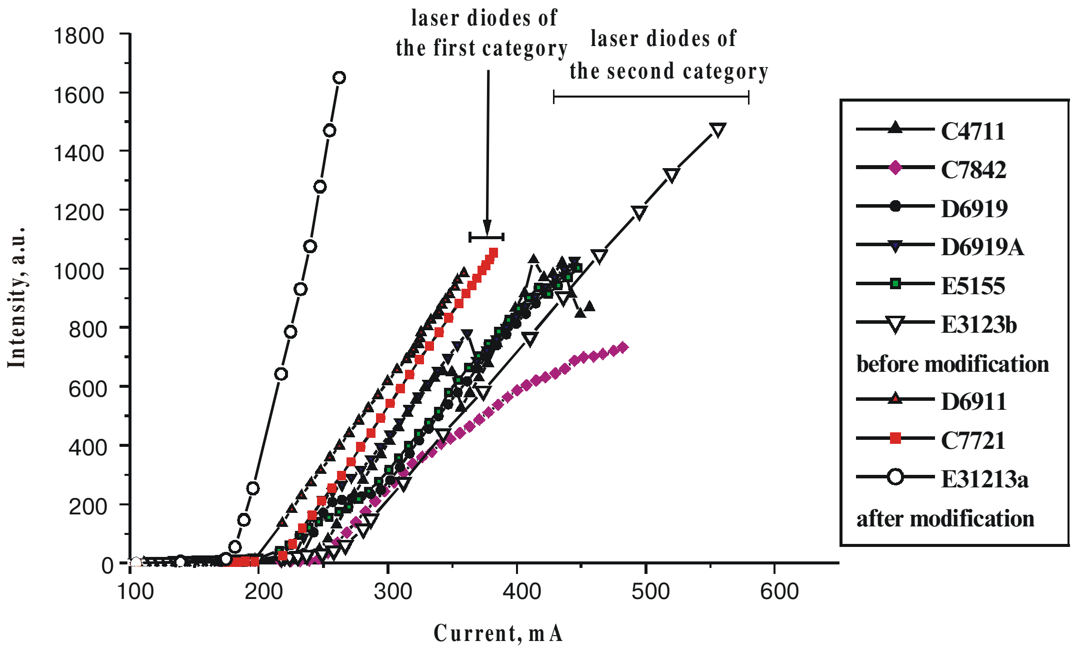

Fig. 8. The L-I Characteristics of laser diodes of the first and second category of Polaroid firm and also the L-I the characteristic of laser diode E3123 after its modification.

of the laser diodes of firm Polaroid has decreased from 43° up to 31°.

For threshold density of currents of LDs before their modification it is possible to write down [4]:

$$J_{th} = \frac{J_{ef} d}{\eta_{in}} + \left(\alpha + \frac{\ln \frac{1}{R_1 R_2}}{2L} \right) \frac{d}{\Gamma \beta \eta_{in}},$$

$$J_{th}' = \frac{J_{ef} d}{\eta_{in}} + \left(\alpha' + \frac{\ln \frac{1}{R_1 R_2}}{2L} \right) \frac{d}{\Gamma \beta \eta_{in}}$$

Here J_{th} and J_{th}' – density of threshold currents of LD before and after their modification, accordingly, α and α' – coefficients of dissipation of optical radiation in resonators of LD before and after their modification, accordingly, J_{ef} – effective density of a current, d – depth of active area, L – length of LD resonator, Γ – coefficient of optical limitation, η_{in} – internal quantum efficiency, R_1 and R_2 – coefficients of reflection of LD mirrors. Let us accept that factors of reflection of mirrors ($R_1 \approx 1$ and $R_2 \approx 0.03$) at modification do not change. That R_1 does not change as the back end-wall of the chip is not modified, and the refractive index of a forward end-wall of the chip is decreased at modification, and the changes of R_2 will be not big consequently such assumption. From here

$$\alpha' = \alpha - (J_{th} - J_{th}') \frac{\Gamma \beta \eta_{in}}{d}.$$

For an estimation α' it is used magnitudes typical for characteristics of LD: $J_{ef} = 4.3\cdot10^{-10}$ $A^{-1}\cdot m^{-1}$, $d = 0.5\cdot10^{-6}$ m^{-1}, $\eta_{in} = 0.9$, $\beta = 4\cdot10^{-10}$ $A^{-1}\cdot m^{-1}$, $\alpha = 1.2\cdot10^3$ m^{-1}, $L = 0.4\cdot10^{-3}$ m, $\Gamma = 0.8$. For the area of injection we shall accept $W\cdot L = 0.04\cdot10^{-6}$ m^2. From Figs 5, 6 $J_{th} = 9.375\cdot10^6$ $A\cdot m^{-2}$, $J_{th}' = 7.95\cdot10^6$ $A\cdot m^{-2}$ (for LDs of firm OPTO POWER Corporation) and $J_{th} = 6.45\cdot10^6$ $A\cdot m^{-2}$, $J_{th}' = 4.575\cdot10^6$ $A\cdot m^{-2}$ (for LDs of firm Polaroid). We have $\alpha' = 1.2\cdot10^3 - (9.375 - 7.95)\cdot10^6\cdot0.8\cdot4\cdot10^{-10}\cdot0.9/0.5\cdot10^{-6} = 380$ m^{-1} (for LDs of firm OPTO POWER Corporation) and $\alpha' = 1.2\cdot10^3 - (6.45 - 4.575)\cdot10^6\cdot0.8\cdot4\cdot10^{-10}\cdot0.9/0.5\cdot10^{-6} = 120$ m^{-1} (for LDs of firm Polaroid). Such small magnitude of the dissipation coefficient at the generation wavelength of the laser diode gives us the basis to assert that properties of a monocrystal have changed along all the length of the resonator. Really, before modification of the laser diode of firm OPTO POWER Corporation, the magnitude of $\alpha\cdot L$ product was equal 0.48, and after modification it became equal $\alpha'\cdot L = 0.152$; before modification of the laser diode of the firm Polaroid the magnitude of $\alpha\cdot L$ product was equal 0.48, and after modification it became equal $\alpha'\cdot L = 0.048$.

It means that modification of a monocrystal occurs, basically, through lateral sides of the laser chip. As the width of the laser chip is equal 100 microns, the size of modification depth of a monocrystal should be not less than 50 microns.

The beam divergence of the laser diode was decreased because the distribution of the refractive index in the resonator near the laser diode end-wall at the modification has changed, and it increased the effective thickness of an optical wave-guide.

4. Conclusions

1. It is described new low-temperature method of correction of basic parameters of laser diodes after its fabrication. A method is very simple, cheap and non-polluting.

2. The method has been tested on laser diodes of the firm OPTO POWER Corporation, USA, and of the firm Polaroid, USA.

3. It is shown that using this method it is possible to decrease a threshold current of laser diodes from 15 % up to 29 % and to increase slope efficiency of laser diodes by 2.33 or 3.74 times.

4. It is shown that the depth of modification of the semiconductor chip of the laser diode exceeds 50 microns.

5. The beam divergence of laser diode can be decreased with assistance of the irreversible gigantic modification.

References

1. A.M.Kamuz, P.F.Oleksenko,V.N.Kizima, and V.G.Kamuz. Irreversible Gigantic Modification of II-VI and III-V Semiconductor Optical Properties.//Opto-Electr.Rev.-1997. -V.5, N 4, -P.243-247.
2. A.M.Kamuz, P.F.Oleksenko, Y.U.Ovsyannikov, F.F.Sizov, and T.A.Dyachenko. Low-temperature photo-hydro-modification of II-VI and III-V semiconductors. //Appl. Surface Science. -1996. -V103, N 2. -P141-148.
3. A.M.Kamuz, P.F.Oleksenko,and T.A.Dyachenko. Irreversible Gigantic Modification of Semiconductor Optical Properties.//Proc.SPIE, -1996.-V.3182. -P.313-318.
4. Gowar J., Optical Communication Systems, Prentica/Hall International, 1982.