The peculiarities of spectra in high power 970 laser diodes

V V Bezotosnyi [1,2], O N Krokhin[1,2], V A Oleshchenko [2], V F Pevtsov [2], Yu M Popov,[1,2] and E A Cheshev [1,2]

[1]National Research Nuclear University MEPhI, Kashirskoe shosse 31, 115409, Moscow, Russia
[2] P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Leninsky Prospect 53, 119991, Moscow, Russia

E-mail: victorbe@sci.lebedev.ru, vvbezotosniy@mephi.ru

Abstract. We present the results of optical power, total efficiency and spectra of CW laser diodes emitting at wavelength 970 nm. Total efficiency in maximum 72 % was measured and reliable operation at 15 W CW was achieved. At the base of measured CW spectral parameters in wide range of pump currents we discuss the possible reasons of observed features in dependences of spectral envelope, spectral maximum and spectral half-width against pumping current.

1. Introduction

High-power laser diodes are still in focus of researchers and engineers who develop different types of the optoelectronic devices. The areas of their applications quickly expands in technology, navigation, medicine and other spheres of science and technique. Taking that in account the increase of reliable and maximum operating optical power and also the brightness of laser diodes becomes more and more actual [1–6]. Several research groups published the results describing the achievements of 20-25 W range CW output power. At the same time the best laser diodes available at market have about 10 W CW power in spectral range 800-1060 nm and much efforts must be applied to get commercial products with 20 W CW power. Spectral features of such devices at high power operation are not well examined and still the object of scientific and practical interest.

2. Optical power and total efficiency

The most important problem for high-power laser diodes is efficient cooling of active region of the laser crystal. To increase the output power and to receive the reliable operation we need to ensure the several important parameters under the assembling of the laser chip at heat conducting elements. First of all we need to make the heat transfer extremely uniform at heat transfer interface and also to prevent the appearance of excess thermo-elastic strain in laser crystal which appear under assembling via the difference of thermal expansion coefficients of semiconductor material and thermo-conducting heatsinks. The experimental dependence of the output optical power and total efficiency regarding the pumping current for laser chip with stripe contact width 95 μm and resonator length 4 mm is presented at figure 1.

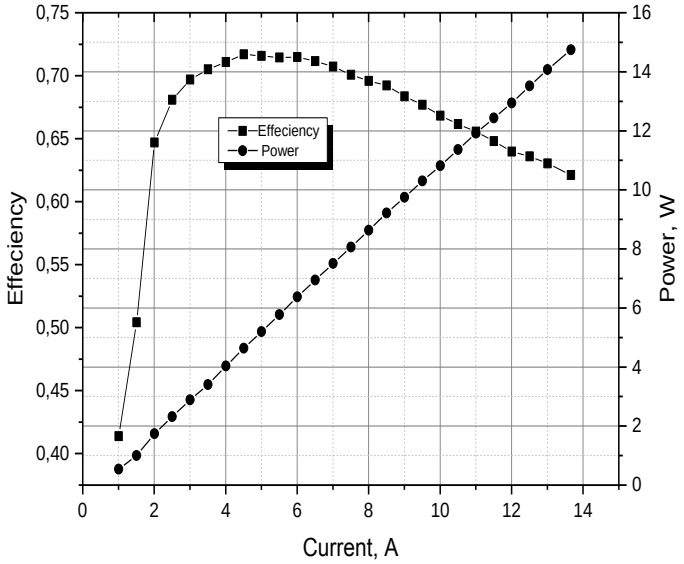

Figure 1. The dependence of output power and total efficiency regarding the pumping current for laser diode emitting at 970 nm assembled on F-mount type heat-sink in CW operation under heat-sink temperature 20 ºC.

Threshold current of laser was 0.9 A, maximum total efficiency was observed at pumping current around 5 A. Average slope of W/ A characteristic 1.12 W/A was measured in pumping current range 1.5 – 14 A. Laser operation was stable at output power 15.1 W under 120 hours without output power change inside the range of power measurement accuracy.

3. Spectral parameters

Spectral map of laser radiation is quite important for several practical applications, particularly the spectral position of spectral envelope maximum and the half- width of spectral envelope are important parameters for matching the spectra of pumping diode laser radiation with absorption spectra of solid-state active media.

The spectral parameters of high power laser diode in current range 1-13 A with 1 A step are presented at figure 2.

The important feature of spectra at figure 2 is the presence of some peculiarities at currents more than 5 A. At currents below 5 A spectral envelope is quite smooth with one maximum and slight asymmetry on the short wavelength side, particularly it have the more long tail on the envelope. By the way at 5 A we observe the maximum of total efficiency. At pumping currents more than 5 A the spectral envelope contains not only single maximum yet. At short wavelength side of the envelope we observe the new peculiarities which appears first as two and later as three competition peaks. At pumping currents more than 6 A the maximum of spectral envelope contains of 3 peaks, and with the increase of pumping current the intensity of these peaks at some currents becomes almost equal. To gain the correct knowledge regarding the appearance of such spectral peculiarities we need to conduct additional research of spacial distribution of radiation in near and far field at the lot of uniform samples.

One of the probable causes of such changes in spectral distribution of radiation with the increase of pumping current can be the spacial inhomogeneity of optical field in the plane of p-n junction associated with thermal effects at high pumping level and nonlinearity of gain medium.

As one of possible explanations we can assume that with pumping level increase the new, more complex optical field configurations can take part in laser action. That configurations may have different peak wavelengths and may more effectively consume inversion of carriers population in peripheral regions of pumped stripe contact. These different field configurations can give a contribution to total spectral envelope finally increasing the uniformity of optical field in the plane of p-n junction.

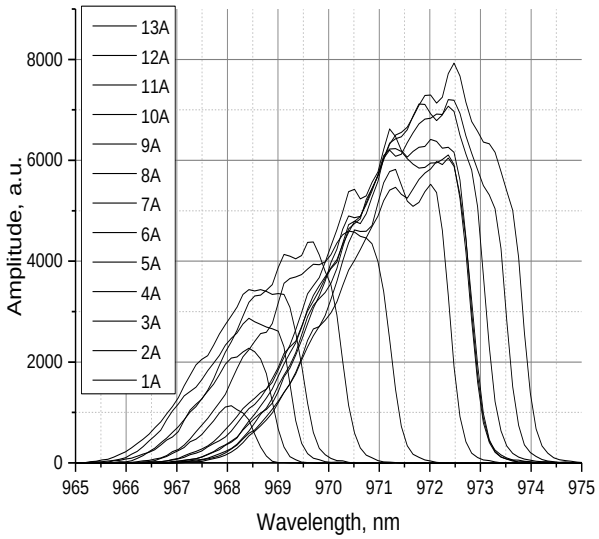

Figure 2. The spectra of laser diode emission at pumping current from 1 to 13 A.

The observed changes in spectral envelope with the increase of pumping current first appear at short wavelength side of the envelope and at higher currents are located at maximum of spectral envelope. This can be the evidence of laser action on other, more complex optical field configurations which propagate in laser resonator at different angles regarding to optical axe, so having different wavelengths as peaks on spectral envelope. The dependence of the peak wavelength of the spectral envelope against the pumping current is presented at figure 3.

At figure 3 we can resolve three typical region of pumping current in which the wavelength dependence against current can be approximated by near to linear with different slope. From threshold current up to pumping current 4 A the slope is around 0.22 nm/A, in the range 4-7 A the slope is 0.85 nm/A and in the range 7-10 A it is 0.26 nm/A. It's interesting that some correlation can be obtained according to the results of spectral envelopes presented at figure 2. Really, in first current region 1-4 A spectral slope at figure 2 has one maximum. At second region 4-7 A we can see the maximum slope of wavelength dependence against current and at the same time in this current range we observe the maximum changes of spectral envelope and formation of configuration with two and three peaks. At third region 7-10 A the slope of wavelength against current dependence is again much less comparably with the second region and close to value for the first region. This third current region corresponds to quasi-stable configuration of the spectral envelope with 3 peaks according to figure 2.

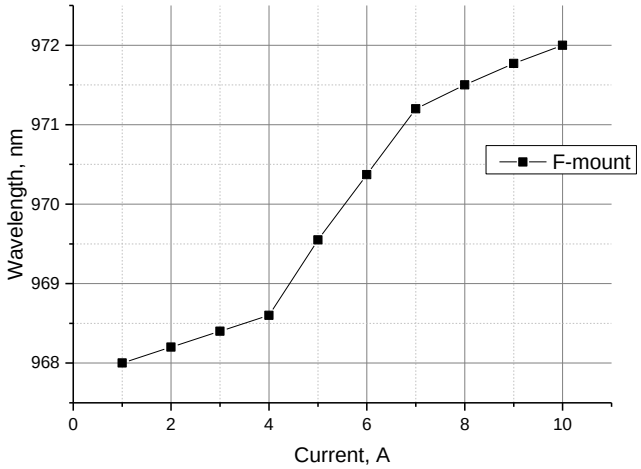

Figure 3. The dependence of the spectral envelope peak against the pumping current.

At figure 4 we present the dependence of spectral envelope half -width against the pumping current.

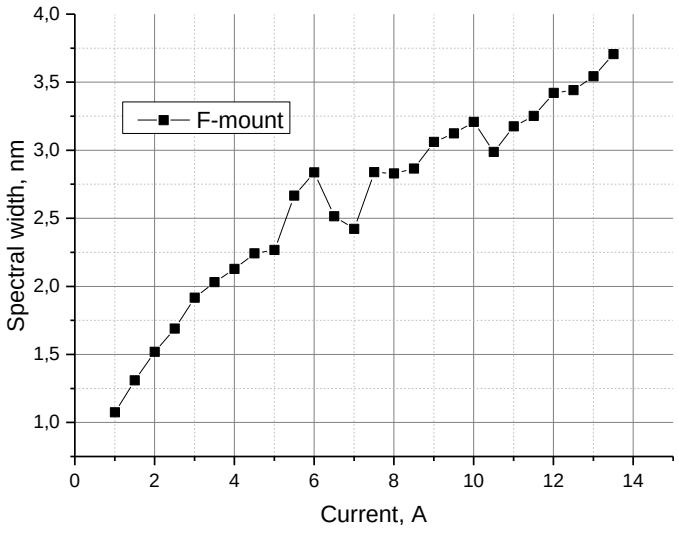

Figure 4. The dependence of spectral envelope half -width against the pumping current.

At this graph we can also conventionally see three regions of pumping current 1-5 A, 5-10 A and 10-14 A. We can also find some correlation with graphs at figure 2 and figure 3. The most smooth is the region from threshold current up to 5 A, and some signs of a slowdown at currents from 3 to 5 A are obvious which can be the evidence of some optical field transformation inside the stripe contact width. For current region from 5 to 10.5 A we see the most serious changes in spectral width which can be the evidence of non-stable optical field distribution. And the last region is more smooth than

the second region but less smooth than the first region. This in principle correlates with the spectral envelopes at figure 2. At currents more than 10 A after formation of 3 peaks the spectra with 3 peaks configuration can say becomes quasi-stable.

4. Conclusions

We investigated the optical output power, total efficiency and spectra of two samples of laser diodes assembled in our laboratory on F-mounts with stripe width 95 μm and resonator length 4 mm. Reliable operation with output power 15.1 W under CW conditions was confirmed by testing during 120 hours. Total efficiency in maximum was 72 %, average slope efficiency of W/A characteristic was 1.12 W/A in current range up to 14 A. Some peculiarities in spectral envelope under high current pumping were observed and possible explanation discussed in correlation with the dependences of spectral envelope maximum and its half width against pumping current. More detailed information can be obtained from the results of far field and near field measurements at wide range of pumping current on uniform lot of samples to clear the matter and get reliable knowledge for practical use of such high-power laser diodes at extremely high power and pumping level around 10 -20 times more than the threshold current.

Acknowledgements

This work was carried at National Research Nuclear University MEPhI and supported by the Russian Federation Ministry of Education and Science, Agreement No. 14.575.21.0047, unique identifier of applied scientific research (project) RFMEFI57514X047.

References

[1] Crump P *et al* 2012 *Proc. of SPIE* **7198** 719814-1
[2] Sin Yongkun, LaLumondiere Stephen D, Presser Nathan, Foran Brendan J, Ives Neil A Lotshaw William T and Moss Steven C 2012 *Proc. of SPIE* **8241** 824116-1
[3] Vinokurov D A *et al* 2006 *Fiz. Tekh. Poluprovodn*. **40**(6) 764
[4] Bezotosnyi V V, Krokhin O N, Oleshchenko V A, Pevtsov V F, Popov Yu M and Cheshev E A 2015 *Quantum Electronics* **45**(12) 1088–90
[5] Bezotosnyi V V, Krokhin O N, Oleshchenko V A, Pevtsov V F, Popov Yu M and Cheshev E A 2014 *Quantum Electronics* **44**(2) 145–8
[6] Bezotosnyi V V, Krokhin O N, Oleshchenko V A, Pevtsov V F, Popov Yu M and Cheshev E A 2014 *Quantum Electronics* **44**(10) 899–902