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Wavelength stabilized laser module for high-power fiber laser pumping

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Abstract. The paper presents the results of development of wavelength stabilized laser modules where wavelength stabilization is achieved due to volume Bragg gratings with a 976 nm operating wavelength. The module was designed to spatially combine the light from six high-power laser diodes with its subsequent coupling into a silica fiber with a core diameter of 105 μm and a numerical aperture of 0.15. Stabilization scheme was realized, where volume Bragg gratings were placed behind the lenses used for light collimation along the slow axis. Laser diode performance was studied for volume Bragg gratings with different reflectivity factors. The measurement results were used to determine optimum reflectivity of volume Bragg gratings; the spectral and power characteristics of the manufactured laser module were measured. The volume Bragg gratings allowed for significant, down to 0.5 nm, narrowing of the laser module spectrum width and wavelength stabilization over the entire range of operating currents. In continuous mode, the manufactured laser module power reached 43.6 W at a pumping current of 10 A and a thermal stabilization temperature of 25°C.

Keywords: high-power laser diodes, volume Bragg grating, volume holographic grating, wavelength stabilization

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Материалы конференции
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Лазерный модуль со стабилизацией длины волны излучения для накачки мощных волоконных лазеров

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Аннотация. В работе представлены результаты разработки лазерных модулей со стабилизацией длины волны излучения с помощью объемных брэгговских решеток с рабочей длиной волны 976 нм. В качестве модуля накачки использовался лазерный модуль с пространственным объединением излучения шести мощных лазерных диодов с последующим вводом в кварц-кварцевое волокно с диаметром сердцевины 105 мкм и числовой апертурой 0,15. Проведены исследования характеристик лазерных диодов при использовании объемных брэгговских решеток с различными коэффициентами отражения, определен оптимальный коэффициент отражения объемных брэгговских решеток, измерены спектральные и мощностные характеристики изготовленного лазерного модуля. Ширина спектральной линии излучения лазерного модуля составила 0,5 нм, стабилизация длины волны излучения наблюдалась во всем диапазоне рабочих токов. Мощность изготовленного лазерного модуля составила 43,6 Вт в непрерывном режиме работы при токе накачки 10 А и температуре термостабилизации 25°C.

Ключевые слова: мощные лазерные диоды, объемная брэгговская решетка, стабилизация длины волны

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Introduction

Laser modules (LMs) based on high-power laser diodes (LDs) used to be a conventional source for high-power fiber laser pumping [1–3]. One of the most important LM characteristics is its pumping efficiency determined, among other factors, by spectral characteristics of the LM used. For pumping the ytterbium fiber lasers, LMs with spectral ranges of 915 nm, 940 nm, and 976 nm are used, while the latter are of the greatest interest as this spectral range corresponds to the absorption peak of ytterbium-doped fibers having maximum absorption coefficient [4]. At the same time, the width of the fiber absorption peak in this region is rather narrow, which imposes certain restrictions on the pump modules used since the spectral width of high-power LDs can reach several nanometers and the typical temperature shift of the lasing wavelength is 0.3 nm/°C [5, 6]. One of the ways to improve the LM spectral characteristics is to use an additional optical element as an output mirror of the LD external resonator. As for LMs that are commercially available nowadays, the most popular schemes are those where this additional optical element is represented by volume Bragg gratings, or volume holographic gratings, that are easy to operate and have smallest dimension, if compared to other schemes [6–8]. Spectral width of LD can be narrowed to less than 0.5 nm and the temperature drift of wavelength can be reduced to 0.01 nm/°C [4].

LD wavelength stabilization using volume Bragg gratings

Volume Bragg gratings (VBGs) are the optical elements with a periodic change in the refractive index, that can fully or partially reflect the incident radiation. The principle of radiation wavelength stabilization with the help of VBG is based on the placement of this element on the laser beam path so that part of the radiation returns to the LD's resonator. Under certain conditions, this feedback suppresses the generation of neighboring longitudinal modes of LD's own resonator, radiation is generated only at the VBG operating wavelength, and the width of the LD spectral line narrows to a value corresponding to the spectral width of the VBG reflection [9]. The extension of range of operating currents and temperatures for which wavelength stabilization is observed is achieved in two ways, namely, by increasing the portion of radiation that returns to the LD resonator and reducing the reflectivity of AR-coating of the LD output facet [10]. In order to increase the portion of feedback, VBG is usually placed behind the optical elements used for the LD light collimation. At that, schemes are common, in which VBGs are mounted both behind the lenses for collimating the LD light divergence along the fast axis [11], and behind the lenses for collimating the divergence of light along the slow axis [7]. Besides, there are schemes where the periodic structure of the refractive index is integrated directly into the lens for collimation of light along the fast axis, which combines the properties of both the VBG and the collimating lens. Though easy to operate and adjust, these optical elements have certain disadvantages, such as significant exceedance of the spectral width of the stabilized LDs compared to that of the VBG reflection [12].

In this work, basic design version of a self-developed LM was used [13], whose optical scheme is designed to spatially combine the radiation from several LDs with its subsequent coupling into a silica fiber with a core diameter of 105 μm and a numerical aperture of 0.15. This LM design allowed for installation of the VBG onto the surface area of a heatsink between the lenses used for collimation of light divergence along the slow axis and the rotary mirrors. Multimode broad area single emitter LDs with the emitter width of 94 μm and the cavity length of 3.6 mm were used as the LM radiation sources. Output facet reflectivity of LDs was less than 0.1%, the LD wavelength corresponded to the range of (965 – 968.5) nm at a pumping current of 1 A and a thermal stabilization temperature of 25°C. The LD spectral width was (4–6) nm and the average pumping current shift of wavelength amounted to 1 nm/A (Figure 1).

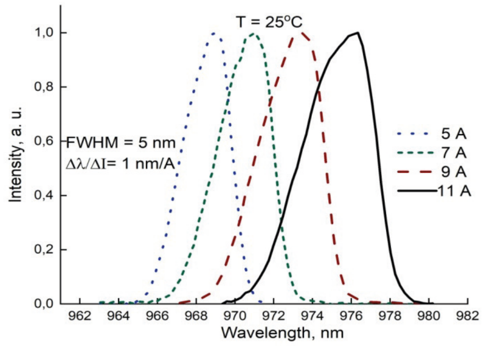

Fig. 1. LD spectrum vs. current

To stabilize the LD wavelength, the VBGs with characteristics presented in Table 1 were used.

Table 1

Spectral characteristics of VBG

Parameter	Value
Wavelength, nm	976 ± 0.5
Reflectivity, %	8;10;12
Spectral width, nm	0.5
AR-Coating	0.5
Thickness, mm	0.7

Experimental results

As a part of this work, we studied the possibility to manufacture an LM with a spectral range of 976 nm and a power of more than 40 W when wavelength is stabilized over the entire range of LM operating currents, i.e. from 1 A to 10 A. As noted above, one of the ways to increase the stabilization range is to use the VBG with a high reflectivity factor. In this work, to stabilize the LD wavelength, the VBGs with reflectivity factors (8–12)% were used. Figure 2 shows the change in the LD's power vs. current characteristic depending on the reflectivity of the VBG used to stabilize the wavelength.

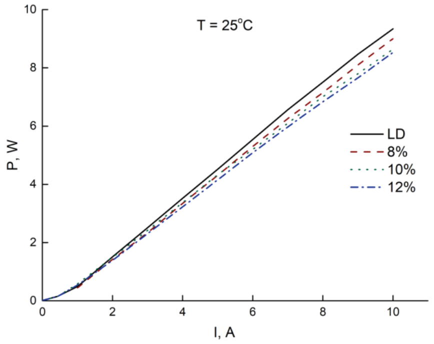

Fig.2. LD's power vs. current curve for VBGs with different reflectivity factors

As can be seen from Figure 2, an increase in the VBG reflectivity leads to a decrease in the slope of the curve. Besides, the use of a high-reflectivity VBG increases the probability of LD failure at maximum pumping current [14, 15]. Thus, the task of determining the optimal characteristics of VBG can be reduced to finding the lowest reflectivity of VBG, at which wavelength stabilization is observed over the entire range of LM operating currents. The VBG was aligned by angular rotation in the direction of the fast and slow axes of the LD while continuously recording the LD spectrum. Figure 3, *a*, *b*, *c* shows the LD spectral data recorded after the mounting of VBG with reflectivity R = 8%.

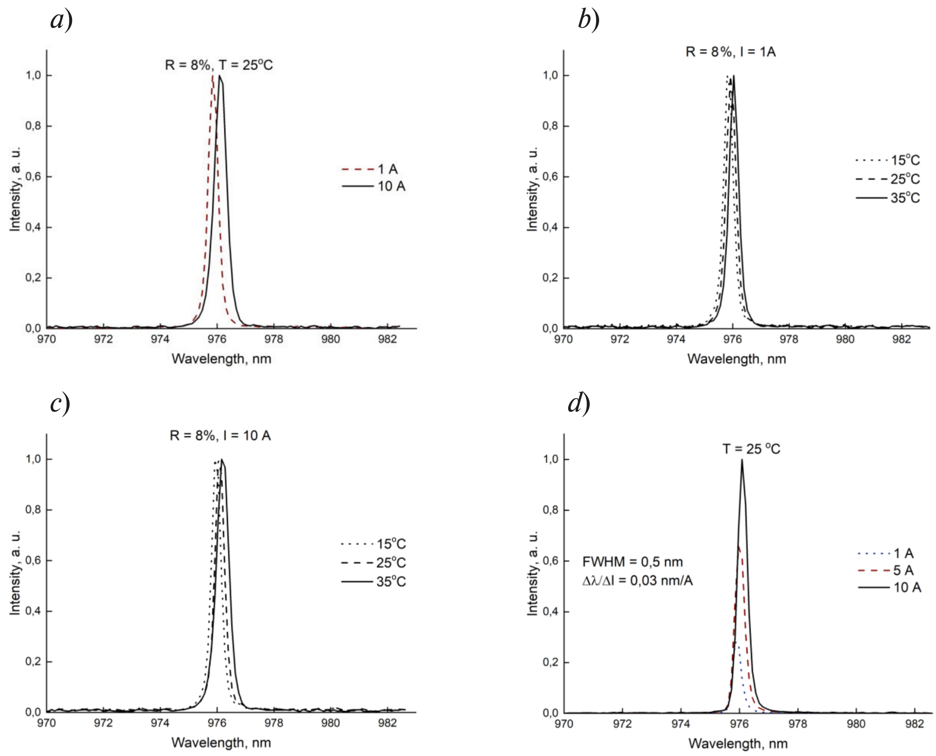

Fig. 3. LD spectrum vs. current (*a*); LD spectrum vs. temperature at 1 A (*b*); LD spectrum vs. temperature at 10 A (*c*); LM spectrum vs. current (*d*)

It can be seen from Figure 3 that wavelength stabilization was observed at all LD's operating currents in the temperature range from 15°C to 35°C. It should be noted that similar results have been achieved for VBG with reflectivity factors of 10% and 12%. Additionally, the generation of the second peak of radiation with a wavelength corresponding to that of the LD was observed only in the case of insufficiently accurate VBG alignment, and angular displacement of VBG in the direction of the fast axis turned out to be most sensitive to misalignment. Since VBGs with lower reflectivity factor are more preferable from the perspective of long life and maximum power of the LM, the VBGs with reflectivity of ~ 8% were chosen to be used in the experimental prototype LMs. To minimize displacement during its installation, the VBG was fixed to the base using a low-shrinkage UV-curable adhesive. The LM spectrum is shown in Figure 3, *d* and its power verses current curve is given in Figure 4. Maximum radiation power of the LMs manufactured was 43.6 W in continuous mode of operation at a current of 10 A and a thermal stabilization temperature of 25°C. Wavelength stabilization was observed at all operating currents of the LM.

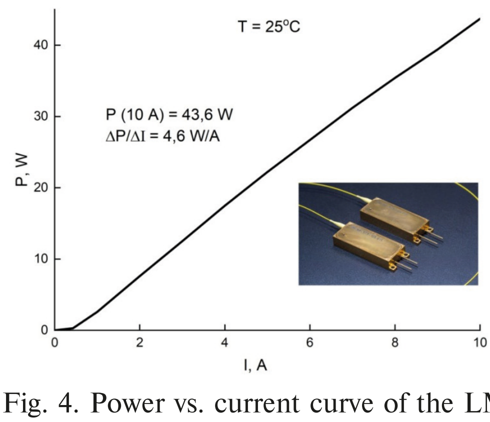

Fig. 4. Power vs. current curve of the LM

Conclusion

Wavelength stabilized LM of ~44 W was designed and manufactured, where wavelength stabilization is realized in continuous mode of operation at a pumping current of 10 A and a thermal stabilization temperature of 25°C. For the LDs with output facet reflectivity less than 0.1%, the VBG with reflectivity of ~8% was demonstrated to be an optimal choice to achieve wavelength stabilization over the entire range of LM operating currents, provided that the VBG is properly aligned and installed. Due to the use of VBG, the LM spectral width narrowed to 0.5 nm and the pumping current shift of wavelength decreased to ~0.03 nm/A.

REFERENCES

1. **Haag M., Kohler B., Bicsenbach J., Brand T.,** Novel high-brightness diode laser device, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications V. Vol. 6546 (64560T) (2007).
2. **Wessling C., Hengesbach St., Geiger J., Dolkemeyer J., Traub M., Hoffman D.,** 50 W passively cooled, fiber coupled diode laser at 976 nm for pumping fiber lasers using 100 μm fiber bundles, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications VI, Vol. 6876 (687614) (2008).
3. **Kelemen M., Gilly J., Friedmann P., Hilzensauer S., Ogrodowski I., Kissel H., Biesenbach J.,** Diode lasers optimized in brightness for fiber laser pumping, In: Proceedings of SPIE. High-Power Diode Laser Technology XVI, Vol. (10514) (105140F) (2018).
4. **Kohler B., Brand T., Haag M.,** Wavelength stabilized high-power diode laser modules, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications VII, Vol. 7198 (719810) (2009).
5. **Samson B., Frith G.,** Diode pump requirements for high power fiber lasers, In: International Congress on Applications of Lasers & Electro-Optics, Paper 501 (2007) 228–233.
6. **Volodin B., Dolgy S., Melnik E., Downs E., Shaw J., Ban V.,** Wavelength stabilization and spectrum narrowing of high-power multimode laser diodes and arrays by use of volume Bragg gratings, Optic Letters, Vol. 29, Issue 16 (2004) 1891–1893.
7. **Xu D., Ma D., Yu Z., Xu L., Chen X.,** Kilowatt wavelength-stabilized CW and QCW diode laser, In: Proceedings of SPIE. High-Power Diode Laser Technology XVIII, Vol. 11262 (112620C) (2020).
8. **Venus G., Smirnov V., Glebov L.,** Spectral stabilization of laser diodes by external Bragg resonator, In: Solid State Diode Lasers Technol. Rev. (2004).
9. **Gapontsev V., Moshegov N., Trubenko P., Komissarov A.,** etc. High-brightness 9XX-nm pumps with wavelength stabilization, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications VIII, Vol. 7583 (75830A) (2010).
10. **Volodin B., Dolgy S., Melnik E., Downs E., Shaw J., Ban V.,** Performance enhancement of the high-power laser diodes and arrays by use of the volume Bragg grating technology, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications III, Vol. 5711 (2005).
11. **Steckman G., Liu W., Platz R.,** Volume Holographic Wavelength Stabilized Laser Diodes. IEEE Journal of selected topics in quantum electronics, Vol. 13 (3) (2007) 672–678.
12. **Hengesbacha S., Witteb U., Traubb M., Hoffmann D.,** Simulation and analysis of volume holographic gratings integrated in collimation optics for wavelength stabilization, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications IX, Vol. 7918 (79180 A) (2011).
13. **Fomin A. V., Usmanov S. R., Ignatev A. N., Kadigrob E. V.,** Fiber coupled laser module with brightness exceeding 10 MW/cm2·sr, Technical Physics. 4 (92) (2022) 616–619.
14. **Takiguchi Y., Asatsuma T., Hirata S.,** Effect of the threshold reduction on a catastrophic optical mirror damage in broad-area semiconductor lasers with optical feedback. In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications IV, Vol. 6104 (61040X) (2006).
15. **Leonhäuser B., Kissel H., Unger A., Köhler B., Biesenbach J.,** Feedback-induced catastrophic optical mirror damage (COMD) on 976 nm broad area single emitters with different AR reflectivity, In: Proceedings of SPIE. High-Power Diode Laser Technology and Applications XII, Vol. 8965 (896506) (2014).

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