DIODE-PUMPED SOLID-STATE ZIGZAG SLAB-LASERS

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Abstract*. We have considered the advantages of diode pumping of solid-state lasers with high-performance active medium. The article describes the design features of solid-state zigzag lasers based on a flat truncated prism. We have identified the range of the angles under which zigzag laser with small output beam transverse size can be obtained that significantly increases the output power density. It was shown that the diode pumping system well combines with the zigzag geometry of the solid laser based on the flat truncated prism.*

Keywords: diode pumping, active medium, solid-state laser, zigzag laser, three-mirror resonator

LASERY PASKOWE TYPU ZYGZAK POMPOWANE DIODAMI

Streszczenie*: Rozważono zalety laserów półprzewodnikowych o wysokosprawnym ośrodku aktywnym, pompowanych diodami. Artykuł opisuje cechy konstrukcyjne laserów na ciele stałym typu zygzak w formie płaskiego graniastosłupa ściętego. Zidentyfikowaliśmy zakres kątów, w których może być otrzymany laser typu zygzak o małym przekroju poprzecznym wiązki wyjściowej, co znacznie zwiększa gęstość mocy wyjściowej. Wykazaliśmy, że diodowy system pompowania dobrze łączy się z laserem typu zygzak w formie płaskiego graniastosłupa ściętego.*

Słowa kluczowe: pompowanie diodami, medium aktywne, laser półprzewodnikowy, laser zygzak, rezonator trójodbiciowy

Introduction

Solid-state lasers are the most versatile sources of coherent radiation among all laser systems because of the ability to vary within a wide range of output power characteristics such as average and peak power, duration and repetition rate, wavelength of radiation [2]. Crystals or glasses doped with rare-earth ions (Nd^{3+}, Er^{3+}, Ho^{3+}, Ce^{3+}, Tm^{3+}, Pr^{3+}, Gd^{3+}, Eu^{3+}, Yb^{3+}, Sm^{2+}, Dy^{3+}, Tm^{2+}) are frequently used as an active media [1, 2]. Population inversion in solid-state lasers is created by optical pumping flash lamps, arc lamps and solid state pump sources [2]. Performance enhancements of solid-state lasers can be achieved by using highly effective active elements (AE), the pumping system and laser cavity design improvements.

1. Solid-state lasers in the zigzag form of a flat truncated prism

Reducing overall dimensions and improving the efficiency of solid-state laser systems can be achieved in lasers with an active element in the form of a flat truncated prism and a zigzag course of an optical beam in the three-mirror cavity (zigzag laser) (Fig. 1) [4, 5].

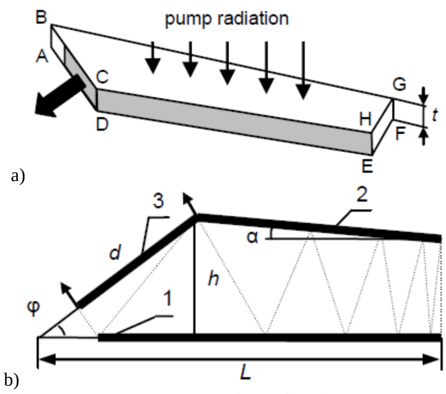

Fig. 1. – Laser with an active element in the form of the flat truncated prism (a) and the optical system of the three-mirror laser cavity (b): 1 and 2 – highly reflective mirrors, 3 – output mirror

Zigzag laser with an active element in the form of the flat truncated prism are hi-tech. AE carved out from crystals or glass and treated accordingly. *BCHG* face of the active element is used to pump the active media (Fig. 1) and on the *ADEF* face highly reflecting coating at the wavelength of the pump radiation from the laser diodes bars and arrays is applied [6]. The use of additional mirrors on the *ADEF* face of the zigzag laser active element can reflect not absorbed in the active element part of the pump radiation for subsequent absorption during propagation in the opposite direction. According to Bouguer law, with a constant coefficient of resonant absorption α_{abs} at the pump wavelength and the harmful losses ratio ρ on various kinds of inhomogeneities of the active medium, changing the energy flow over the length z is given by:

$$I = I_0 \exp[-(\alpha_{abs} + \rho)z], \quad (1)$$

where I_0 – initial value of the stream. According to (1) Fig. 2 shows the distribution of the absorbed power of the pump I_{abs} over the thickness t of the solid-state zigzag laser active element for the active medium Nd:YAG with the parameters $\alpha_{abs} = 12$ cm^{-1}, $\rho = 0{,}1$ cm^{-1} for diode-pumping from GaAlAs laser diode arrays with the value of the output power continuous radiation $I_0 = 40$ watts.

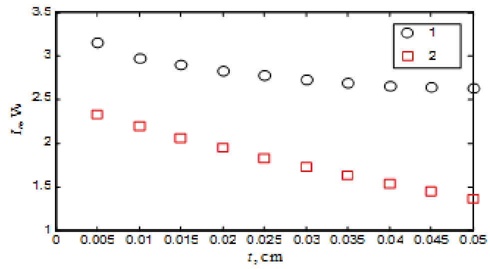

Fig. 2. – The distribution of the absorbed power I_{abs} from the pumping source with I_0 = 40 watts over the active element thickness for the construction with t = 0,05 cm: 1 – with an extra mirror on the ADEF face with reflectance r = 0,998; 2 – without a mirror on the ADEF face

For the AE with thickness $t = 0{,}05$ cm with highly reflecting coating on the face *ADEF* the inhomogeneity of the absorbed radiation power I_{abs} distribution, defined by $\beta = \frac{I_{abs\,max} - I_{abs\,min}}{I_{abs\,max}}$ with $I_{abs\,max}$ and $I_{abs\,min}$ - respectively the minimum and maximum absorbed power, is less than $\beta = 0{,}25$ and in the absence of the mirror on the *ADEF* face $\beta = 0{,}41$. The absorption efficiency η of the pump power, defined as the part of the energy absorbed in the active medium for the AE thickness $t = 0{,}05$ cm with coating on the *ADEF* face is η = 69,5% and in the absence of mirror η = 42,59%. Consequently, the use of additional mirror on the *ADEF* face of the solid-state zigzag laser active element can reduce the absorbed power distribution inhomogeneity over the AE thickness and increase the pump radiation absorption efficiency in the active element.

Three-mirror optical cavity of the zigzag laser in form of the flat truncated prism is formed by mirrors *1*, *2* and *3* which partially or fully cover the *ABGF*, *CDEH* and *ABCD* faces respectively (Fig.1b). Highly reflecting mirrors *1* and *2* are arranged at a small angle α and provide a zigzag course of radiation in the cavity. Output mirror *3* forms an angle φ with the mirror *2*. The number of possible reflections of an optical beam in such a system is defined as $N = 1 + \varphi / \alpha$. Hence it is easy to get the requirement imposed on the angles α and φ of the flat truncated prism: $\varphi \geq \alpha$

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and $\varphi / \alpha = n$, where n is integer. With the values of the angle $0{,}1° \le \varphi \le 30°$ the width of the output mirror *3*, and thus the beam width of the output radiation d is less than the transverse (height h) and longitudinal (length L) size of the AE. When the propagation of the laser beam is almost orthogonal to the axis of the crystal the length of the trajectory l of radiation single pass in this cavity is much greater than the length L. This can de achieved at high values of the number of reflections N obtained at $0{,}1° \le \alpha \le 5°$ and $0{,}1° \le \varphi \le 45°$. Thus, for the values of the angles $0{,}1° \le \varphi \le 30°$ and $0{,}1° \le \alpha \le 5°$ structure of the laser is characterized by a high ratio of l/L, small output radiation aperture and compact size.

2. Diode pumped solid state lasers

The most effective solid-state lasers pumping sources are the light-emitting diodes (LEDs) or laser diodes [1, 2]. Semiconductor laser diodes from practical point of view have a number of merits: efficiency, low inertia, compactness, simplicity of the device, high reliability and can easily rebuild the emission wavelength by changing the composition of the semiconductor component. For output power increasing the semiconductor lasers or LEDs are grouped into one-dimensional bars, or two-dimensional arrays. As a result, the output power of continuous radiation from one-centimeter length of laser diodes bar is 50 W/cm with an efficiency of about 40 – 50 % (Fig. 3) [1].

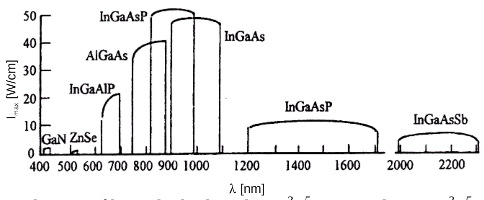

Fig. 3. Spectral range of laser diodes based on A^3B^5 semiconductors A^3B^5 and the corresponding maximum power

Note that the pump system in the form of arrays or bars of semiconductor light sources combines well with a planar geometry of the zigzag laser in form on the flat truncated prism.

Solid-state diode-pumped lasers have many advantages compared to solid-state lasers with lamp pumping. First of all it is associated with high directivity and small size of the emitting region of diode compared to lamp pump sources, which lead to creating a compact laser system. In addition to increased pumping efficiency, as compared to the flash lamp, semiconductor sources have a narrow emission spectral band, which can provide almost perfect alignment of the emission spectra with narrow absorption bands of the active substance. Full compliance with the absorption of the active medium and emitting spectrum of LEDs and laser diodes can minimize the input energy spent on heating and thus reduce the influence of thermo-optic effects on output radiation beam quality [2]. Durability and reliability of solid-state diode-pumped lasers is much higher than that of lamp-pumped systems, as an array of laser diodes have lifetimes of about 10^4 hours in continuous mode and generate about 10^9 pulses, and a flash unit can generate 10^8 pulses and operate continuously for 500 hours [2]. Thus, solid-state diode-pumped lasers are characterized by high efficiency (> 10%), long lifetime and better stability of the radiation.

3. Laser active media

Most solid-state laser emits in the spectral range from 400 nm to 3 microns [2]. For the active element of solid-state lasers the most effective are crystals or glasses doped with rare earths ions such as Nd^{3+}, Er^{3+}, Yb^{3+}.

The most common classic laser, emitting in the near infrared (1.064) is a laser based on YAG with neodymium $Nd^{3+}{:}Y_3Al_5O_{12}$ (Nd:YAG). The absorption spectrum of Nd^{3+} has a broad band at a wavelength of ~ 0.8 microns, and a perfect matching of the absorption spectrum of Nd^{3+} ions and radiation $Ga_{1-x}Al_xAs$–matrix is possible (Fig. 3). YAG crystal is transparent over a wide spectral range (0.2–5 microns), mechanically robust, have high thermal conductivity. Highly effective active medias doped with neodymium ions are $Nd^{3+}{:}YVO_4$ и $Nd^{3+}{:}LiYF_4$ crystals [2].

Solid-state lasers with Er^{3+} ions are of great interest due to the generation in secure for eyes areas of the spectrum (1.54 micron and 2.9 micron) [2]. The absorption spectrum of Er^{3+} ions lie at ~ 0.97 microns. The diode-pumped crystals of YAG, highly dopped with Er^{3+} ions (50%), generate at the 2.9 micron with an efficiency around 4–5%. Lasers based on Yb:YAG generate by three-level scheme at 1.03 mm [2]. Yb^{3+} ions have a single but strong absorption band in the 0.9 – 1.02 microns. Intense absorption lines of Yb^{3+} can be used effectively for laser diode pumping near 0.98 micron radiation by InGaAs-matrix (Fig. 3).

4. Conclusion

Solid-state zigzag lasers based on the flat truncated prism with diode pumping are of practical interest because of the possibility of increasing compactness and efficiency of conversion the input energy into radiation. The use of diode pumping can increase the efficiency, stability and reliability of the laser system. The application of coating on the face opposite to the one through which the pumping from the arrays of laser diodes is realized provides a more uniform pumping throughout the volume of the pump and increases its efficiency. Glasses or crystals with rare-earth ions Nd^{3+}, Er^{3+}, Yb^{3+} can be used as an active media providing the generation at wavelengths that are widely used in various applications.

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