Tunable near infrared laser

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Abstract. The article introduces a tunable NIR laser. The tuning process realizes by the dispersion elements placed inside the resonator. Energy parameters depending on the laser operating mode are presented. The possibility of smooth tuning of the fundamental lasing wavelength depending on the rotation parameters of the dispersion element is shown.

The development of medical technologies, materials processing technologies requires the development and creation of new sources of powerful radiation with specific parameters. One of the lasers that can change parameters without significantly changing their design are lasers with the ability to tune the fundamental wavelength. A unique tunable material is the synthetic alexandrite medium, which is capable of operating in both continuous and pulsed modes.

The use of a synthetic alexandrite crystal (BeAl2O4:Cr³⁺) as an active gain medium allows creating a tunable laser in the range of 700 - 850 nm [1, 2]. The wide absorption spectrum of alexandrite allows using laser diodes, flash lamps, or use the double frequency of Nd:YAG lasers as pump sources.

Fine tuning of the fundamental wavelength of the generated radiation is carried out by additional placing of dispersive elements into the resonator. Such elements are birefringent filters and prisms. A dispersive element leads to frequency-selective losses in the resonator, i.e. the conditions for generating modes become different. Thus, there is an effective limitation of the spectral band of the generated radiation. The narrowing of the radiation spectrum occurs due to the deterioration of the Q-factor of the cavity [2].

To determine the length of the resonator, it is necessary to take into account the phase incursion of an electromagnetic wave that bypasses the distance between the resonator mirrors. It is necessary to provide a phase condition for generation, in which the electromagnetic wave was successively reflected from two mirrors and added in phase. This condition provides maximum output, preventing the successively amplifying signal from getting out of phase. The optimal length is determined by an integer number of half-waves that fit between the resonator mirrors:

\[ L_{avg} = n \cdot \frac{\lambda}{2}, \]

where \( n \) – integer; \( \lambda \) – radiation wavelength.

At a central generation wavelength of the alexandrite laser of ~ 750 nm, the optimal cavity length is in the range from 573 to 611 mm with a step of 1 mm.

The power transmission of the resonator at each frequency is determined by the magnification of the transmission coefficients of the intracavity elements and the reflectivity of the mirrors. The spectral
transmission profile of a selective resonator depends on the dispersion element, due to losses produced by other optical elements are non-selective and affect power losses.

We have taken the optimal resonator length of 600 mm and determined the resonant frequencies of the generated radiation.

\[ \nu = n \cdot \left( \frac{c}{2 \cdot L_{avg}} \right) = 3.7 \cdot 10^{16} \text{ Hz} \]

According to the optimal cavity length, the reflection coefficient of the output mirror was determined by the equation:

\[ R_{avg} = \exp \left[ -2 \cdot L_{avg} \cdot \left( \sqrt{x \cdot \eta} - \eta \right) \right]. \]

To determine the Q-factor of the resonator, we have calculated the photon lifetime:

\[ \tau_c = \frac{-2 \cdot L_{avr}}{c \cdot \ln (R1 \cdot R2)}, \]

where R1 and R2 – reflecting coefficients of high-reflecting and output coupler mirrors; c – light speed.

The reflecting coefficient of high-reflecting mirror is equal to 1, and output coupler 0.75. Using the equation, the calculated photon lifetime in the cavity results in 28 ns.

The Q-factor of the resonator as the magnification of the resonant frequency, according to the phase changing and lifetime of the photon in the resonator:

\[ Q = 2\pi \cdot \nu \cdot \tau_c = 6 \cdot 10^9. \]

The obtained value of the Q-factor of the resonator explains that the loss of electromagnetic wave energy per one pass of the resonator is minimal.

According to the calculations the optical scheme of the resonator of a tunable alexandrite laser can be divided into different groups: prismatic dispersive resonators, dispersive resonators with diffraction gratings, and dispersive resonators with birefringent filters. The main advantages and disadvantages of dispersive resonators with prisms and diffraction gratings described in [2].

The article describes a resonator with a birefringent filter, which is placed between laser mirrors. The scheme of the considered resonator is presented in Figure 1.

Fig. 1. Optical scheme of solid-state laser: OC - output coupler mirror, BF - birefringent filter located at a Brewster angle (BA°), AR - ends of the rod with an antireflection coating, HR - high reflective mirror.

The optimal length of the resonator was chosen according to the conditions of the experiment. A birefringent filter must be placed in the resonator, but it would also be possible to use adjustment elements for fine tuning and use commercially available quantrons. The adjusting mechanisms and the birefringent filter were placed inside the cavity at the Brewster angle to the optical axis.

To realize the research and experimental work, a laboratory prototype of a pulsed lamp-pumped tunable laser was developed [3, 4].

The laser was operated at a pump pulse repetition rate of 1 to 10 Hz at a fundamental wavelength of 750 nm. Figure 2 shows the energy characteristics.
Fig. 2. The average power of laser radiation depending on the pulse repetition rate.

The detection of spectral and temporal characteristics have realized by recording diffusely reflected laser radiation with the spectrometer Ocean Optics HR4000 and the photodetector Avesta OD-08A. The radiation spectrum width have not exceeded 1.5 nm (Fig. 3).

Fig. 3. The central wavelength of the alexandrite laser.
The installing and adjusting of the dispersion element (birefringent filter) allow to smooth tune the radiation spectrum in the range of ~ 735 - 770 nm. The dynamics of the tunable spectrum of laser radiation is shown in Figure 4.

Fig. 4. The tuning of the fundamental wavelength depending on the position of the dispersive element.

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