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Single-frequency hybrid laser with an output power up to 3 W at a wavelength of 1064 nm

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Abstract. **A high-power single-frequency laser with an output power of 2.5 W in the cw regime at a wavelength of 1064 nm has been developed using a hybrid scheme based on a master single-frequency semiconductor laser (wavelength 1064 nm, lasing linewidth less than 3 MHz) and a two-cascade fibre amplifier pumped by high-power laser diodes. At pump powers of 4.8 W in the first cascade and 6.8 W in the second cascade the total gain is about 100.**

Keywords: *single-frequency semiconductor laser, fibre amplifier, diode pumping.*

1. Introduction

A modern tendency in the development of solid-state (in particular, fibre) lasers is to increase their output power. The main factor limiting the output power of fibre lasers is the influence of nonlinear effects: stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), etc. As a result, the maximum power of fibre lasers with a beam quality factor close to unity is limited by a value of ~1 kW. To obtain high power densities, it is proposed to sum coherently radiations from several sources [1, 2].

To this end, it is necessary to develop and implement a high-power single-frequency master oscillator, providing a sufficient coherence length. A generally accepted approach is to use a narrow-band master oscillator and several cascades of fibre amplifiers [3–5]. In most studies a single-frequency fibre laser with lasing linewidth of ~10 kHz was used as a master oscillator. One of the main drawbacks of these lasers is the high sensitivity of their radiation frequency to external effects. Their active medium is generally an ytterbium-doped double-clad fibre; therefore, specialised multiplexers must be used to implement pumping.

In this study we propose to use a hybrid circuit. Here, the master oscillator is a frequency-selected semiconductor laser (selection is performed by a fibre Bragg grating). This laser is highly stable to external effects, because both the semiconductor structure and Bragg grating are placed in a thermally stabilised housing. The active medium is an ytterbium-doped multiclad fibre. Our purpose was to implement a high-power ytterbium-doped fibre amplifier and to study the influence of gain on the width of the hybrid laser spectrum and its polarisation state.

2. Experimental results

We used a single-frequency semiconductor laser based on an InGaAs structure with a fibre distributed Bragg reflector [6] as a master oscillator. The front face of the laser was coated with an antireflection coating, and the radiation was introduced into a single-mode optical fibre with a previously recorded Bragg grating. The maximum reflection coefficient of the grating was ~30% at a wavelength of 1064 nm. The maximum power of the semiconductor laser was 25 mW. The laser radiation was linearly polarised (with a degree of polarisation close to 0.99). We chose the wavelength of 1064 nm because this laser is planned to be used as a master oscillator in a high-power laser system on solid-state amplifiers, where Nd-doped crystals are applied as an active medium.

The active medium of the amplifier was an optical cladding-pumped fibre with an ytterbium-doped aluminosilicate core. This optical fibre is generally used in high-power fibre lasers [7]. To improve the summation of the signal and pump radiations, the active fibre was multiclad [8]. The core diameter was 13 nm, and the difference between the refractive indices of the core and cladding was $\Delta n = 3 \times 10^{-3}$. The absorption at the pump wavelength of 910 nm at the cladding input was 0.8 dB m^{-1}.

We failed to develop a single-cascade system with a desired gain (~100), because a large gain led to spontaneous generation in the range of 1080–1090 nm, which corresponds to the peak of spontaneous luminescence for ytterbium-doped cladding-pumped fibres based on aluminosilicate glass [9]. In a two-cascade system, the gain of each cascade is not so high, and an optical insulator inserted between the cascades excludes optical coupling between them and self-excited generation. Hence, the total gain of the entire system can be increased.

A schematic diagram of the two-cascade amplifier is shown in Fig.1. The master oscillator is a single-frequency semiconductor laser (*1*) with a lasing linewidth less than 3 MHz; this parameter was measured using a scanning fibre ring interferometer [10]. Figure 2 shows the spectrum of radiation at the output of the system, which was also recorded by a scanning fibre ring interferometer. The radiation linewidth at the amplifier output was 3.3 ± 0.1 MHz.

The pump sources were high-power laser diodes (*2*) and (*6*), emitting at a wavelength of 915 nm. The active medium (*4*, *8*) was a GTWave fibre with an ytterbium-doped core. The fibre length in each cascade was 15 m; it was optimised with respect to the maximum gain at the lasing wavelength of

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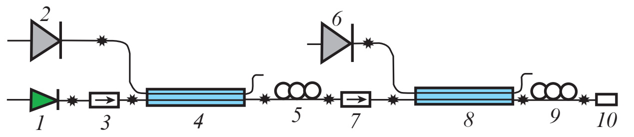

Figure 1. Schematic diagram of a single-frequency hybrid laser: (*1*) single-frequency semiconductor laser; (*2, 6*) pump laser diodes; (*3*) optical insulator (300 mW); (*4, 8*) GTWave fibre; (*5, 9*) polarisation controllers; (*7*) optical insulator (3 W); and (*10*) collimator.

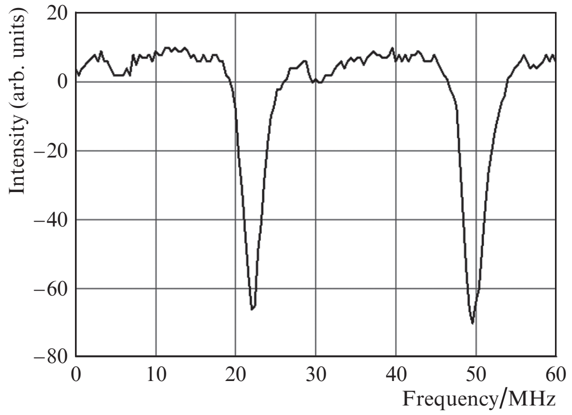

Figure 2. Spectrum of radiation at the output of the system.

1064 nm. The single-frequency master laser was protected with the aid of optical insulators (*3*) and (*7*) with ultimate powers of 300 mW and 3 W, respectively, and collimator (*10*) with a low reflectance (reflected signal at a level of 60 dB) at the lasing wavelength. Polarisation controllers (*5*) and (*9*) were applied to restore the polarisation linearity.

The radiation spectra after the first cascade and at the output of the entire system, recorded at different pump powers, are shown in Fig. 3. The lasing line of the single-frequency semiconductor laser peaks at a wavelength of 1063.35 nm.

Figure 4 shows the dependence of the radiation power after the first cascade on the pump power, and Fig.5 presents the dependence of the output power of the entire system on the pump power in the second cascade at a constant pump power (4.8 W) in the first cascade. The measurements were performed under optimal pump conditions for the single-frequency semiconductor master laser (crystal temperature 22 °C and pump current 127 mA). At pump powers of 4.8 W in the first cascade and 6.8 W in the second cascade the output power of the system was 2.5 W, which corresponds to a gain of about 100.

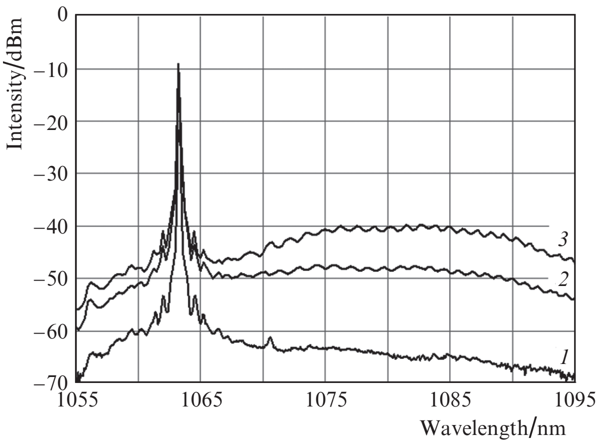

Figure 3. Spectra of radiation (*1*) at the output of the first amplification cascade (pump power 3.8 W) and (*2, 3*) at the output of the system at a pump power of 4.8 W in the first cascade and pump powers of (*2*) 4 and (*3*) 6.8 W in the second cascade.

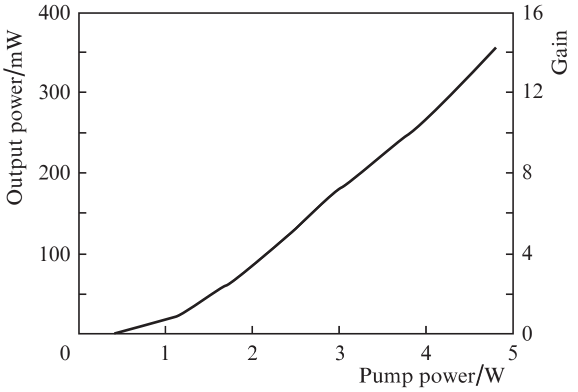

Figure 4. Dependence of the radiation power and gain at the output of the first amplification cascade on the pump power.

Integration over the spectrum showed that the fraction of spontaneous-radiation power in the total generated power is less than 10%. The limitation on the output power is related to the occurrence of generation at the fundamental wavelength for ytterbium (1085 nm for the fibre used) with a further increase in the pump power in the second cascade. Spectra (*2*) and (*3*) in Fig. 3 indicate that the increase in the pump power from 4.8 to 6.8 W leads to an increase in the spontaneous radiation power by almost an order of magnitude, whereas the fundamental radiation power rises only by a factor of 1.5 (Fig. 5).

In the absence of polarisation controllers the amplified radiation becomes elliptically polarised. The reason is that the optical fibre used by us does not exhibit pronounced birefringence. Having mounted polarisation controllers at the output of each cascade, we could restore the degree of polarisation to a level of 0.93. The degree of polarisation P was calculated from the formula

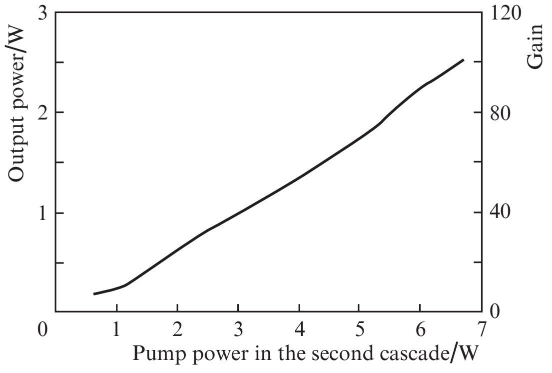

Figure 5. Dependence of the radiation power and gain at the output of the entire system on the pump power in the second cascade, at a constant pump power (4.8 W) in the first cascade.

$$P = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}}, \tag{1}$$

where $I_{\max}$ and $I_{\min}$ are, respectively, the maximum and minimum intensities of the radiation transmitted through a polariser.

3. Conclusions

Our study showed that the developed two-cascade fibre amplifier does not change the spectral and polarisation characteristics of the single-frequency master laser during amplification. The lasing-line shape and width change only slightly during radiation transmission through the two-cascade amplifier. The degree of polarisation is retained at a level of more than 0.9. The output power of the hybrid laser was 2.5 W, a value corresponding to a gain of ~100. This hybrid laser can be used as a master oscillator in high-power laser systems.

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