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High-power fibre Raman lasers emitting in the 1.22 – 1.34-μm range

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Abstract. A set of diode-pumped fibre lasers producing a cw output of 4 – 7.5 W in the range from 1.05 to 1.15-μm is realised on the basis of an ytterbium double-cladded fibre. The output of the ytterbium fibre laser was used to pump a Raman phosphor-silicate fibre converter, resulting in fibre lasers producing a cw output power of more than 3 W at 1.26 and 1.3-μm.

1. Introduction

High-power fibre radiation sources emitting in the region from 1.22 to 1.34 μm can find applications in fibre optic communication, material processing, spectroscopy, medicine, and other fields. At present the most promising method for the development of such sources is Raman conversion of radiation from a fibre laser made of active double-cladded optical fibres. The use of phosphor-silicate fibres in the converter substantially simplifies its scheme [1].

This is explained by the fact that the Raman shift in such optical fibres is 1330 cm^{-1}, whereas this shift in a silica glass is only 440 cm^{-1}. The use of a phosphor-silicate fibre for conversion of radiation from a neodymium fibre laser resulted in the creation of a SRS radiation source with a cw output power of 2.5 W pumped by a 10-W diode laser [2].

At the same time, the use of optical fibres doped with ytterbium ions in fibre lasers increases the efficiency of their diode pumping. This is explained by a high absorption cross section for pump at 0.98 μm equal to 2.5×10^{-20} cm^2 and the absence of absorption from the excited state and cooperative effects. In [3], we have demonstrated a fibre laser with the differential efficiency of about 80 %. We suppose that even greater powers can be achieved in the phosphor-silicate fibre SRS converter with one conversion. In addition, doping with ytterbium provides lasing within a substantially broader spectral range compared to neodymium [4]. Therefore, the possibility appears of developing SRS lasers emitting at different wavelengths.

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This paper is devoted to SRS converters of radiation from an ytterbium fibre laser and the measurement of the spectral range in which high-power radiation from such sources can be achieved.

2. Ytterbium fibre laser

An ytterbium fibre laser was pumped at 978 nm by a 10-W diode laser, which had a fibre output with a core diameter of 250 μm and a numerical aperture of 0.22. The pump radiation was coupled into an ytterbium fibre with an inner square cladding measuring 120×120 μm. To provide the efficient radiation coupling, an active fibre had a Teflon coating, which provided the numerical aperture of 0.6. A fibre on which the Bragg grating was recorded, which was used as an input reflector of the fibre laser, had the same coating. A great difference between the refractive indices of the inner and external claddings of the fibres used in the laser provided, using a fibre taper, the pump coupling efficiency that exceeded 95 %.

The concentration of ytterbium ions within the core of an active fibre was 7×10^{19} cm^{-3}. The absorption coefficient for pump radiation was 1.5 – 2 dB m^{-1} for different samples, which allowed us to use an active fibre of length 15 – 20 m in the laser. The difference between the refractive indices of the core and cladding of the active fibre was 0.009 – 0.011 and the core diameter was ~ 6 μm. The core of the fibre used for recording Bragg gratings had the same parameters, which minimised optical losses produced upon its splicing with the active fibre.

The resonators of the fibre lasers were formed by Bragg gratings of the refractive index written inside the fibre and reflecting light at specified wavelengths. The reflection coefficient of the input gratings was above 99 % and that of the output gratings was from 5 to 10 % (depending on the wavelength chosen). The reflection Bragg gratings were written by the holographic method by using the second harmonic from an argon laser [5]. The power density of the UV source was

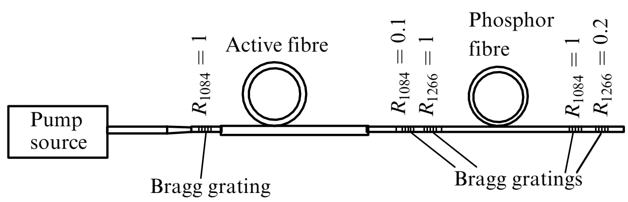

Figure 1. Scheme of a fibre laser and converter.

100 W cm^{-2}. To increase the fibre photosensitivity, it was impregnated with hydrogen at a pressure of 100 atm.

Fig. 2 shows the dependences of the output power of the ytterbium fibre laser on the pump power at different radiation wavelengths. The maximum output power 7.5 W was achieved at 1089 nm and a pump power of 10.5 W. The differential efficiency was 80 %. Fig. 3 shows the dependence of the differential efficiency on the radiation wavelength. One can see that the differential efficiency exceeds 75 % in the range from 1.07 to 1.12 μm and 50 % in the range from 1.05 to 1.14 μm.

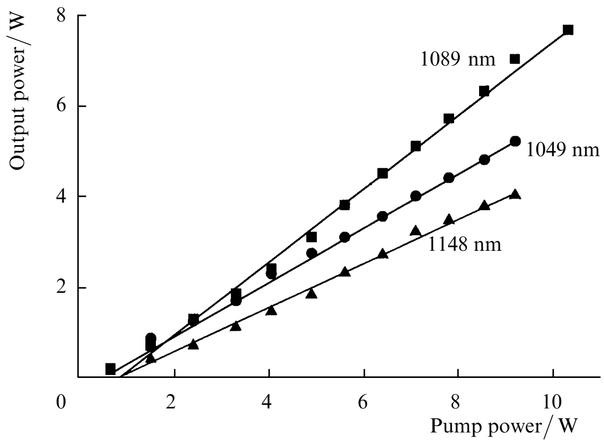

Figure 2. Dependences of the output power of an ytterbium fibre laser on the diode pump power at 978 nm for different emission wavelengths.

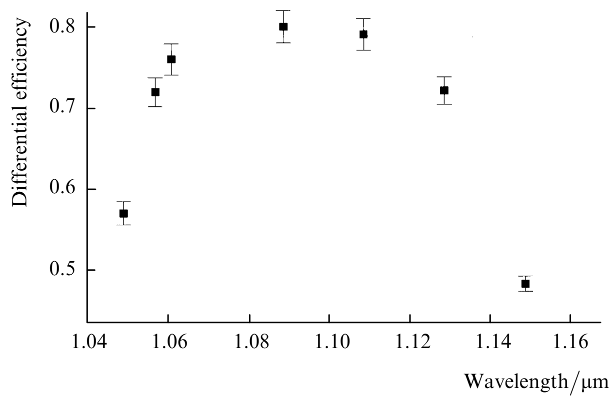

Figure 3. Spectral dependence of the differential efficiency of a fibre laser.

Note that the maximum of luminescence of ytterbium ions in a silica glass is located in the range between 1.03 and 1.04 μm. However, the influence of losses in the long-wavelength tail of the absorption line centred at 978 nm results in the shift of the wavelength corresponding to the maximum laser efficiency. A drastic decrease in the differential efficiency at the wavelengths above 1.12 μm is caused by the corresponding decrease in the luminescence intensity.

3. SRS converter

We used an optical fibre of length 700 m with a core made of phosphor-silicate glass as an active medium of the Raman converter. The molar concentration of the P_2O_5 co-dopant was 13 % and the difference Δn of the refractive indices of the core and cladding was 0.011. Optical losses in the spectral region of pumping were about 1.8 dB km^{-1} and about 1 dB km^{-1} at the radiation wavelengths.

We made two converters emitting at 1266 and 1300 nm in which ytterbium fibre lasers emitting at 1084 and 1108 nm were used, respectively. A resonator was formed by splicing a phosphor-silicate fibre with fibre Bragg gratings with specified reflection wavelengths (1266 and 1300 nm), which were written in a standard Flexcore-1060 optical fibre. The reflection coefficient of the input grating for converters emitting at $\lambda = 1266 \pm 1$ and 1300 ± 0.5 nm exceeded 99 % and the reflection coefficient of the output grating was 20 and 50 %, respectively. In addition, to utilise radiation of the ytterbium laser more efficiently, the Bragg grating with the reflection coefficient above 99 % at the pump wavelength was written near the output grating.

Fig. 4 shows the dependences of the output power of converters on the diode pump power. One can see that the output power of both converters exceeds 3 W upon 10-W pumping, i.e., the conversion efficiency exceeds 30 %. Fig. 5 shows the emission spectrum of the SRS laser emitting at 1266 nm. The suppression of emission of the ytterbium laser is $\sim$ 20 dB.

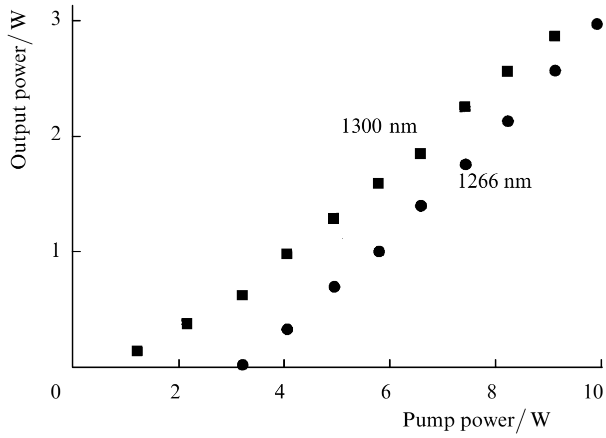

Figure 4. Dependences of the output power of fibre SRS converters on the diode pump power at 978 nm for different emission wavelengths.

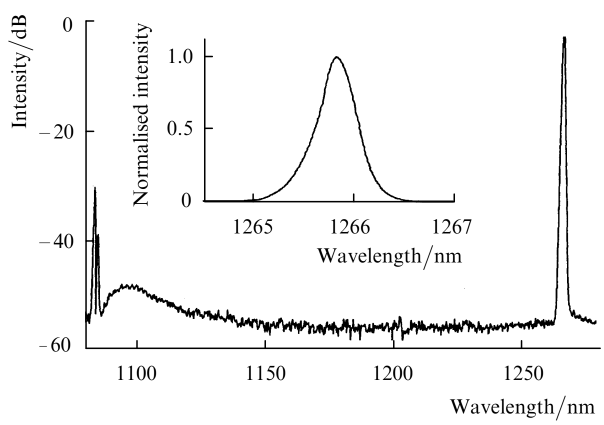

Figure 5. Emission spectrum of a fibre converter.

The obtained output power exceeds the best result achieved for a neodymium fibre laser upon the same diode pumping. Note that the increase in the efficiency of the SRS laser was achieved first of all due to the higher efficiency of an ytterbium fibre laser compared to that of a neodymium laser.

Based on the data on the spectral efficiency of the ytterbium fibre laser presented in Fig. 3, we can conclude that the obtained conversion efficiency (above 30 %) should be achieved in the wavelength region between 1.07 and 1.12 μm, which corresponds to the spectral range from 1245 to 1315 nm for the single-conversion phosphor-silicate fibre SRS laser. When pumping is performed by the ytterbium laser emitting between 1.05 and 1.07 μm and between 1.12 and 1.14 μm, radiation sources emitting in the regions from 1220 to 1245 nm and from 1315 to 1340 nm with the efficiency of conversion of the diode pumping above 20 % can be obtained.

4. Conclusions

Thus, we have demonstrated that conversion of radiation of the ytterbium fibre laser based on single Raman conversion in a phosphor-silicate fibre allows one to create high-power fibre radiation sources. The advantage of the scheme suggested over the scheme involving a neodymium fibre laser is a greater efficiency of conversion of the diode pumping and a broad spectral range in which highly efficient conversion can be achieved.

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