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High-power erbium-doped fibre amplifier pumped by a phosphosilicate fibre Raman converter

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Abstract. **A high power erbium-doped fibre amplifier pumped by single-mode radiation at 1478 nm is fabricated and tested. A Raman converter based on a fibre with a phosphosilicate core was used as the pumping source. The maximum output power achieved in spectral ranges C (1.53 – 1.56 μm) and L (1.56 – 1.60 μm) is 28 dBm.**

Keywords: *erbium-doped fibre amplifier, Raman converter, high-power fibre amplifier.*

1. Introduction

Erbium-doped fibre amplifiers (EDFAs) are widely used in modern fibreoptic communication systems operating at 1.55 μm. An efficient amplification of the signal is achieved both in the generally accepted spectral range 1.53 – 1.56 μm (the C band) and in the long-wavelength region 1.56 – 1.60 μm (the L band). An important characteristic of the amplifier is its saturation power or the maximum output power upon amplification of a signal whose input power provides a considerable suppression of spontaneous luminescence. An increase in the saturation power of the amplifiers is important for their application in dense wavelength-division-multiplexed (WDM) communication systems, because an increase in the number of the wavelength channels leads to an increase in the total optical power of the signal propagating in the fibre.

The maximum output power of the amplifiers used at present in communications is 100 – 200 mW. It is restricted by the power of single-mode semiconductor pump sources emitting at 0.98 μm or in the spectral region from 1.45 to 1.48 μm. However, WDM systems require amplifiers with a power close to 1 W.

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Several methods have been proposed at present for attaining a high output power of EDFAs. One of them involves the use of a double-clad optical fibre with an erbium-doped core which allows pumping by high-power multimode sources [1]. However, the efficiency of core pumping is reduced upon pumping to the fibre cladding and it is difficult to achieve the high population inversion required for an efficient amplification of radiation in a three-level system. Consequently, a high output power of the amplifier (400 mW) can be achieved only in the region from 1.56 to 1.60 μm (the L band), where the reabsorption of the signal is not significant.

To increase the absorption of the pumping radiation, an additional doping of the optical fibre by ytterbium ions was proposed. These ions have a large absorption cross section at the pump wavelength of 0.98 μm and their exitation energy can transfer to erbium ions [2, 3]. However, an efficient transfer of energy requires the use of fused silica doped with phosphorus oxide. In turn, this leads to a narrowing of the luminescence spectrum of erbium ions compared to the spectrum in the generally accepted alumosilicate matrix. Therefore, EDFAs doped with ytterbium cannot amplify the optical signal in a broad spectral range.

A high output power of the amplifier can also be achieved by increasing the power of single-mode pumping, in particular, by using a Raman fibre converter emitting in the spectral range from 1.45 to 1.48 μm. The simplest device of this type can be fabricated by using a phosphosilicate optical fibre as the active medium of the converter [4]. In this paper, we study the characteristics of an EDFA based on a single-mode fibre with the alumosilicate glass core pumped by a Raman fibre converter at 1478 nm.

2. Experimental setup

Fig. 1 shows the scheme of the experimental setup. A Raman converter was pumped by an ytterbium-doped double-clad fibre laser [5]. The ytterbium laser was pumped by a 5.5-W semiconductor laser at 978 nm coupled to an optical fibre with a core diameter of 200 μm. The pumping source was coupled with the active fibre via a fibre cone. Two fibre Bragg gratings reflecting at 1061 nm formed the fibre-laser cavity. The output cw power of the laser at this wavelength was 3 W for the pump semiconductor laser power equal to 5 W.

A single-mode fibre with a phosphosilicate glass core was used as the active medium of the Raman converter. Optical losses in this fibre were 1.55, 0.92 and 0.75 dB km^{-1} at the wavelengths 1.061, 1.24 and 1.48 μm, respectively.

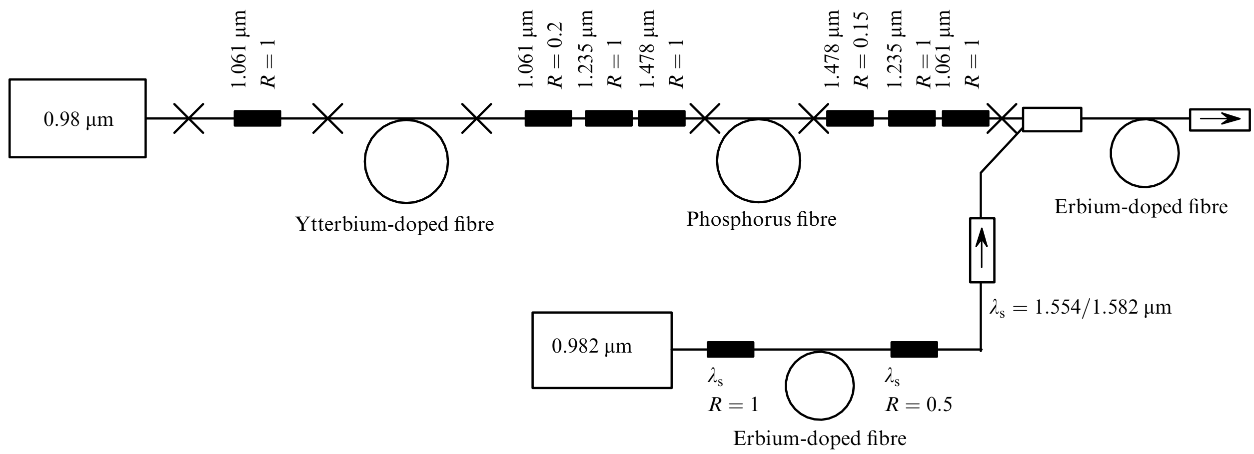

Figure 1. Scheme of the setup (splicings are shown by crosses, and the dark rectangles correspond to gratings).

Pairs of fibre Bragg gratings reflecting at 1235 and 1478 nm formed the cavity of the converter. In addition, a grating with a high reflection coefficient at 1061 nm was placed at the output of the scheme to reflect the untransformed part of the ytterbium laser radiation. The reflection coefficient of the output Bragg grating at 1478 nm, selected from the results of numerical optimisation of the Raman converter [6], was 15 %. The dependence of the output power at 1478 nm on the power of the ytterbium fibre laser is shown in Fig. 2. The resulting quantum efficiency was 36 %, in good agreement with the results of simulation for the given optical losses in a phosphosilicate fibre and integral losses caused by the splicing of Bragg gratings and additional scattering from the gratings. The losses in the input and output chains of the converter were 4 % each.

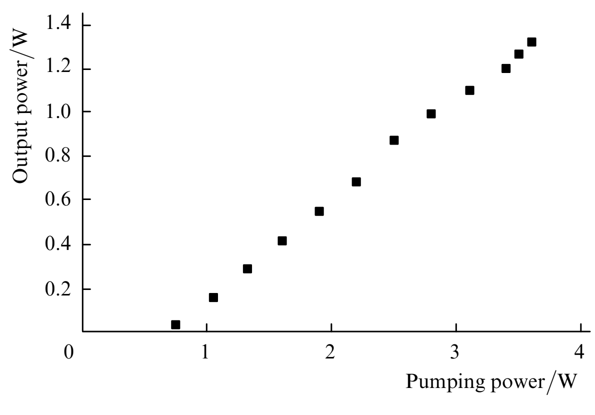

Figure 2. Dependence of the output power of a Raman converter at 1478 nm on the pumping power of the ytterbium laser.

Erbium-doped fibre lasers pumped by a single-mode semiconductor laser at 982 nm were used as the signal sources. The radiation wavelengths of the fibre lasers λ_s (1554 and 1582 nm) were determined by the parameters of fibre Bragg gratings and corresponded to the C band (1530 – 1560 nm) and the L band (1560 – 1600 nm).

The active medium of the amplifier was a single-mode erbium-doped optical fibre fabricated by MCVD technology with deposition of all dopants from the gaseous phase. The concentration of erbium ions in the fibre core was 1.2×10^{19} cm^{-3}. In addition, the core was also doped with Al_2O_3 at a molar concentration of 5 %. The fibre used in the experiment was 8 m long. To prevent lasing due to reflection at the end faces of the erbium fibre at a high pumping power, two isolators were used, one between the signal source and the coupler, and the other one at the amplifier output.

3. Results

The power and the gain of the EDFA were measured at different pumping powers and input signal powers. Fig. 3a shows the dependence of the output signal power at 1554 nm on the pumping power for different input signal

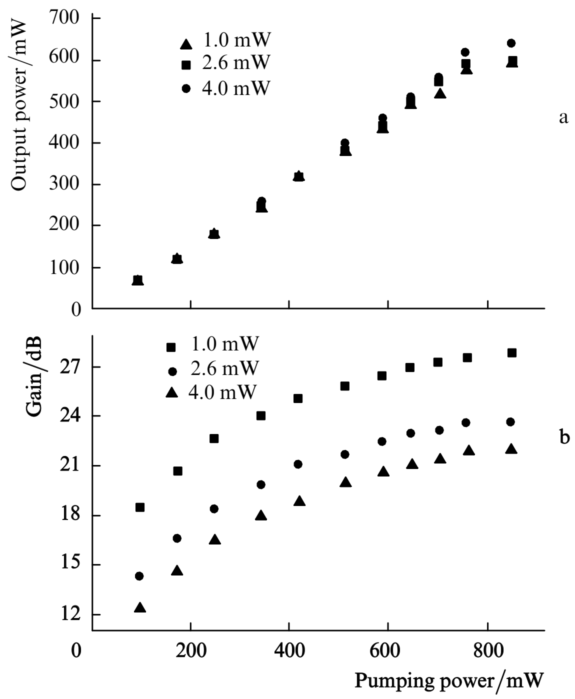

Figure 3. Dependences of the output power (a) and the gain (b) of an erbium-doped fibre amplifier at 1554 nm on the pumping power at 1478 nm.

powers. An output power above 600 mW was achieved for a pumping power of 900 mW and a signal power of 4 mW. The suppression of spontaneous luminescence was about 40 dB. One can see from Fig. 3 that the output power of the amplifier is almost independent of the input signal power in the interval 1 – 4 mW. For an input signal power of 1 mW, the gain was 28 dB (Fig. 3b).

Similar dependences were obtained for the signal at 1582 nm (Fig. 4). The maximum output power at 1582 nm was close to the output power at 1554 nm. Note that the input signal power has a considerable effect on the output power in this case. This may be due to the fact that the wavelength 1582 nm corresponds to the spectral region with a sharp decrease in the luminescence cross section, which results in a stronger competition with the amplified spontaneous luminescence as compared to the signal at 1554 nm. However, the gain at both wavelengths under consideration is virtually the same (23 dB) for the same power of the input signal (2.5 mW).

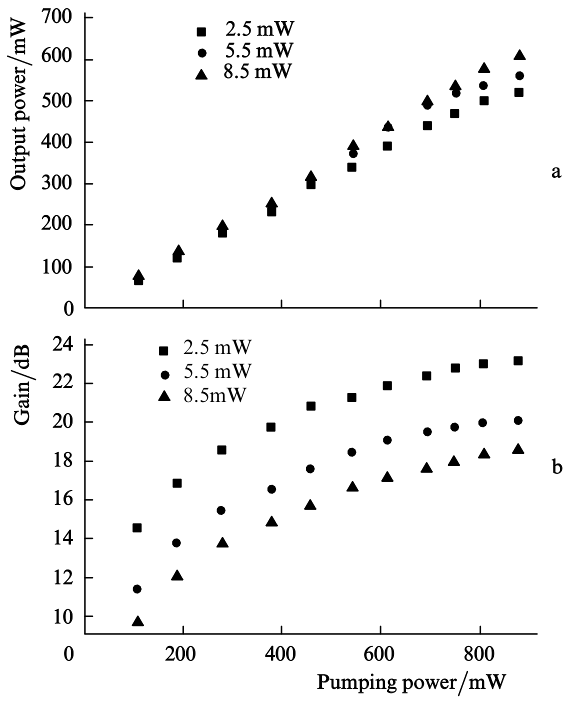

Figure 4. Dependences of the output power (a) and the gain (b) of an erbium-doped fibre amplifier at 1582 nm on the pumping power at 1478 nm.

4. Conclusions

In this work, a high-efficiency Raman converter emitting at 1478 nm was used for pumping EDFAs with a high output power. The amplifier parameters were studied for optical signals in the C and L spectral bands. An output power of over 600 mW (corresponding to a gain of 28 dBm) was achieved. The use of an erbium-doped fibre with a high concentration of Al_2O_3 in the core permits the efficient amplification in both C and L bands. One of the advantages of this scheme is the possibility of obtaining a powerful output signal by using a single-mode erbium-doped fibre with an arbitrary composition of the core as the active element.

References

1. Bousselet P, Bettiati M, Gasca L, Goix M, Boubal F, Sinet C, Leplingard F, Bayart D *Techn. Dig. OFC'2000* (Baltimore, Maryland, 2000), p. WG5
2. Grubb S G, DiGiovanni D J, Simpson J R, Cheung W Y, Sanders S, Weltch D F, Rockney B *Techn. Dig. OFC'96* (San Jose, California, 1996), p. TuG4
3. Pasquale F D, Grass G, Meli F, Sacchi G, Turolla S *Techn. Dig. OFC'99 (San Diego, California, 1996), p. WA2*
4. Dianov E M, Grekov M V, Bufetov I A, Vasiliev S A, Medvedkov O I, Plotnichenko V G, Koltashev V V, Belov A V, Bubnov M M, Semjonov S L *Electron. Lett.* **33** 1542 (1997)
5. Kurkov A S, Karpov V I, Laptev A Yu, Medvedkov O I, Dianov E M, Gur'yanov A N, Vasil'ev S A, Paramonov V M, Protopopov V N, Umnikov A A, Vechkanov I I, Artyushenko V G, Fram Yu *Kvantovaya Electron.* **29** 239 (1999) [*Quantum Electron.* **29** 516 (1999)]