Raman fibre 1 μm => 2 μm converter

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Abstract: A Raman fibre laser with the output in the spectral range beyond 2 μm, converting 1.06 μm radiation into 2.06 μm, has been demonstrated. Raman fibre converter of 1 μm to 2 μm consists of two successive Raman lasers based on phosphosilicate and germania-core fibres.

1. Introduction

Nowadays Raman fibre lasers based on highly P_2O_5- and GeO_2-doped silica fibres are able to generate radiation in the entire region between 1 and 1.6 μm, as it is described in [1]. However, the important problem to be solved at the time is to obtain laser radiation beyond 2 μm.

A seemingly obvious solution is to use multi-cascaded Raman conversion of Yb- or Er-doped fibre laser radiation. Actually, optical losses in silica-based fibres grow rapidly beyond 1.7 μm, while Raman gain coefficient decreases substantially in that region. It is known, however, that quality of fibre as a Raman laser medium is characterized by an expression, proportional to α/g, as shown in [2], where α is the optical losses coefficient, g is the Raman gain coefficient of the fibre; the less is this ratio, the better is the fibre. Since this ratio grows beyond 1.7 μm, it is impossible to construct an efficient Raman fibre laser based on silica fibres in that region at moderate pump powers.

At the same time, the minimum of optical losses in germania glass is near 2 μm region [3, 4]. Also, Raman scattering cross-section in germania glass is about 10 times higher than in silica glasses [5]. Besides, due to high value of Δn~0.1, single-mode germania-core fibres with silica cladding have smaller MFDs and, therefore, higher fibre Raman gain coefficients. There are, however, some technological problems in producing low-loss germania fibres, which we have only recently overcome. We managed to fabricate single-mode germania fibres with losses of 20 dB/km at the wavelengths of 1.8-1.9 μm, using MCVD technique [6]. Besides, these fibres are photosensitive enough to allow Bragg gratings inscription without hydrogen loading.

All these properties allowed us to construct an efficient 3 m long one-cascaded Raman laser at 1.12 μm [7]. The measured value of the fibre Raman gain coefficient was $g_0(1.12/1.06)$ = 300 dB/(km · W), where 1.12 μm is the Stokes wavelength, 1.06 μm – pump wavelength. We have also measured Raman gain coefficients in this fibre for other wavelengths: $g_0(1.57/1.47)$ = 114 dB/(km · W), $g_0(1.72/1.61)$ = 59 dB/(km · W). These figures demonstrate the mentioned reduction of g_0 at longer wavelengths.

2. Experiment

In this work we demonstrate a multi-cascaded phosphosilicate and germania-based fibre Raman converter of 1 μm to 2 μm radiation, with output at 2.062 μm.

The multi-cascaded laser (see in Fig. 1.) consisted of Raman Laser 1 and Raman Laser 2 (RL1, RL2 in Fig. 1), pumped by Ytterbium Laser (YbL), the pump wavelength being 1057 nm. Raman Laser 1 is a two-cascaded Raman fibre converter based on phosphosilicate fibre with output at 1472 nm [8]. The output radiation of RL1 was used to pump RL2, which is a four-cascaded Raman fibre converter based on germania-core fibre. The output radiation of Raman Laser 2 was at 2062 nm.

As Raman fibre in RL2 we used a germania-core fibre with core glass composition of 75 mol% GeO_2 + 0.25 mol% SiO_2 and silica cladding. The core diameter was about 2μm, the core cross-section having elliptic shape with the axes ratio of ¾. Refractive index difference between core and cladding was Δn = 0.105, the cut-off wavelength λ_c = 1.42 μm, the length of the fibre – 18 m. The maximum output power of RL1 was 6.5 W at the wavelength λ_p = 1.472 μm. The Bragg gratings were written directly in the Raman fibre of RL1 using the 193 nm radiation together with hydrogen loading and in the fibre of RL2 using the second harmonic of argon laser radiation without hydrogen loading. The transmission of the output grating was ~50%.

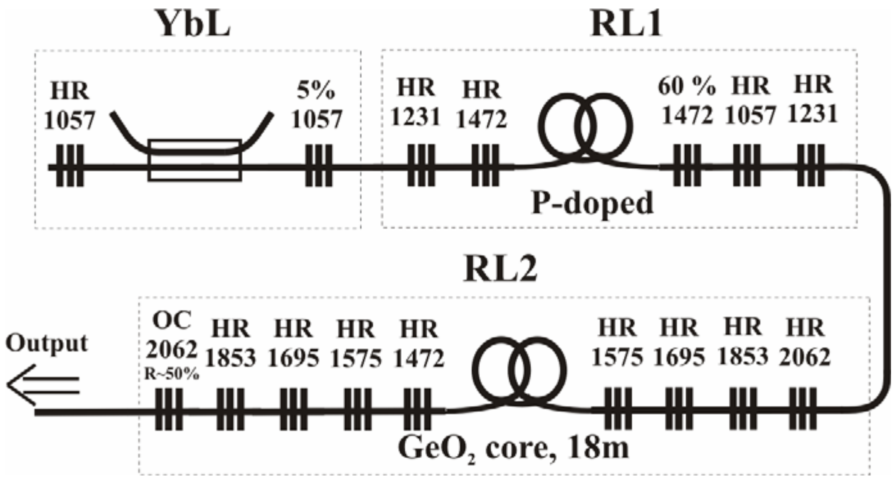

Fig. 1. The scheme of the four-cascaded Raman fibre laser.
YbL – Ytterbium laser, 1057 nm
RL1 – Raman laser 1: two-cascaded Raman fibre converter based on phosphosilicate fibre, 1472 nm
RL2 – Raman laser 2: four-cascaded Raman fibre converter based on germania-core fibre

Wavelength analysis of output radiation has been carried out using a monochromator with a 300 grooves per mm grating, mostly in the second (1.0-2.0 μm) and partly in the first order (>2.0 μm). The complete spectrum of output laser radiation is shown in Fig. 2. The power launched at 1472 nm is 3.9 W. Peak 1 corresponds to Yb laser pump radiation at 1057 nm. Peaks 2 and 3 represent the two cascades of RL1. 4, 5 and 6 are the first three germania Raman fibre cascades. The generation wavelength 2062 nm (peak 8) is observed next to the peak of pump radiation, since they appear in different orders of diffraction. Peak 7 corresponds to the maximum of Raman amplification at 2017 nm, pumped by 1853 nm: the frequency shift between peaks 7 and 6 is ~440 cm^{-1}. Its occurrence is due to the larger frequency shift between the 3rd and 4th cascades, which is ~550 cm^{-1}. The detailed structure of separate parts of the spectrum is shown in Fig. 3.

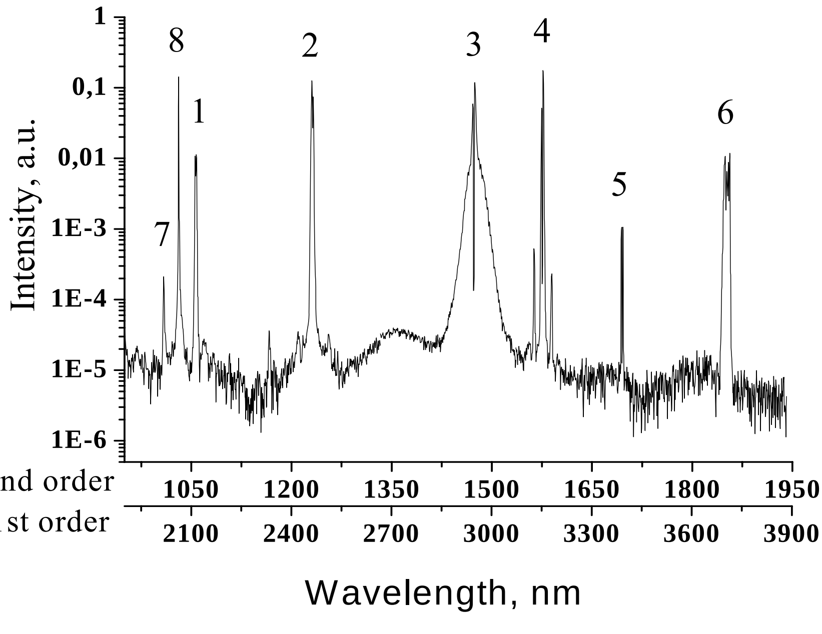

Fig. 2. Laser radiation spectrum. Launched power – 3.9 W.
1 – Yb laser pump radiation at 1057 nm (YbL)
2, 3 – two cascades of Raman Laser 1 based on phosphosilicate fibre: 1231 nm and 1472 nm
4, 5, 6 – the first three cascades of four-cascaded Raman Laser 2: 1575 nm, 1695 nm and 1853 nm
7 – Raman amplification maximum (2017 nm), corresponding to the 440 cm^{-1} shift from 1853 nm
8 – the fourth cascade of RL2, 2062 nm.

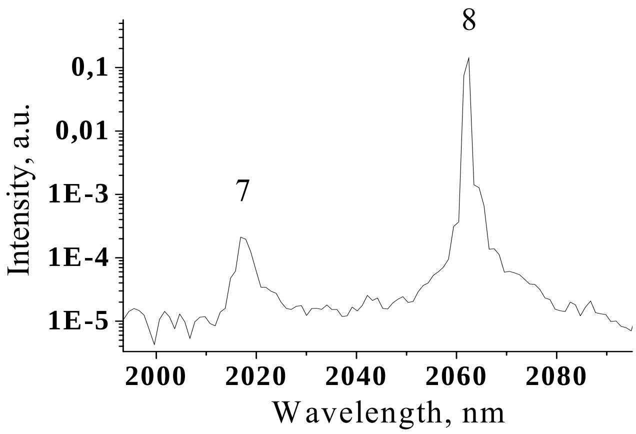

Fig. 3. The detailed spectrum of generated radiation at 2062 nm.

It is clearly seen from Fig. 2, that 1575 nm peak has two sidebands, shifted at ~50 cm^{-1} from the main peak. They are shown in detail in Fig. 4. The same structure was observed in the case of one-cascaded Raman fibre laser with output at 1571 nm, which we have built on the same kind of fibre [9]. The effect is accounted for by parametric amplification (four-wave mixing), the phase-matching being reached due to the birefringence of this fibre due to elliptical core.

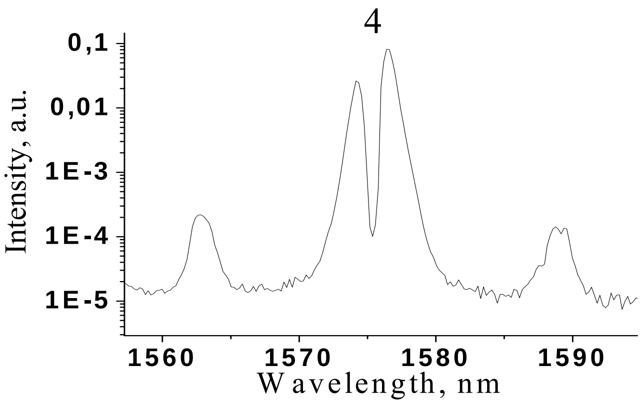

Fig. 4. The structure of the 1575 nm peak. Frequency shifts are ~50 cm^{-1}.

The results of power measurements are presented in Fig. 5. The output power at 2062 nm reached 220 mW, the efficiency of the laser being approximately 3.5% and the slope efficiency reaching 8.2%. No doubt, that these values can be essentially improved by Raman laser optimisation.

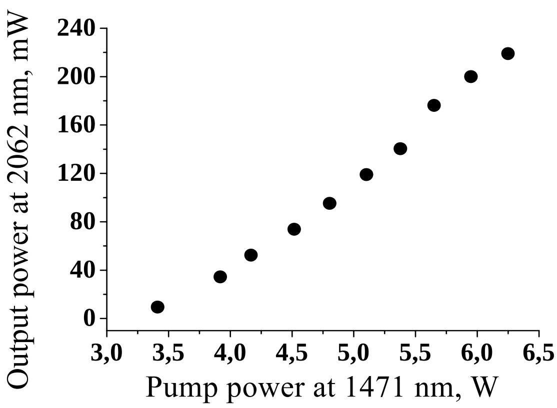

Fig. 5. The dependence of the output power at 2062 nm on pump power at 1472 nm.

3. Conclusion

The results of this work demonstrate the possibility of designing Raman lasers in the spectral range beyond 2 μm using the fibre with germania core as the active medium for Raman amplification. It also provides evidence of outstanding non-linear properties of such fibre.

4. References

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