Ultra-Broadband Tunable Fiber Laser

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Abstract: We demonstrate the ultra-broadband gain medium exploiting cascaded Raman amplification. Pumping the 5-km long linear cavity fiber laser at 1349 nm we show the tunability of the laser operation from 1400 to 1622 nm.
OCIS codes: (140.3510) Lasers, fiber; (140.3550) Lasers, Raman; (140.3600) Lasers, tunable; (140.3280) Laser amplifiers

1. Introduction

Increase of the operational bandwidth of telecommunication links by using additional spectral bands is one of the possible solutions to meet the growing demand on capacity of optical networks. This would require not only a new generation of optical amplifiers but also a number of new components operating in new spectral bands. Various approaches and solutions have to be comprehensively studied before commercially viable products will be available. Main focus in the development of optical amplifiers is now on the rare-earth doped fibers, however, for some applications semiconductor optical amplifiers and Raman-effect based techniques can offer good performance [1-3].

An ultra-broadband gain medium would be of a great interest for telecom applications, as well, as for widely tunable lasers, which can be used for inspection and testing. Tunable lasers would allow telecom operators to substantially reduce inventories (number of back-up lasers to replace failed sources) in wave-division-multiplexing systems. An even more important role will be played by tunable laser sources in the next generation of future reconfigurable flexible network architectures that include requirements on switchable wavelengths, burst and label switching, bandwidth on demand, and other functions related to spectral tunability. Widely tunable laser is an attractive light source both for fundamental science and industry. Spectral tunability is one of the important features of laser source, highly desirable in a vast range of applications in various research functions, astronomy, spectroscopy, measurement applications, laser isotope separation, medical applications, material processing, diagnostics, and remote sensing.

The key idea of this work is to exploit the gain produced by several Raman cascades covering a broad spectral range. In contrast to the usual multi-stage Raman lasers, we propose to choose the wavelength of the laser action at the "red" edge of the amplification band where the gain is small. This concept allowed us to develop the Raman fiber laser tunable in the range of 1400-1622 nm with 29-nm gap exploiting only one Raman cascade in the laser scheme. With additional Raman cascades it would be possible to cover a much larger spectral interval. We anticipate that the proposed schemes might be promising for ultra-broadband amplification.

2. Experimental setup

The linear cavity of the fiber laser included a fiber Sagnac mirror comprising the gain fiber, the 1474 nm highly reflective (HR) fiber Bragg grating (FBG), and a polarization controller. The spectrally selective coupler was represented by a system of bulk elements allowing spectral tunability. A 1% fiber coupler was inserted into the cavity for radiation output. The laser was pumped at the wavelength of 1349 nm by a continuous-wave (CW) Raman fiber laser described in [4].

In the first configuration shown in Fig. 1a the active medium was the 5-km long SMF-28 fiber span. The radiation emerging from the fiber end was collimated by the optical lens with 11.21-mm focal length and transmitted through a flint glass prism onto a dielectric spectrally broadband mirror. The spectral selection was implemented by changing the mirror angle respectively to the falling beam. The total pump power was 1.9 W. In the second configuration shown in Fig. 1b the active medium inside the Sagnac mirror was a 30-m long piece of the Bi-doped fiber provided by FORC RAS and used in our previous experiments [4]. It had approximately 8 dB small-signal pump absorption. The output of the Sagnac mirror was spliced with to the end of the 5-km long SMF-28 fiber span. The radiation emerging from another end of the fiber span was collimated by a collimator and directed on the reflective diffraction grating operating in the Littrow configuration. The spectral selection was implemented by changing the grating angle respectively to the falling beam. The maximum pump power was 2.3 W. The spectra were recorded with an optical spectrum analyzer.

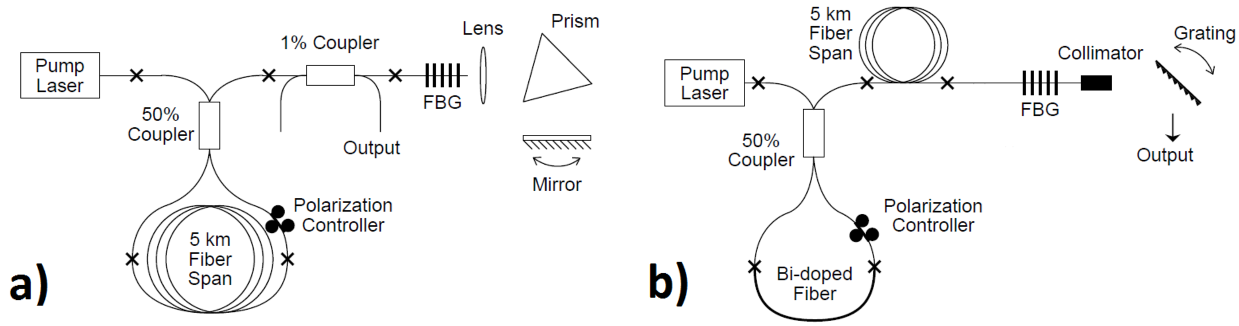

Fig.1. Laser configurations, 1st (a), and 2nd (b).

3. Results

The laser operating in the first configuration showed tunability in the range of 1415-1605 nm with a gap from 1445-1545 nm. Also, it was possible to achieve laser action at the wavelength of 1465 nm. The laser action achieved in the range of 1415-1445 nm was not accompanied with laser generation at the FBG wavelength of 1474 nm. In contrast, laser action in the range of 1545-1605 nm was accompanied with laser generation at 1474 nm. However, tuning to the wavelengths longer than 1555 nm resulting in suppressing of the 1474-nm laser line intensity, which became negligible. The maximum output power reached 15 mW, Fig. 2a.

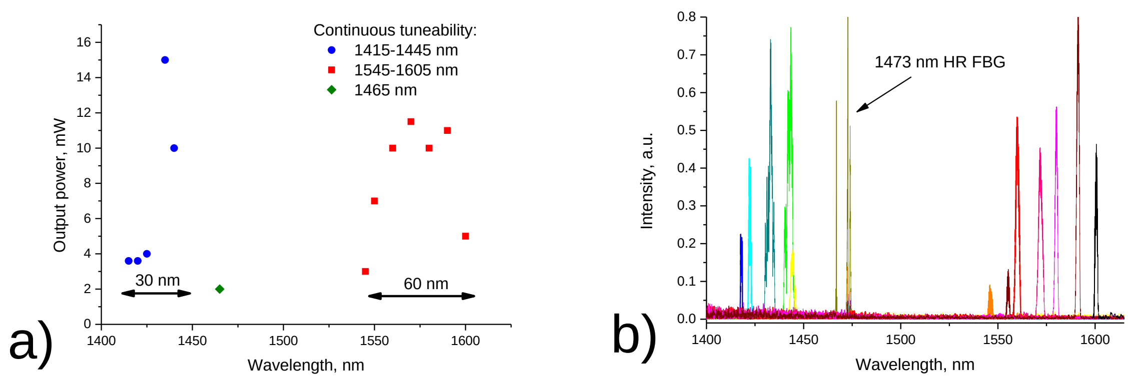

Fig.2. Laser output power (a) and spectra (b) in the 1st configuration.

The full width at half maximum (FWHM) of the tunable laser line varied in the ranges of 1-3 nm and 1.5-2 nm for the tunability ranges of 1415-1445 and 1545-1605 nm, respectively. The laser line in the tunability range of 1415-1445 nm also had a complex internal structure. These phenomena were mainly attributed to a relatively weak spectral selection provided by the prism.

In order to suppress the sensitivity of the laser to the environmental conditions, in the second configuration the 5-km long fiber span was replaced with the 30-m long piece of the Bi-doped fiber. This fiber span was spliced to the Sagnac mirror output thus remaining in the laser cavity and providing Raman gain. Also, the diffraction grating was used in this configuration instead of the prism with the bulk mirror.

The laser operating in the second configuration was tunable in the range of 1400-1622 nm with a 29-nm gap from 1455 to 1484 nm, Fig. 2a. The laser action achieved in the range of 1400-1455 nm was not accompanied with laser generation at the FBG wavelength of 1474 nm. However, the laser emission at the wavelength of 1474 nm was observed in the tuning range of 1484-1622 nm. Also, the unabsorbed pump radiation at the wavelength of 1349 nm was observed in the spectra. The laser line FWHM did not exceed 0.5 and 0.3 nm in the ranges of 1400-1455 and 1455-1622 nm, respectively, see Fig. 2a. Thus, the peak power of the laser lines shown in Fig. 1a and recorded with resolution of 2 nm corresponds to the total power of the laser emission. It reached 36 mW at the wavelength of 1520 nm.

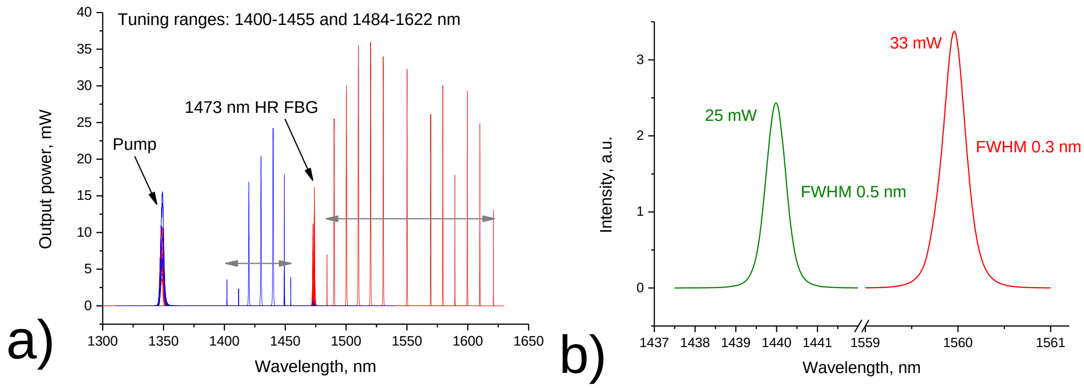

Fig.2. Laser output spectra recorded with resolution of 2 (a) and 0.02 nm (b) for the 2nd laser configuration.

To reach the maximum output power, it was still necessary to adjust the polarization controller; however, the long-term stability was improved in this configuration.

4. Discussion and conclusions

In this work we proposed a novel technique of the extension of the amplification bandwidth using several Raman cascades. In traditional multi-stage Raman lasers the spectral position of the Raman cascade is set to be close to the peak of the Raman scattering. In this case, the net gain outside the vicinity of the laser line does not exist. In contrast to conventional approach, we choose the wavelength of the Raman cascade apart from this peak (1435 nm for our silica-based fibers) at the wavelength of 1474 nm where the spontaneous Raman scattering intensity is approximately an order of magnitude smaller. When the laser is tuned to the area of the positive small-signal gain for a certain pump power, the lasing at 1474 nm does not occur because of the competition with the lasing at the wavelength defined by the tuning system. When the tuning system is adjusted to other wavelengths, the laser generation at 1474 nm takes place. Therefore, it is possible to utilize both broad areas of the Raman gain produced by 1349- and 1474-nm pump. In the 1st configuration the pump power is absorbed more effectively, because the Sagnac mirror includes 5-km long fiber span. However, the long-term stability is improved for the 2nd configuration with the piece of the Bi-doped fiber. It is supposed, that the stability is affected by the temperature- and stress-assisted change of the polarization state of the laser radiation inside the cavity. We anticipate that the use of the polarization-maintaining fibers would allow to achieve a highly stable laser action in the 1st configuration exploiting only Raman gain. Also, the total bandwidth of the tuning can be further extended using new Raman cascades. The gap in the tuning range can be suppressed by use of a more transparent output coupler at the wavelength of 1474 nm.

In conclusion, we have experimentally demonstrated Raman fiber laser with the record tenability over the range of 1400-1622 nm with 29-nm gap exploiting only one Raman cascade in the laser. Such a demonstration represents a significant advance in the area of tunable lasers, and paves the way towards various new applications, e.g. ultra-broadband amplifiers

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