Ultra-wide-tunable fibre source of femto- and picosecond pulses based on intracavity Raman conversion

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ABSTRACT

This report for the first time presents the results of experimental investigations into femto- and picosecond all-positive dispersion wavelength-tuneable Yb-doped fibre laser with efficient intra-cavity and extra-cavity Raman conversion of radiation in the range of 1070-1300 nm. We demonstrate smooth spectral detuning of radiation Stokes components within ranges 1130-1174, 1190-1235, and 1255-1300 nm generated when the fundamental harmonic of the laser was tuned within the 1075-1120-nm range. The average output power of the laser radiation at different Stokes components reached up to 250 mW.

Keywords: Yb-doped fibre laser, Raman conversion , femtosecond, picosecond, ultra-wide-tunable laser

1 INTRODUCTION

Raman conversion of laser wavelength is a convenient and efficient mechanism which allows one to shift wavelength of radiation into long-wave region. Amount of this shift is determined by properties of non-linear media used for Raman conversion. In the case of fixed single wavelength of pump source the spectrum of red-shifted radiation contains one or several long-wavelength peaks which correspond to different Stokes components. Raman effect can be used both for intra-cavity conversion of laser radiation and for extra-cavity conversion as well. Intracavity conversion method is a quite widely-used technique for wavelength conversion of solid-state lasers [1-5]. Efficient Raman crystals are placed inside laser cavity and provide usually generation of one or two red-shifted spectral lines. As for fiber lasers, the method of intra-cavity laser conversion was used quite rarely until now [6-8].

When Raman conversion is used wavelength tuning of master oscillator may lead to synchronous tuning of Stokes components. In this case spectral range of wavelength tuning for the whole system can be several times as wide as spectral range of wavelength tuning of master oscillator. However for ultra-short pulses fiber lasers it's a challenge due to following two reasons:

- wavelength tuning of ultra-short pulses fiber lasers requires broad-band reflectors which was exotic until very recent times;
- efficient Raman conversion requires relatively long fibers (hundreds of meters and even more) what may result in dispersion spreading of pulses.

This work is aimed for development and investigation of a method for spectral tuning of ultra-short pulses Yb-based fiber laser as well as Raman spectral conversion of this laser using either intra-cavity and extra-cavity conversion schemes.

2 EXPERIMENT

In order to make a spectrally tunable ultra-short pulses Yb-based fiber laser we used linear cavity scheme with a conventional prism-based spectral tuning element at one fiber and a special ultra-broadband loop reflector [9] at another end. The laser scheme is shown in Fig. 1. Ultra-broadband loop reflector was created on the basis of conventional optical circulator. As it was demonstrated earlier [10, 11], by connecting the output and input ports of such a circulator it is possible to make it into a type of fiber optical reflector, the so-called circulator-based loop reflector. In the course of the

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present work we have established that such fiber reflector has high reflectivity (> 80–90%) within spectral ranges dozens of nanometres wide and relatively high reflectivity (> 50%) within approximately 180 nm. A wide operating spectral band of this reflector in conjunction with wide operating band of prism selector allows the laser to generate relatively short pulses and to tune their spectrum within the amplification band of active medium.

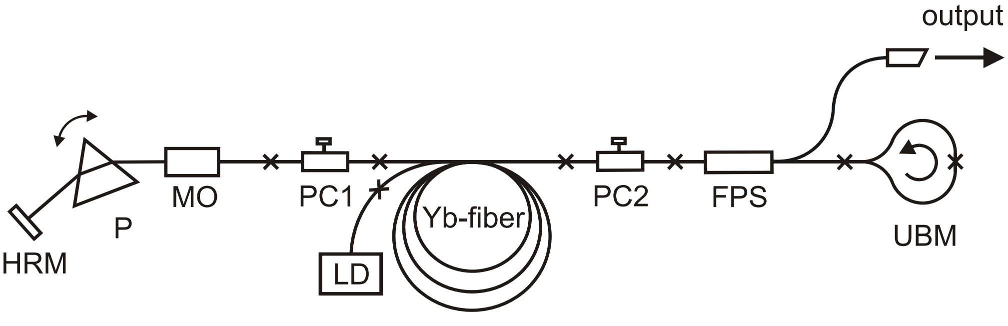

Fig. 1. Schematic of spectrally-tunable linear ultra-short pulse Yb fiber laser: UBM – ultra-broadband fiber mirror, PC1/2 – fiber polarization controllers, FPS – fiber polarization splitter, MO – micro-objective, HRM – high- reflective mirror, P - prism, LD – pump laser diode.

Adjustment of the laser for start of mode-locked operation was carried out with the help of two polarization controllers. The cavity was ~20 m long, thereby leading to the pulse repetition rate 4,9 MHz. Coupling of output radiation from the laser's linear resonator was done with a fiber polarisation splitter, therefore the laser output was linearly polarised. Maximal output power of the laser radiation amounted to 150 mW at 1100 nm when pumped with 0.5 W at 980 nm. It was only limited by the power rating of the fibre polarisation splitter. Maximum rated radiation power for the circulators was higher (300 mW), and therefore did not limit the laser radiation power.

The laser cavity did not contain any special elements (fibers, gratings, etc) for dispersion compensation. There were also no additional spectrally selective elements limiting the output spectrum. Figure 2 shows spectra of ultra-short pulses linear Yb-based fiber laser at different adjustment of prism reflector. The central laser wavelength could be tuned within spectral range with full width of 45 nm (starting from 1075 nm up to 1120 nm) at average output power of 150 mW. Auto-correlation trace of laser pulse is shown in Fig. 3.

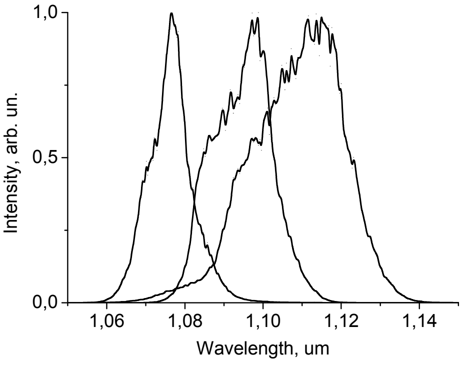

Fig. 2. Spectra of ultra-short pulses linear Yb-based fiber laser at different adjustment of prism reflector.

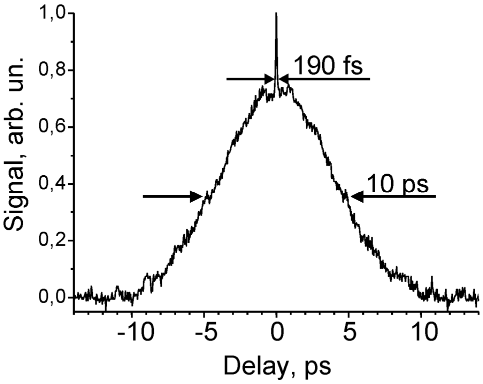

Fig. 3. Background-free autocorrelation trace of the laser output pulses.

It can be readily seen that the auto-correlation function contains a short central peak with width of 190 fs sitting on top of a pedestal with ~ 10-ps duration. As it was shown in [12] such double shape of auto-correlation trace of all-positive-dispersion laser pulses correspond to generation of picosecond-long pulse trains with stochastic femtosecond-scale-long "stuffing".

For experiments with intra-cavity Raman radiation conversion the laser cavity was transformed according to Fig. 4. A piece of 1060XP optical fiber was added into the cavity, as well as the second polarization beam splitter which was inserted close to the introduced fiber. At the exit of this polarization beam splitter we observed quite intensive Stokes components with spectra shown in Fig. 5 for different lengths of 1060XP fiber.

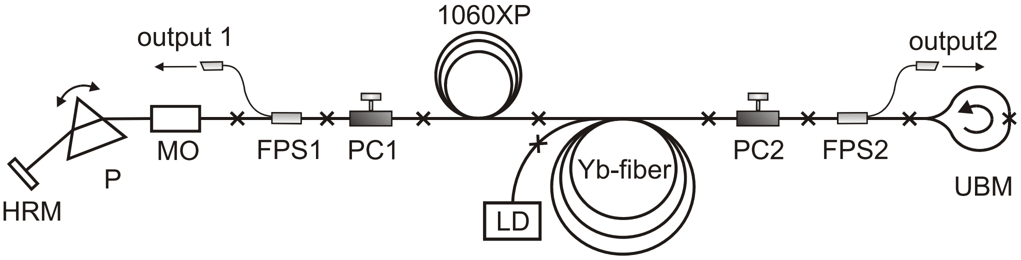

Fig. 4. Schematic of spectrally-tunable linear ultra-short pulse Yb fiber laser with intracavity Raman conversion: UBM – ultra-broadband fiber mirror, PC1/2 – fiber polarization controllers, FPS1/2 – fiber polarization splitters, MO – micro-objective, HRM – high- reflective mirror, P - prism, LD – pump laser diode.

At maximum length of additional 1060XP fiber we observed three Stokes components. Central wavelength of the most long-wavelength component was 1.27 um. We measured auto-correlation functions for all three Stokes components and compared them to the auto-correlation trace of original laser radiation obtained from polarization beam splitter from the side of active fiber (Fig. 6). As can be seen from Fig. 6 additional piece of fiber increases duration of picosecond pulses however not more than by a factor of two.

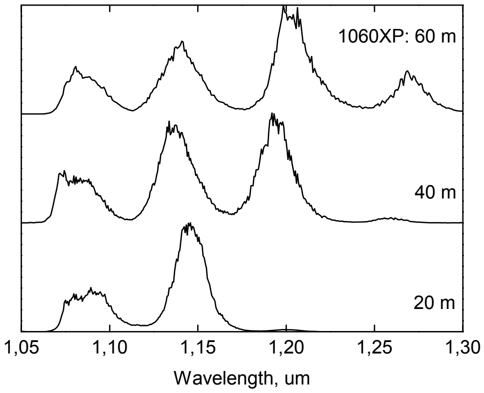

Fig. 5. Spectra of radiation at the exit of second polarization beam splitter which is located close to 1060XP fiber.

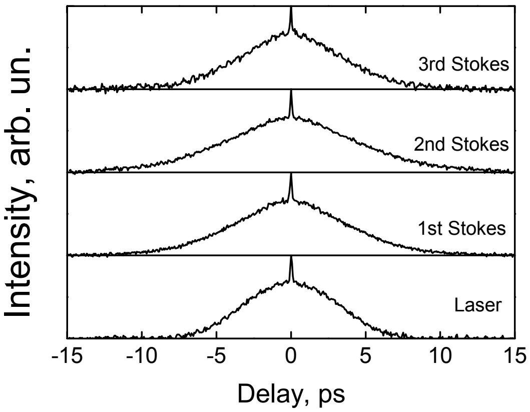

Fig. 6. Auto-correlation traces of laser pulses and pulses of all three Stokes components with length of extra 1060XP fiber is 60 m.

Tuning laser wavelength by means of prism reflector allowed us to tune wavelengths of all Stokes components in the range of ±22,5 nm around their central position.

It's necessary to note that despite possibilities of pump power increase, output laser power was limited by a quite moderate level which was determined by maximum power values for fiber beam splitter and fiber circulator used as a loop reflector. In order to increase power level of master oscillator radiation as well as its Stokes components we investigated extra-cavity Raman conversion system. Optical scheme of this system is shown in Fig. 7.

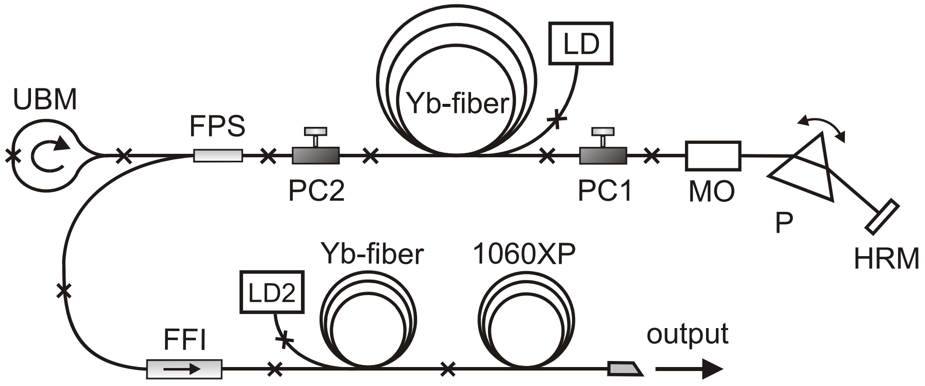

Fig. 7. Schematic of spectrally-tunable ultra-short pulse Yb-based fiber laser system with extracavity Raman conversion: UBM – ultra-broadband fiber mirror, PC1/2 – fiber polarization controllers, FPS – fiber polarization splitter, MO – micro-objective, HRM – high- reflective mirror, P - prism, LD1/2 – pump laser diodes, FFI - Fiber Faraday Isolator.

Laser radiation was amplified in single-stage amplifier up to average power of 6 W and then entered 80-m-long stretch of 1060XP fiber. As average power at the input of 1060XP fiber was increased from 0 up to 6 W typical Raman peaks appeared in output spectrum. At maximum power level the number of Raman peaks was equal to 3, and tuning of master oscillator wavelength in the range of 1075-1120 nm resulted in synchronous tuning of Stokes components in the ranges of 1130-1174, 1190-1235, and 1255-1300 nm. Figure 8 shows spectra of the most long-wavelength Stokes components registered at different power levels at input of 1060XP fiber and for different wavelengths of master oscillator radiation. Long-wavelength Stokes components can be selected by means of spectral filters. After being spectrally selected the radiation of Stokes components had average power of 150-250 mW in the range of 1190-1300 nm with small gaps in 1174-1190 nm and 1235-1255 nm.

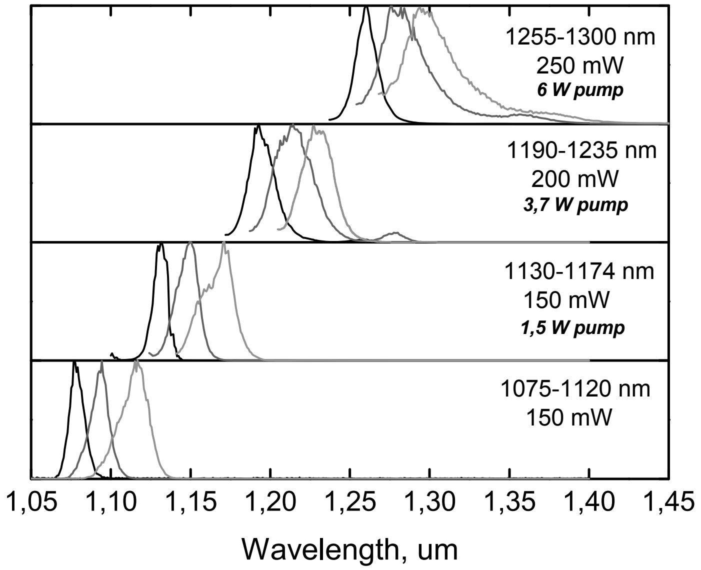

Fig. 8. Spectra of the most long-wavelength Stokes components registered at different pump power levels at input of 1060XP fiber and for different wavelengths of master oscillator radiation.

3 CONCLUSIONS

This work presents for the first time efficient intra- and extra-cavity Raman conversion on the basis of spectrally-tunable ultra-short pulse Yb fiber laser. Wavelength tuning of mode-locked laser in the range of 45 nm was realized with the use of special ultra-broadband loop reflector based on a standard circulator. Using Raman conversion of laser radiation we observed also wavelength tuning of Stokes components in the range of ±22,5 nm around their central positions. Both intra-cavity and extra-cavity Raman conversion allowed us to achieve total range of wavelength tuning as wide as 1075-1300 nm with small gaps in 1120-1130 nm, 1174-1190 nm and 1235-1255 nm. Duration of picoseconds-scale pulse trains of master oscillator radiation as well as of Stokes components amounted to 5-10 ps.

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