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Stabilisation of a radiation wavelength of a nanosecond fibre laser by a passive nonlinear loop mirror

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Abstract. **A method for stabilising the radiation wavelength of a mode-locked fibre nanosecond laser is proposed and realised. Generation of nanosecond laser pulses with a spectral bandwidth of 50 MHz, which corresponds to a transform-limited pulse, is demonstrated.**

Keywords: *optical fibre, fibre laser, nanosecond pulses, passive loop mirror, transform-limited pulse.*

1. Introduction

Laser sources generating nanosecond pulses are widely used in materials processing and light detection and ranging (LIDAR) systems. However, despite a large number of proposed constructions for nanosecond fibre lasers, the problem of high reliability, stability and low cost of such lasers is still open. The master oscillators based on saturable absorbers of SESAM type [1, 2] or carbon nanotubes [3, 4] operating in the Q-switching regime suffer from structural degradation, which may arise when such a laser system starts operation. One more critical factor is the influence of instantaneously varying ambient conditions on a polarisation component of the operation mode in optical fibres, which limits the number of actually promising systems. In particular, the employment of polarisation-insensitive components in the schemes based on polarisation rotation [5, 6] makes impossible the fabrication of a commercial product capable of operating beyond laboratory conditions. In a series of works, it was proposed to use active Q-switching schemes for generating nanosecond pulses [7, 8]. Nevertheless, complicated electronics inherent in such schemes substantially increases the laser cost. In addition, the requirement of the exact matching of the modulation frequency of the active element with the round-trip frequency of the laser cavity makes out-of-laboratory employment of such sources problematic, because temperature variations change the wavelength of the fibre laser cavity and the corresponding resonant frequency. Thus, search for simple and, more importantly, stable schemes for generating nano- and sub-nanosecond pulses is now an important and actual problem from the practical point of view.

Earlier, we have proposed and realised the scheme of a master oscillator with a passive nonlinear loop mirror (PNLM) for the spectral ranges around 1 μm [9] and 1.55 μm [10]. A principal schematic diagram of the laser with the PNLM is shown in Fig. 1. It comprises a wavelength division multiplexer (WDM), active fibre, isolator, X-type fibre coupler with a typical ratio 5 : 95 to 30 : 70, polarisation controller (for the scheme not supporting propagation of polarised emission) and Y-type coupler, which extracts part of radiation from the laser system. An advantage of such a laser construction is absence of bulk elements: radiation is entirely concentrated inside the fibre system. In addition, the scheme can be realised on a polarisation-sensitive fibre, which enhances such an important parameter as the long-term stability of laser operation; the latter was tested for more than 1000 hours of continuous operation. It worth noting simplicity of the fibre scheme realisation: the system only employs standard step-index, single-mode fibres that are commercially available. In addition, an important feature of the scheme with a negative total dispersion is the possibility of mode-locking and generating nanosecond radiation pulses with a spectral width not exceeding the resolution of a commercially available spectrum analyser ($\Delta\lambda \leqslant 0.01$ nm).

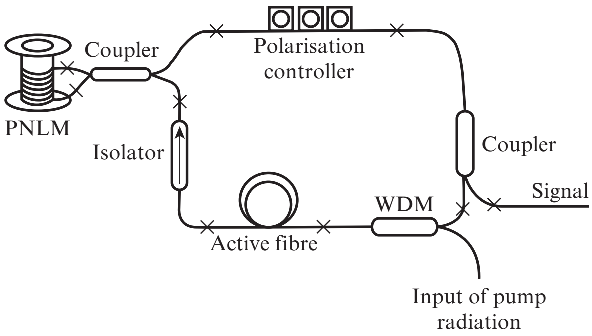

Figure 1. Principal scheme of a master oscillator with the PNLM (crosses show splicing points).

It is worth noting that the measurement of the real width of the radiation spectral line in previous works was hindered by time instability of a centre wavelength of the laser light (Fig. 2). This is related to the fact that the scheme comprised no spectral-selective elements for fixing the generation wavelength. The aim of the present work is to stabilise the radiation wavelength of a fibre laser with the PNLM and measure the spectral width of such laser.

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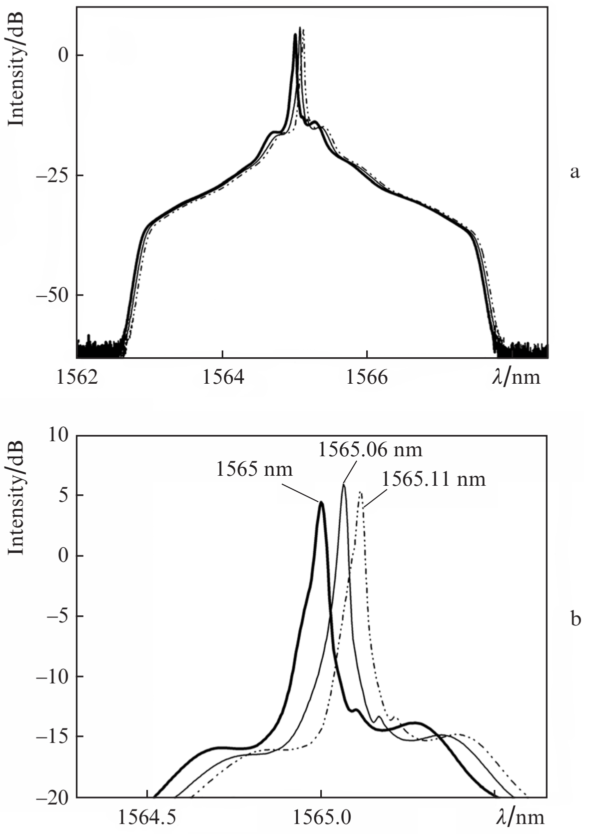

Figure 2. (a) Three successively detected emission spectra of the laser with the PNLM and normal total dispersion and (b) magnified image of the spectral range near the centre wavelength of laser generation.

2. Scheme of the laser with the PNLM and stabilised wavelength

The most evident method for stabilising the laser wavelength is the employment of a narrow-band filter. In the present work, a fibre Bragg grating (FBG) was used as such a filter. The scheme of the laser was modified (Fig. 3): the FBG was spliced to port 2 of a commercial circulator placed between the loop mirror and the 10 : 90 coupler, through which radiation was extracted from the laser system. Two FBGs were made with different values of reflection coefficients and spectral widths. The first FBG had a reflection coefficient of 95% with the spectral width of about 0.5 nm at a transmission level of 3 dB. The spectral width of the second FBG was increased to 1.7 nm (at the level of 3 dB), and the reflection coefficient was 50%. In the latter case, the wider spectral width was attained by reducing the number of grooves (the length of grating); this is also the reason of the lower reflection coefficient. The centre wavelengths of reflection coefficients for both FBGs were near 1553 nm. To avoid the influence of polarisation effects on laser output characteristics, all elements of the scheme were made of a standard polarisation-maintaning fibre. Since standard fibres possess an anomalous dispersion in the range of 1.5 μm, for attaining the generation regime with a small spectral linewidth, the PNLM was made of a specially developed single-mode polarisation-maintaining, anomalous-dispersion fibre [10]. The fibre dispersion measured at the operation wavelength was 23 ps nm^{-1} km^{-1} and its length was 530 m. A 2.5-m-long erbium fibre with the absorption of 11.8 dB m^{-1} at the pump wavelength was used as the active fibre. Spectral measurements were performed by using a Yokogawa AQ6370C spectrum analyser, and time traces were recorded by a Tektronix TDS3054C oscilloscope.

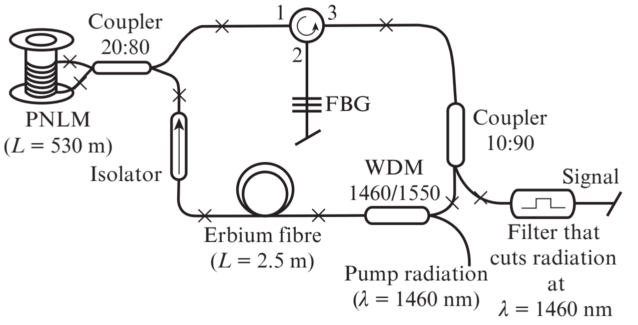

Figure 3. Scheme of the laser with the PNLM and the radiation wavelength stabilised by the FBG.

3. Experimental results

Employment of a FBG with the reflection spectral width of 0.5 nm did not admit realisation of the mode-locking regime. At a low pump power, the laser operated in the cw regime at a wavelength of 1553 nm; at a higher pump power, pulsations of the output power were observed. The absence of mode-locking is, probably, related to an insufficient number of modes generated in the laser system. From Fig. 2 one can see that if stable generation is established, the output spectrum has a wide 'base' (at a level of 20 dB the spectral width is several nm) that will be completely 'cut-off' by the narrow-band grating. The replacement of a narrow-band FBG by a FBG with the reflection spectrum width of 1.7 nm allowed one to realise the self-starting pulsed regime; however, the pulse repetition rate did not correspond to the round-trip time of laser cavity, and generation was unstable. One may assume that the low spectral selectivity of the FBG prevented proper stabilisation of the radiation wavelength and lasing might occur at several wavelengths simultaneously.

Simultaneous employment of two FBGs ('wideband' and 'narrowband') placed one after another makes it possible to obtain a wide reflection spectrum and provide the maximal reflection in a sufficiently narrow spectral range. In the scheme with two FBGs, the single-pulse regime of laser generation was successfully realised. As in [9, 10], the pulse was rectangular in shape (see the inset in Fig. 4a). The pulse durations as well as their average and peak powers increased with increasing pump power. Dependences of the output power and pulse duration on the pump power are presented in Fig. 4a. The pulse repetition rate was 382 kHz and corresponded to the round-trip time of the laser cavity. A spectrum of laser radiation detected by the spectrum analyser with a resolution of 0.02 nm in the spectral range of 1551 – 1556 nm is shown in Fig. 4b. Precise measurements of the spectral width performed by using a scanning confocal interferometer (with the scanning range of 1500 MHz and resolution of 15 MHz) show that at a pulse duration of 24 ns and an output power of 240 μW, the emission spectrum has a width of $\sim 4 \times 10^{-4}$ nm

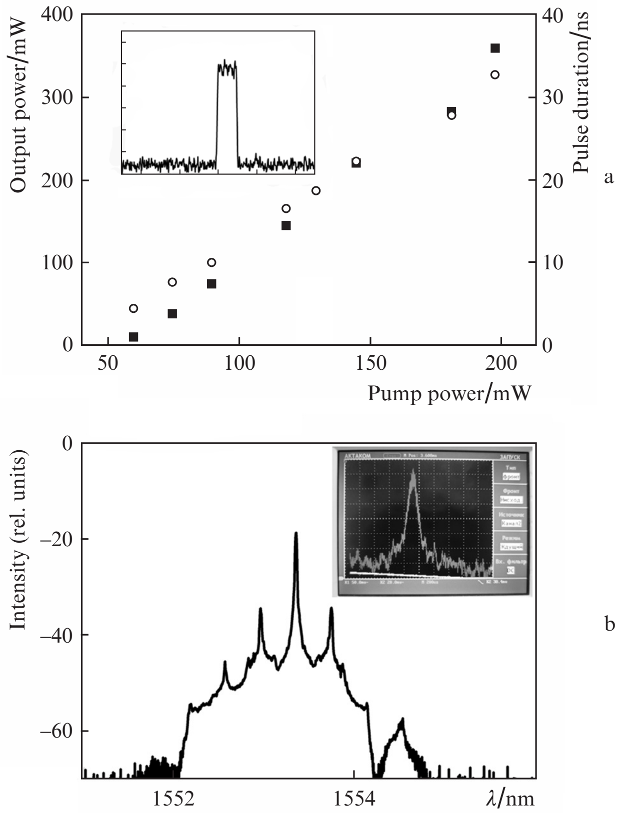

Figure 4. (a) Average power of output radiation (■) and pulse duration (○) vs. pump power (a typical oscillogram of the pulse is shown in the inset) and (b) spectrum of output radiation (the emission spectrum obtained by using a scanning confocal interferometer is shown in the inset).

(50 MHz), which corresponds to a transform-limited pulse duration.

Hence, it was shown that a radiation wavelength of the laser with the PNLM can be stabilised by using a system of fibre Bragg gratings. Realisation of such a scheme allowed us to establish that nanosecond pulses generated in a laser with the PNLM possessing normal dispersion are transform-limited.

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