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Picosecond holmium fibre laser pumped at 1125 nm

V.A. Kamynin, S.A. Filatova, I.V. Zhluktova, V.B. Tsvetkov

Abstract. **We report a passively mode-locked, all-fibre holmium laser based on nonlinear polarisation rotation. As a pump source use is made of an 1125-nm ytterbium-doped fibre laser. The pulse repetition rate of the holmium laser is 7.5 MHz, and the pulse duration does not exceed 52 ps at wavelengths of 2065 and 2080 nm. The average laser output power reaches 5 mW.**

Keywords: *fibre lasers, holmium fibre, passive mode locking, nonlinear polarisation rotation, generation of short pulses.*

1. Introduction

Holmium-doped fibre lasers are attractive sources for generating light with the largest wavelengths in silica fibres as compared with rare-earth-doped fibre lasers. Currently, laser wavelengths from 2030 to 2210 nm have been mastered [1 – 4]. Laser sources operating in this spectral range can be used in laser surgery [5], optical atmospheric communication, lidars [6] and in advanced communication systems based on hollow-core fibres [7 – 9]. Thus, the development and implementation of various schemes of lasers based on holmium fibres is an urgent task. One of the promising directions is the generation of short pulses. There are works in which mode locking is realised and, accordingly, short laser pulses are generated. For example, Chamorovskiy et al. [4, 10] described holmium fibre lasers based on semiconductor saturable absorber mirrors and single-wall carbon nanotubes, which made it possible to produce pulses of about 890 fs at a wavelength from 2030 to 2120 nm; however, these schemes are linear and contain bulk dichroic mirrors. Li et al. [11] demonstrated mode locking exploiting nonlinear polarisation rotation in holmium fibres. As a result, they produced pulses in the spectral range from 2040 to 2070 nm with an energy of 800 pJ and a duration of 920 fs. Unfortunately, this scheme was also not devoid of bulk elements. As a rule, an all-fibre scheme is most advantageous for improving stability and simplifying the design. This paper presents an all-fibre scheme of a mode-locked holmium laser.

V.A. Kamynin A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia; Ulyanovsk State University, ul. L. Tolstogo 42, 432017 Ulyanovsk, Russia; Photonics Laboratory, Perm Scientific Centre, Ural Branch of the Russian Academy of Sciences, ul. Lenina 13A, 614990 Perm, Russia; e-mail: kamyninva@gmail.com;
S.A. Filatova A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia; Ulyanovsk State University, ul. L. Tolstogo 42, 432017 Ulyanovsk, Russia;
I.V. Zhluktova A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia; Moscow Technological University (MIREA), ul. Stromynka 20, 107996 Moscow, Russia;
V.B. Tsvetkov A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, ul. Vavilova 38, 119991 Moscow, Russia; National Research Nuclear University 'MEPhI', Kashirskoe sh. 31, Russia, 115409 Moscow

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2. Experimental setup

The optical scheme of the experimental setup is shown in Fig. 1. As a pump source we used an ytterbium-doped fibre laser operating at a wavelength of 1125 nm. The diode-pumped ytterbium-doped laser made it possible to generate a cw output with a power from 1 to 10 W. The cavity of the laser in question consisted of active holmium-doped fibre pieces and an SM332 standard fibre segment. The active fibre was pumped through a fibre multiplexer operating in the range of 1125/2100 nm. To realise mode locking due to nonlinear polarisation rotation, we inserted two polarisation controllers and a fibre polariser into the cavity. A propagation direction of the generated light was selected by a fibre isolator operating around 2 μm; the loss of the laser light in the forward direction was equal to 0.6 dB and in the backward direction – to more than 30 dB. The laser light was coupled out of the cavity by a 9/1 coupler, which provided 90% output of the power. The active fibre doped with holmium ions was produced by MCVD and had a core/cladding refractive index difference of 0.007; the core diameter was 10 μm and the cutoff wavelength was 2 μm. The length of the active fibre in the cav-

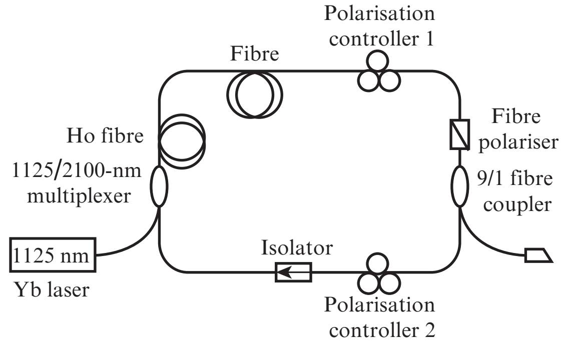

Figure 1. Scheme of the experimental setup.

ity varied from 4 to 6.3 m, and the cavity dispersion was evaluated to be –2.5 ps^2.

In measuring the output laser power, the unabsorbed part of the pump power was cut off by an optical filter suppressing the laser output over 30 dB in the spectral range of 1.5 μm. To accurately measure the pulse duration, the laser output was converted into the second harmonic in an optical lithium niobate crystal in order to fit into the working spectral range of the photodetector with a bandwidth of 10 GHz.

3. Experimental results

In the mode-locked regime we obtained a pulse train whose oscillogram is shown in Fig. 2. The pulse repetition rate was 132 ns, which corresponds to the round-trip time of the cavity. The spectrum of the output light with a centre wavelength of 2065 nm (Fig. 3) had a FWHM of 2.5 nm, which may correspond to the duration of ~2 ps for a transform-limited pulse. The presence of characteristic peaks in the output spectrum [12] and of anomalous dispersion in the cavity suggests that the holmium laser operates in the soliton regime. The laser output power was 4 mW, and the pulse repetition rate was 7.5 MHz. The pulse duration was measured in a scheme with frequency doubling, because we used a photodiode (10 GHz) operating in a range of 0.9–1.7 μm. The resulting oscillograms (Fig. 4) allow us to conclude that the pulse duration does not exceed 52 ps. Negative signals in the oscillogram are caused by a transient response of the electric path from the photodiode to the oscilloscope.

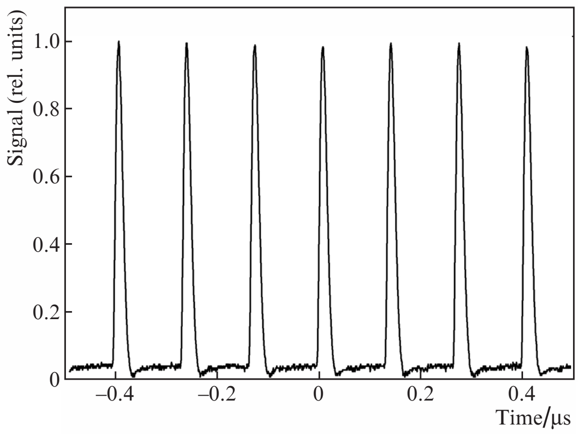

Figure 2. Oscillogram of output pulses.

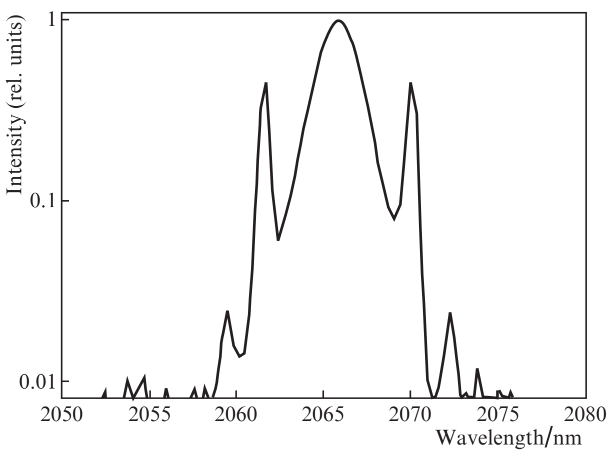

Figure 3. Emission spectrum of the output at a 4 m length of active fibre.

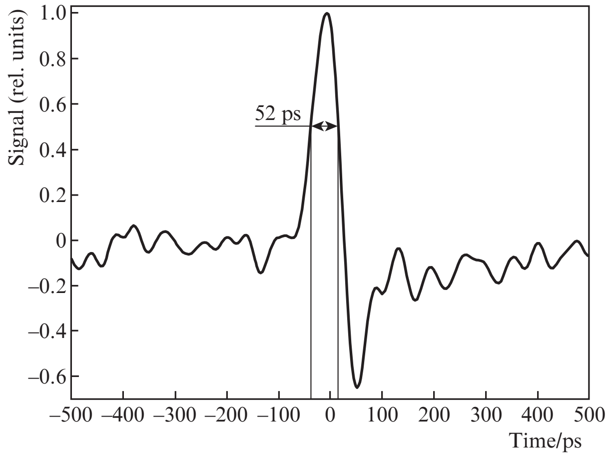

Figure 4. Oscillogram of the signal from the photodetector when fixing a single pulse.

With increasing length of the active fibre by 2 m, we obtained the same pulse duration and a slight increase in the repetition rate. In this case, the spectrum was shifted to the red by 15 nm; as a result, the centre wavelength was 2080 nm (Fig. 5). The output power was 2 mW. A shift to the red and a reduction in the average output power can be explained by reabsorption of the fibre doped with holmium ions at the emission wavelength.

At a slight increase in the pump power of the laser, we observed doubling of the pulse repetition rates from 7.5 to 15 MHz (Fig. 6). Thus, we can say that harmonic mode locking, like the one in papers [13, 14], is obtained in a holmium fibre laser.

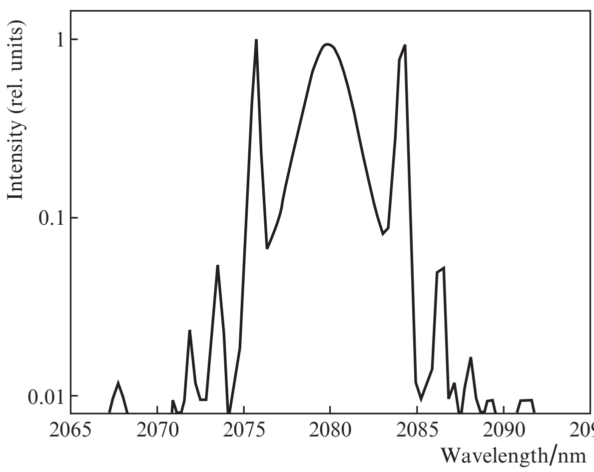

Figure 5. Emission spectrum of the output at a 6.3 m length of active fibre.

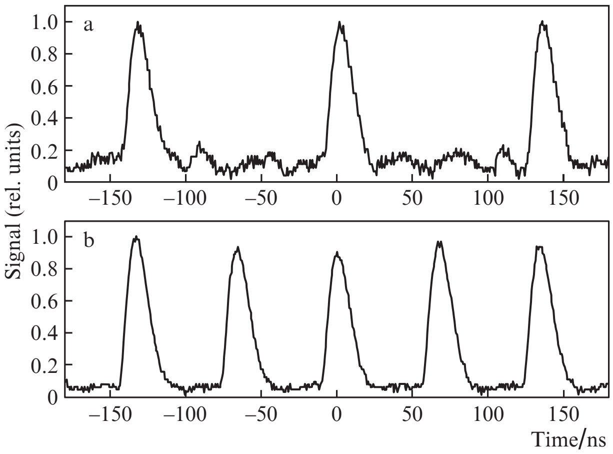

Figure 6. Oscillograms of pulse trains with a pulse repetition rate of (a) 7.5 and (b) 15 MHz.

Thus, we have developed a passively mode-locked, all-fibre holmium laser. Modulation was induced by nonlinear rotation of the polarisation ellipse. The resulting pulse repetition rate was 7.5 MHz, the duration was no more than 52 ps, and the average output power was 2–4 mW. By increasing the length of the active fibre we have demonstrated the possibility of changing the centre wavelength of the laser light from 2065 to 2080 nm. The harmonic mode locking is obtained with frequency doubling from 7.5 to 15 MHz.

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