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Holmium-doped fibre amplifier operating at 2.1 μm

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Abstract. **A small-signal holmium-doped fibre amplifier is demonstrated. The seed source is a cw holmium-doped fibre laser whose output power is modulated by an electro-optical modulator. The maximum gain reached (wavelength, 2.1 μm; power, 0.25 mW; pulse duration, 100 ns; pulse repetition rate, 1 μs) is 28.5 dB.**

Keywords: *holmium-doped fibre laser, fibre amplifier, two micron spectral region.*

1. Introduction

With the advent of holmium-doped fibre lasers, a number of efficient radiation sources have been created at wavelengths slightly above 2 μm, which are of interest for medical applications and atmospheric communications. To date, a number of holmium-doped fibre oscillators have been demonstrated, including lasers with emission wavelengths from 2.02 [1] to 2.21 μm [2], tunable fibre lasers [3, 4], cw fibre lasers with output powers of up to 400 W [5], pico- and femtosecond pulsed lasers [6, 7] and holmium fibre lasers with a quantum efficiency of 0.81 [8].

In addition, a pulsed holmium fibre laser/holmium fibre amplifier configuration was recently demonstrated [9]. The amplifier was pumped by a cw ytterbium fibre laser at 1.12 μm and was used to amplify pulses of a self-*Q*-switched holmium fibre laser. Unfortunately, the pulses generated in this regime had a rather long duration, up to 2.5 μs, with the inverse of their duty cycle as small as about 3. Moreover, the input signal of the amplifier had a rather high average power. At an average signal power of 18 mW, the gain was 18.5 dB. The highest average output power of the fibre amplifier was 1.65 W at an input signal power of 35 mW. The slope efficiency with respect to the absorbed pump power of the ytterbium fibre laser was 23%.

This paper examines the amplification of a small 2.1-μm signal amplitude-modulated by an electro-optical modulator.

2. Experimental setup

The configuration used in our experiments (Fig. 1) comprised a master oscillator and fibre amplifier. The master oscillator, in turn, incorporated a cw holmium fibre laser end-pumped at 1.12 μm by an ytterbium fibre laser, an optical isolator, a Sm^{3+}-doped fibre segment and an electro-optical modulator. The holmium fibre laser in the master oscillator provided cw 2.1-μm radiation. The Sm^{3+}-doped fibre segment, 1.5 m in length, was used to filter off the residual 1.12-μm pump radiation. The cw holmium fibre laser output was modulated by an electro-optical fibre modulator manufactured at Perm Research and Production Instrument Co. The duration of the resultant pulses reached 100 ns, and their period was 1 μs. Thus, the inverse of the duty cycle of the master oscillator was 10, which exceeded the value obtained with a self-*Q*-switched holmium fibre laser by more than a factor of 3. The average output power of the master oscillator was reduced to 0.25 W. To suppress oscillation in the amplifier, a fibre-optic isolator with a reverse loss of 21 dB and forward loss within 0.6 dB was placed before a multiplexer which combined the ytterbium-doped fibre pump laser output at 1.12 μm and the pulses being amplified.

In our experiments, a number of active fibres similar in holmium concentration (around 5×10^{19} cm^{-3}), with their length

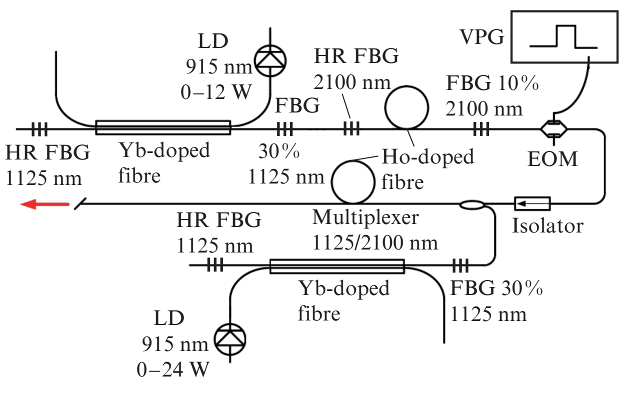

Figure 1. Schematic of the holmium fibre amplifier with a master oscillator generating weak optical signals: (HR FBG) high-reflectivity fibre Bragg grating, (LD) pump laser diode, (VPG) voltage pulse generator, (EOM) electro-optical modulator.

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optimised for reaching the highest gain, were used in the fibre amplifier. In all cases, the active fibre was pumped by the ytterbium fibre laser, the cutoff wavelength of the fibres was ~2 μm, and the core – cladding index difference was 0.01.

3. Results

Varying the active dopant concentration and optimising the fibre length at a given pump power, we were able to obtain a larger gain coefficient than had been reported previously. In particular, in the case of a holmium-doped fibre with an ion concentration of 5×10^{19} cm^{-3}, the average power of the amplified signal reached 175 mW at an input signal power of 0.25 mW, which corresponded to a gain coefficient of 28.5 dB.

Examining the effect of active fibre length on the gain indicated that the maximum gain coefficient was ensured by a fibre length of 3.5 m. Figure 2 shows the gain coefficient as a function of absorbed pump power for fibre with a holmium concentration of 5×10^{19} cm^{-3}, and Fig. 3 shows oscilloscope traces of amplified pulses at different absorbed pump powers.

Thus, a small-signal gain of 28.5 dB was reached at an average input power of 0.25 mW. The average power at the amplifier output was 175 mW. Analysis of the output signal spectrum leads us to conclude that using a fibre-optic isolator and angle cleaving the output end face of the active fibre in the amplifier were effective in preventing oscillation in the holmium-doped fibre amplifier.

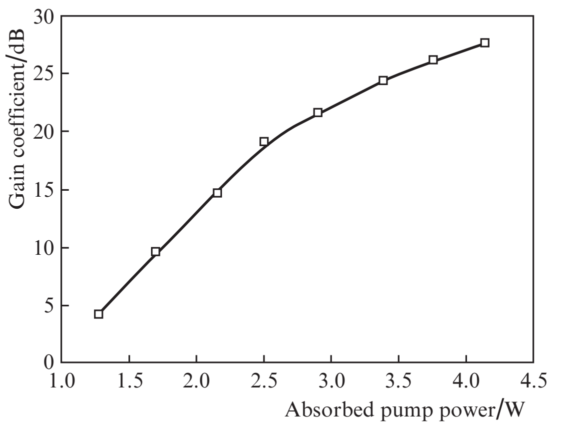

Figure 2. Gain coefficient as a function of absorbed 1.12 μm pump power at an input signal power of 0.25 mW, signal wavelength of 2.1 μm and holmium concentration of 5×10^{19} cm^{-3} in the fibre.

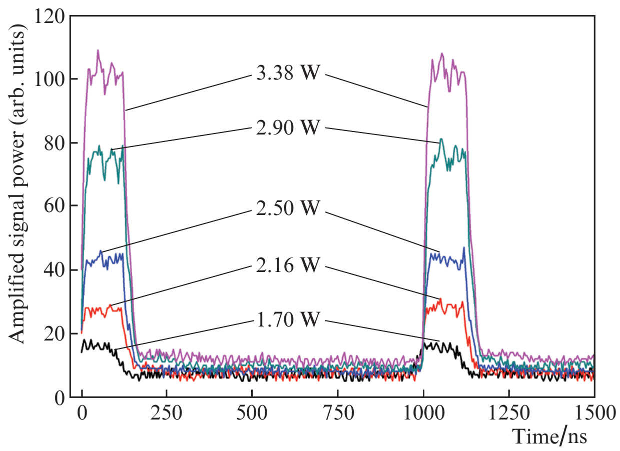

Figure 3. Oscilloscope traces of amplified pulses at five absorbed pump power values.

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