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Q-switching of a thulium-doped fibre laser using a holmium-doped fibre saturable absorber

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Abstract. **We have proposed and demonstrated a new passively *Q*-switched thulium-doped fibre laser configuration. A distinctive feature of this configuration is the use of a heavily holmium-doped fibre for *Q*-switching. Lasing was obtained at 1.96 μm, with a pulse energy of 3 μJ and pulse duration of 600 ns. The highest pulse repetition rate was 80 kHz.**

Keywords: *fibre laser, Q-switching.*

1. Introduction

Pulsed fibre lasers are of considerable interest because they allow high peak powers and energies to be obtained at relatively low pump powers and can find application in materials processing, medicine, laser radar systems, etc. Such applications require various laser wavelengths, pulse durations and pulse repetition rates. To date, a number of pulse generation methods have been proposed, using both mode locking and *Q*-switching of lasers. One approach for *Q*-switching a fibre laser is passive *Q*-switching using a fibre saturable absorber [1]. This approach has the advantage that it is easy to implement in an all-fibre configuration, which significantly facilitates both the fabrication and use of such lasers.

Pulsed operation of fibre lasers (and other lasers) can be obtained by fitting the laser cavity with an element having a nonlinear absorption in the lasing range. The relaxation of excited absorber ions to the ground level may follow various paths. Tordella et al. [2] demonstrated a neodymium-doped fibre laser *Q*-switched by Cr^{4+}-doped fibre, and Fotiadi et al. [3] reported an ytterbium laser with a Sm^{3+}-doped fibre absorber. In both cases, the relaxation of the absorber ions was due to a nonradiative transition. Dvoyrin et al. [4] studied an ytterbium-doped laser *Q*-switched by a bismuth-doped fibre. The relaxation of the bismuth ions was due to intrinsic lasing in the absorber. An erbium-doped fibre laser with a heavily thulium-doped fibre absorber was demonstrated by Kurkov et al. [5]. In that study, the relaxation of a significant fraction of the absorber ions was due to ion–ion interaction.

Jackson [6] made an attempt to achieve pulsed operation of a thulium-doped fibre laser using holmium-doped fibre for *Q*-switching. The laser configuration was based on discrete components and contained no wavelength-selective components. The holmium-doped fibre was inserted at the output of the thulium-doped fibre laser. Lasing was observed at several wavelengths, typical of both thulium and holmium lasers, so the configuration used is rather difficult to interpret as a thulium laser.

In this paper, we report a new passively *Q*-switched fibre laser configuration: a thulium-doped fibre laser with a holmium-doped fibre *Q*-switch located in a cavity formed by selective fibre Bragg reflectors. The concentration of absorber ions was taken to be high enough to ensure their relaxation via ion–ion interaction. It is worth noting that Kurkov et al. [7] used holmium-doped fibre for *Q*-switching a pulsed ytterbium- doped fibre laser. Such fibres were used as well for efficient lasing in the 2 μm range [8], at wavelengths of up to 2.21 μm [9].

2. Experimental

Figure 1 shows the configuration of the *Q*-switched thulium-doped fibre laser. The gain medium used was fibre doped with thulium ions to a concentration of about 5×10^{19} cm^{-3}. The fibre length in the cavity was 2 m, which ensured pump absorption at the level of 30 dB. The core diameter of the active fibre was about 10 μm. Thulium ions in silica glass have a $^3F_4 \rightarrow {}^3H_6$ optical transition, which ensures lasing in the range 1.85–2.05 μm. In our case, the laser wavelength (1.96 μm) was determined by fibre Bragg gratings (FBGs) that formed the cavity and differed in reflectance R. Pumping the thulium-doped fibre laser ensured the $^3H_6 \rightarrow {}^3H_5$ transition (1.2 μm). A similar approach was used previously [10]. As a pump source, we used a single-stage Raman laser based on SMF-28 standard single-mode fibre. The Raman laser was in turn pumped by an ytterbium-doped fibre laser emitting at a wavelength of 1.13 μm.

Q-switching was ensured by a section of fibre doped with holmium ions to a concentration of 3×10^{20} cm^{-3}, which was inserted between the input grating and thulium-doped fibre and had a core diameter of about 10 μm. Its length was 5 cm, which ensured an absorption level of about 10 dB at the laser wavelength. At this fibre length, the absorption at 1.96 μm, due to the $^5I_8 \rightarrow {}^5I_7$ transition, was about 10 dB. The fraction

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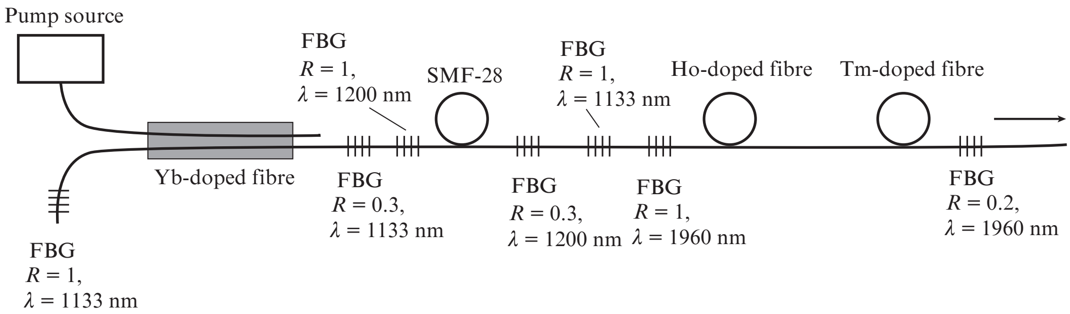

Figure 1. *Q*-switched thulium-doped fibre laser configuration.

of holmium ions in clusters that relaxed nonradiatively via ion–ion interaction was about 30% [11].

3. Results and discussion

At an absorber length of 5 cm, the lasing threshold was 700 mW. Lasing occurred at a wavelength of 1.96 μm, determined by the Bragg gratings. The emission spectrum (Fig. 2) was measured with an Avesta-Proekt ASP-IR spectrometer. The laser emission linewidth was about 0.5 nm, approaching the resolution of the spectrometer.

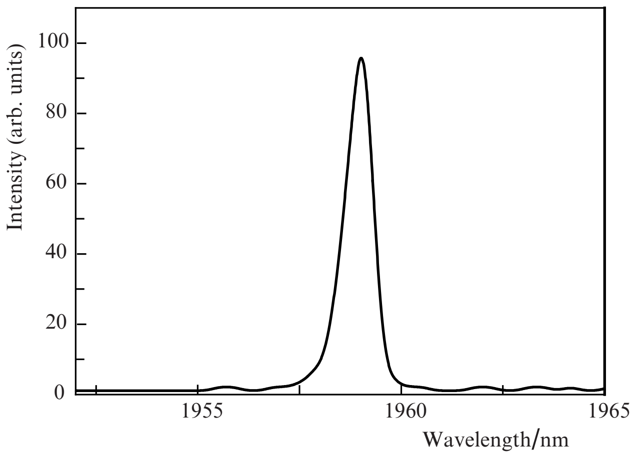

Figure 2. Emission spectrum of the thulium-doped fibre laser.

Dynamic characteristics were studied using an InGaAs photodetector, which had a spectral range from 1.2 to 2.6 μm and frequency response up to 15 MHz. Figure 3 shows a characteristic sequence of pulses at the output of the laser. The pulse repetition rate was found to increase linearly with increasing pump power, reaching 80 kHz at the highest pump power in this study, 2.1 W. The pulse duration was 600 ns.

Figure 4 shows the average output power as a function of pump power. The slope efficiency is 17%, and the maximum average power is 235 mW. The pulse energy was estimated at 3 μJ, and the peak power, at 5 W. The ratio of the pulse repetition time to the pulse duration is about 20, suggesting that there is considerable potential for raising the pulse energy and peak power by using an amplifier. Note that the energetic characteristics can be improved by using pump wavelengths near 0.8 or 1.55 μm, because under pumping at 1.2 μm the efficiency drops because of the effect of excited state absorption.

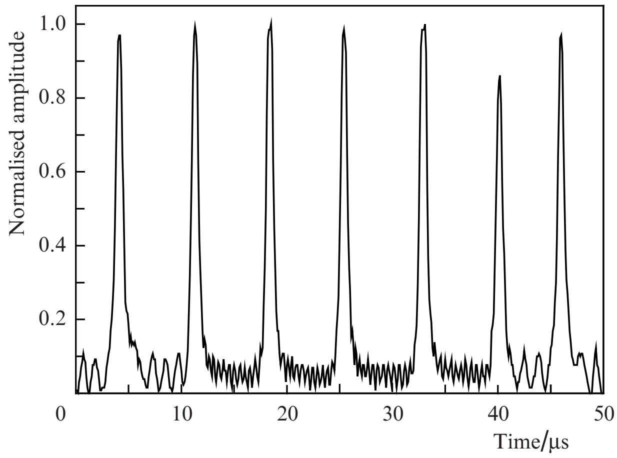

Figure 3. Sequence of pulses generated by the thulium-doped fibre laser.

In conclusion, compare the energetic characteristics of the described laser to those obtained with other absorbers, e.g. those based on graphene layers. A typical pulse duration in such fibre lasers is several microseconds, and the output pulse energy is tens of nanojoules [12]. Therefore, the proposed configuration compares well to widespread *Q*-switching techniques.

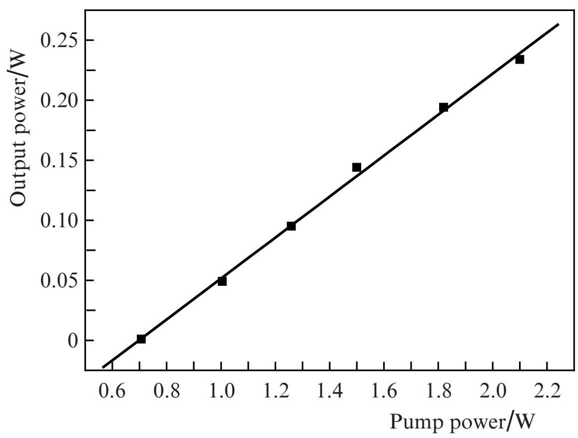

Figure 4. Average output power as a function of pump power for the thulium-doped fibre laser.

Thus, we have proposed and demonstrated a new passively Q-switched thulium-doped fibre laser configuration, which utilises a heavily holmium-doped fibre for Q-switching. In this configuration, the relaxation of a significant fraction of the absorber ions is due to ion–ion interaction.

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References

1. Kurkov A.S. *Laser Phys. Lett.*, **8**, 335 (2011).
2. Tordella L., Djellout H., Dussardier B., Saissy A., Monnom G. *Electron. Lett.*, **39**, 1307 (2003).
3. Fotiadi A.A., Kurkov A.S., Razdobreev I.M. *Proc. Conf. Lasers Electro-Optics* (Baltimor, OSA, 2005) p. 515.
4. Dvoyrin V.V., Mashinsky V.M., Dianov E.M. *Opt. Lett*., **32**, 451 (2007).
5. Kurkov A.S., Sadovnikova Ya.E., Marakulin A.V., Sholokhov E.M. *Laser Phys. Lett*., **7**, 795 (2010).
6. Jackson S.D. *Appl. Opt*., **46**, 3311 (2007).
7. Kurkov A.S., Sholokhov E.M., Medvedkov O.I. *Laser Phys. Lett.,* **6**, 135 (2009).
8. Kurkov A.S., Sholokhov E.M., Tsvetkov V.B., Marakulin A.V., Minashina L.A., Medvedkov O.I., Kosolapov A.F. *Kvantovaya Elektron*., **41**, 492 (2011) [*Quantum Electron*., **41**, 492 (2011)].
9. Antipov O.S., Kamynin V.A., Medvedkov O.I., Marakulin A.V., Minashina L.A., Kurkov A.S., Baranikov A.V. *Kvantovaya Elektron*., **43**, 603 (2013) [*Quantum Electron*., **43**, 603 (2013)].
10. Kravtsov K.S., Bufetov I.A., Medvedkov O.I., Dianov E.M., Yashkov M.V., Gur'yanov A.N. *Kvantovaya Elektron*., **35**, 586 (2005) [*Quantum Electron*., **35**, 586 (2005)].
11. Kurkov A.S., Sholokhov E.M., Marakulin A.V., Minashina L.A. *Kvantovaya Elektron*., **40**, 386 (2010) [*Quantum Electron*., **40**, 386 (2010)].
12. Ismail M.A., Ahmad F., Harun S.W., Arof H., Ahmad H. *Laser Phys. Lett*., **10**, 025102 (2013).