PACS numbers: 42.55.Wd; 42.55.Rz; 42.60.Fc
DOI: 10.1070/QE2009v039n05ABEH013884

High-energy pulsed fibre laser based on a two-fibre assembly

S.M. Kobtsev, S.V. Kukarin, Yu.S. Fedotov

***Abstract*. We demonstrate for the first time a relatively simple fibre laser system with a passively *Q*-switched master oscillator and a polarised output pulse energy of up to 110 μJ at 1080 nm. The system is pumped by a single 12-W multimode cw source at 980 nm. Depending on the pump power, the pulse duration varies from 280 ns to 1.8 μs and the pulse repetition rate, from 45 to 140 kHz. The maximum average output power is 5 W. The system has been tested for its performance in metal and glass processing.**

Keywords: *ytterbium-doped fibre laser, Q-switching, two-fibre assembly, fibre amplifier.*

1. Introduction

Lasers with a relatively high pulse energy (0.1 – 1 mJ and above) are used in a variety of applications, including material processing (laser marking etc.). Many such radiation sources are based on solid-state lasers (Nd : YAG/YVO_4, Yb : YAG, Nd : YLF and others) [1, 2], including hybrid bulk/fibre systems [3]. At the same time, considerable effort is focused on alternative solutions, such as fibre-laser-based sources [4 – 10]. To achieve high pulse energies, such systems usually take advantage of master oscillator/power amplifier (MOPA) configurations, with separate pump sources for the master oscillator and amplifier in most all-fibre systems. This is because fibre couplers are incapable of operating at high beam powers and, accordingly, cannot ensure delivery of a small fraction of the output of a high-power pump source to the master oscillator. For this reason, the fibre master oscillator is typically pumped by a separate, relatively low-power source, and the amplifier is pumped by one or several [9, 10] high-power sources.

A *Q*-switched MOPA fibre system with a single pump source was first demonstrated by Paschotta et al. [11]. A 980-nm cw Ti : sapphire laser beam was launched into an Er-doped fibre amplifier, and the residual pump light from the amplifier was used to pump the Er-doped fibre oscillator. At a single-mode pump power of 2.1 W, the pulse energy was up to 0.11 mJ with a repetition rate below 10 kHz and an average output power of 190 mW. The drawback to this system is that the amplifier gain must be restricted to ensure a residual pump power sufficient to pump the master oscillator. In this paper, we describe for the first time an alternative approach to designing MOPA systems with a single pump source. In the configuration proposed by us, pump light is first coupled into the master oscillator, and the residual pump power from the oscillator is used to pump the amplifier. As demonstrated below, this approach can be realised with a side-pumped two-fibre assembly (so-called GTWay fibre [12, 13]), which can be used to fabricate both an amplifier and a master oscillator.

The two-fibre arrangement, with one active fibre [12], enables a simple and efficient side pumping of the active fibre using a standard passive silica fibre. The pump light is transferred from the cladding of the passive fibre to that of the active fibre because the fibres are in optical contact throughout their length. At typical ion (e.g. Yb) concentrations in the active fibre, its (optimal) length must be 20 – 25 m for $\sim 90\,\%$ of launched pump power to be absorbed. With a shorter active fibre section, the 'excess' pump power can be used in the amplifier stage (or several stages) of the system. Therefore, the oscillator fibre can be shorter, and the residual pump power from the oscillator can be coupled into the analogous two-fibre assembly of one or several amplifier stages.

Such a system, based on a passively *Q*-switched fibre laser, is demonstrated for the first time and tested experimentally in this work.

2. Experimental

Our experimental setup is shown schematically in Fig. 1. The master oscillator was made using a two-fibre (Yb/silica glass) assembly 3 or 5 m in length, with the active fibre core 7 μm in diameter and the active (Yb) and passive (silica) fibre claddings 125 μm in diameter. The beam was coupled into and outcoupled from the active fibre using microscope objectives. Passive *Q*-switching was ensured by a semiconductor saturable absorber mirror with a modulation depth of 15 % at 1080 nm. The beam was focused onto this mirror by a lens with a focal length of 100 mm. A polarising cube beamsplitter acted as the output coupler of the laser and ensured linear polarisation of the oscillator output. The orthogonally polarised beam reflected from the beamsplitter was redirected to the cavity by a highly reflective mirror.

Figure 2 shows a typical pulse shape obtained with our system. The pulse is seen to be modulated by multiple, relatively small peaks with a spacing equal to the cavity

S.M. Kobtsev, S.V. Kukarin, Yu.S. Fedotov Novosibirsk State University, ul. Pirogova 2, 630090 Novosibirsk, Russia;
e-mail: kobtsev@lab.nsu.ru

Received 18 April 2008; revision received 19 October 2008
Kvantovaya Elektronika **39** (5) 417 – 420 (2009)
Translated by O.M. Tsarev

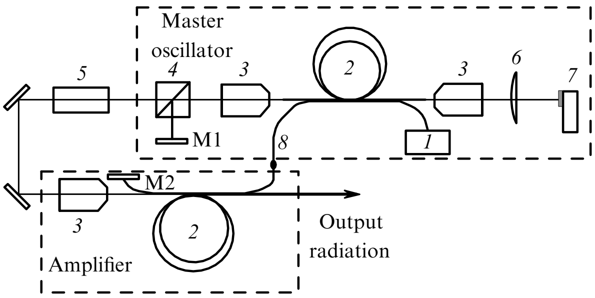

Figure 1. Schematic of a fibre laser based on a two-fibre assembly: (*1*) pump diode; (*2*) two-fibre assembly; (*3*) microscope objective; (*4*) polarising beamsplitter; (*5*) Faraday isolator; (*6*) focusing lens; (*7*) saturable absorber mirror; (*8*) splice between the passive silica pump fibres; M1 and M2 are highly reflective mirrors for the master oscillator and pump beams, respectively.

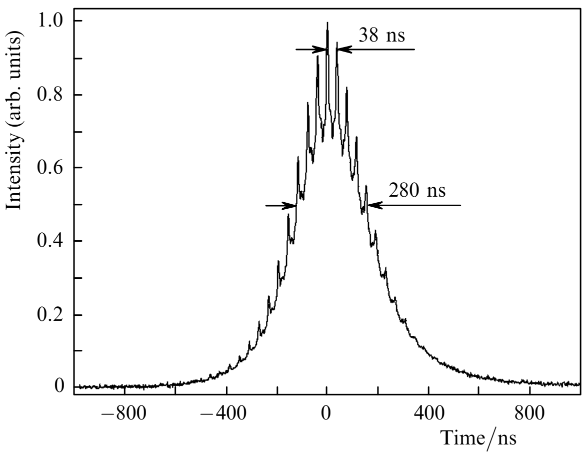

Figure 2. Pulse shape obtained with the laser system (satellite spacing, 38 ns).

round-trip time (38 ns for the master laser with a cavity length of ~ 5 m). The width of the satellite peaks is within 10 ns, and they point to partial mode locking. We failed to achieve complete mode locking in the laser system under consideration.

Passively Q-switched laser operation was sufficiently stable over the entire range of oscillator output powers (up to 200 mW). Changes in the laser output power were accompanied by changes in the pulse duration and repetition rate. Figure 3 shows these parameters as functions of the oscillator output power. The pulse duration varied from 1.8 μs to 280 ns at the maximum output power, and the pulse repetition rate varied from 45 to 140 kHz, respectively. The master oscillator (and the entire system) was pumped by a 12-W multimode laser diode ($\lambda_p = 980$ nm) coupled to a 116/125 μm fibre. The output beam was launched into the passive fibre of the two-fibre assembly through a splice. Because of the small length of the master oscillator, it absorbed a small fraction of the pump power (2–3 W), and the rest was coupled into the passive fibre of the amplifier assembly. The oscillator output was launched into the active fibre of the amplifier using a microscope objective. The average output power of the amplifier was up to 5 W, which corresponded to an output pulse energy of 36 μJ at the maximum repetition rate (140 kHz) or 110 μJ at the minimum repetition rate (45 kHz).

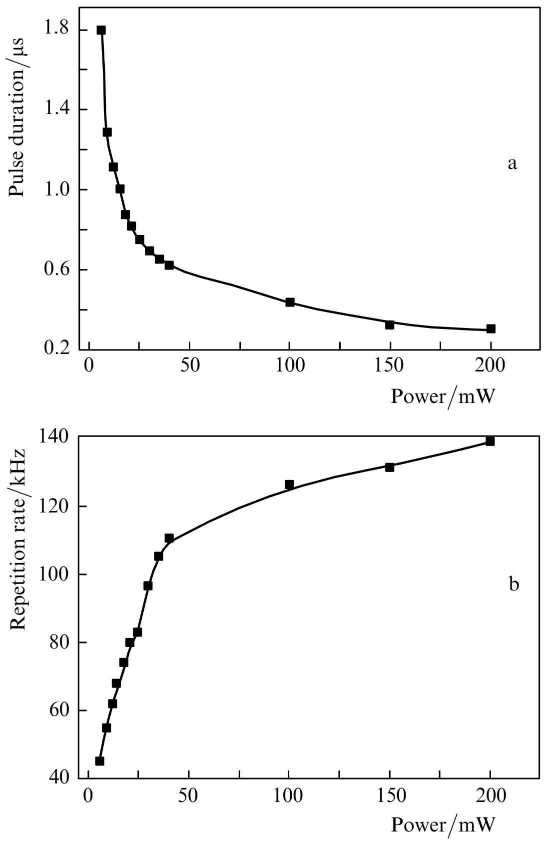

Figure 3. (a) Pulse duration and (b) pulse repetition rate as functions of the oscillator output power.

When the average output power exceeded 5 W, the laser operation was unstable because of the incomplete optical isolation between the master oscillator and amplifier. The input/output fibre ends were perpendicularly cleaved. At relatively high beam powers, this facilitated the formation of a coupled-cavity system even though a single-stage Faraday isolator was used between the master oscillator and amplifier. As a result, the pulse sequence contained irregular, higher power pulses. Figure 4 shows a typical temporal distribution of the output intensity in the unstable lasing regime. The temporal distribution of the output intensity for higher power, irregular pulses differs from that for pulses generated during steady-state operation by the larger amplitude of the closely spaced satellite peaks at the top of the pulse.

When the average output power was below 5 W, stable pulse generation was obtained at any beam power. The amplifier did not change the beam polarisation, even though the active fibre used in it was not polarisation maintaining. Nevertheless, the amplifier output was linearly polarised, which opens up the possibility of nonlinear spectral conversion of radiation in this laser system.

3. Application in metal and glass processing

Owing to the relatively high pulse energy in the described system (up to 110 μJ), it can be used for laser marking (engraving) of both metal and glass surfaces. Figure 5 shows surfaces that were exposed to a focused beam with a pulse energy from 30 to 50 μJ. The beam was focused by an 8×0.2 microscope objective. The exposure produced

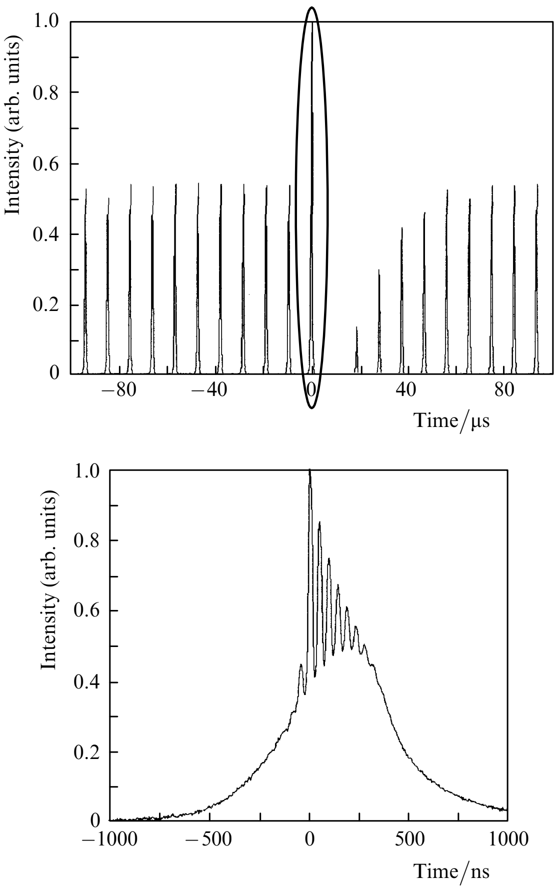

Figure 4. Temporal distribution of the laser output intensity in the unstable lasing regime due to optical feedback between the master oscillator and amplifier at high output powers.

microstructural changes on the stainless steel and chalcogenide glass surfaces, associated with local melting and evaporation of the surface layer. Note that, under certain processing conditions, we observed short-term output power modulation (at a level of 15 % to 25 %) because some of the radiation reflected from the surface being processed reached the amplifier and, possibly, the master oscillator. The modulation, however, did not produce any irreversible changes in the performance of the laser system.

4. Conclusions

We have demonstrated for the first time a relatively simple passively *Q*-switched fibre laser system with a polarized output pulse energy of up to 110 μJ at 1080 nm, pumped by a single 12-W multimode cw source at 980 nm. Depending on the pump power, the pulse duration varies from 280 ns to 1.8 μs and the pulse repetition rate, from 45 to 140 kHz. The maximum average output power is 5 W. It is to be noted that the output power (and the pulse energy) of the laser system can be raised easily by using a Faraday isolator capable of ensuring better optical isolation between the master oscillator and amplifier.

The system was tested for its performance in metal and glass processing. The results suggest that the proposed fibre laser system, with a novel configuration and a single, relatively low-power cw source, is potentially attractive for laser marking (engraving) of materials and for other technologies where a comparatively high laser pulse energy is needed.

Acknowledgements. This work was supported by the Federal Agency for Science and Innovations (State Con-

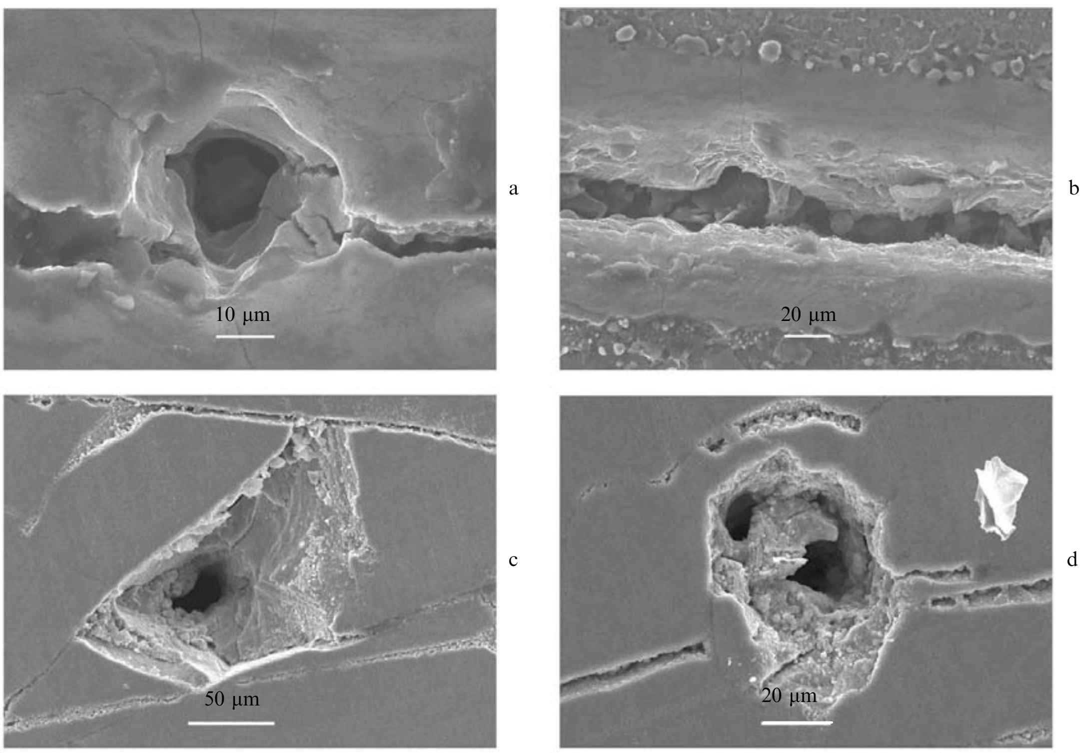

Figure 5. Electron micrographs illustrating microstructural changes produced by a focused laser beam on the surface and in the near-surface region of (a, b) stainless steel and (c, d) a chalcogenide glass.

tract No. 02.513.11.3360) and the RF President's Grants Council for Support to Leading Scientific Schools (scientific school headed by Corresponding Members of the Russian Academy of Sciences A.M. Shalagin and S.G. Rautian).

References

1. Gower M.C. *Opt. Express*, **7**, 56 (2000).
2. Steen W.M. *Laser Material Processing* (London – Berlin – Heidelberg: Springer-Verlag, 2003).
3. Salas-Montiel R., Bastard L., Grosa G., Broquin J. *Mater. Sci. Eng. B*, **149**, 181 (2008).
4. Richardson D.J., Britton P., Taverner D. *Electron. Lett.*, **33**, 1955 (1997).
5. Mackenzie J.I., Shepherd D.P. *Opt. Lett.*, **27**, 2161 (2002).
6. Cruz Vicente S.G., Martinez Gamez M.A., Kir'yanov A.V., Barmenkov Yu.O., Andres M.V. *Kvantovaya Elektron.*, **34**, 310 (2004) [*Quantum Electron.*, **34**, 310 (2004)].
7. Grukh D.A., Levchenko A.E., Kurkov A.S., Paramonov V.M. *Kvantovaya Elektron.*, **35**, 442 (2005) [*Quantum Electron.*, **35**, 442 (2005)].
8. Materials Processing with Fiber Lasers. http://www.ipgphotonics.com/apps_materials_lab.htm.
9. Roser F., Schimpf D., Schmidt O., Ortac B., Rademaker K., Limpert J., Tunnermann A. *Opt. Lett.*, **32**, 2230 (2007).
10. Tanigawa S., Tanaka H., Kitabayashi T., Saito M., Shimada N., Nakai M., Shima K., Sakai T., Shimokoshi K., Taya H. *Fujikura Techn. Rev.*, (36), 5 (2007).
11. Paschotta R., Haring R., Gini E., Melchior H., Keller U., Offerhaus H.L., Richardson D.J. *Opt. Lett.*, **24**, 388 (1999).
12. Grudinin A.B., Payne D.N., Turner P.W., Nilsson L.J.A., Zervas M.N., Ibsen M., Durkin M.K. Patent USA, No. 6826335, 30.11.2004.
13. Mel'kumov M.A., Bufetov I.A., Bubnov M.M., Shubin A.V., Semyonov S.L., Dianov E.M. *Kvantovaya Elektron.*, **35**, 996 (2005) [*Quantum Electron.*, **35**, 996 (2005)].