Education and Training in Optics and Photonics ETOP 2007 (Ottawa, Canada, June 3-5, 2007)

A passively Q-switched erbium-doped fiber laser using an unpumped erbium-doped fiber as a saturable absorber

Fang-Wen Sheu and Sheng-Lung Deng
Department of Applied Physics, National Chiayi University, Chiayi 60004, Taiwan
Tel: +886-5-2717993; Fax: +886-5-2717909; E-mail: fwsheu@mail.ncyu.edu.tw

Abstract: We experimentally demonstrated a stable passively Q-switched erbium-doped fiber laser system using an unpumped erbium-doped fiber as a saturable absorber. The pulse width will be reduced down and the pulse repetition rate will grow up as we increase the pump power. This is a simple and cheap laser system for producing a pulse train with good quality, and is suitable for exploring the phenomena of pulsed lasers in an optics experiment course.

OCIS codes: (140.3510) Lasers, fiber; (140.3540) Lasers, Q-switched

1. Introduction

Erbium-doped fiber (EDF) lasers are very popular light sources in fiber communication and fiber sensor systems. The EDF is often used as a gain medium to produce laser light at a wavelength of 1550 nm, which meets the requirement of least light loss in silica optical fiber. Usually a 980- or 1480-nm pump laser light should be coupled into the laser cavity through a wavelength division multiplexer (WDM) to excite the EDF and generate the population inversion necessary for the stimulated emission process of the EDF. From another point of view, if an EDF is not under pump, it could modulate the laser light intensity and thus might behave as a saturable absorber [1,2], which is frequently used in single-longitudinal-mode fiber laser systems [3,4] based on a standing-wave filtering effect. In this study, we try to construct a passively Q-switched erbium-doped fiber laser system using directly a single-passed unpumped EDF as a saturable absorber, and investigate the laser performance in the pulse width and the pulse repetition rate for the unpumped EDF with various lengths as a function of the pump power. The pulse-train output waveforms and their optical spectra were also measured and discussed.

The Q-switching methods of pulsed lasers may be active [5,6] or passive [7]. Nevertheless active Q-switched lasers often contain bulk modulating elements and delicate electronic drivers, making their systems very complicated. Several passively Q-switched lasers have been proposed, such as a laser with distributed backscattering [8], a laser with a gallium liquefying mirror [9], and a laser with a semiconductor saturable-absorber mirror [10]. Yet high pump powers are necessary in these laser systems. Therefore we propose in this paper a passively Q-switched laser system, which requires low pump power and consists of all-fiber components.

2. Experimental Setup and Results

2.1 One-WDM configuration

The schematic configuration of the first type of passively Q-switched fiber laser system with one WDM for producing a pulse-train output is shown in Fig. 1. A 980-nm laser diode (LD) is used as the pump light source, which is coupled into the ring laser cavity by a WDM. A first section of 10-m-long EDF serves as the gain medium, which will emit the light around 1550 nm under pump. An isolator is inserted in the ring cavity to ensure a unidirectional propagation of laser light, and also to filter away the majority of the residual 980-nm pump laser light because it has a band-pass range of 1530-1570 nm. Thereafter a second section of unpumped EDF with various lengths serves as the saturable absorber, which will absorb and modulate the laser light periodically. A fiber polarization controller must also be added into the laser cavity to adjust the polarization state of laser light in best resonance.

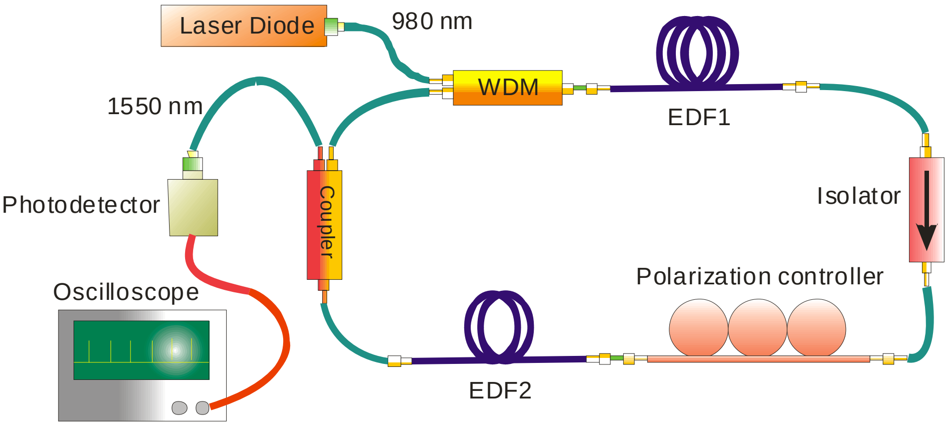


Fig. 1. The schematic configuration of the passively Q-switched fiber laser system with one WDM.

The obtained experimental results are shown in Fig. 2 and Fig. 3. The pulse width will be reduced down (Fig. 2, dashed curves) and the pulse repetition rate will grow up (Fig. 2, solid curves) as we increase the pump power. This observation is due to the fact that at higher pump powers the speed of the population inverting of the gain medium or the optical bleaching of the saturable absorber will be faster. Using a 1-m unpumped EDF as the saturable absorber, we cannot have a pulse-train output. This might be due to the fact that too short unpumped EDF cannot provide sufficient absorption modulation to start Q-switching. The pulse-train output waveforms and their optical spectra for 2-m, 3-m, and 5-m unpumped EDFs, respectively, are shown in Fig. 3. It is worth noting that at a longer unpumped EDF, the number of survived longitudinal modes will decrease and the pulse width will be broadened, since the absorption rate of an unpumped EDF at a longer length is stronger. In the other aspects, the peak intensity ratio (Fig. 3) is 1.0 : 4.4 : 3.1, for 2-m, 3-m, and 5-m unpumped EDFs, respectively. It elucidates that a suitable length of the unpumped EDF must be chosen to obtain a better laser output. In this case, the 3-m unpumped EDF is the best saturable absorber in this Q-switched fiber laser system.

The pulse width of the laser output is at the order of tens of μs because the lengths of the EDFs are at the order of several meters. If highly doped EDFs are used as the gain medium and the saturable absorber, the EDF lengths as well as the cavity length could be greatly shortened, and, as a consequence, the pulse width should be significantly reduced down [5].

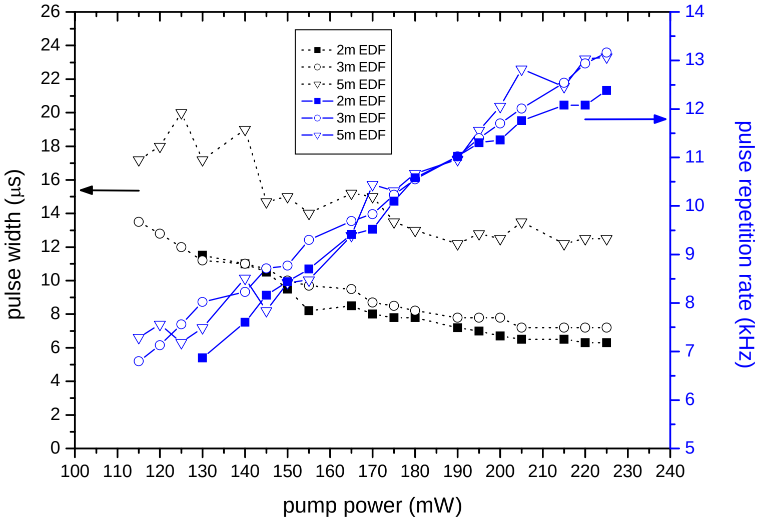
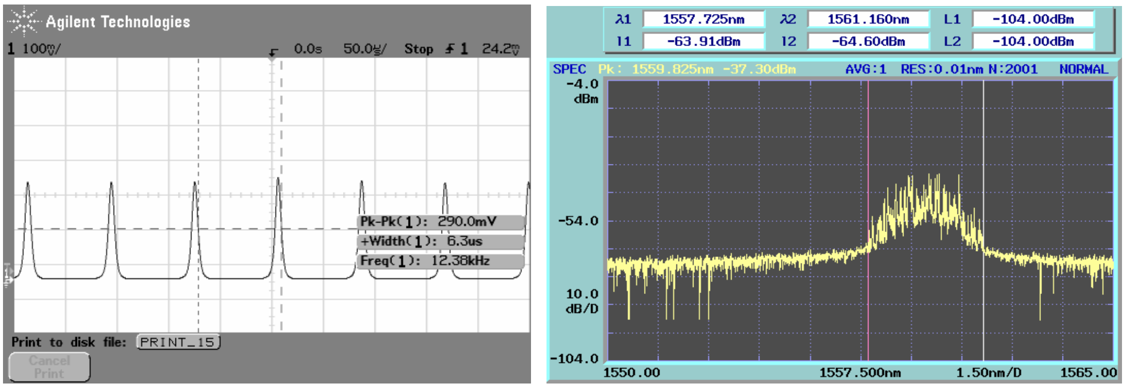


Fig. 2. The pulse width (dashed curves) and the pulse repetition rate (solid curves) versus the pump power for 2-m, 3-m, and 5-m unpumped EDFs, respectively, in one-WDM configuration.

(a) unpumped EDF length: 2 m, pump power: 225 mW, pulse width: 6.3 μs



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1 100㎷/          0.0s  50.0㎲/  Stop  ƒ 1  24.2㎷
Pk-Pk(1): 290.0mV
+Width(1): 6.3us
Freq(1): 12.38kHz
Print to disk file: PRINT_15
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λ1  1557.725nm   λ2  1561.160nm   L1  -104.00dBm
l1  -63.91dBm    l2  -64.60dBm    L2  -104.00dBm
SPEC  Pk: 1559.825nm -37.30dBm   AVG:1  RES:0.01nm N:2001  NORMAL
-4.0 dBm
-54.0
10.0 dB/D
-104.0
1550.00          1557.500nm    1.50nm/D     1565.00
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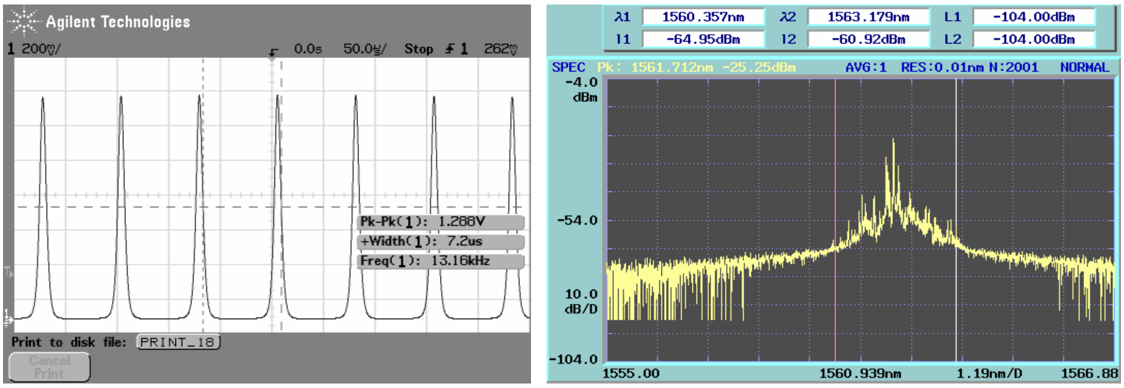
(b) unpumped EDF length: 3 m, pump power: 225 mW, pulse width: 7.2 μs



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1 200㎷/          0.0s  50.0㎲/  Stop  ƒ 1  262㎷
Pk-Pk(1): 1.288V
+Width(1): 7.2us
Freq(1): 13.16kHz
Print to disk file: PRINT_18
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```
λ1  1560.357nm   λ2  1563.179nm   L1  -104.00dBm
l1  -64.95dBm    l2  -60.92dBm    L2  -104.00dBm
SPEC  Pk: 1561.712nm -25.25dBm   AVG:1  RES:0.01nm N:2001  NORMAL
-4.0 dBm
-54.0
10.0 dB/D
-104.0
1555.00          1560.939nm    1.19nm/D     1566.88
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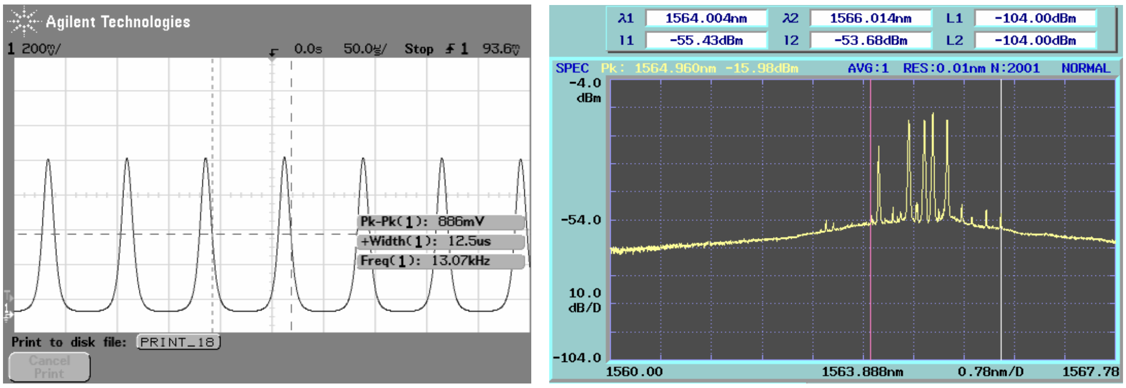
(c) unpumped EDF length: 5 m, pump power: 225 mW, pulse width: 12.5 μs



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1 200㎷/          0.0s  50.0㎲/  Stop  ƒ 1  93.6㎷
Pk-Pk(1): 886mV
+Width(1): 12.5us
Freq(1): 13.07kHz
Print to disk file: PRINT_18
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λ1  1564.004nm   λ2  1566.014nm   L1  -104.00dBm
l1  -55.43dBm    l2  -53.68dBm    L2  -104.00dBm
SPEC  Pk: 1564.960nm -15.98dBm   AVG:1  RES:0.01nm N:2001  NORMAL
-4.0 dBm
-54.0
10.0 dB/D
-104.0
1560.00          1563.888nm    0.78nm/D     1567.78
```

Fig. 3. The pulse-train output waveforms and their optical spectra for 2-m, 3-m, and 5-m unpumped EDFs, respectively, in one-WDM configuration. In the oscilloscope traces, the horizontal (temporal scan) unit is 50 μs per division. The vertical (detector voltage) unit for (a) is 100 mV per division, and that for (b) and (c) is 200 mV per division.

2.2 Two-WDM configuration

Though the isolator has the effect of filtering the residual pump laser light at a wavelength of 980 nm, yet there still was some pump laser light observed to survive in the cavity through the measurement of an optical spectrum analyzer. In another improved cavity configuration as shown in Fig. 4, we added another contra-directional WDM between the isolator and the polarization controller to filter all the residual pump laser light out of the cavity. This structure of fiber laser also generated stable passively Q-switched short pulse train by the similar mechanism analogous to the previous one.

The obtained experimental results were also alike. The pulse width will be reduced down (Fig. 5, dashed curves) and the pulse repetition rate will grow up (Fig. 5, solid curves) as we increase the pump power. Using a 1-m unpumped EDF as the saturable absorber, we also cannot have a pulse-train output. The only great difference is that when we use the 5-m unpumped EDF as the saturable absorber, no pulse-train output could be observed. This phenomenon might be due to the enhanced absorption of the totally unpumped EDF at a greater length. The pulse-train output waveforms and their optical spectra for 2-m and 3-m unpumped EDFs, respectively, are shown in Fig. 6, and are similar to those in the one-WDM configuration. In the two-WDM configuration, the Q-switched fiber laser using the 3-m unpumped EDF as the saturable absorber would also produce a more intense laser pulse by about 3 times than using the 2-m unpumped EDF. In Fig. 5, we also find that the threshold pump power (120 mW) to start Q-switching for the 3-m unpumped EDF is lower than that (150 mW) for the 2-m unpumped EDF. These observations elucidate again that a suitable length of the unpumped EDF must be chosen to obtain a better pulsed laser output. A strong enough, but not too strong, saturable-absorbing effect could provide the Q-switched fiber laser system with a more appropriate pulse formation mechanism.

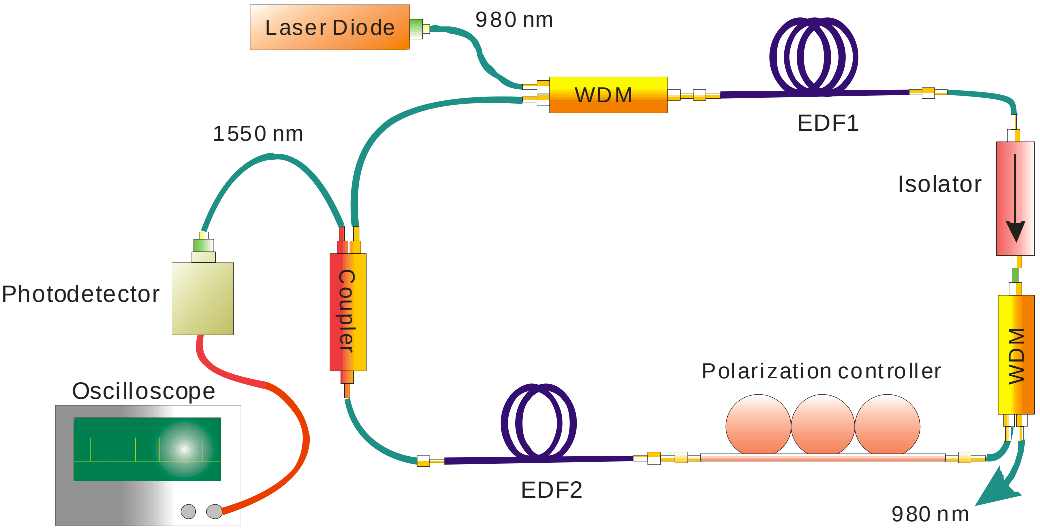


Fig. 4. The schematic configuration of the passively Q-switched fiber laser system with two WDMs.

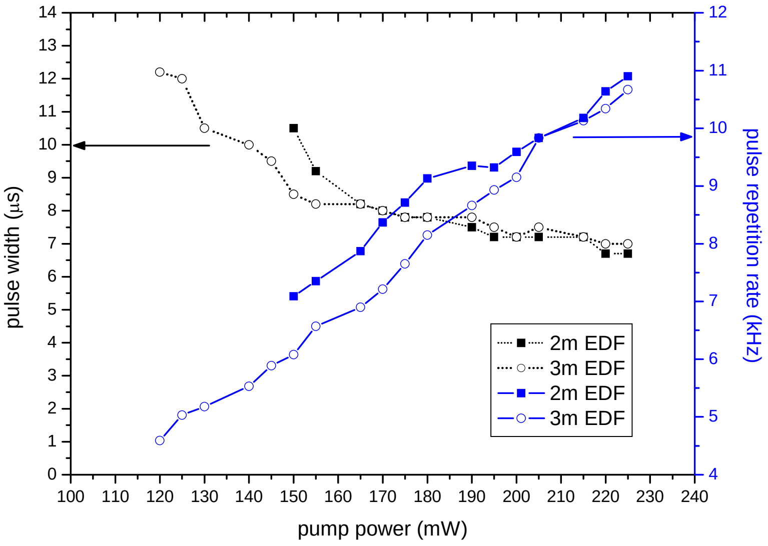
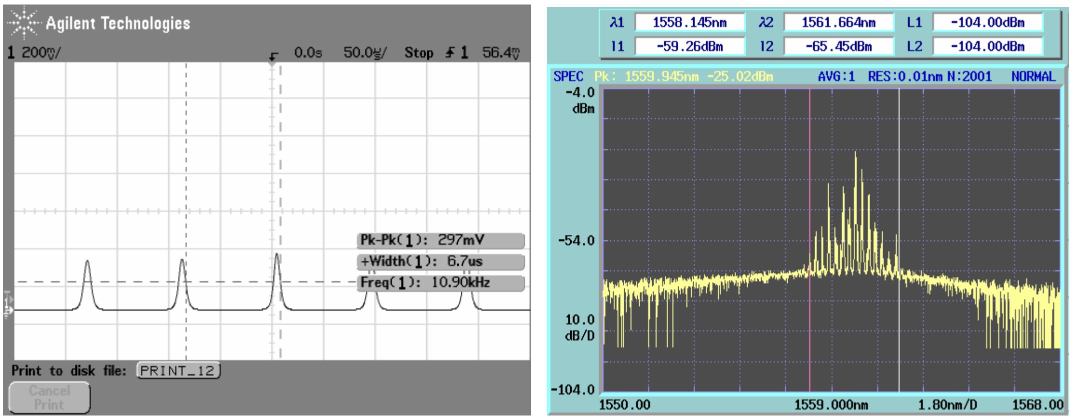


Fig. 5. The pulse width (dashed curves) and the pulse repetition rate (solid curves) versus the pump power for 2-m and 3-m unpumped EDFs, respectively, in two-WDM configuration.

(a) unpumped EDF length: 2 m, pump power: 225 mW, pulse width: 6.7 μs



(b) unpumped EDF length: 3 m, pump power: 225 mW, pulse width: 7.0 μs

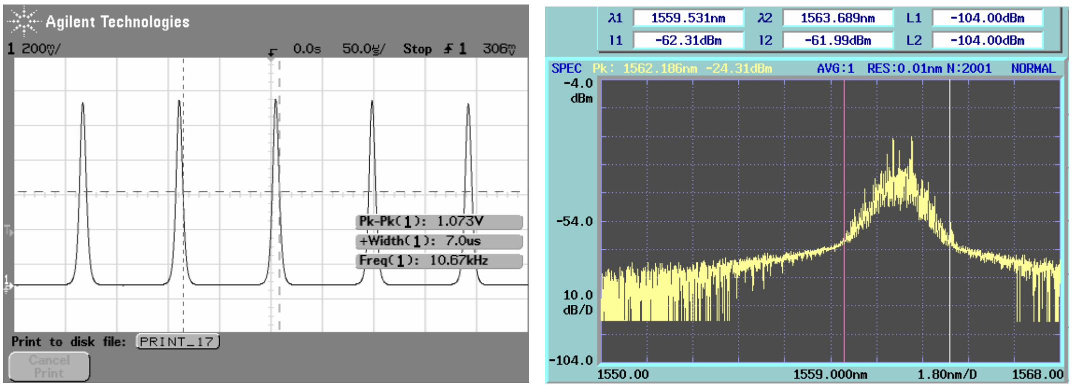


Fig. 6. The pulse-train output waveforms and their optical spectra for 2-m and 3-m unpumped EDFs, respectively, in two-WDM configuration. In the oscilloscope traces, the horizontal (temporal scan) unit is 50 μs per division and the vertical (detector voltage) unit is 200 mV per division.

3. Conclusion

Using an unpumped EDF as a saturable absorber, we experimentally demonstrated a stable passively Q-switched erbium-doped fiber laser system. The pulse width will be reduced down and the pulse repetition rate will grow up as we increase the pump power. This simple and cheap laser system has been shown capable of producing a pulse train with good quality, and it is very suitable for exploring the phenomena of passively Q-switched pulsed lasers in an optics experiment course.

Acknowledgements

We acknowledge the financial support from the National Science Council, Taiwan, through projects NSC-93-2112-M-415-004 and NSC-94-2815-C- 415-001-M.

References

[1] Y.W. Song, S.A. Havstad, D. Stradubov, Y. Xie, A.E. Willner, and J. Feinberg, "*40-nm-wide tunable fiber ring laser with single-mode operation using a highly stretchable FBG*", IEEE Photon. Technol. Lett. **13**, 1167 (2001).

[2] N. Libatique, L. Wang, and R. Jain, "*Single-longitudinal-mode tunable WDM- channel-selectable fiber laser*", Opt. Express **10**, 1503 (2002).

[3] U. Sharma, C.S. Kim, and J.U. Kang, "*Highly stable tunable dual- wavelength Q-switched fiber laser for DIAL applications*", IEEE Photon. Technol. Lett. **16**, 1277 (2004).

[4] C.S. Kim, F.N. Farokhrooz, and J.U. Kang, "*Electro-optic wavelength tunable fiber ring laser based on cascaded composite Sagnac loop filters*", Opt. Lett. **29**, 1677 (2004).

[5] J. Limpert, N. Deguil-Robin, S. Petit, I. Manek-Hönninger, F. Salin, P. Rigail, C. Hönninger, and E. Mottay, "*High power Q-switched*

Yb-doped photonic crystal fiber laser producing sub-10 ns pulses", Appl. Phys. B **81**, 19 (2005).

[6] H.L. Offerhaus, N.G. Broderick, D.J. Richardson, R. Sammut, J. Caplen, and L. Dong, "*High-energy single-transverse-mode Q-switched fiber laser based on a multimode large-mode-area erbium-doped fiber*", Opt. Lett. **23**, 1683 (1998).

[7] V.N. Filippov, A.N. Starodumov, and A.V. Kir'yanov, "*All-fiber passively Q -switched low-threshold erbium laser*", Opt. Lett. **26**, 343 (2001).

[8] S.V. Chernikov, Y. Zhu, J.R. Taylor, and V.P. Gapontsev, "*Supercontinuum self-Q-switched ytterbium fiber laser*", Opt. Lett. **22**, 298 (1997).

[9] P. Petropoulos, H.L. Offerhaus, D.J. Richardson, S. Dhanjal, and N.I. Zheludev, "*Passive Q-switching of fiber lasers using a broadband liquefying gallium mirror*", Appl. Phys. Lett. **74**, 3619 (1999).

[10] R. Paschotta, R. Haring, E. Gini, H. Melchior, U. Keller, H.L. Offerhaus, and D.J. Richardson, "*Passively Q-switched 0.1-mJ fiber laser system at 1.53 μm*", Opt. Lett. **24**, 388 (1999).