Low repetition rate high energy 1.5 µm fiber laser

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Abstract: In this paper, we report, for the first time, that by modulating pump beam to suppress ASE effect we realized ultra-low repetition rate output in an all fiber based Er:Yb codoped master oscillator power amplifiers (MOPA) system. Combined with pulse shaping technology, pulses with up to 205 µJ pulse energy and 200 ns pulse duration were obtained at Hz level.

OCIS codes: (140.3510) Lasers, fiber; (140.3500) Lasers, erbium; (140.3538) Lasers, pulsed.

References and links

1. H. Hemmati, M. Wright, and C. Esproles, "High efficiency pulsed laser transmitters for deep space communications," SPIE **3932**, 188–195 (2000).
2. J. B. Hartley, "NASA's future active remote sensing missions for earth science," SPIE **4153**, 5–12 (2001).
3. G. C. Valley and M. Wright, "Modeling transient gain dynamics in a cladding pumped Yb doped fiber amplifier pulsed at low repetition rate," CLEO, (2001).
4. S. W. Henderson, *et al.*, "Eye safe coherent laser radar for range and micro Doppler measurement," *Proceeding of IRIS Active Systems 1997*, Vol. 1, Tucson, AZ (1997).
5. J. B. Abshire, G. J. Collatz, X. Sun, H. Riris, A. E. Andrews, and M. Krainak, "Laser sounder technique for remotely measuring atmospheric CO2 concentrations," Eos Trans. AGU **82**, 47 (2010).
6. G. Canat, J. C. Mollier, J. P. Bouzinac, G. M. Williams, B. Cole, L. Goldberg, Y. Jaouën, and G. Kulcsar, "Dynamics of high-power erbium-ytterbium fiber amplifiers," J. Opt. Soc. Am. B **22**(11), 2308 (2005).
7. V. Philippov, C. Codemard, Y. Jeong, C. Alegria, J. K. Sahu, J. Nilsson, and G. N. Pearson, "High-energy in-fiber pulse amplification for coherent lidar applications," Opt. Lett. **29**(22), 2590–2592 (2004).
8. G. Canat, L. Lombard, S. Jetschke, S. Unger, J. Kirchhof, H. R. Müller, A. Durécu, V. Jolivet, and P. Bourdon, "Er-Yb-Doped LMA fibre structures for high energy amplification of narrow linewidth pulses at 1.5 µm," Conference on Lasers and Electro-Optics. (OSA Technical Digest Series (CD)—Optical Society of America), Baltimore MD (May): 6–11 (2007).
9. W. Shi, E. B. Petersen, Z. Yao, D. T. Nguyen, J. Zong, M. A. Stephen, A. Chavez-Pirson, and N. Peyghambarian, "Kilowatt-level stimulated-Brillouin-scattering-threshold monolithic transform-limited 100 ns pulsed fiber laser at 1530 nm," Opt. Lett. **35**(14), 2418–2420 (2010).
10. T. Yanagisawa, K. Asaka, K. Hamazu, and Y. Hirano, "11-mJ, 15-Hz single-frequency diode-pumped Q-switched Er, Yb:phosphate glass laser," Opt. Lett. **26**(16), 1262–1264 (2001).
11. P. Wan, J. Liu, L. Yang, and F. Amzajerdian, "Pulse shaping fiber lasers for free-space and lidar applications," SPIE **7817**, 78170K, 78170K-10 (2010).
12. C. E. Dilley, M. A. Stephen, and M. P. Savage-Leuchs, "High SBS-threshold, narrowband, erbium codoped with ytterbium fiber amplifier pulses frequency-doubled to 770 nm," Opt. Express **15**(22), 14389–14395 (2007).

1. Introduction

High energy pulsed fiber lasers have been considered as an enabling technology with many applications, such as laser sensing, laser imagery coherent Lidar, holography, free space optical communications, and material processing due to their many advantages such as compact, light-weight and high wall-plug efficiency [1–8]. In eye safe wind-profiling Lidar applications, 200 ns pulse width is required at low repetition rate down to Hz level. However, due to amplified spontaneous emission (ASE) effect and the gain dynamics in Er-doped fiber lasers, the repetition rate is limited to kHz [6–9]. Q-switched solid state lasers are usually applied with comparatively low pulse repetition rates [10], but these lasers are bulky and less robust to environment change

In recent publication we demonstrated a 10 kHz repetition rate, 130 µJ pulse energy at a wavelength of 1.5 µm with a pulse width of 200 ns [11]. In this paper, we have explored the

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possibility of lowering the repetition rate to Hz level without losing pulse energy and sacrificing optical signal to noise ratio (OSNR). We report, for the first time, to apply modulated pulsed pump scheme in Er:Yb codoped fiber laser to solve these drawbacks of ASE accumulation, pulse narrowing, and nonlinear effects. As demonstrated below, we have succeeded in generating 200 ns pulses with pulse energy of 240 µJ at 100 Hz and 205 µJ at Hz level. To our knowledge, this is the highest pulse energy from an all fiber based 1.5 µm laser at such a low repetition rate.

2. Experiment

Experimental setup is shown in Fig. 1. The seed laser was a 1535 nm distributed feedback (DFB) laser with 200 kHz linewidth. The seed laser was driven by a home-made driving board. The shaped pulse was generated by changing the driving current format and bias of the direct modulation DFB laser. The pulse width was set to 200 ns. The shaped pulses were sent to a two-stage pre-amplifier (A1 and A2), which had been optimized and characterized as well. The repetition rate of seed laser was set at 15 kHz to guarantee that the OSNR would be greater than 30 dB after preamplifiers. Two 976 nm multimode laser diodes were used as pump for the final power amplifier. The active medium in the final amplifier was a 1.6 m-long double-clad Er:Yb co-doped fiber with a core diameter of 17 µm and a clad diameter of 200 µm (Nufern). An acoustic optical modulator (AOM) was used as pulse picker to lower the seed repetition rate for the final power amplifier.

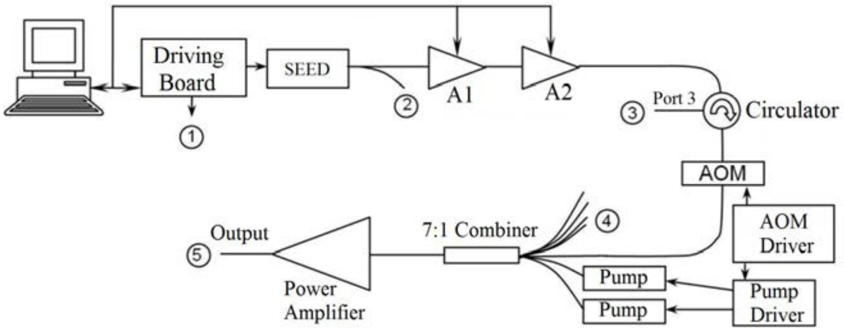

Fig. 1. Experiment system block diagram. There are 5 ports to monitor system and collect data.① Electronic modulation signal or trigger signal from seed laser driving board; ② Seed laser monitor; ③ Circulator port 3 (exit) monitor; ④ Combiner's unused channel monitor; ⑤ Final output

In our experiment, the pump laser diodes of the final amplifier were working under pulse mode. The pump time was 500 µs for each selected pulse. The peak pump power was tuned up to 17.2 W. The seed laser arriving time, AOM trigger time and pump driver trigger time were synchronized by an AOM driving board manufactured in house. Figure 2 is a screen shot of oscilloscope during experiment to show the synchronization. The lower trace represents seed laser electrical monitor with a repetition rate of 15 kHz. The middle trace represents AOM trigger signal with a gate width of 3 µs. The synchronized triggering of the AOM allows the transmission of 200 ns seed pulses to power amplifier at the selected rate. In this specific case, the pulse picker repetition rate is 100 Hz and the gate time for pump was set to 200 µs (upper trace in Fig. 2). The selected signal pulse arrives 20 µs after the pump trailing edge. This delay time is tuned during experiment to maximize the output power.

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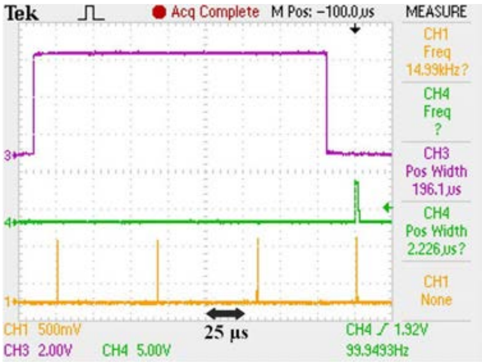
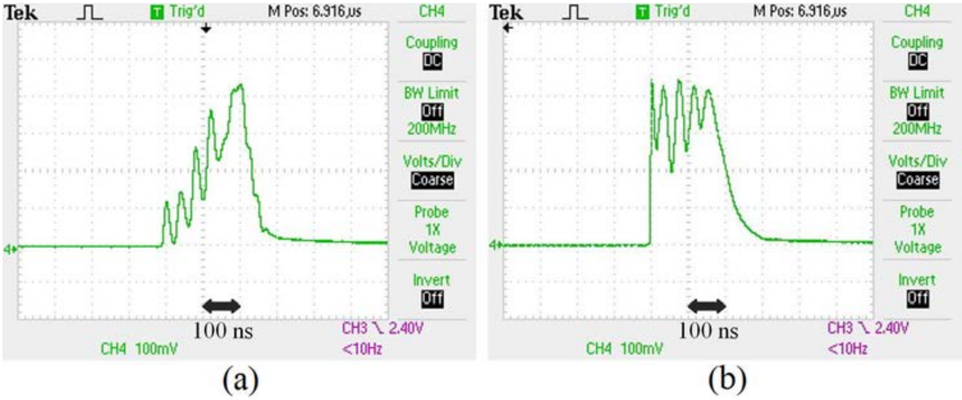


Fig. 2. Oscilloscope screenshot of trigger signals from the AOM driver. The upper trace represents the trigger signal for pump driver, the middle trace represents the AOM trigger signal and the lower trace represents seed laser electrical monitor with a repetition rate of 15 kHz.

A laser driver was successfully developed that is capable of generating different wave formats with varying pulse widths in our experiment. The laser driver generates a series of micro-pulses in order to produce a single macro-pulse with the desired pulse shape. This capability allows for mitigating both stimulated Brillouin scattering (SBS) effect (by shaping micro-pulse) and gain narrowing effect (by shaping macro-pulse) while generating high energy pulse amplification at 1.5 µm wavelength. The pulse shape of seed laser is a 200 ns macro-pulse containing 5 micro-pulses with increasing amplitude (as shown in Fig. 3a). After power amplification, an output pulse with 200 µJ pulse energy and 200 ns macro pulse width was obtained (as shown in Fig. 3b). The SBS is effectively suppressed during amplification. This is due to the fact that each micro-pulse has a shorter pulse width which increases the SBS threshold dramatically. Detailed explanations were discussed in other publications [11, 12]. In this experiment, the back-reflected SBS from the circulator port 3 is monitored. No obvious SBS effect was observed at pump peak power of up to 17.2 W (500 µs, ≤100 Hz).



(a) (b)

Fig. 3. Oscilloscope screenshots for: (a) Manipulated seed shape; (b) Output pulse shape with 200 µJ energy and ~200 ns macro-pulse width.

200 ns pulses were generated at the output of the high energy amplifier at various pump peak powers and repetition rates. The pump peak power was tuned from 0 to 17.2 W with a fixed width of 500 µs. Repetition rate was gradually reduced from 100 Hz to 1 Hz. The result of output pulse energy is shown in Fig. 4.

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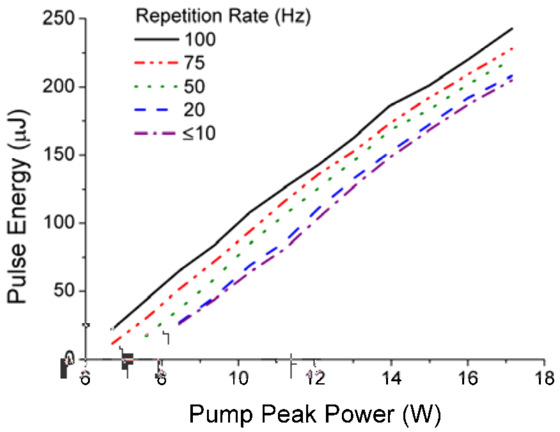

Fig. 4. Output pulse energy vs. Pump peak power at various repetition rates.

Output pulse energy was measured with a pyroeletric detector (Newport). At a repetition rate of 100 Hz, pulse energy of up to 240 μJ was obtained. When the repetition rate is at a few Hz level, pulse energy of 205 μJ was obtained at pump peak power of 17.2 W. It was noticed that for the same output pulse energy, a lower pump peak power was required for a higher repetition rate. For an example, to generate 200 μJ pulse energy, 14.9 W, 15.4 W, 15.9 W, and 16.8 W pump peak power is needed for 100 Hz, 75 Hz, 50 Hz and 10 Hz respectively. For repetition rates less than 10 Hz, the output pulse energy dependence on peak pump power are the same. This is due to Erbium fluorescence lifetime which is about 10 milliseconds. At a high repetition rate, when the new pulse comes in, there are still some left over energy stored in fiber, which is not extracted by the previous pulse. At low repetition rates, when the new pulse comes in, any leftover energy stored in fiber which is not extracted by the previous pulse, will completely decay before the arrival of new pulse. The overall effect lowers the required pump power at higher repetition rates.

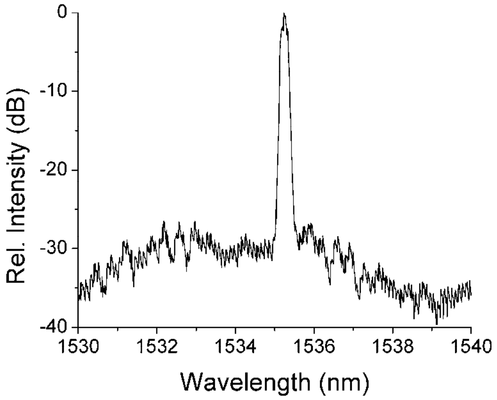

Fig. 5. Output spectrum for 10 Hz, 180 μJ pulse energy output. Over 26 dB of OSNR was obtained.

Comparing with CW pumping, the ASE was significantly reduced by the scheme of modulated pulse pumping, especially at an ultra low repetition rate. This is because the energy level inside the gain fiber remains at a low level at most times when no seed pulse is generated. Figure 5 shows an optical spectrum for output beam at 10 Hz repetition rate. An OSNR of greater than 28 dB was obtained with 180 μJ pulse energy output. If using CW pumping, most of the output energy will be ASE at such a low repetition rate.

To further increase output pulse energy, higher pump peak powers were tested. However both SBS and ASE started to build up significantly. Further increasing the pump power also led to self-pulsing in the amplifier. More development effort is needed to suppress such effects.

3. Discussion and conclusion

In summary, we have demonstrated a modulated pulsed pump scheme combined with a pulse shaping technology to generate high energy pulses at a wavelength of 1.5 µm with low repetition rates. This method has been proven to be an efficient way to mitigate ASE in high energy 1.5 µm Er:Yb codoped fiber lasers. SBS and pulse narrowing effect were suppressed as well by using pulse shaping technology. We successfully generated a 200 ns seed macro-pulse comprising of a series of micro-pulses each with a pulse width less than 20 ns. After power amplification, we obtained pulse energy of 205 µJ at ultra low repetition rates (<10 Hz).

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