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Compact Tunable 10 W picosecond Source based on Yb-doped Fiber Amplification of Gain Switch Laser Diode

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***Abstract*—**A compact tunable 10 W picosecond source based on Yb-doped fiber amplification of gain switch laser diode has been demonstrated. A gain switch semiconductor laser diode was used as the seed source, and a multi-stage single mode Yb-doped fiber preamplifier was combined with two large mode area double-clad Yb-doped fiber main amplifiers to construct the amplification system. The tunable pulses with high stability and excellent beam quality (M^2<1.2) of 10 W average power 150 ps pulse duration at 1 MHz repetition rate were obtained. The central wavelength with the line width of 2.5-3 nm was tunable from 1053 nm to 1073 nm.

***Keywords*—**Fiber laser, fiber amplifier, picosecond laser, high power laser

I. Introduction

ULTRA fast fiber lasers have attracted much attention for the advantages they offer, such as high single pass gain, excellent beam quality, freedom from alignment, superior thermal handling, broad gain bandwidth, and the potential of all-fiber integrity. Fiber tunable high-power laser sources with picosecond-scale pulse duration have been studied intensively for their potential applications to laser radar, remote sensing, micro-machining, medical treatment, space telecommunication, laser projection display, underwater optical-communication system, etc [1, 2]. In recent years, many significant results have been obtained in pulse operation and continuous wave [3, 4]. An average power over 300 W with a repetition rate of 1 GHz and pulse duration at 20 ps was demonstrated by P. Dupriez [5]. 97 W average power at a repetition rate of 47 MHz, corresponding to a peak power as high as 200 kW was obtained by J. Limpert [6]. An average power of 321 W with a repetition rate of 1 GHz, Pulse duration of 10 ps at 1064 nm was reported by the university of Southampton by using An 8-m double-clad fiber [7]. By using a single-mode Yb-doped fiber preamplifier and a two-stage large-mode-area Yb-doped double-clad-fiber power amplifier, 280 W average power of 3 ns pulse duration at 1.9 MHz repetition rate was obtained at 1034 nm [8]. By using a Q-switched microchip laser generating 1064 nm wavelength, sub nanosecond pulses at 13.4 kHz repetition rate as the seed source and an Yb-doped photonic-crystal fiber (PCF) as the power amplifier, an average power of 9.5 W with peak power at 1.5 MW was reported by Aculight Corporation [9]. A cw power as mach as several hundreds watts have been achieved by cladding pumped technique in some laboratories [10, 11]. A highly-efficient cladding-pumped Yb-doped fiber laser generating 1.36 kW of continuous-wave output power at 1.1 μm with 83% slope efficiency and near diffraction-limited beam quality was demonstrated by Y. Jeong [12]. In addition, 74-fs bandwidth-limited pulses with an average power of 0.4 W, pulse energy of 8 nJ, and central wavelength tunable from 1.00 to 1.070 μm were generated by IMRA American [13]. The wavelength tunable from 1030 nm to 1081 nm Yb-doped fiber laser using the nonlinear optical loop mirror (NOLM) for mode-locked operation generated 2.05 mW average power of 234.375 ps pulse duration at a repetition rate of 3.842 MHz [14]. The first picosecond mode-locked operation of an Yb-doped fiber laser tuning over a 90 nm range from 980 nm to 1070 nm, delivering pulses of 1.6-2 ps in duration was reported by O. G. Okhotnikov [15]. However, there have been few reports of the fiber tunable high-power picosecond system with non-mode-locked operation. To our knowledge, the first time to investigate the generation of tunable high-power picosecond laser based on Yb-doped fiber amplification of gain switch semiconductor laser diode was reported by Hongjun Liu [16]. Nevertheless, the output power could be further increased by adding the power of the amplifiers which constructed by a short fiber with a large core and a relatively small inner cladding to the present system. The pulse distortion caused by the fiber nonlinearities and dispersion can be effectively eliminated by using the short gain fiber.

In this paper, the generation of fiber tunable high-power picosecond laser with non-mode-locked operation and its system design based on master oscillator power amplifier (MOPA) [5], have been investigated. The MOPA is an attractive technology for the compact and reliable picosecond pulse sources. In order to obtain higher power, two stage main amplifiers were employed after the preamplifiers. The first main

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amplifier was constructed by a large mode area double clad Yb-doped fiber with the core diameter of 20 μm and the numerical aperture (NA) of 0.08. The second main amplifier was also constructed by a large mode area double clad Yb-doped fiber with the core diameter of 25 μm and the NA of 0.06. After the multi-stage amplification, the picosecond pulses with high stability and excellent beam quality at 1 MHz repetition rate, 10 W average power, 150 ps pulse duration, and central wavelength tunable from 1053 nm to 1073 nm were generated. To our beat knowledge, this is the highest average power generated by the tunable picosecond source based on Yb-doped fiber amplification of gain switch laser diode.

II. Experimental Setup and Results

The multi-stage fiber amplifier system is depicted in Fig. 1, which constructed by two preamplifiers and two main amplifiers cascade connections. A broadband picosecond gain switch semiconductor laser diode which generates 70 ps pulses with adjustable repetition rate among 1 MHz, 500 KHz, 200 KHz…10 Hz and single shot, 15 nm bandwidth, 1064 nm central wavelength, and 15 μW average power put out by a single mode fiber coupling, was used as the seed source to ensure the laser system high stability and compactness. The spectrum of the seed source is illustrated in Fig. 2. The power in the shorter wavelength is very low but the spectral line width is wider, i.e. the rising edge in the spectrum profile is gently, whereas, the falling edge is very sharp.

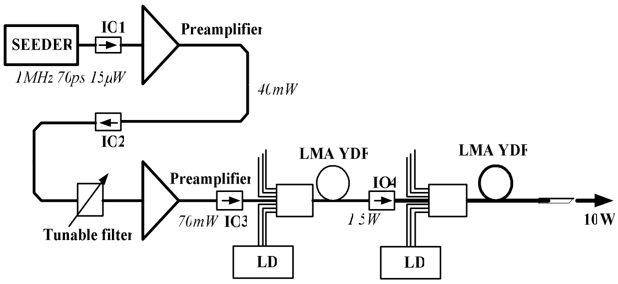

Fig. 1. Schematic of the fiber tunable high power picosecond laser system

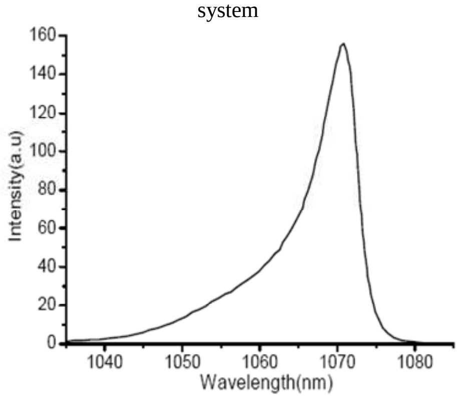

Fig. 2. The spectrum of the seed source

As demonstrated in Ref. [16], a single-mode Yb-doped fiber was used as the amplification medium for the first stage preamplifier and a "flat top" spectrum was obtained by optimizing the length of Yb-doped fiber and the pump power to compensate the seed spectrum gain, which is shown in Fig. 3. After the first preamplifier, the picosecond pulses with 20 nm line width and 40 mW average power were generated. By inserting a self-made tunable filter between the two preamplifiers, a narrow spectral bandwidth at 0.8-2 nm with 88 ps and the central wavelength tunable from 1053 nm to 1073 nm was obtained. The tunable spectral bandwidth was as broad as 20 nm. It is necessary to add another preamplifier before the main amplifiers, because the signal pulses have experienced a high loss caused by the filter. The signal with the tunable range of 1053-1073 nm was amplified to a higher power after the second stage preamplifier, but the tunable spectrum was broadened and the spectral pedestal was introduced due to the nonlinearities. Therefore, a Sagnac loop was used to compress the spectrum and eliminate the pedestal. The results are shown in Fig. 4. The spectral bandwidth of the seed pulse after the second stage preamplifier was broadened from 1.8 nm to 3.2 nm, and was again compressed to 1.8 nm by the spectrum shaping filter. After the spectrum shaping, 70 mW average power was still obtained.

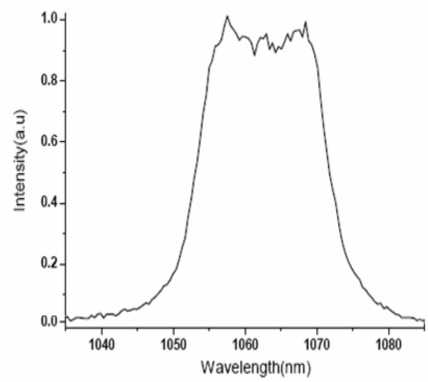

Fig. 3. The output spectrum of the first stage preamplifier

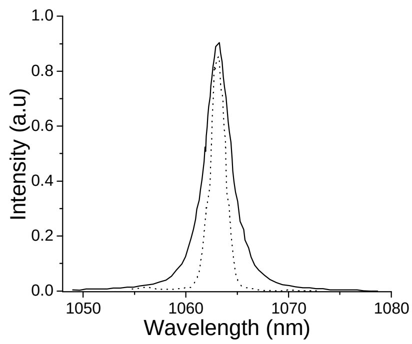

Fig. 4. The signal spectra at 1063 nm: before (solid line) and after (dot line) the spectrum shaping filter.

The single mode gain fiber is no longer suitable as the gain medium to acquire higher average power due to the limitations of the nonlinearities such as the self-phase modulation (SPM) and the stimulated Raman scattering arising in the active core and the gain saturation. The Cladding pumping technology is very effective in high power fiber laser systems due to the higher coupling efficiency and the lower thermal load [17-19]. In order to achieve higher power output in the tunable picosecond source, a large mode area double clad Yb-doped fiber was used as the gain medium by utilizing the cladding pumping technology in the main amplifiers and is shown in Fig. 1. A large mode area double-clad Yb-doped fiber with a core diameter of 20 μm and a NA of 0.08 was used as the gain fiber in the first stage main amplifier. The output average power of 1.5 W was generated by 4.2 W multimode semiconductor laser at 976 nm with 3.5 m long of the gain fiber. The second stage main amplifier was also constructed by the large mode area double clad Yb-doped fiber with the core diameter of 25 μm and the NA of 0.06. Six multimode semiconductor lasers with the total power of 31 W at 976 nm were coupled into the large mode area double-clad Yb-doped fiber with the seed source by a (7+1)*1 multimode fiber coupler. In order to prevent the damage caused by the feedback light, the end of the gain fiber was polished to a bevel angle. Finally, in our experiment, the output amplified pulses with an average power of 10 W at 1MHz repetition rate were obtained. The output central wavelength was tunable from 1053 nm to 1073 nm with high stability and excellent beam quality (M^2<1.2). The output spectral line width was about 2.5-3 nm and is shown in Fig. 5. Fig. 6 is the output pulse duration which has been broadened to 150 ps.

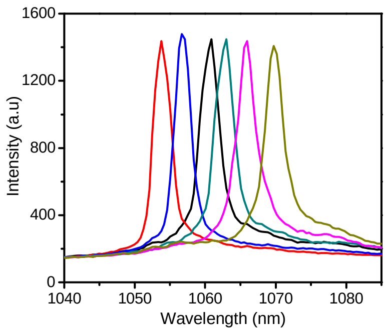

Fig. 5. The output tunable spectrum after the main amplifiers

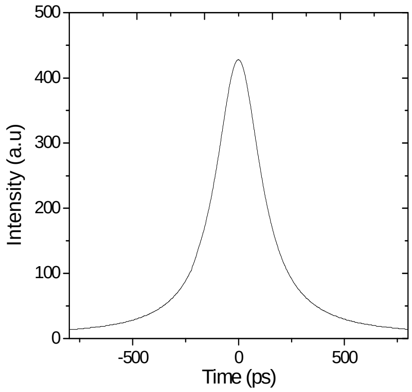

Fig. 6. The signal pulse shape after the main amplifiers

III. Conclusion

In summary, we have experimentally demonstrated a fiber tunable high-power picosecond laser source, which is constructed by the two stage preamplifiers and the two stage main amplifiers. A gain switch semiconductor laser diode was used as the seed source to ensure the stable picosecond pulses output. Furthermore, a single-mode Yb-doped fiber was used as the gain medium to obtain broadband output. A self-made tunable filter was inserted to obtain variable tunable wavelength output after the first preamplifier. A sagnac loop was set up to compress the spectrum and optimize the spectrum shape. The preamplified signal was again amplified by two stage main amplifiers and the output average power of 10 W of 150 ps pulse duration at 1 MHz repetition rate was obtained. The attractive advantage of this approach lies in the possibility to build up a very compact, robust, reliable and completely fiber tunable high-power picosecond source.

Acknowledgment

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