All-fiber nanosecond pulsed fiber amplifier

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An all fiber structure nanosecond pulse is realized through two stage amplifiers, which has 8.78 W in average power, 1 064 nm in wavelength, 11 kHz in repetition frequency, 125 ns in impulse duration, 0.8 mJ in single pulse power, 5.3 kW in peak power. The optic-optic conversion efficiency is 55.6%. Meanwhile, we setup another system, a nanosecond pulse is realized through just one stage amplifier, which has 10.10 W in average power, 1 064 nm in wavelength, 11 kHz in repetition frequency, 150 ns in impulse duration, 0.92 mJ in single pulse power, 6 kW in peak power. The optic-optic conversion efficiency is 67%. The only one stage of amplifier simplifies the system structure and reduces the cost.

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With the development of fiber technology, fiber laser is getting more and more important in industry because of its small volume, high efficiency, high quality, good stability. Recently pulsed fiber laser which has high peak power, high repetition, and high pulse energy is becoming the focus especially for middle and low power processing[1−6,9,10]. All fiber lasers with three or more stage amplifiers are expensive.

A nanosecond fiber laser seed source is obtained and optimized, while taking a Q-switch as modulator and single cladding Yb-doped fiber as gain medium; with all fiber master oscillator power amplifier (MOPA) structure, a nanosecond pulse is realized through two stage amplifiers, which has 8.78 W in average power, 1 063.8 nm in wavelength, 11 kHz in repetition frequency, 125 ns in impulse duration, 0.8 mJ in single pulse power, 5.3 kW in peak power. The optic-optic conversion efficiency is 55.6%. Meanwhile, we setup another system, a nanosecond pulse is realized through just one stage amplifier, which has 10.10 W in average power, 1 064 nm in wavelength, 11 kHz in repetition frequency, 150 ns in impulse duration, 0.92 mJ in single pulse power, 6 kW in peak power. The optic-optic conversion efficiency is 67%.

The system with MOPA structure contains seed source, pre-amplifier, and main amplifier[7,8]. The configuration of seed is shown in Fig. 1, a pair of fiber grating with reflectivity 99% and 7% composes the resonance, while taking fiber acousto-optic modulation as Q-switch, single cladding Yb-doped fiber with 3 m, core diameter 5 μm, absorption 80 dB/m@976 nm as gain medium. A 976-nm diode is coupled with the fiber through a WDM.

The nano-second pulse signal is coupled into pre-amplifier, a 5 m, 10/125 μm, absorption 1.6 dB/m915 nm double cladding fiber, through an isolator1 and combiner1, while taking 915 nm diode as pump source. Then the pulse is coupled into the main amplifier, 0.3 m, 15/130 μm, absorption 54 dB/m976 nm double cladding fiber, through isolator2 and combiner2, while taking 915 nm diode as pump source. A collimating isolator3 is fused with the fiber to get a parallel pulse output, and it prevents the back reflected light from the end, which would destroy the components.

The system contains seed source and just one stage amplifier. The configuration of seed is shown in Fig. 3, a pair of fiber grating with reflectivity of 99% and 5% composes the resonance, while taking fiber acousto-optic modulation as Q-switch, double cladding Yb-doped fiber with 5 m, core diameter 10 μm, absorption 1.5 dB/m915 nm as gain medium. A 976 nm diode is coupled into the cavity through a combiner.

The nano-second pulse signal is coupled into the amplifier, a 3 m, 15/130 μm, absorption 6 dB/m@975 nm double cladding fiber, through isolator1 and combiner1, taking two 975 nm diodes as pump source.

The splicing loss of the system is lower by using matched fiber to fuse and splicing parameters optimized. Air cooling method with temperature supervising and

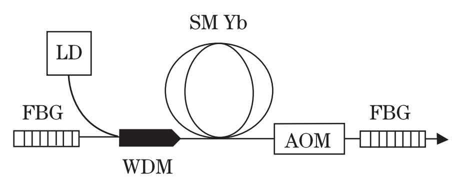

Fig. 1. Setup of all-fiber nano-second pulse seed source.

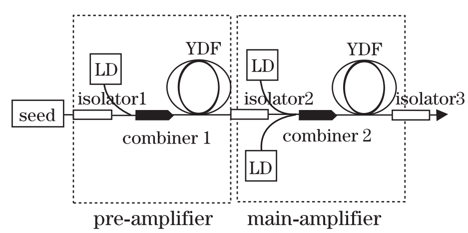

Fig. 2. Setup of all-fiber nano-second pulse amplifier.

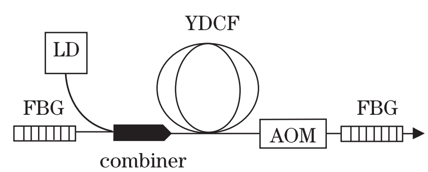

Fig. 3. Setup of all-fiber nano-second pulse seed source.

controlling is used to stabilize the pump wavelength, not only promotes the pumped efficiency but also reduces the volume. The only one stage of amplifier simplifies the system structure and reduces the cost.

Seed source, nano-second pulse sequence appears when pump input increase to 38 mW, then it goes up with the pump input power increasing. When it comes to 430 mW, a stable pulse with 1 064-nm wavelength, 11-kHz repetition, 150-ns duration is obtained. Then replace 2-m and 3.5-m Yb-doped fiber for the same experiment process without other changings, the output power are 60 mW and 92 mW. The former has obvious pumping remaining because of short of gaining; the later has the signal power loss by the over length of the fiber. So 3 m could be the optimal length of the fiber.

The signal goes through the isolator1 to the pre-amplifier, the output power got 6.6 mW at 0.17 W of the pumping input. Then it increases to 1.5 W when the pumping comes to 5 W. Figures 5 and 6 show the single pulse duration and Q-switch pulsed sequence, respectively, where the 11 kHz is decided by AOM. The output power increases with the pumping input, and there is no saturation at 1.5 W infrared output.

The Yb fiber length should be a little longer to absorb the remaining pump, which might be transfer to the next stage and destroy other components. The same as the seed, the characters of pre-amplifier pulse directly influences the main part, so the 915 nm diode are used for pumping, because its absorbing spectrum range is three times wider as that of 976 nm for Yb fiber. So the

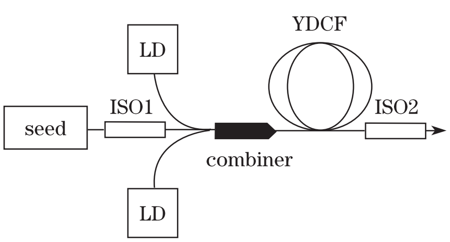

Fig. 4. Setup of all-fiber nano-second pulse amplifier.

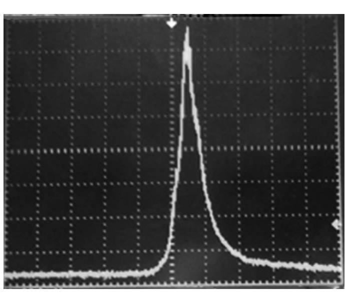

Fig. 5. Single pulse duration of pre-amplifier.

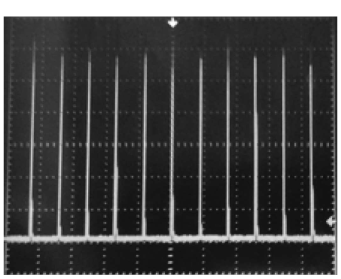

Fig. 6. Q-switch pulse sequence of pre-amplifier.

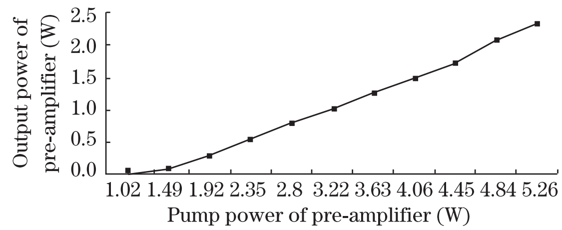

Fig. 7. Output power versus pump power of pre-amplifier.

influence caused by the little drift of wavelength is much less, we just need to increase the fiber length.

The amplified nano-second pulse goes through isolator2 to the main amplifier. The output power increases with the pumping power, while the output spectrum is monitored to make sure no other wavelength caused by remaining pumping or nonlinear effect but just the signal.

At the beginning there is still remaining pump left (over 20 dB compared with the signal) without being absorbed. Considering the gain 18 dB, which decided by the 0.3 m, 54 dB/m@976 nm fiber, theoretically, there shouldn't be happened. The combiner and Yb fiber which are connected by splicing are slightly different in physical dimension, which lead to the pumping transfer in cladding that could not be absorbed. Then the problem is solved by adjusting the fusing parameters and repeating the splicing. But there is still a small part of pumping transfer through the cladding, which is at high power, so the splicing point where Yb fiber and isolator3 connected get threaten to burn by thermal accumulation. We adjust the bare fiber length and recoating it with cement which matches the cladding index to avoid the point being destroyed.

After the treating above, when the pumping input is 15.8 W, the 8.78 W nano-second pulse, which is 1 064 nm in wavelength, 11 kHz in repetition, 0.8 mJ of single pulse, 150 ns duration, 5.3 kW in peak power is obtained. The optic-optic conversional efficiency is 55.6%.

Adopting the 20 μm double cladding fiber, we realized the gaining sufficiently, and efficiently control the power density in fiber to depress the nonlinear affect like stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS). Figure 6 shows no other wavelength spectrum exist but the signal, which gained 18.7 dB without any saturation in power. So the system could be used to realize higher power nano-second pulse.

The seed source structure is similar with the above one but using double-cladding fiber to gain, which could utilize more pumping energy. Here we got 0.956 W 1 064 nm pulse. The signal goes through the isolator1 to the amplifier, the output power got 0.4 W at 0.5 W of the pumping input (including the signal power). Then it increases to 10.1 W when the pumping comes to 15 W with 1 064 nm in wavelength, 11 kHz in repetition, 150 ns in duration, which is the same as the seed.

The output power increases with the pumping power, and meanwhile, we used spectrometer for supervising to check if any remaining pumping light or SRS caused by nonlinear effect exist. At 10 W pumping power, the slope rate of output power curve increases, and optic-optic conversion efficiency increases, owing to the pumping wavelength drifts to 975 nm at high power, which lead to thefiber absorption efficiency raises.

When the pumping input is 15 W, the 10.1 W nanosecond pulse, which is 1 064 nm in wavelength, 11 kHz in repetition, 0.92 mJ of single pulse, 150 ns duration, 6 kW in peak power is obtained. The optic-optic conversional efficiency is 67%. The structure is simplified compare with Setup1, the higher conversional efficiency may come from the much more suitable absorption of the amplifier fiber.

In conclusion, a nanosecond fiber laser seed source is obtained and optimized, while taking a Q-switch as modulator and single cladding Yb-doped fiber as gain medium; with all fiber master oscillator power amplifier (MOPA) structure, a nanosecond pulse is realized through two stage amplifier, which has 8.78 W in average power, 1 063.8 nm in wavelength, 11 kHz in repetition frequency, 125 ns in impulse duration, 0.8 mJ in single pulse power, 5.3 kW in peak power. The optic-optic conversion efficiency is 55.6%. Meanwhile, we setup another system, a nanosecond pulse is realized through just one stage amplifier, which has 10.10 W in average power, 1 064 nm wavelength, 11 kHz in repetition frequency, 150 ns in impulse duration, 0.92 mJ in single pulse power, 6 kW in peak power. The optic-optic conversion efficiency is 67%. The only one stage of amplifier simplifies the system structure and reduces the cost, which is more significant for commercial laser industry. Through the experiments above, we realized all fiber structure pulsed amplifier with different configurations of 10 W and 5–6 kW in peak power, which directly satisfied the requirement of some industrial applications. What's more, both the systems can be adopted for achieving higher power of fiber laser pulse.

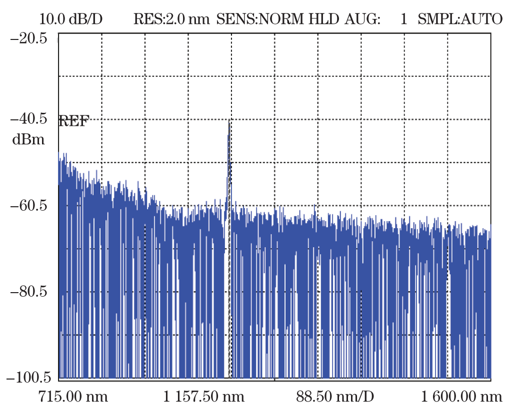

Fig. 8. Pulse spectrum of the main amplifier.

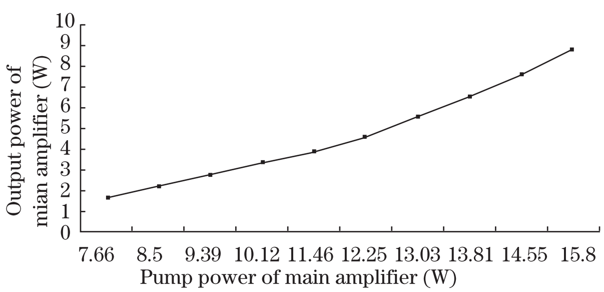

Fig. 9. Output power versus pump power of main amplifier.

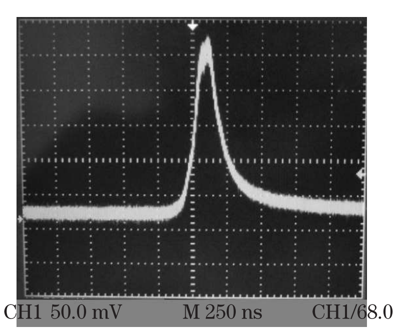

Fig. 10. Single pulse duration of amplifier.

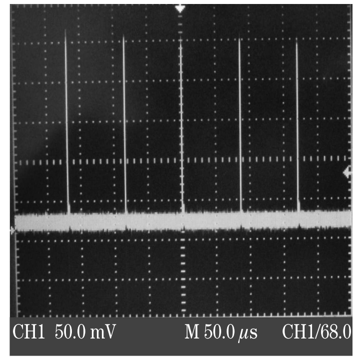

Fig. 11. Q-switch pulse sequence of amplifier.

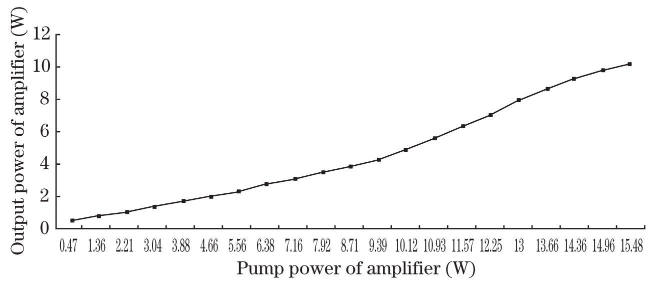

Fig. 12. Output power versus pump power of amplifier.

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