



11-mJ pulse energy wideband Yb-doped fiber laser

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ABSTRACT

We report a wide bandwidth ($\Delta\lambda=8$ nm) optical pulsed MOPA (master oscillator power amplifier) source emitting 11.23 mJ pulses (1.25 MW peak power) in the wavelength centered at ($\lambda=1064$ nm). Pulse duration and repetition rate were 9 ns and from 10 Hz to 100 Hz, respectively. In order to suppress amplified spontaneous emission (ASE), multi-stage pulse pump technology is applied. And the large core diameter (90 μm) and wide bandwidth ensures the high peak power and energy output.

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1. Introduction

High-power fiber lasers and amplifiers attract more and more attentions for its high beam quality compactness, robustness, excellent heat dissipation and higher efficiency compared to conventional bulk solid-state lasers in many applications. Many applications require high energy and peak power which is not easy to be satisfied in fiber laser with limited size of the fiber core and the relatively long propagation lengths. A lot of researchers have devoted to develop high energy and peak power fiber laser and amplifiers. Akhmediev and coworkers have provided a roadmap to design passively mode-locked laser oscillators that generate pulses of extremely high energy [1]. And some impressive results have been achieved: the pulse energy of small core (below 10 μm) fiber laser has already reached above microjoule [2,3]. Moreover, mJ level energy fiber laser and amplifiers have been realized in Large-Mode-Area (LMA) fiber. Q-switched 7.7 mJ for 250 ns beam and 8 mJ for 50 ns beam have been reported in [4,5]. Schmidt et al. reported 3.7 mJ of pulse energy and 1.7 MW of pulse peak power from a spectral combination of four 2 ns pulsed fiber amplifier systems [6]. The resulting record peak power of 3.8 GW has been achieved with a mode field diameter of 105 μm [7]. Maryashin and coworkers [8] reported 300 ns all-fiber format 10-mJ energy and 200 W average power Yb-doped laser at 1–50 kHz variable repetition frequencies. In this laser, a seed that utilizes first relaxation peaks is applied the pulse shape of which could not be varied easily. Cheng and coworkers [9] obtained record 82-mJ energy in 500 ns pulses at 100 Hz repetition

frequency using a 200 μm core highly multimode Yb-doped amplifier. According to the summed results, to get large energy, the pulse widths are always tens or hundreds to decrease peak power which contributes to reduction in the risk of non-linearity. In the last two results, the spectral line is around 1 nm; however, to improve laser-beam uniformity [10] and suppress transverse SRS [11] and SBS [12] in some large aperture laser equipments, wide-band laser beam with spectral line more than 10 nm is required. In this paper we report, for the first time to our knowledge, 1062 centered 8 nm bandwidth, more than 11 mJ energy, less than 10 ns pulse width laser at lower than 100 Hz repetition rate obtained from a fiber.

2. Experimental setup

A schematic of the high-energy fiber laser is shown in Fig. 1. It is a MOPA system seeded with an electric-pulse-driven super luminiferous diode emitting a 30-nm-bandwidth signal at 1062 nm which supplies wide-band laser for the whole system and determines the pulse shape and repetition rate in the range from 1 to 100 ns, and from 1 Hz to 100 Hz, respectively.

The peak power of SLD is about 20 mW which produces 1.6 nJ energy in 80 ns width at 20 Hz repetition rate. The whole system consisted of four main amplification stages: a dual-stage single-mode (SM) core preamplifier, a 15-mm core double-clad fiber amplifier, a 30-mm core double-clad fiber amplifier, and a 90-mm core double-clad fiber main amplifier. 2-m long gain fiber with core diameter of 8 μm was employed to core-pump seed pulses in the singlemode (SM) core preamplifier stage with two singlemode fiber coupled laser diode which could provide 650 mW peak power launched in by WDM to suppress ASE in the preamplifier

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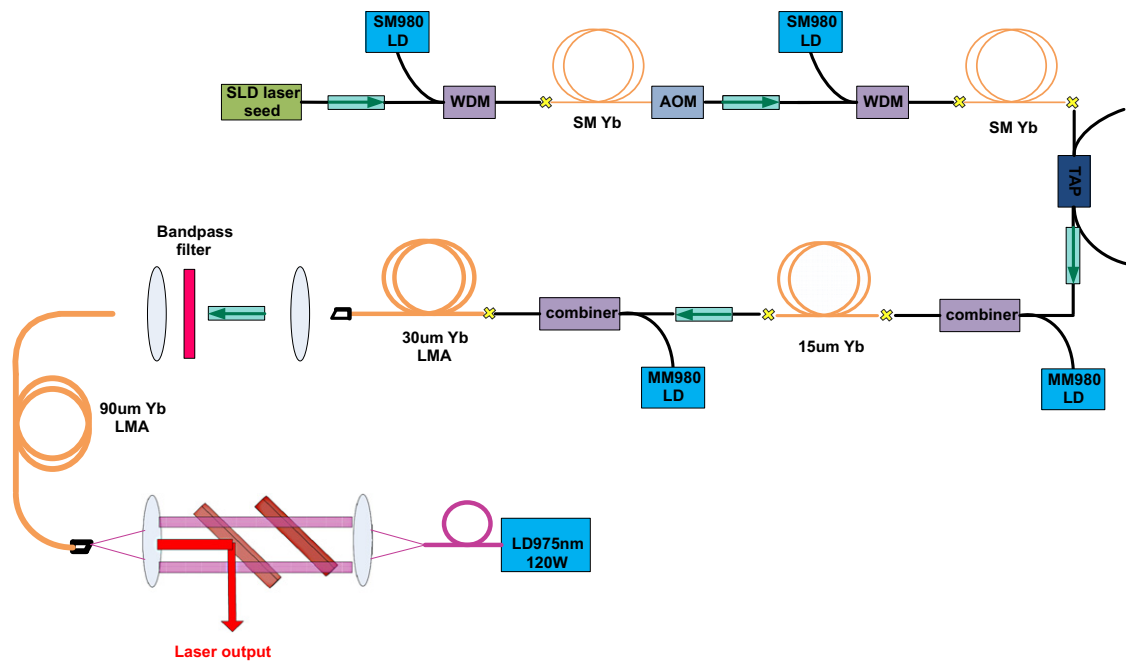


Fig. 1. Experimental setup: AOM, acousto-optic modulator; SLD, super luminiferous diode.

stage, 10 nm bandpass filters centered at 1064 nm and an acousto-optic gate were applied. These filters blocked the 1039-nm ASE peak which contained the majority of the total ASE power. The temporal gate produced by the AOM also reduces the spontaneous emission background seeded into the amplifier. The modulator was pigtailed with single mode fiber from both sides. Transmission losses of the opened AOM were measured to be 2 dB. The acousto-optic gate trigger pulses were synchronized to seed pulse and the pulse width produced by it is 100 ns around which not only ensures the high transmission of seed pulse but also eliminates the ASE as much as possible. The overall gain in this stage could provide about 40 dB gain and 35 dB signal to noise ratio. After the amplification of single mode amplifier, seed pulses were launched into 3.8 m-long multimode fiber with a 15 μm-diameter, 0.087 NA core and 130 μm-diameter, 0.46 NA cladding with an octagonal shape. 15 W peak power at 970 nm was launched into this stage which could ensure an 18 dB small-signal gain. After this stage, seed pulses were then amplified in 4 m-long multimode fiber with a 30 μm-diameter, 0.087 NA core and 250 μm-diameter, 0.46 NA cladding with an octagonal shape pumped by Up to 50 W peak power at 960 nm. After this amplification in this stage, the energy of seed pulses had grown to 1 mJ around and the pulse duration is reduced from 80 ns to 9 ns. And M^2 value turns out to be 1.6. The surface damage threshold of fused silica at 1064 nm is approximately given by [8]

$$22(\Delta\tau_p)^{0.4} \text{ J/cm}^2$$

where $\Delta\tau_p$ is the pulse duration (ns). In this case, the surface damage threshold is calculated to be 0.37 mJ. To avoid the fiber facet damage, we splice a 220-μm core-less 1.5 mm long end cap on the output side of the fiber amplifier. The light from the 30 μm stage was transmitted into 90 μm core fiber through a pair of lens between which we set up an isolator and filter. The filter has a 10 nm 3 dB bandwidth centered at 1064 nm and 70% peak transmission at 1064 nm. The final power amplifier stage was realized by a large-core double-clad 2.8-m long Yb-doped fiber amplifier with 90-μm diameter 0.06-NA core and 600-μm diameter 0.46-NA octagon-shaped inner pump cladding. The amplifier was

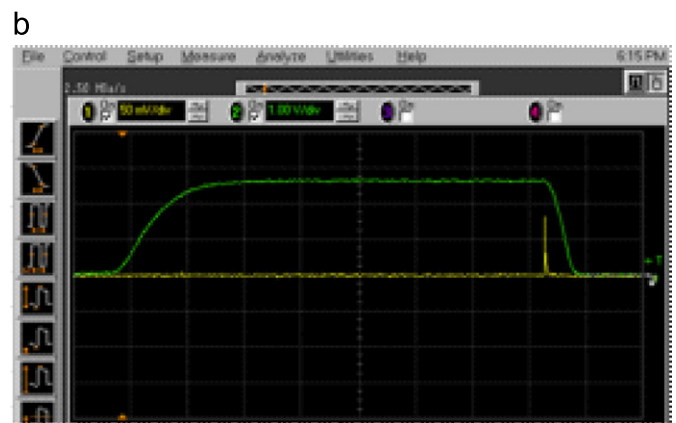
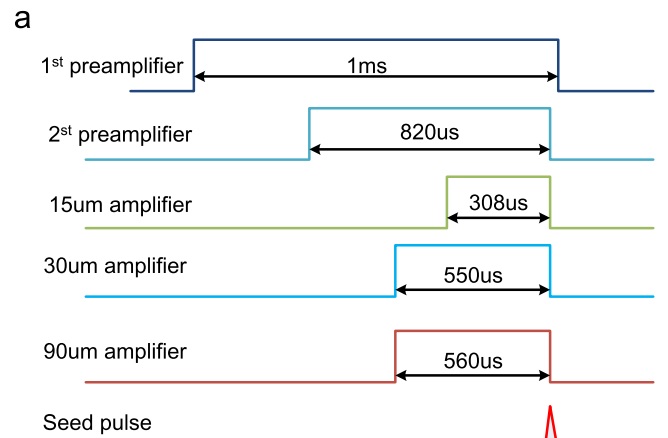


Fig. 2. (a) Time sequence of pump pulse and seed pulse (b) measured optical pulses of preamplifier and seed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

end backward pumped with as much as 130 W of peak power from a 975-nm diode laser. Considering that this system operates in rather low repetition (1–100 Hz), to suppress ASE, release the heat load and

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