321 W average power, 1 GHz, 20 ps, 1060 nm pulsed fiber MOPA source

P. Dupriez[1], A. Piper[1], A. Malinowski[1], J. K. Sahu[1,2], M. Ibsen[1], Y. Jeong[1], L. M. B. Hickey[2], M. N. Zervas[2], J. Nilsson[1,2], and D. J. Richardson[1,2]

[1]*Optoelectronic Research Centre, University of Southampton, Southampton SO17 1BJ, UK*
[2]*Southampton Photonics, Inc., 3 Wellington Park, Hedge End, SO30 2QU, United Kingdom.*
Tel: +44 23 8059 4527, Fax: +44 23 8059 3142, email: pad@orc.soton.ac.uk

Abstract: Pulses from a gain-switched laser diode were amplified in a fiber MOPA system to produce in excess of 320 W of average power in 20 ps pulses at 1 GHz repetition rate at 1060 nm.

1. Introduction

High average power laser sources with picosecond pulse durations in the 1 μm wavelength range are useful for applications such as micro-machining [1] and laser projection [2]. Gain switching of laser diodes has proved to be a convenient and practical method to generate picosecond pulses. Gain-switched distributed feedback (DFB) and Fabry-Pérot (FP) lasers were primarily developed for telecommunications applications [3-5] and offer only limited pulse powers, however recently they have also been utilized as seed lasers for high-power cladding pumped erbium:ytterbium doped fiber master-oscillator power amplifier (MOPA) sources emitting at 1.55 μm [6]. The recent development of gain-switched FP laser diodes emitting around 1 – 1.1 μm has now permitted extension of this approach to the realization of efficient ytterbium-doped fiber MOPA systems [7]. Cladding-pumped ytterbium-doped fiber sources are capable of producing kilowatt-level output power with high efficiency and excellent beam quality in the continuous-wave regime [8,9]. The combination of telecommunication-grade, low-power gain-switched laser diodes and fiber-based power-amplifier system thus constitutes an attractive technological approach for the development of versatile, robust, and compact high power short-pulse sources. We demonstrate here a 20-ps pulsed ytterbium-doped fiber MOPA source with 321 W of average output power seeded by a gain-switched laser diode emitting at 1060 nm. This is a considerable improvement over other picosecond sources, which have so far been restricted in power to the sub-100 W level [10,11]. In addition, compared to non-fiber sources, fiber MOPAs provide high efficiency, compactness, and robustness, as well as versatility and flexibility in terms of pulse parameters such as repetition rate and pulse duration. This is a result of the unique combination of high gain, high power, and high efficiency that fiber amplifiers can offer.

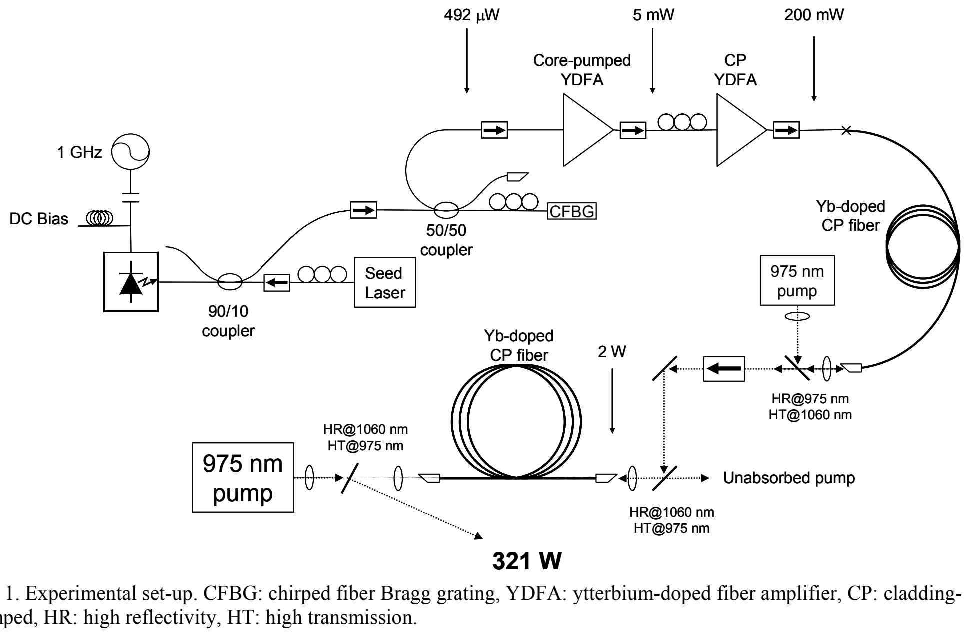

Fig. 1. Experimental set-up. CFBG: chirped fiber Bragg grating, YDFA: ytterbium-doped fiber amplifier, CP: cladding-pumped, HR: high reflectivity, HT: high transmission.

2. Experiment and results

The fiber MOPA system is depicted in Fig. 1. A 1060 nm FP laser diode in a high-speed fiber-pigtailed package was gain-switched by driving it with a 1 GHz sinusoid with a DC bias current. The FP diode was seeded with a CW DFB fiber laser source emitting at 1059.94 nm through a 90/10 coupler to ensure single longitudinal mode operation. A chirped fiber Bragg grating (CFBG) designed for compensating the chirp of the pulses was inserted after the seed laser via a 3 dB coupler. The compression process resulted in 20 ps duration pulses with a corresponding average power of 492 μW. The gain-switched laser diode system was followed by four cascaded ytterbium-doped fiber amplifiers (YDFA's). The compressed pulses were first amplified by a 4 m long, core-pumped YDFA and by a 6 m long, single-mode cladding-pumped YDFA. The output end of this first cladding-pumped YDFA was spliced to a second 8 m long, 13 μm core diameter, double-clad Yb-doped fiber, cladding-pumped by a 975 nm diode. This amplified the signal up to an average power of 3 W. After transmission through a high-power free-space isolator with 1.5 dB of insertion loss, the signal was free-space coupled into the final high-power fiber amplifier stage which was cladding-pumped in a counter propagating configuration by a diode stack at 975 nm. The fiber of the power amplifier had a 43 μm diameter Yb-doped core with a numerical aperture (NA) of 0.09. Although the large core makes the fiber slightly multimode, it provides important advantages in terms of higher pump absorption, lower nonlinear effects, and higher damage threshold. The D-shaped inner cladding had a 650/600 μm diameter for the longer/shorter axis and was coated with a low index polymer coating providing a nominal NA of 0.48. The pump absorption rate in the inner cladding was ~3 dB/m at the pump wavelength. The fiber length used in the final stage of amplification was 8 m.

The power amplifier was seeded with 2 W of average power and could produce pulses with average powers up to 321 W. The slope efficiency of the power amplifier was 78% with respect to launched pump power (79% with respect to absorbed pump power) as shown in Fig. 2(a). The beam quality (M^2) at the output of the amplifier was measured to be 2.4. Autocorrelation traces measured at various power levels up to 221 W reveal no degradation in the 20 ps pulse duration as well as in the pulse shape as illustrated in Fig. 2(b). At higher power, pulse shapes were measured with a 20 GHz communication analyzer. Although the measurement was resolution limited, it confirmed that the pulse quality was preserved at the maximum level of amplification as shown in Fig. 2(c).

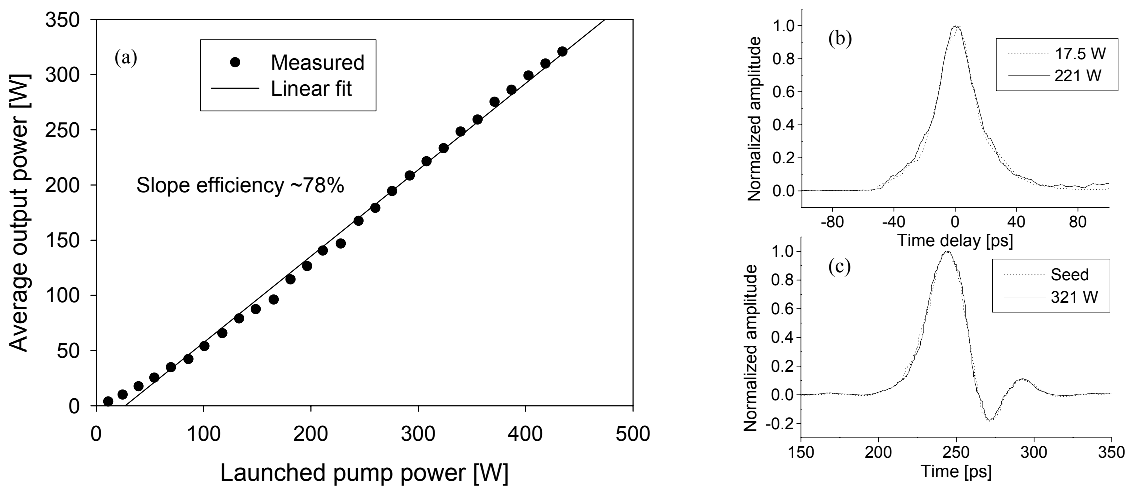

Fig. 2. (a) High average power amplifier efficiency. (b) Autocorrelation traces of the pulses measured at 17.5 W and 221 W of average output power (at higher power autocorrelation measurements were less stable due to thermal effects but showed no change in the pulse shape). (c) Pulse shapes at seed and 321 W of average power measured with a 20 GHz communication analyzer (resolution limited).

The optical spectra of the seed and the output of the MOPA measured over a broad wavelength range are shown in Fig. 3(a). At 321 W of average output power the 1060 nm signal peak was 20 dB above the peak of the background amplified spontaneous emission (ASE). Although the level of ASE increased significantly at the maximum power, it was estimated from the spectrum that the signal power represented 82% of the total average output power leading to an estimated peak power of 13 kW. Mid-stage spectral filtering would significantly improve the spectral quality. Stimulated Raman Scattering (SRS) was not observed even at the maximum power.

A detailed view of the spectrum presented in linear scale in Fig 3(b) reveals spectral broadening caused by self-phase modulation obtained along the high-power fiber amplifier. As a result the 0.12 nm linewidth of the seed source, preserved at the input of the power amplifier, was broadened to 0.49 nm at 321 W of average power. This is still a relatively low value thanks to the large core area of the ytterbium-doped fiber and is fully compatible with frequency doubling, for example.

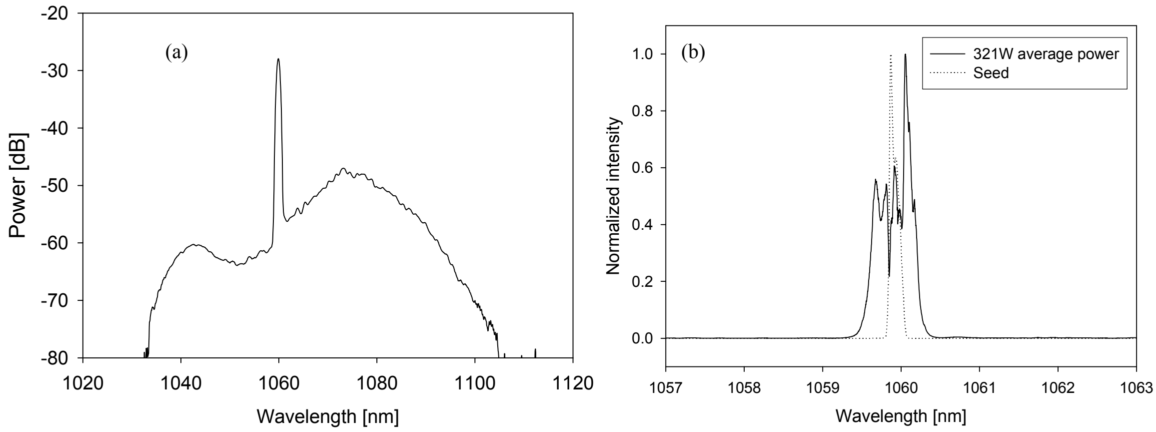

Fig. 3. (a) Optical spectrum at seed and at various average powers (resolution: 0.5 nm). (b) Detailed view of the optical spectrum showing spectral broadening due to self-phase modulation (resolution: 0.01 nm).

3. Conclusions

We have demonstrated a 321 W, 20 ps pulse source with a 1 GHz repetition rate based on an ytterbium fiber amplifier chain seeded by a gain-switched laser diode at 1060 nm. The high repetition rate regime enabled the generation of high average power while maintaining a reasonable peak power leading only to relatively moderate self-phase modulation and no observed stimulated Raman scattering in the fiber amplifier. In addition, the low-power electrically driven high-speed diode offers high flexibility with respect to repetition rate, easily set to obtain peak powers suited for specific applications.

Our results show that high-power fiber technology, previously demonstrated at > 1 kW in the cw regime, can also be used to power-scale pulsed picosecond-sources to several hundred watts. Since the obtained output power was only limited by available pump power, we believe that further power-scaling is possible with the current configuration. This kind of high average power, high repetition rate source represents an attractive technology for the generation of high average powers in the visible via nonlinear frequency conversion.

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4. References

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