High peak power pulsed single-mode linearly polarized LMA fiber amplifier and Q-switch laser

V. Khitrov*, B. Samson, D. Machewirth, D. Yan, K. Tankala, A. Held
Nufern, 7 Airport Park Road, East Granby, CT 06026
* vkhitrov@nufern.com; phone: (860) 408-5000; fax: (860) 408-5080; www.nufern.com

ABSTRACT

We report on the recent progress in the design and development of completely monolithic linearly-polarized pulsed fiber amplifiers seeded by Q-switched fiber laser oscillators. We demonstrate near diffraction limited beam quality with ~20kW peak power (1mJ pulse energy, ~45nsec) pulses and an average power ~20W at 20kHz repetition rate with linearly polarized (>17dB PER) output from a simple MOPA design. The laser produces spectrally narrow pulses with ~0.5nm linewidth centered at 1064nm, suitable for various non-linear applications including generation of visible and UV light. The simple MOPA design consists of a monolithic fiber amplifier based on an optimized coil of polarization maintaining large mode area (PM-LMA) fiber with 30μm-core and low power Q-switched fiber oscillator. Excellent output beam quality is achieved through the mode selectivity of the coiled PM-LMA fiber in the amplifier stage. Such compact and robust fiber lasers are suitable for a variety of applications, such as nonlinear wavelength conversion processes using a variety of nonlinear materials, laser radars, etc.

Keywords: large mode area optical fiber, linearly polarized laser, pulsed fiber laser

1. INTRODUCTION

Pulsed single-mode fiber lasers and amplifiers emitting multiple-kW peak powers with average powers in 10-20W range are ideal laser sources for many of today's applications in materials processing such as marking and engraving. Such fiber-based devices have numerous advantages over other types of lasers, such as flexible pulse durations/repetition rates, compact air cooled platforms due to the high efficiency and maintenance-free operation. There is an interest in linearly polarized single-mode pulsed fiber devices with a similar set of generic specifications. Although non-polarized single-mode pulsed fiber devices in the 10-20W average power regime have been successfully demonstrated[1-2], developing high-power linearly polarized single-mode pulsed devices is challenging due to management of the fiber non-linearities coupled with polarization control in the large mode area (LMA) fibers that are required for generating high peak powers. In addition, producing pulses at 10-20kW peak powers with spectrally narrow linewidth, which is required for efficient conversion to visible and UV wavelengths through frequency doubling/tripling can be very challenging[3].

Here we report a monolithic PM-MOPA system using Q-switch fiber oscillator and single stage PM-LMA fiber amplifier that delivers ~20kW peak power, (1mJ pulse energy, 45nsec) and 21W average power with a spectral linewidth ~0.5nm. The simple MOPA design uses a coiled length of PM-LMA Yb-doped fiber amplifier stage which effectively amplifies linearly polarized signal from Q-switch fiber laser oscillator whilst maintaining excellent beam quality. The entire device has a compact, robust, all-fiber design but the flexibility of the Q-switched oscillator allows for variable repetition rates.

Alternative methods in the literature based on seeded fiber amplifiers where the seed source is either a DPSSL[3] or passively Q-switched microchip laser[4] suffer from the need to fiber couple the output from the solid state laser into the fiber power amplifier stage. Alternatives based on either diode sources[5,6] or CW fiber lasers that are subsequently modulated[7] usually deliver low peak power from the seed laser and subsequently require multiple (two or three) fiber amplifier stages to generate the ~20kW peak power targeted for these applications. The flexibility of a single low power Q-switched fiber laser together with a power amplifier stage allows a range of pulse durations and repetition rates that would be difficult to achieve if we tried to optimize a single stage Q-switched oscillator to deliver the same power/pulse energy. Furthermore the reliability of key components in the Q-switched oscillator is improved at the lower operating power.

2. EXPERIMENTAL SETUP

Figure 1 illustrates the design of the PM pulsed fiber laser. It consists of a low power AOM based fiber Q-switch laser and a single high power PM fiber amplifier stage. Because of the fairly high average power from the Q-switch oscillator (typically ~300mW) this simple MOPA architecture requires less amplifier stages than fiber lasers designed around diode lasers as the seed source. Typically those schemes would require 2 or 3 amplifier stages to deliver the targeted ~20kW peak power[5,6]. Other schemes using Q-switched solid state lasers can achieve this peak power and higher in a single stage, but usually involve free space coupling of the seed laser to the power amplifier. In figure 1 the amplifier consists of coiled Yb-doped PM LMA 30/250µm fiber and signal/pump fiber multiplexer arranged in a co-pumped configuration. A 3m length of Yb-doped fiber was used in these experiments corresponding to around ~10dB of pump absorption, coiled onto an 8cm diameter mandrel to maintain good beam quality[8]. A fiber multiplexer coupled input signal and pump light into the Yb-doped 30/250µm fiber. The input signal port was a standard single-mode PM 6/125µm fiber; the pump port a multimode 200/220µm 0.2NA fiber. A fiber coupled 976nm diode bar (~40W) was used as pump source for the power amplifier stage with linewidth ~3nm FWHM.

The Q-switch fiber laser has been used as a seed source for high power amplifier. The Q-switch laser is based on Yb-doped 6/125µm fiber. It was operated at 300mW output power. The output from the Q-switch laser was coupled into the fiber amplifier through a commercially available fiber coupled PM isolator.

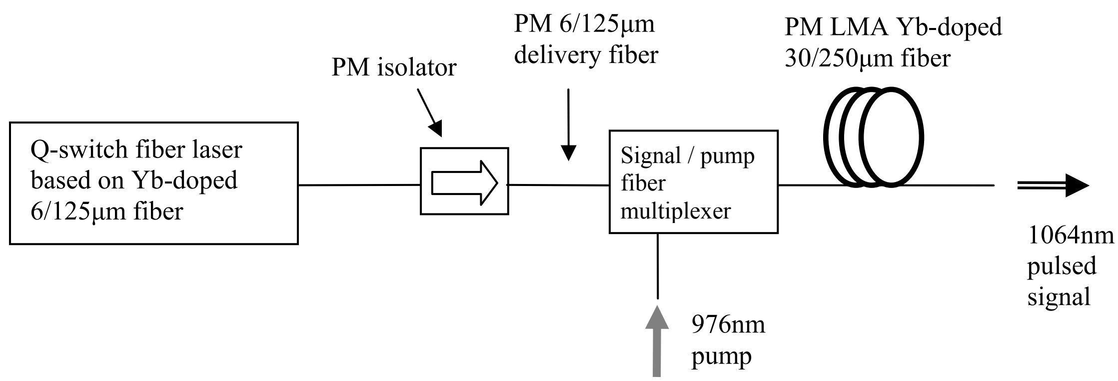

Figure 1 - Q-switch fiber laser and pulsed fiber amplifier design.

The panda-type PM-LMA, ytterbium doped fiber (YDF) used in the power amplifier has been developed for achieving high laser powers. The fiber has 30µm diameter core doped with ytterbium, a 250 micron octagonally-shaped inner cladding, a 0.06 core NA and a 0.46 cladding NA. Two borosilicate stress rods surround the core to induce birefringence and provide PM behavior. The birefringence of this structure is as high as 2.5×10^{-4}. Fiber image is shown in Figure 2.

The fiber is inherently multi-mode, capable of supporting a number of transverse modes. The coiling technique[8] was used to obtain single-mode linearly polarized operation. Coiling induces a bend loss for higher order modes while allowing the fundamental linearly polarized mode to propagate with no substantial passive loss (<0.01dB/m)[9].

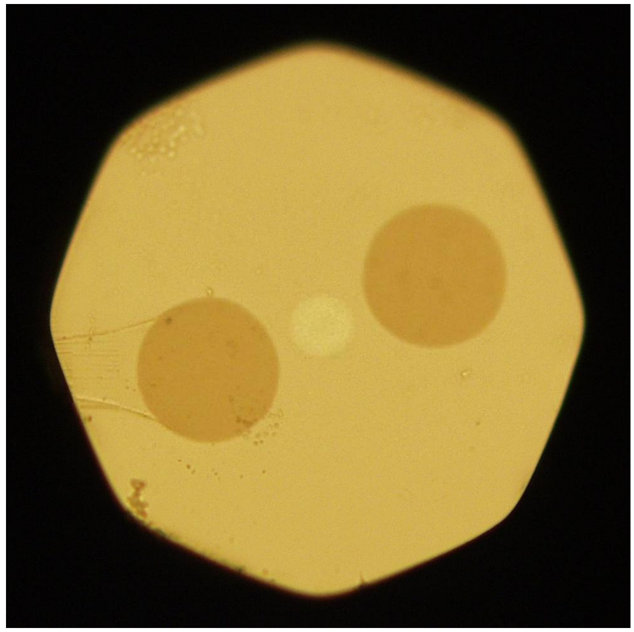

Figure 2 - Microscope image of fiber cross section.

3. EXPERIMENTAL RESULTS

Output power from the Q-switch oscillator was ~300mW (average power) corresponding to peak powers of ~400W. At those power levels the reliability of the components are acceptable for industrial laser applications. This is a major advantage of the MOPA design where the oscillator power is kept relatively low. The pulse repetition rate from the Q-switched oscillator can be varied between ~10kHz and >100kHz typically and the results presented here was collected at a fixed rep rate of 20kHz. The pulses from the Q-switch laser were amplified in the power amplifier stage after the mid-stage PM fiber isolator. Figure 3 shows the amplified 1064nm signal output vs coupled pump power. 21W average output was achieved at highest available coupled pump power (35W). Overall amplifier optical efficiency was 60%. A Polarization Extinction Ration (PER) of 17dB was measured at the amplifier output.

Figure 4 shows the output pulse shape from the power amplifier stage. Pulse duration was 42ns at 20kHz repetition rate which is fairly typical for this Q-switch fiber laser. Pulse energy at ~1mJ corresponding to a peak power of ~20kW. Figure 5 shows the measured laser output spectrum. The laser had a relatively narrow line-width (0.53nm), determined by the spectrum of the FBG used in the oscillator and is measured at ~1mJ pulse energy/20kHz rep rate. This line-width would be acceptable for frequency doubling the fiber laser to the green or UV using standard non-linear crystals. Furthermore, because of the broad nature of the Yb-gain spectrum we believe the system can be readily tuned to another wavelength simply by changing the operating wavelength of the FBGs in the oscillator. In particular, operating such a pulsed system at shorter wavelengths around 1030nm would be interesting, opening up UV wavelengths that may otherwise be difficult to access.

Figure 6 shows output beam quality measurement. The laser produced a near diffraction limited beam. M2 was measured as 1.2 from the power amplifier stage. It is noted the 30/250µm fiber used with the power amplifier stage here also suitable for amplifying other types of lasers operating at very different repetition rates/pulse durations to that demonstrated here and indeed is capable of generating >1MW powers[10]. However the flexibility and reliability of operating this amplifier with a fiber based Q-switched oscillator is very attractive for applications where pulse durations of ~40nsec and peak powers in the 10's of kWatts are acceptable. We believe the adaptation of these all-fiber Q-switch MOPA systems to a PM-design delivering a narrow spectral linewidth, good PER and excellent beam quality will become useful IR sources for efficient frequency conversion to green and UV wavelengths.

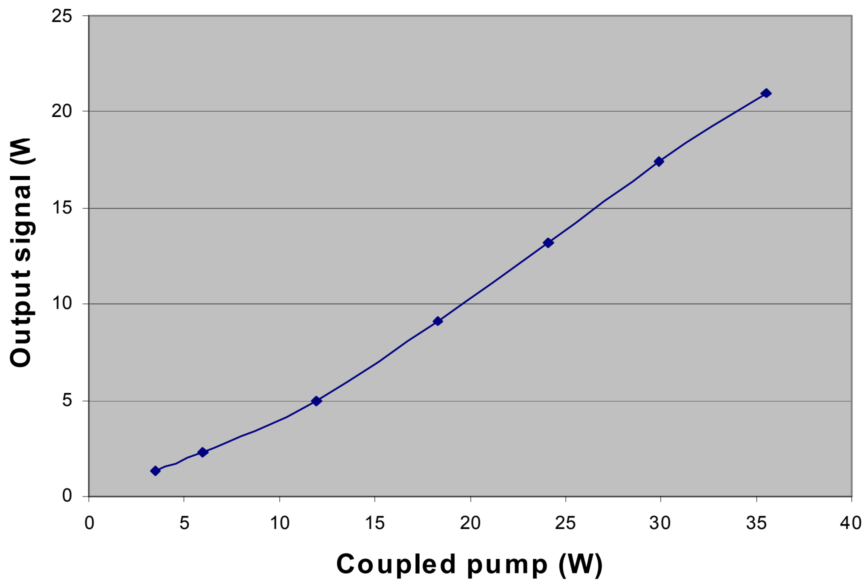

Figure 3 – Laser efficiency

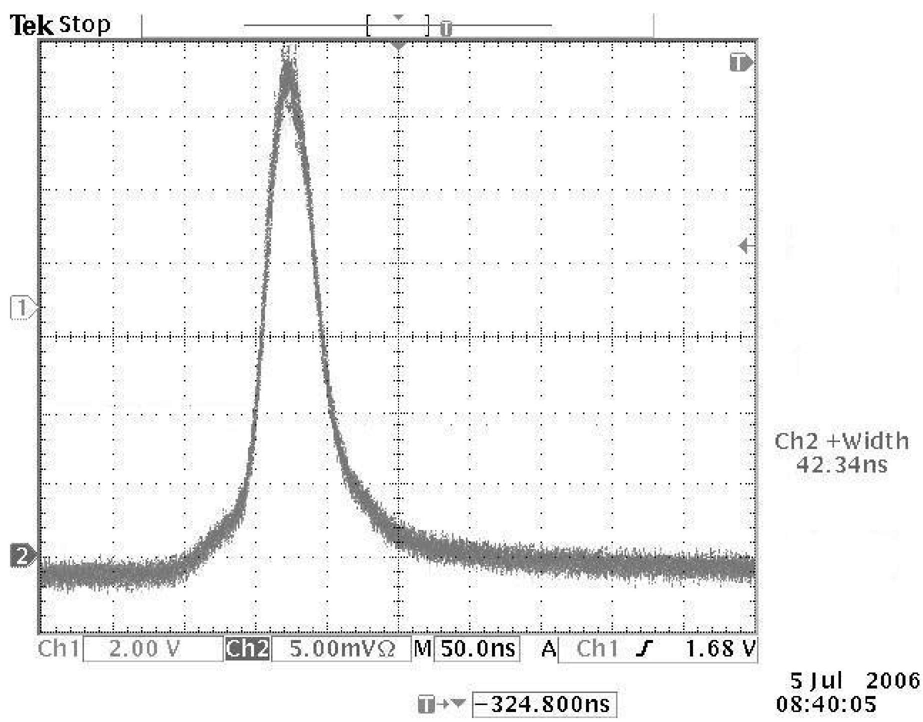

Figure 4 – Laser output pulse shape

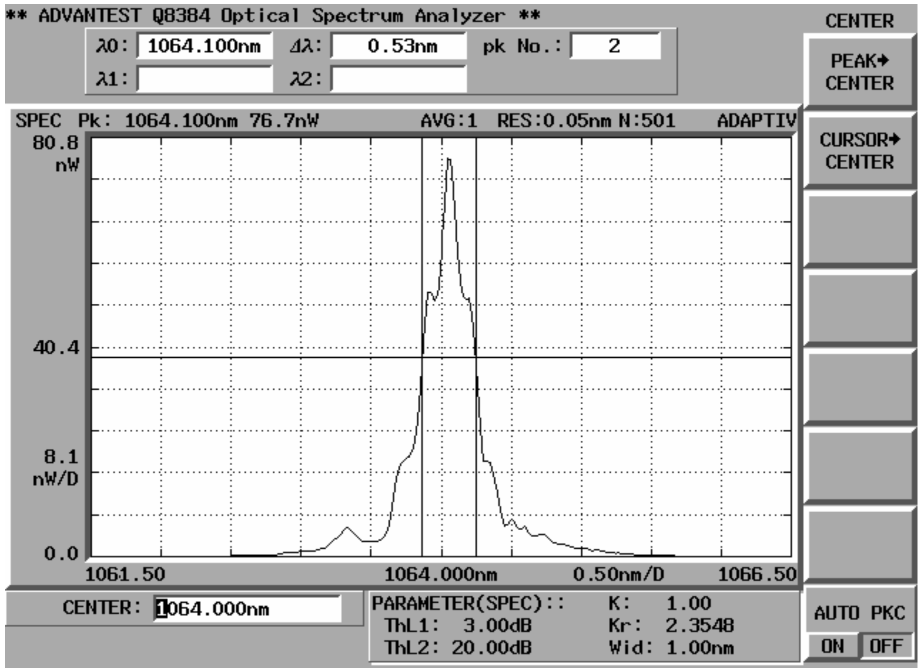

Figure 5 – Laser output spectrum

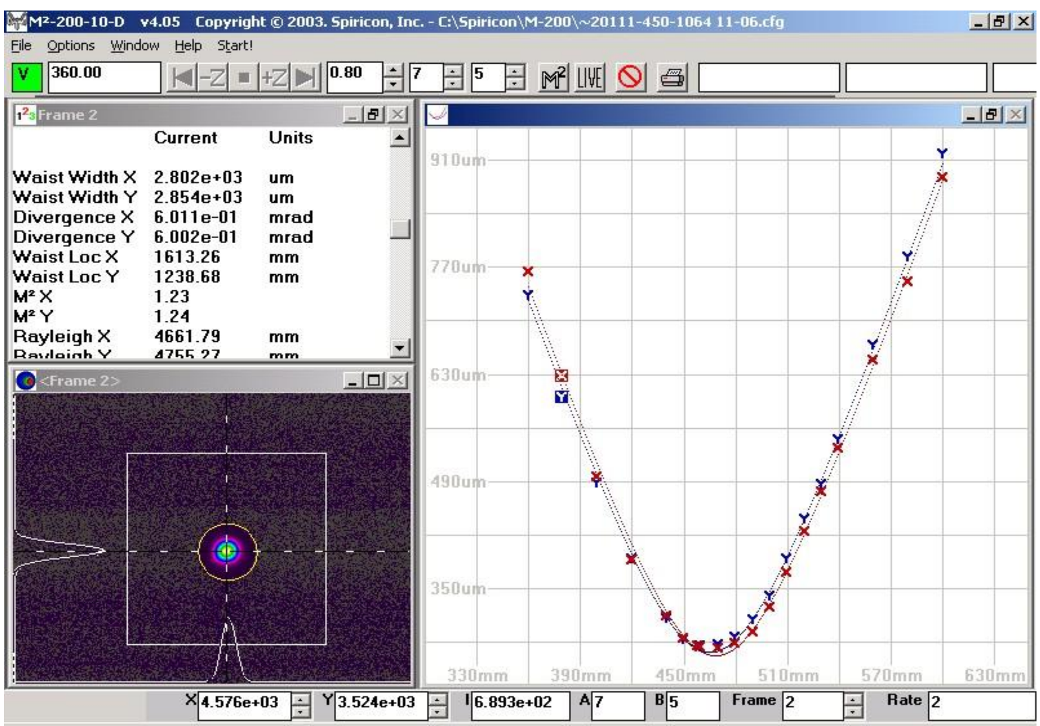

Figure 6 – Output beam quality measurement

CONCLUSION

In conclusion, we have demonstrated a monolithic, all-fiber PM pulsed fiber laser based on Q-switch fiber oscillator and PM-LMA fiber amplifier that delivers 1mJ pulse energy, ~45nsec pulse duration (~20kW peak power) and 21W average power (20kHz rep rate) operating at 1064nm. The system had a spectral linewdith of 0.5nm, M^2 of 1.2 and PER of 17dB. Such linearly polarized, spectrum-stabilized and single-transverse mode output from a compact and robust package is particularly suitable for a number of applications: driving high-power nonlinear wavelength conversion processes in a variety of nonlinear materials, LIDAR, etc.

REFERENCES

1. From IPG Photonics website, www.ipgphotonics.com
2. A.Piper, A.Malinowski, K.Furusawa, D.J.Richardson "1.2mJ, 37ns single-moded pulses at 10kHz repetition rate from Q-switched ytterbium fiber laser" in CLEO proceedings, CMK3, San-Francisco, CA, USA, 2004
3. C. Ye, M. Gong, P. Yan, Q.Lui and G. Chen, "Linearly polarized single-transverse-mode high energy multi-ten nanosecond, fiber amplifier with 50W average power", Optics Express, **14**, 17, 7604, (2006)
4. F.Di Teodoro, J. P. Koplow, S.W. Moore, D.A.V. Kliner, "Diffraction-limited, 300-kW peak-power pulses from a coiled multimode fiber amplifier, Optics Letters, **27**,7, 518, (2002).
5. D.Creeden, J.McCarthy, R.Day, P.Ketteridge, E.Chicklis, "Near diffraction-limited, 1064nm, all-fiber master oscillator fiber amplifier (MOFA) with enhanced SRS suppression for pulsed nanosecond applications" in SSDTL Technical Digest 2006, Fiber1-4
6. W. Torruellas, Y. Chen, B. McIntosh, J. Farroni, K. Tankala, S. Webster, D. Hagan, M. J. Soileau, M. Messerly, J. Dawson, "High peak power Yb-doped fiber amplfiers", in *Fiber Lasers III: Technology, Systems, and Applications*, Proc. SPIE Vol. 6102, 61020N (2006).
7. A. Liu, M. Norsen and R. Mead, "60W green output by frequency doubling a polarized Yb-doped fiber lasers", Optics Letters, **30**, 1, 76, (2005).
8. J. P. Koplow, D.A.V. Kliner and L.Goldberg, "Single mode operation of a coiled multimode fiber amplifier", **25**, 7, 442, (2000).
9. U. Manyam, B.Samson, V. Khitrov, D. Machewirth, J. Abramczyk, N. Jacobson, J. Farroni, D. Guertin, A. Carter and K. Tankala "Laser fibers designed for single polarization output" in Advanced Solid-State Photonics technical digest MA6, Santa Fe, NM, USA, 2004
10. R.L. Farrow, D.A.V. Kliner *et al*, "High-peak-power (>1.2MW) pulsed fiber amplifier" in *Fiber Lasers III: Technology, Systems, and Applications*, Proc. SPIE Vol. 6102, 61020L (2006).