Frequency Doubling of Tm-doped Fiber Lasers for Efficient 950nm Generation

G. Frith[a], T. McComb[b,a], B. Samson[a], W. Torruellas[c], M. Dennis[c], A. Carter[a], V. Khitrov[a], K. Tankala[a]
[a]Nufern, 7 Airport Park Road, East Granby, CT USA 06026
[b]CREOL, UCF, 4000 Central Florida Blvd., Orlando, FL USA 32816
[c]JHU-APL, 11100 Johns Hopkins Road, Laurel, MD USA 21010

Abstract: We demonstrate a robust, highly efficient pulsed Tm-doped fiber laser systems operating at 1908nm and producing 6W average power. Using PPLN crystal we demonstrate 60% conversion efficiency to 954nm.

OCIS Codes: (140.3280) Laser Amplifiers; (060.3510) Lasers, Fiber; (140.3298) Laser Beam Combining

1. Introduction

There is an emerging interest in efficient, compact sources which generate light in the wavelength range of 900-950nm, where traditional solid-state lasers struggle to operate or may do so but with much reduced efficiency. High power 790nm cladding pumped Tm-doped fiber lasers have been shown to operate efficiently between 1850-2135nm in CW form [1,2] and more recently have produced pulse energies in the range of 0.5mJ with ~20nsec pulses [3,4], more than enough for efficient frequency doubling. In this paper we will present the progress of pulsed Tm-doped fiber systems which are currently producing over 4kW of peak power at 30kHz PRF (~6W average power) with 25ns pulse width and a linear polarization output. This, together with their near diffraction-limited beam quality make them an ideal source for efficient frequency doubling. In preliminary experiments using a PPLN crystal, we achieved efficient frequency doubling of 1908nm light and produced ~1W at 954nm. We anticipate these results will be steadily improved over the coming months.

2. Experimental Details

To date, attempts to either actively or passively Q-switch thulium-doped fiber lasers have been only marginally successful, often plagued by poor stability and chaotic pulsing. Recently Jiang and Tayebati demonstrated the ability to produce stable nanosecond-regime pulses from a Tm-doped fiber laser gain-switching Tm-doped fiber lasers [5]. For our experiments we chose to use a similar concept. As shown schematically in Figure 1, the system essentially consisted of three parts: an acousto-optically Q-switched Er:Yb fiber laser, a 20cm long Tm-doped linear cavity and finally, a single-mode polarization-maintaining amplifier. The Q-switched Er:Yb laser produced 100ns pulses at 1.55µm from 20 to 100kHz pulse repetition frequency (PRF). This was used to core-pump the Tm-doped fiber laser cavity which consisted of two 1908nm FBGs (nominally 99% and 15% reflectivity) that were cleaved as close to the grating as possible and spliced to the Tm-doped fiber. A multi-element IR fused silica aplanatic lens was used to collimate the output from the oscillator which was then passed through a polarization-sensitive isolator before being coupled back into the amplifier. The isolator served to provide higher stability from the amplifier and single polarization output.

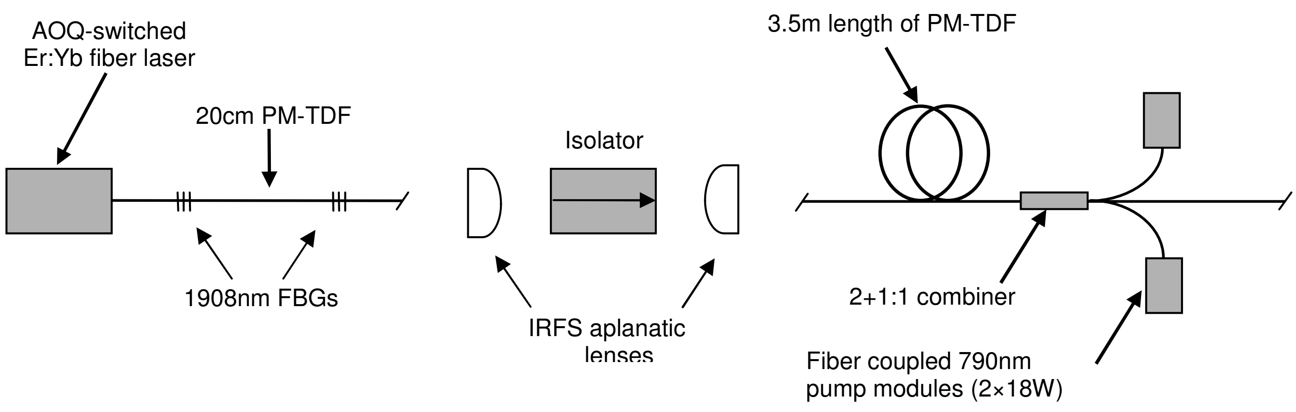

Fig. 1. Schematic of pulsed laser system based on Tm-doped fiber and operating around 1908nm

3. Results To Date

For a gain-switched oscillator, the pulse width is essentially defined by two factors: the gain and the round-trip time. During cutback experiments, the shortest pulse width was achieved using a 20cm length of that fiber. As the fiber was further shortened, the benefit of any reduction in the round-trip was offset by a decrease in gain from lower pump absorption. In an effort to shorten the cavity length, we investigated using a fiber with double the Tm concentration. In this case the results were actually worse which may be accounted for by a reduction in the upper-state lifetime due to concentration quenching. With 20cm the lower concentration fiber pumped by 100ns pulses from the 1.55µm laser, we were able to produce gain-switched pulses from 25 to 60ns as shown in Figure 2. A typical beam image from the single-mode fiber (in this case taken from the oscillator) is shown in Figure 3.

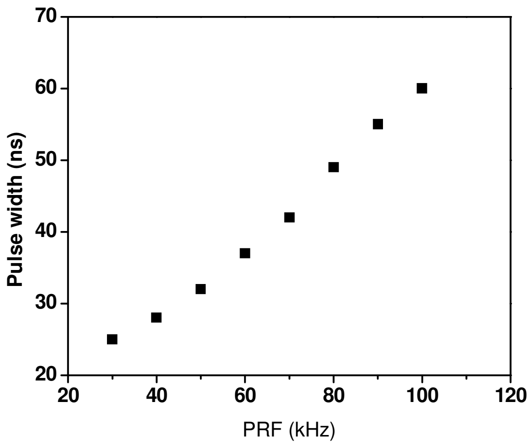

Fig 2. Pulse width vs. PRF for oscillator.

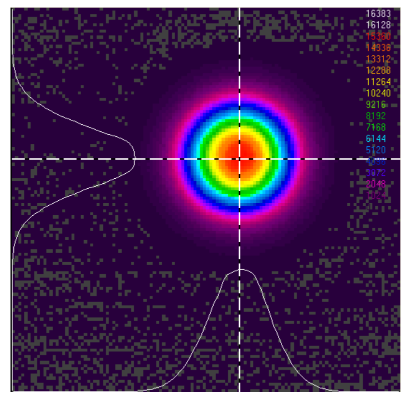

Fig 3. Beam image from SM fiber.

After polarizing the output of the oscillator and taking into account the coupling losses, the seeded power to the amplifier was ~75mW. The amplifier was constructed with 3.5m of the same single-mode fiber that was used in the oscillator. It should be noted here that this fiber incorporated *panda*-type stress-rods to provide polarization-maintaining (PM) operation. The amplifier was counter-pumped through a 2+1:1 combiner at 790nm. In Figure 4 we show the maximum output powers of the amplifier at various PRFs. The maximum output power was limited not by available pump power, but rather the stability of the amplifier. The values shown in Figure 4 therefore reflect the power at which the onset of chaotic self-pulsing was observed. A typical amplified pulse at 40kHz is also shown in Figure 5. From 100kHz down to 60kHz, the measured slope efficiency of the amplifier was ~36%. Below 60kHz, the efficiency was observed to decrease. At 30kHz the efficiency was ~30%.

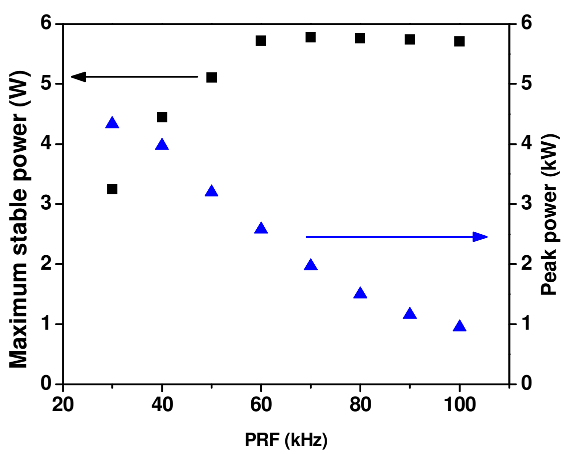

Fig 4. Average and peak powers vs. PRF

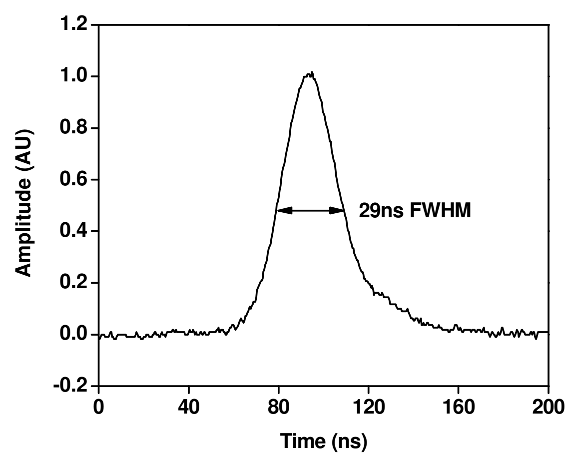

Fig. 5. Typical amplified pulse at 40kHz

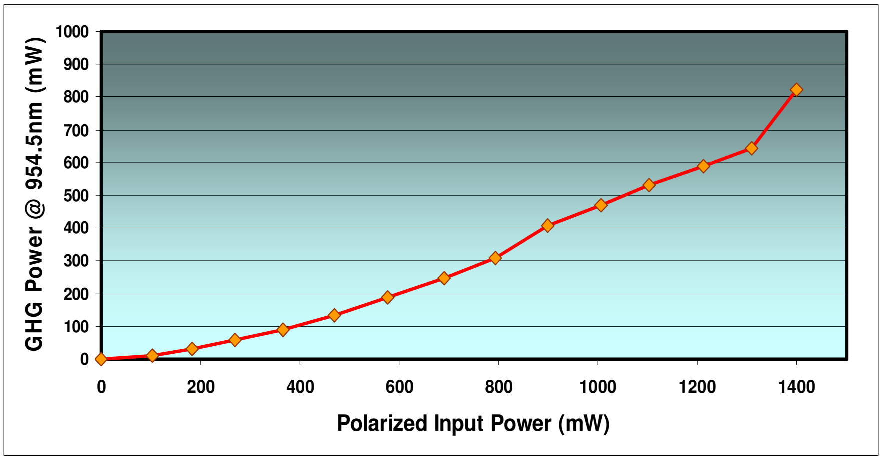

Fig 6. Efficient (60%) frequency doubling of pulsed 1908nm source using PPLN to produce ~1W of 950nm

By temperature tuning a commercially available PPLN crystal with Λ=27.25µm to ~160°C we obtained up to 60% conversion efficiency of the pulsed 1908nm source, generating almost 1W average power at 954nm as shown in Figure 6. It is significant to note that with 1m of germanium-doped fiber (GDF) on the input of the amplifier, 3.5m of Tm-doped fiber and 2m of GDF on the output, no evidence of stimulated Raman scattering was observed up to the maximum generated peak power of 4.3kW. Furthermore, considering a 10µm $1/e^2$ MFD, the peak irradiance at the output exceeded $10MW/cm^2$ without any observed fiber facet damage. Further power scaling could be achieved by adding a second amplifier stage to the system with mid-stage isolation [3], potentially generating pulse energies approaching the mJ level (albeit at lower repetition rates than the current system). Furthermore, shifting of the operating wavelength to shorter wavelengths may be investigated by changing the FBG's in the oscillator in combination with optimization of the fiber design for shorter wavelength operation. This potentially opens us a route to high pulse energy systems in the 900-950nm regime based on monolithic, efficient Tm-doped fiber technology.

4. References

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