A High Peak Power, Nanosecond Tm:fiber MOPA System for Mid-IR OPO Pumping

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Abstract: We report on a thulium fiber MOPA system utilizing a photonic crystal fiber (PCF) based power amplifier generating >40 kW, ~6.5 ns pulses as a tunable, narrow linewidth source for mid-IR OPO pumping.

OCIS codes: (060.5295) Photonic Crystal Fibers; (140.3540) Lasers, Q-switched; (190.4970) Parametric oscillators and amplifiers

Introduction

Thulium fiber based laser sources provide output in the spectral band from ~1.8-2.1 µm, at the near IR edge of the mid-IR wavelength regime from 2-15 µm. Due to their long wavelength, high average and peak output powers, and integrated construction, Tm:fiber lasers are useful to pump mid-IR optical parametric oscillators (OPO) directly [1] or indirectly [2].

For direct OPO pumping, a Tm:fiber laser system must provide short pulse duration, narrow spectral linewidth, and high-energy/peak power. There are two requirements for high-energy/peak power extraction from fibers: high nonlinear thresholds and sufficient stored energy. Both of these require ultra large mode thulium fibers for the final amplifier. Following the path of ytterbium fiber laser developments [3], photonic crystal fiber (PCF) geometries have recently been demonstrated in thulium doped fibers scaling past the ~500 µm^2 mode field area (MFA) limit of conventional step-index large mode area (LMA) fibers.

We have investigated flexible Tm:PCF with MFA of >1000 µm^2 for the first time as a Q-switched laser source generating ~9 kW peak power pulses [4]. More recently we have demonstrated a master oscillator power amplifier (MOPA) system using a flexible Tm:PCF and a rod-type Tm:PCF, with MFA >2800 µm^2, to amplify 6.5 ns pulses to MW peak power level [5]. Here we report on the utility of these novel nanosecond thulium fiber laser systems for pumping mid IR OPOs based on $ZnGeP_2$ (ZGP) and orientation-patterned GaAs (OP-GaAs) nonlinear crystals.

Experimental Setup

The initial experimental OPO setup can be seen in figure 1. The Q-switched oscillator is based a 10/130 µm core/cladding thulium fiber (Nufern) pumped by a 35 W pump 790 nm laser diode (DILAS). This system uses an acousto-optic Q-switch (NEOS) to generate ~100 ns pulses with ~37 µJ pulse energies at 20 kHz repetition rate. The oscillator output passes through an electro-optic (EO) pulse slicer/picker (FastPulse Technologies) which reduces the repetition rate (1-20 kHz) and reduces the pulse duration to a minimum duration of ~6.5 ns.

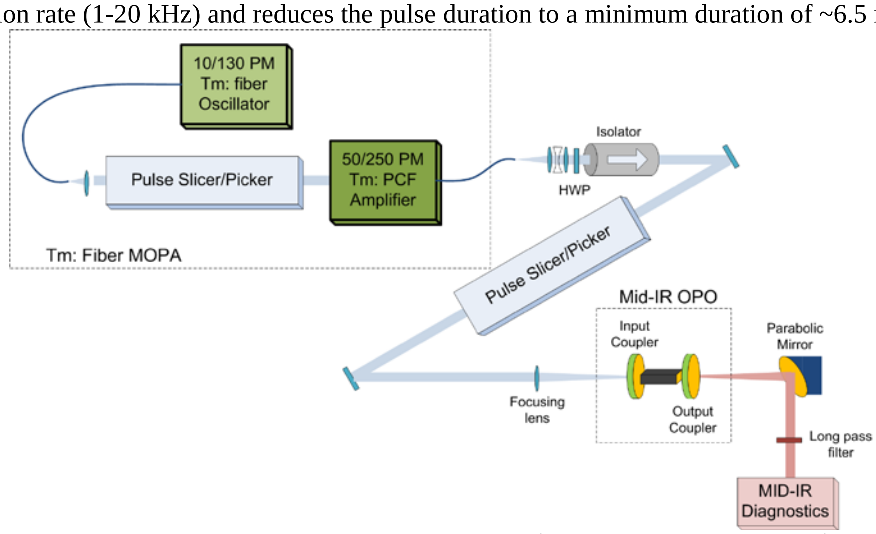


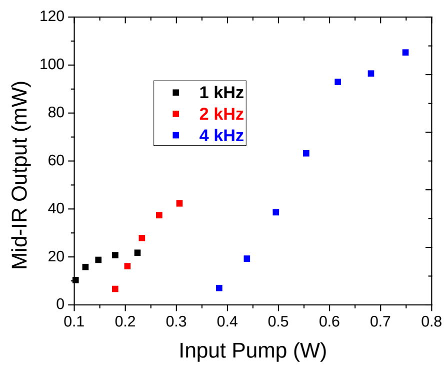
Figure 1: The experimental setup shows the MOPA system where a 10/130 SMF fiber is the oscillator and seeds a flexible Tm:PCF amplifier through a pulse slicer. The output is again passed through a pulse picker and a 400 mm focusing lens focusses the beam into a nonlinear crystal (ZGP) enclosed in an OPO cavity. The output is then collimated by a parabolic mirror and sent to beam diagnostics through a mid IR filter.

The “sliced” pulses are then amplified in a flexible Tm:PCF amplifier which is pumped by a 100 W, 793 nm laser diode (DILAS). We have achieved >200 µJ pulse energies at 20 kHz, and >400 µJ at 1 kHz with ~6.5 ns pulse duration. The spectral linewidth remains <1 nm (FWHM) during amplification, with no sign of nonlinear degradation.

The output passes through an optical isolator and an extra-cavity EO pulse picker, before being focused by a 400 mm focusing lens to a ~225 µm diameter waist in a ZGP crystal with dimensions of 4mm x 5mm x 12mm cut at theta of 57.5^0. This ZGP crystal is placed between two flat mirrors forming a doubly resonant OPO cavity. The input coupler is >99% reflective and output coupler ~50 % reflective for 3-5 µm wavelength range, while both are highly transmissive at the pump wavelength. The mid-IR output is characterized after passing through a long pass filter to remove residual pump light.

Results

Figure 2(a) shows the output characteristics for three different repetition rates. The maximum total mid-IR energy is ~24 µJ which corresponds to about ~2 kW peak power for the signal (~3.55 µm). The OPO thresholds at different repetition rates are shown in figure 2(b) to be 3-4 MW/cm^2 for ~100 ns pulses and 10-14 MW/cm^2 for ~7 ns pulses. This is comparable to the threshold value obtained in [6].



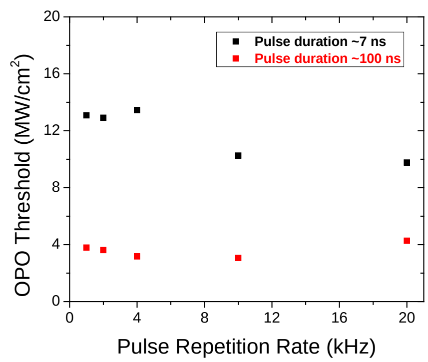


Figure 2: a) The OPO output for PRFs 1, 2 and 4 kHz at ~6.8 ns pulse duration and b) the OPO threshold for ~6.8 ns and 100 ns pulses.

Future Work

The mid-IR output peak power levels we have so far achieved in this initial work are competitive for directly thulium fiber laser pumped direct ZGP OPO. We are continuing to increase the peak power for OPO pumping using the ~MW peak power Tm:fiber MOPA with a Tm:PCF-rod power amplifier. Future work includes further OPO testing and optimization in terms of efficiency, pulse energies and peak powers to develop a nanosecond mid-IR source extending beyond 5 µm wavelengths with sufficient energy and peak power for laser materials processing studies.

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