Amplification of ns-pulses beyond 1 MW-peak power in Tm^{3+}-doped photonic crystal fiber rod

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Abstract: We utilize thulium doped PCF rods for amplification of ns-pulses in MOPA configuration and achieve MW-level peak powers with sub 10 ns pulses at 2 µm. The utilization of end caps will enable multi MW peak powers.

OCIS codes: (140.3510) Lasers, fiber; (060.5295) Photonic Crystal Fibers; (140.3540) Lasers, Q-switched

1. Introduction

In Ytterbium-based fiber lasers more than 4 MW-peak power and 26 mJ pulse energy have been demonstrated [1] [2]. However, further power scaling within a fiber laser system while maintaining quasi diffraction-limited beam quality is very challenging at 1 µm wavelength. Thulium-based fiber laser systems have a twofold advantage for peak power scaling. Since the threshold for nonlinear effects scale with the wavelength, thulium-based fiber laser systems at 2 µm wavelength should enable much higher peak powers. In addition, twice larger mode field diameters are feasible while maintaining single mode behavior due to the wavelength dependence of the V-parameter.

Recently the photonic crystal fiber (PCF) design was introduced for thulium doped flexible fibers with mode field diameters of 36 µm [3]. Subsequently an increase of mode field diameter was achieved with the first thulium doped rod-type PCF (MFD=54 µm) [4] and rod type large pitch fiber (MFD>60 µm) [5]. The large pitch fiber has been utilized in a Q-switched oscillator configuration producing 2.4 mJ pulse energy and >150 kW-level peak power [6]. We have just recently achieved MW-level peak power by implementing the PCF rod design as the main amplifier in a master oscillator power amplifier (MOPA).

2. Experimental setup

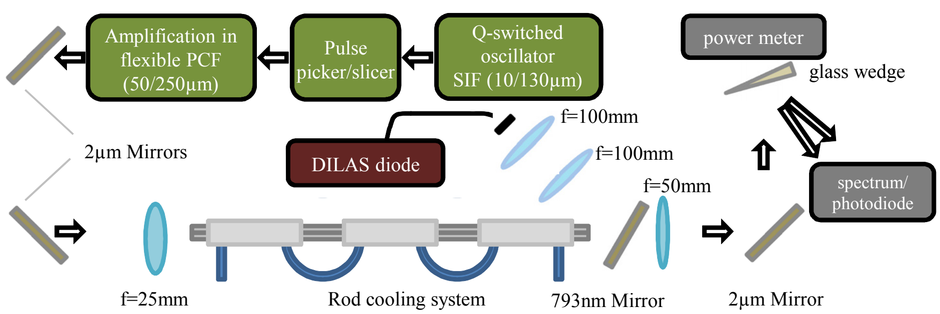

Fig.1 Schematic setup for pulsed amplification in a rod-type PCF in counter-propagating pump configuration.

The schematic setup is depicted in figure 1. The output of the MOPA described in [7] seeds amplification in a PCF rod with 80 µm core diameter (NKT Photonics, as described in [4]). The oscillator consists of a 10/130 µm thulium doped polarization maintaining (PM) fiber (Nufern) with a free-space AOM (NEOS Technologies) as the Q-switching element. The oscillator produces 100 ns pulses with 750 mW average power at a repetition rate of 20 kHz and 1965 nm wavelength. The MOPA includes an electro optical modulator (EOM, FastPulse Technologies) that is used to slice out a pulse with >6.5 ns as well as reduce the repetition rate (1 kHz-20 kHz). This “sliced” pulse is first amplified in a flexible PCF (MFD=36 µm) and subsequently amplified in the PCF rod (MFD=54 µm) that is water cooled to 13 ºC. The rod is pumped in a counter-propagating configuration with a pump diode at 793 nm (DILAS). A wedge at the output is used for simultaneous observation of power, spectrum and temporal pulse evolution.

3. Experimental results

In order to achieve highest peak powers we reduced the repetition rate to 1 kHz and minimized the pulse duration. We achieved a slope efficiency of >9 %, obtained a maximum average power of 7.3 W and did not observe roll off or energy saturation. With at least 90% of the total power in the core and very conservatively estimating the ASE power to be <500mW, the output peak power is >890 kW with 6.4 mJ pulse energy. This is record peak power from a thulium-doped fiber nanosecond laser system. Figures 2 and 3 show the temporal pulse, its spectrum and an image of the output beam at highest peak power.

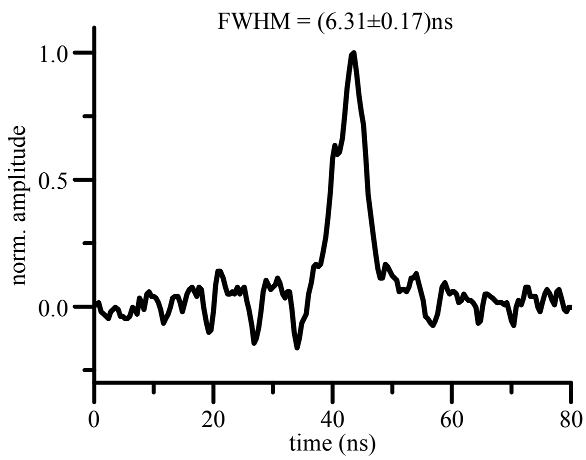

Fig.2 Temporal evolution of the amplified pulse at >890 kW peak power

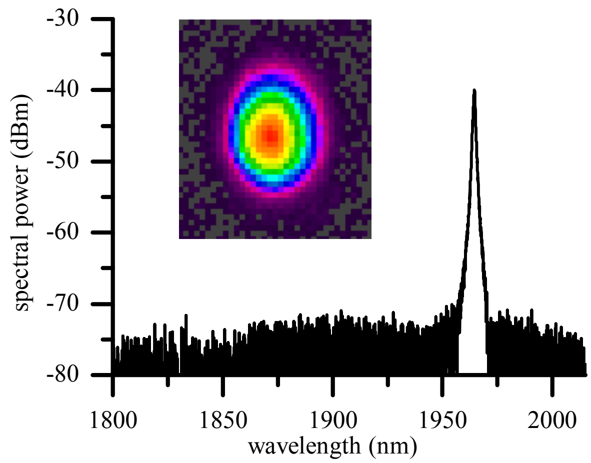

Fig.3 Spectrum of the signal and image of the beam at highest peak power.

4. Outlook

The absence of energy saturation, roll off, or nonlinear temporal/spectral degradation of the pulses proves this thulium doped PCF rod is capable of greater average power, energy and peak power scaling. We are currently working to develop simulation models to estimate the extractable energy and to optimize pulse duration, repetition rate and pump power in order to continue scaling peak power well beyond 1 MW in the near future.

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5. References

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