

Microjoule-level widely tunable gain-switched thulium-doped fiber laser

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Abstract: We demonstrate the hybrid-pumped (continuous-wave+pulsed) gain-switched small-core thulium-doped fiber laser tunable in 1825-2064nm spectral range that delivers 50-300ns pulses with energies up to 12μJ (65μJ of injected pump) reaching performance of larger-core gain-switched laser systems. © 2019 The Author(s)

OCIS codes: (140.3538) Lasers, pulsed; (060.2320) Fiber optics amplifiers and oscillators

1. Introduction

Gain-switched (GS) thulium-doped fiber lasers (TDFL) combine multiple features, such as simple cavity geometries, high oscillator output energies (from sub-μJ to mJ), narrow linewidth and wide spectral tunability in 1700-2200 nm range. These properties make GS TDFLs promising tools for middle-infrared (MIR) light generation through nonlinear conversion and supercontinuum broadening [1-2], for LIDAR and sensing applications [3], as well as pumping sources for other laser materials [4]. Recently, a number of GS TDFLs, distinguished by their design and functionality, has been presented. Linear cavity laser with 20% out-coupling mirror that provided output pulse energy up to 0.12 μJ and tunability within 1860-2000 nm range, was reported [5]. All-PM-fiber linearly polarized high-energy (25 μJ) TDFL, operating at 2044 nm, was proposed as a pumping source for the difference-frequency generation in MIR [6]. Despite the fact that a regular pulse duration, delivered by GS laser, does not fall below tens of ns, a short-resonator design (<1m) enabled generation of 1.5 ns pulses with 8 kW peak power [7].

Normally, single-band sources (793 nm or 1550 nm) are used as a pump for the GS TDFLs. In this case, relatively high pulse energies are required: from 8 μJ for the TDF of 6.3 um diameter, up to few mJ for large-mode-area fibers [3]. To lower the pump threshold energy and also improve temporal characteristics of the output pulses, a hybrid excitation scheme was proposed: a continuous-wave (CW) source drives the resonator close to the lasing threshold point, and the pulsed source triggers the GS operation [8]. Applying this method to the ring cavity with a bandpass filter, the researchers demonstrated a 24 THz (1765-2055 nm) tunable GS TDFL, emitting 200-450 ns pulses with a maximum energy of 0.56 μJ (vs. 30 μJ of injected pump) [9]. In this paper, we present an efficient hybrid-pumped GS TDFL with a comparable wavelength tuning range of 19 THz (1825-2064 nm) that delivers microjoule-energy pulses (up to 12 μJ vs. 65 μJ of injected pump) thanks to the low-loss cavity design, and variable-transmission out-coupler, based on the fiber loop mirror.

2. Experimental setup

Proposed GS TDFL operates in a linear cavity (Fig. 1). Active medium (0.8m of thulium-doped fiber, TmDF200 by OFS Fitel, 4 μm core diameter) is single-side core-pumped through a wavelength-division multiplexer (WDM) with a hybrid CW+pulsed signal at 1550 nm. The pulsed pump component represents a pulse train with 5 kHz repetition rate, 20 ns duration and 65 μJ energy. The power of CW pump component is set to the CW lasing threshold value. The laser wavelength is tuned by tilting of the Bragg grating (BG), used in a Littrow configuration as a high reflector (HR). Using off-axis parabolic mirror (OAP) collimator ensures broadband HR operation with spectrally uniform loss lower than 1 dB. A fiber loop mirror (FLM) with 50%/50% broadband directional coupler (DC) is used as an output coupler, and its transmission can be varied in 0-100% range by tuning the in-line polarization controller (IPC2) to maximize the laser output power.

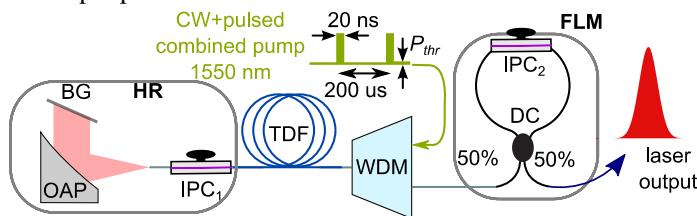


Fig. 1: Gain-switched thulium-doped fiber laser layout. HR: tunable high reflector; OAP: off-axis parabolic mirror; BG: Bragg grating; TDF: thulium-doped fiber; WDM: wavelength-division multiplexer; FLM: fiber loop mirror; DC: coupler; IPC: inline polarization controller.

3. Results and conclusions

The laser delivers microjoule-level pulses that are spectrally-tunable within more than 200 nm bandwidth (Fig. 2). The pulse energy exceeds by order of magnitude the performance of previously reported widely tunable small-core GS TDFL [9], approaching the performance of GS laser systems, based on TDF with larger core dimensions [6]. The CW pump component allows for two-fold increase of the laser pulse energy in the middle of the TDF gain profile (up to 12 μ J), and enables a GS-regime at the spectral edges. The pulse FWHM varies from 50 to 300 ns (Gaussian fitted), significantly increasing beyond 2040 nm due to a rapid drop of TDF emission cross-section, as predicted by theoretical models of GS lasers [10]. The pulse peak power higher than 300 W is reached around the wavelength of 1850-1900 nm for 45-50 ns long pulses.

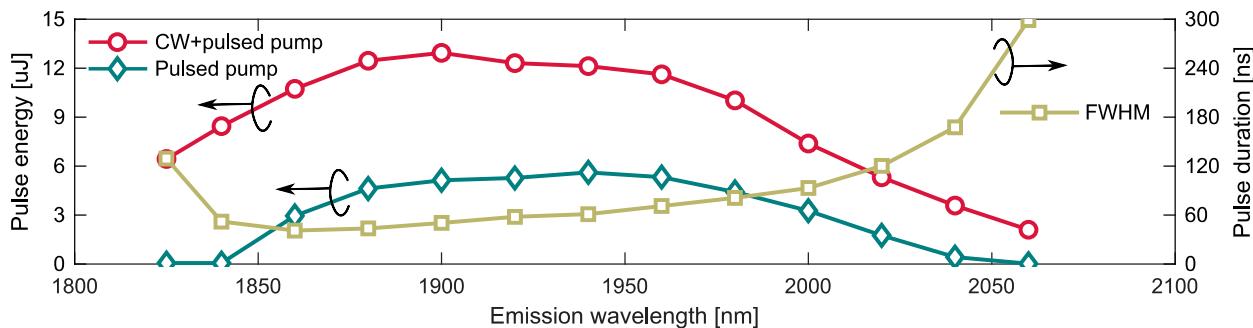


Fig. 2: Pulse energy of the GS TDFL for the cases of hybrid (CW+ pulsed) and pulsed excitation schemes (left axis). The pulse duration is evaluated for a hybrid-pump case as a FWHM of corresponding Gaussian fits (right axis).

The OSNR better than 40 dB/1nm is achieved for all of the emission wavelengths (Fig. 3). It should be noted that on the blue edge of the spectral tunability is primarily limited by the WDM transmission window (cut-off -3 dB wavelength λ_c of 1815 nm, see also reduced TDF ASE spectrum). Otherwise, the shorter-wavelengths TDFL operation would be possible, similar to [9].

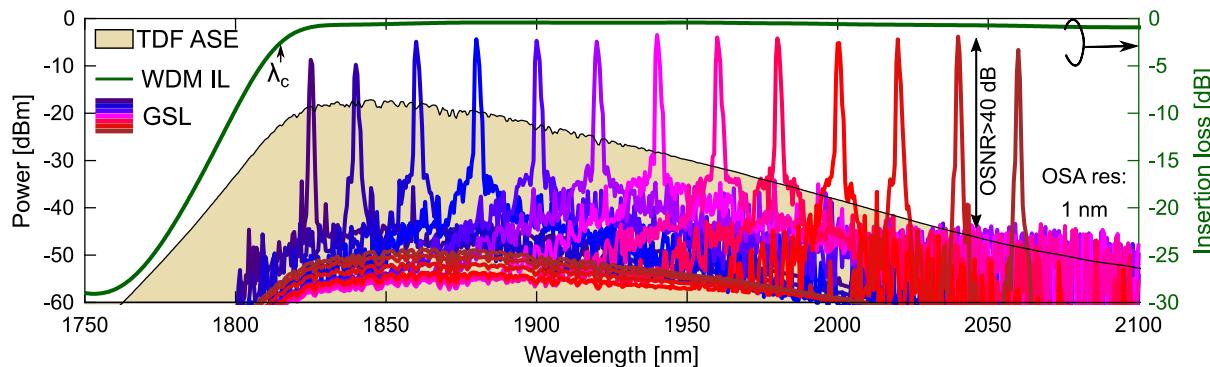


Fig. 3: Optical spectra of the tunable GS TDFL, superimposed with TDF amplified spontaneous emission and WDM transmission spectrum.

In conclusion, we demonstrated an efficient hybrid-pumped gain-switched small-core TDFL, broadly tunable in 1825-2064 nm range and delivering 50-300 ns pulses with energies up to 12 μ J. Thanks to the low-loss cavity design with the variable out-coupler this laser approaches the performance of conventional larger-core GS TDFLs.

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