Q-switched and Mode-locked 3.5 µm Fiber Laser

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Abstract: We report on a tunable mid-infrared erbium fiber laser mode-locked via frequency shifted-feedback provided by an acousto-optic tunable filter. Q-switched pulses were produced when the driving frequency of the acousto-optic tunable filter was square-wave modulated. © 2019 The Author(s)

1. Introduction

Frequency-shifted feedback (FSF) has recently been shown to be a useful technique in producing pulsed lasers at the 3 µm wavelength region with pulse durations on scale of picoseconds [1-3]. Woodward *et al*. used an acousto-optic tunable filter (AOTF) and Dy^{3+}-doped fiber to produce pulses as short as 33 ps while allowing for wavelength tuning from 2.97 to 3.3 µm [2]. Majewski *et al*. subsequently demonstrated 4.7 ps pulses at 2.86 µm using a Ho^{3+}/Pr^{3+} co-doped fiber and an acousto-optic modulator (AOM) [3]. In this case, the larger bandwidth of the AOM allowed for the formation of shorter pulses, although filtering as a result of the limited gain bandwidth may also be responsible.

The FSF technique requires a combination of frequency shifting and spectral filtering inside the laser resonator [4, 5]. On each pass through an acousto-optic device, the diffracted light undergoes a frequency shift equal to the drive frequency with the direction of the shift given by the sign of the diffraction order. After many round trips the light shifts beyond the bandwidth of the either the gain or diffraction, supressing coherent continuous wave operation. The presence of self-phase modulation (SPM) can however, counteract the frequency shift resulting in short pulsed operation which enhances the degree of SPM. This gives rise to steady state pulsed output with a repetition rate equal to the cavity free spectral range (FSR). The benefit of this technique compared to nonlinear polarisation rotation or the use of 2D materials is that it has long term reliability with minimal cavity complexity.

2. Experimental Setup and Results

A schematic of the experimental setup used for Q-switching and FSF mode-locking experiments is shown in Figure 1. The combined pump light was passed through a dichroic mirror that is highly reflective at 3.5 µm before being launched into the 7 mol% Er^{3+}-doped fiber by an aspheric lens. The double clad fiber manufactured by Le Verre Fluoré had a 16 µm core and a 240/260 µm double truncated circular inner cladding with a measured core NA of 0.08 at 3.5 µm. The other end of the fiber was butted against a mirror that was 95% reflective at 3.5 µm. The laser light transmitted through this mirror was used for diagnostics. The laser light reflected by the dichroic at the pump input end is passed through the quasi-co-linear TeO_2 AOTF (Gooch & Housego). The diffracted light was retro reflected by a silver mirror and the zero order was used as the primary laser output. The diffracted wavelength was controlled by changing the frequency of the RF drive signal.

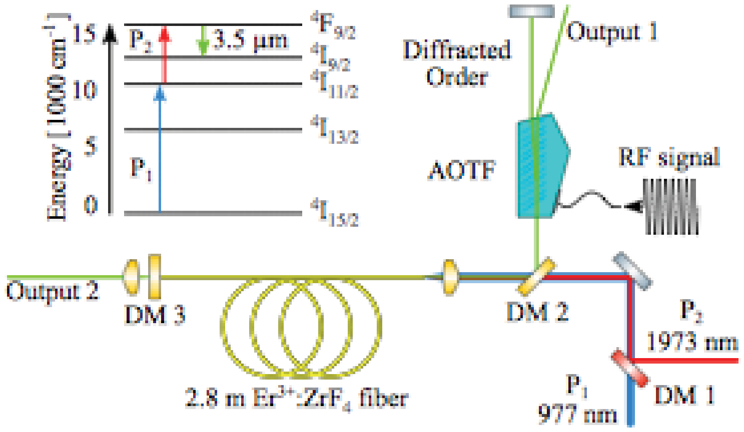

Figure 1: Experimental setup for Q-switching and FSF mode-locking experiments. P1 and P2 pump powers were set to 4.8 and 4.9 W respectively. Inset: simplified energy level diagram showing the dual-wavelength pumping scheme. DM - dichroic mirror.

For a continuously applied RF drive signal, stable single pulsed mode-locked operation was observed when above threshold. Double and multi-pulsing occurred at higher pump powers. The highest average output power

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for which stable single pulsing could be achieved was 50 mW. While single pulsing, the repetition rate was 36.25 MHz, in agreement with the cavity FSR. An autocorrelator based on two-photon absorption was constructed to measure the pulse durations [6]. The autocorrelator consisted of a Michelson interferometer, motorised translation stage and an amplified extended InGaAs photodetector (Thorlabs PDA10DT). An autocorrelation measurement is shown in Figure 2(a). Assuming a Gaussian shaped pulse, the measured pulse duration is 53 ps after deconvolution. The operating wavelength of the system could be tuned by changing the frequency of the RF signal driving the AOTF. By doing this we could achieve over 200 nm of tunability centred on 3.5 µm, shown in Figure 2(b).

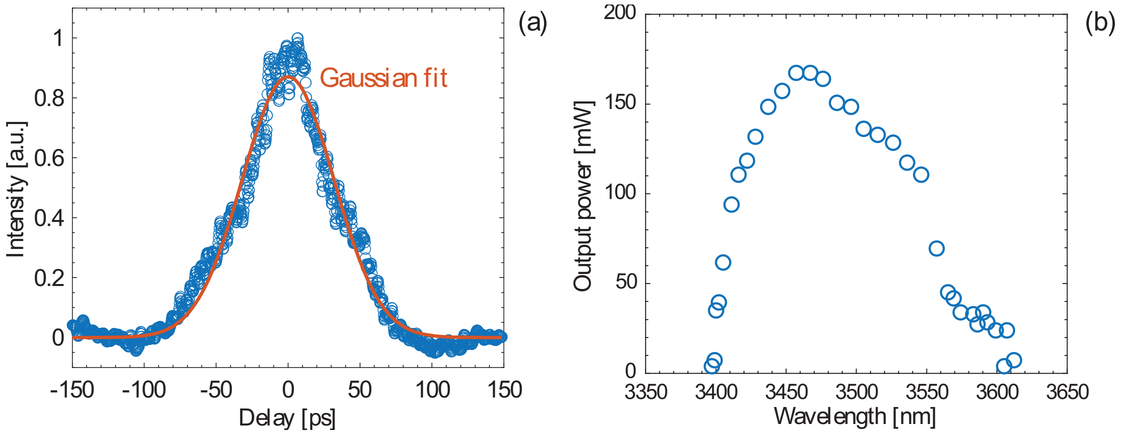

Figure 2: Measured characteristics of the FSF mode-locked laser. Figures reproduced from [1]. (a) Two-photon absorption autocorrelation trace for an operating wavelength of 3.47 µm. The deconvolved pulse duration is 53 ps assuming a Gaussian shaped pulse. (b) Average output power of the laser across its wavelength tuning range.

Q-switched operation was implemented by switching the sinusoidal modulation to the AOTF on and off to modulate the Q of the resonator. Q-switched pulses were produced for repetition rates from 0.5 to 40 kHz (Figure 3). The shortest and most energetic pulses occurred at a repetition rate of 7.5 kHz with a FWHM of 463 ns and an energy of 6.4 µJ. The operating wavelength of the Q-switched system was also tunable over 200 nm at a repetition rate of 10 kHz.

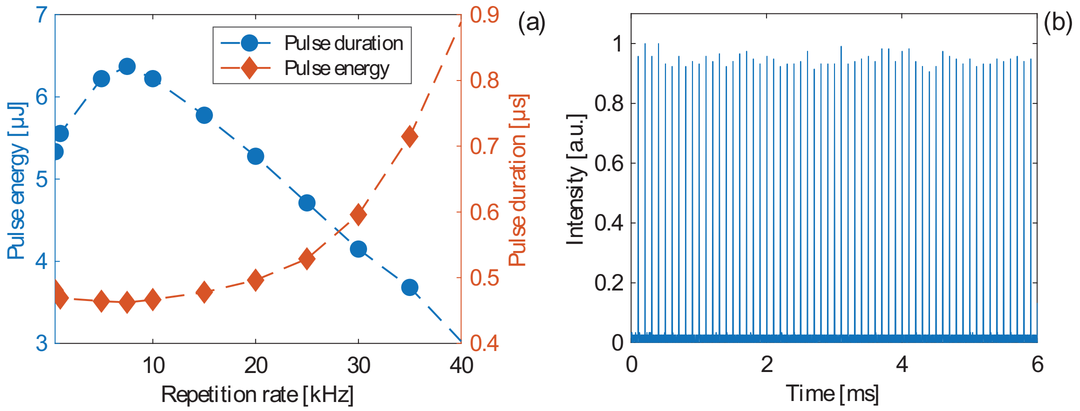

Figure 3: Measurements of the Q-switched laser at an operating wavelength of 3.47 µm. (a) Pulse energy and duration at various repetition rates. (b) Pulse train at a repetition rate of 10 kHz.

3. References

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