Supporting Information

Deep-tissue two-photon microscopy with a frequency-doubled all-fiber mode-locked laser at 937 nm

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1. Layout of the all-fiber laser system

The below photo is the 1.8-μm all-fiber laser, including the cavity (Part 1) and the 1st amplifier (Part 2). Part 3 is the 2nd amplifier, which has not been used for this experiment. It can be used to further boost the laser average power.

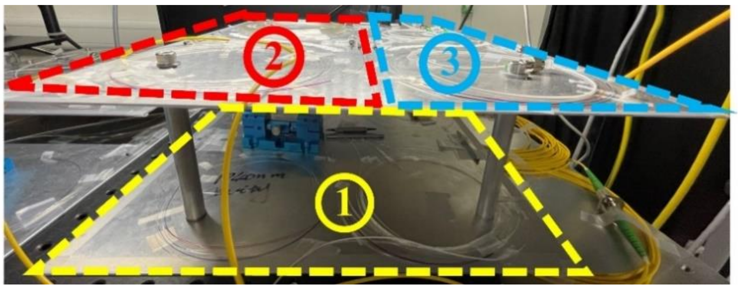

Fig. S1 Layout of the all-fiber laser system.

2. 1-mm-long PPLN crystal for frequency-doubling

As the acceptance bandwidth is inversely dependent on the PPLN length, a shorter PPLN will convert a wider bandwidth. A 1-mm-long PPLN is ideal for the femtosecond pulse with the bandwidth of over 30 nm. As shown in the below figure, the frequency-doubled laser spectrum has a 3-dB bandwidth up to ~8 nm, thus the corresponding transform-limited pulse width (TLPW) is ~115 fs ($sech^2$ fitting) and ~162 fs (Gaussian fitting). As a comparison, the 3-dB bandwidth is ~3 nm when using a 10-mm-long PPLN, thus the corresponding TLPW is ~307 fs ($sech^2$ fitting) and ~431 fs (Gaussian fitting). Therefore, by simply switching the PPLN crystal to a 1-mm-long one, the frequency-doubling process can be further optimized.

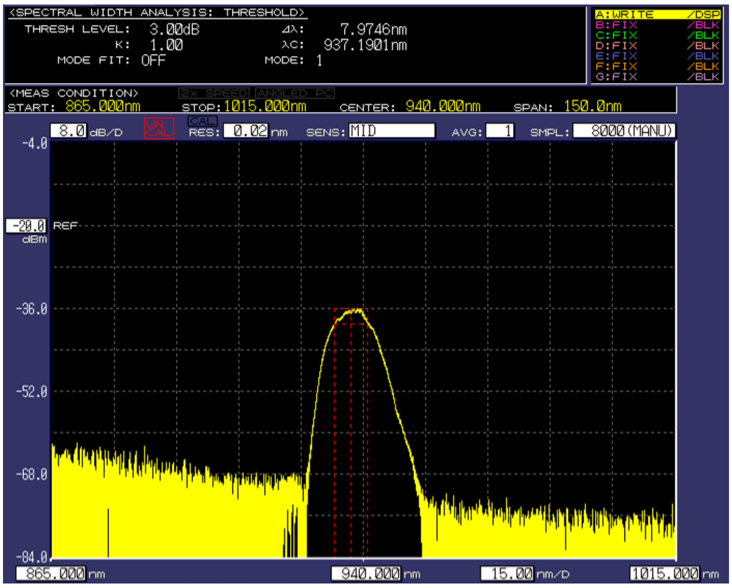

Fig. S2 Frequency-doubled spectrum using a 1-mm-long PPLN crystal.

3. Quantitative comparison of lasers with different repetition rate for 2PM

We have compared the parameters among paper [35], [36], and our work in the Table below. At the 600~700 μm depth region, the average power used in our work is much lower, i.e., less than 10% of that in [35] and [36]. And according to the comparison, our work is only ~30% of the peak power used in [35] and [36]. These indicate our laser source is much more efficient for two-photon excitations owing to the low repetition rate and high SNR of the directly mode-locked laser.

Table S1 Quantitative comparison of lasers with different repetition rate for 2PM

Parameter / Work	Repetition rate (MHz)	Depth (mm)	Average Power (mW)	Peak power (kW)
[35]	80	~600	<100	8.9
[36]	70~80	~680	160	~12.5
Our work	9	~620	~10	~3.1
Comparison	-	-	~10% of [35] ~6% of [36]	~35% of [35] ~25% of [36]

4. Stability of the laser system

The stability of the laser oscillator is shown in Fig. S3. The fluctuation of the average output power over 2 hours is about ±1.1%. During the three-month experiments, the laser system worked well without mis-locked. For the tolerance of mechanical vibration, when the nonlinear optical loop mirror in the laser cavity was tightly fixed on the iron plate, general movements and vibrations would not affect the laser performance. Adequate thermal silicone greases were filled in the gap between TDF (in the amplifier) and the iron plate, aiming to efficiently dissipating the heat.

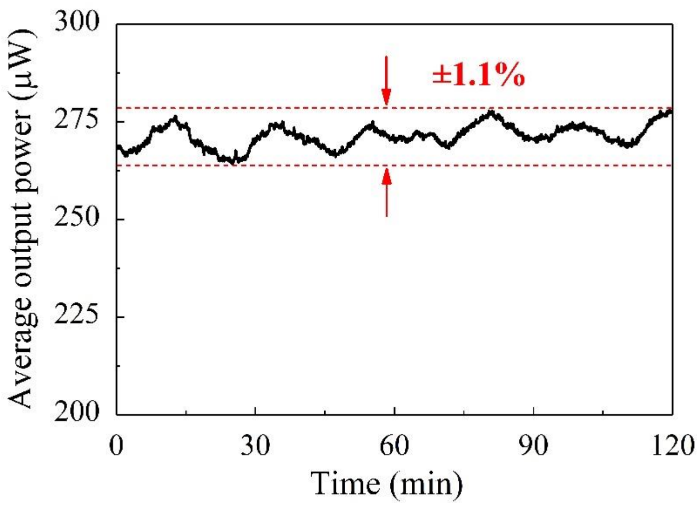

Fig. S3 Average-output-power stability of the laser oscillator over 2 hours.