Pump Modulation Induced Actively Mode-locked Thulium-doped Fiber Lasers

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Fiber lasers at the wavelength of 2μm offer exceptional advantages for free space applications compared to conventional systems that operate at 1.55μm or 1.06μm. In particular, mode-locked thulium-doped fiber (TDF) lasers emitting ultra-short pulses have attracted lots of interest as it can be applied for supercontnuum generation at mid-infrared region, plastic material processing and gas sensing. Compared with passive mode locking with saturable absorbers, active mode locking can achieve higher repetition rate with harmonic mode locking. In addition, active mode locking is the better solution when pulse trains are required which are synchronized with some electronic signal, or when many lasers need to be operated in synchronism. An actively mode-locked sub-nanosecond TDF laser with an acousto-optic modulator have been studied for high power operation. However, the modulators add extra intracavity loss, which is not good for high power operation.

Here, for the first time to our knowledge, we realized an actively mode locked TDF laser without need for the intracavity modulator. We achieved the active mode locking by modulated pumping at 1.57μm. We recently found that the output of TDF lasers are influenced by the modulated pump light due to the short life time of the upper laser lever of Tm^{3+} (400~500μs,). It turns out that the intracavity modulation, that is, active mode locking, is possible by simply modulating the pump light, without the need for the lossy and expensive intracavity modulator. With modulated pumping, we achieve active CW mode locking with the pulse duration of 5ps, the spectral width of 0.9nm and the repetition rate of 6.70MHz.

Fig.1 shows the experimental setup. A length of TDF, a wavelength-division multiplexing (WDM) coupler, an isolator (ISO) and a 50/50 coupler constitute a ring cavity. The TDF is pumped by a high-power light at 1.57μm seeded by a tunable laser and then amplified by a high-power C-band Er-doped fiber amplifier (EDFA). The tunable laser is directly modulated by the sinusoidal signal from a function generator. The total cavity length is around 30.5m, corresponding to the estimated fundamental repetition rate of 6.7MHz. The estimated intracavity net dispersion is -1.67ps^2.

By setting the modulation frequency at 6.69850MHz with the modulation index of 30%, we achieve active CW mode locking. The output spectrum has several Kelly sidebands, which infers that the laser generates soliton pulses as shown in Fig.2. The spectral width is 0.9nm. The CW mode locking is confirmed by measuring the pulse train with an InGaAs photodetector followed by an oscilloscope, as shown in Fig.3. The FWHM autocorrelation width is 8ps indicating that the estimated pulse duration is 5ps, assuming that the pulse shape is hyperbolic secant as shown in Fig.4. Thus, the time-bandwidth product is 0.338, which is nearly a value of a transform-limited pulse waveform (0.315).

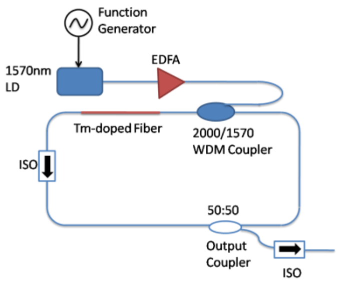

Fig. 1 Schematic diagram of experimental setup.

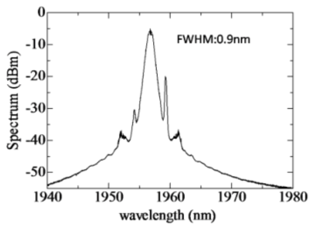

Fig. 2 The output spectrum of the CW mode locking.

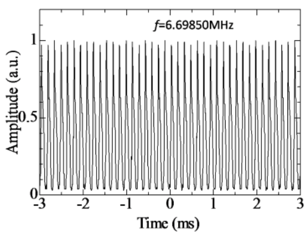

Fig. 3 Output pulse train

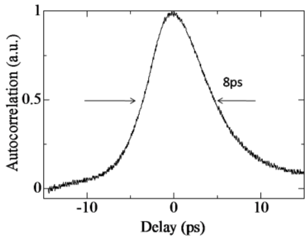

Fig. 4 The autocorrelation trace of the output pulse