Compact 85 fs frequency doubled 810 nm fiber system with 60 mW of average power

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Abstract: We demonstrate a sub-100 fs frequency doubled fiber laser operating at 810 nm. The laser produces 60 mW of average power at a repetition rate of 50 MHz. Extremely low amplitude noise (below 0.1%) and compact size makes this source ideal replacement for low power ultrafast Ti:Spphire lasers.

Keywords: Raman soliton compression, frequency doubling, femto-second

1. Introduction

Ultra-fast high-power laser sources, generating pulses of sub-picosecond duration in the 800 nm wavelength range are becoming increasingly important in applications areas ranging from micro-machining to non-intrusive surgery, bio-detection, and homeland security - terahertz imaging systems demonstrating enormous potential for security screening in airports and public venues. Until now, such high-power short pulsed sources are mainly provided by Ti:sapphire or similar bulk lasers, which have significantly undesirable features such as high-cost, large footprint, and relatively poor reliability. Fiber lasers make attractive alternatives due to the small size and compactness. Moreover, the Raman soliton compressor technique in fiber can be used to generate very short pulses [1, 2]. Recent published results include 105 fs 117 mW 812 nm source [3], where the last stage amplifier was based on a cladding pumped co-doped Er/Yb fiber.

Here, we demonstrate an alternative approach by using a core-pumped large mode area erbium-doped fiber which allowed us to develop a compact, all-in-fiber (except for the frequency doubler) 85 fs 810 nm source. A master-oscillator is pre-amplified to increase power and to stretch the pulse, which is amplified and compressed through a power-amplifier using Raman soliton compressor. Finally, this fundamental 1600 nm broadband pulsed source was frequency-doubled using periodically poled $LiNbO_3$ with a conversion efficiency of 44 %.

2. Experimental setup and results

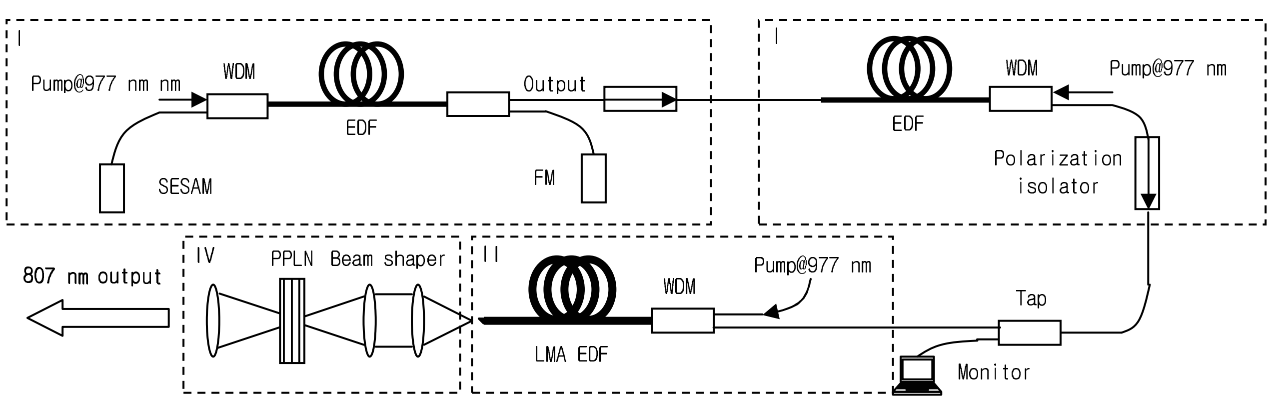

Figure 1. Experimental setup. I: Master-oscillator, II: Pre-amplifier , III: Power amplifier and Raman soliton compressor, and IV: Frequency doubler

Figure 1 shows the experimental setup. It was comprised of four parts, namely, a master-oscillator, a pre-amplifier, a power-amplifier (or a Raman soliton compressor), and finally a frequency doubler. The master oscillator is a passively mode-locked soliton laser operating at 1560 nm with 50 MHz repetition rate. Modelocking is initiated using a semiconductor saturable absorber mirror (SESAM) as one of the cavity mirrors. The laser was truly self starting, producing 560 fs transform-limited with an average power of 1.7 mW. A fiber mirror (FM) was used as the other cavity mirror. The Er-doped fiber was 1 m long and was core-pumped through a 980/1550 nm WDM with 80 mW 977 nm single mode laser diode (JDS Uniphase). The spectrum and autocorrelation of the master source are shown in figures 2 and 3, respectively.

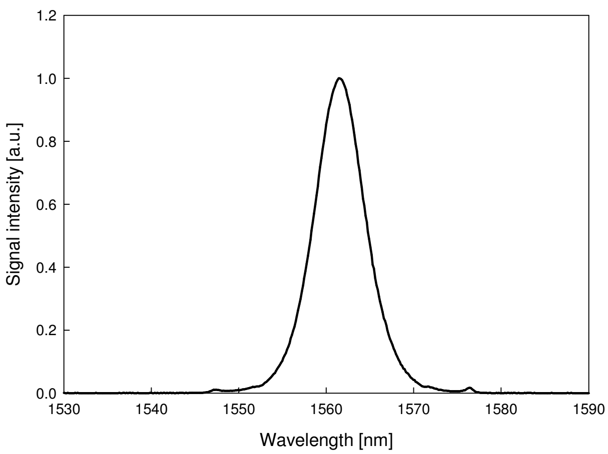

Figure 2. Output spectrum of master oscillator. (1 nm resolution)

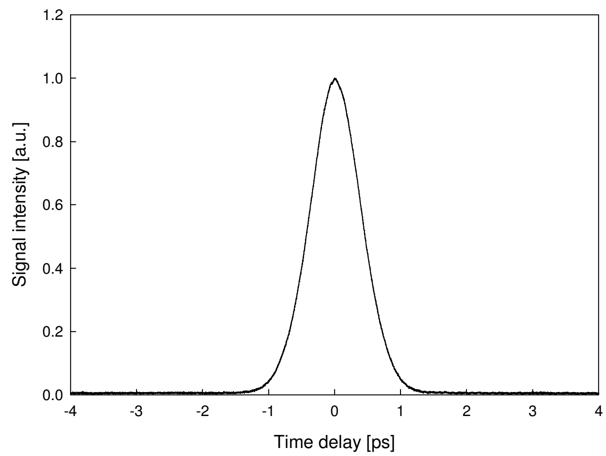

Figure 3. Autocorrelation of master oscillator

It is well known that ultra-short pulse amplification in optical fibers is accompanied by nonlinear effects such as self-phase modulation and stimulated Raman scattering. In our case when pulse amplification takes place in the region of anomalous dispersion, the combined effect of the Kerr nonlinearity and anomalous dispersion leads to multisoliton pulse compression which is also accompanied by the effect of soliton self-frequency shift [2]. Thus simultaneous amplification, compression and Raman shift effects result in the formation of ultra-short (~ 100 fs) pulses at a red-shifted wavelength [1-3]. Note that these pulses are fundamental solitons and their energy is set by the pulsewidth, fiber nonlinearity and dispersion. Since soliton energy is also proportional to the core area of the fiber, which is erbium-doped fiber in our case, then in order to increase the average power at fundamental wavelength a large mode area fiber was used in the last stage amplifier.

The Er-doped power amplifier was designed for simultaneous direct power amplification and Raman soliton compression. A 3 m long large-mode-area (LMA) Er-doped fiber with 17 µm diameter and 0.13 NA was core-pumped with 500 mW single-mode fiber-pigtailed 977 nm laser diode. Figure 4 shows the spectrum at the output of the power amplifier. The Raman soliton compressor shifted the signal center wavelength from 1560 nm to 1614 nm (54 nm difference) and compressed the pulse duration to 82 fs FWHM. The average power at the output of the amplifier was 131 mW. Spectral integration of figure 4 estimated the power portion of the Raman soliton compressed region (centered at 1614 nm) was as high as 80 % of the total power. The amplifier output was measured to be approximately 85% linearly polarized.

A PPLN crystal with 20.2 µm poling period and 0.46 mm length was used for frequency doubling of radiation at fundamental wavelength. The PPLN was kept at an elevated temperature of 70 °C to optimise the doubling efficiency. The output end of the power-amplifier Er-doped fiber was angle-cleaved in order to prevent signal feedback. For efficient frequency doubling we have used a two-lens beam shaper to focus on the PPLN. Optimisation of the laser produced a stable average output power of 60 mW at 807 nm. The frequency conversion efficiency was 44 %.in respect to total power at the fundamental wavelength. However, if we consider the ‘useful’ fundamental power – namely linearly polarized and Raman soliton compressed portion (centered at 1614 nm) of the power amplifier output, the frequency conversion efficiency was calculated as 64 %.

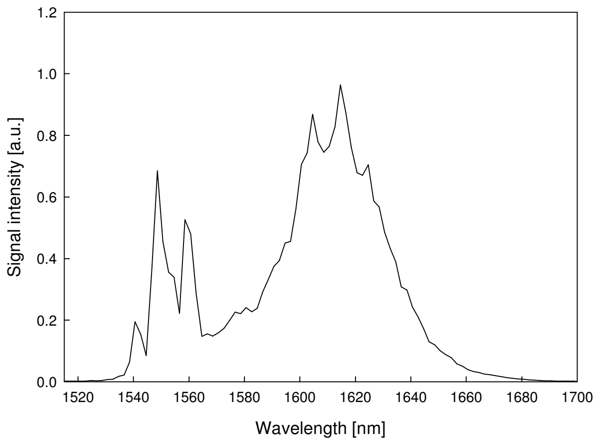

Figure 4. Output spectrum of power amplifier. (1 nm resolution)

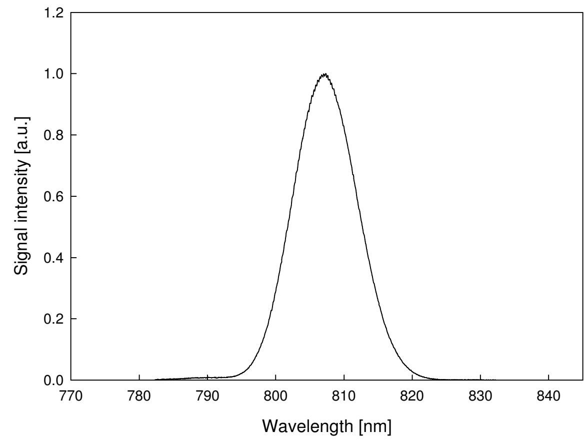

Figure 5. Frequency doubled 807 nm spectrum (0.5 nm res.)

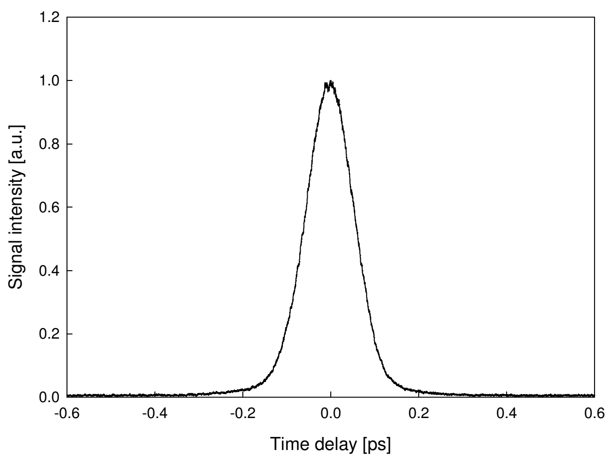

Figure 6. Autocorrelation of 807 nm source.

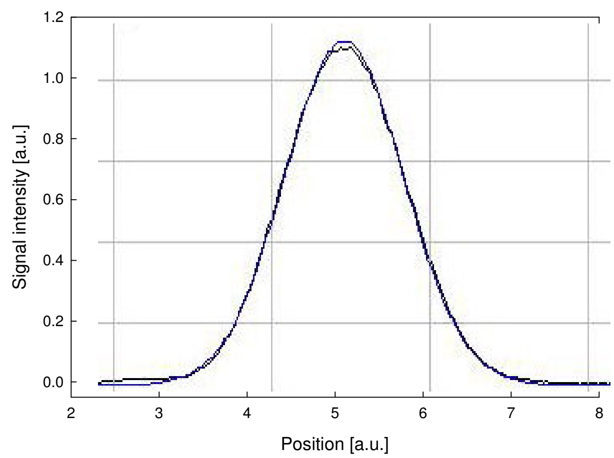

Figure 7. Beam spatial profile and Gaussian fit of 807 nm.

Figure 5 shows the clean spectral property of the 807 nm source. The 3 dB bandwidth was 11 nm. Figure 6 shows the autocorrelation of frequency doubled 807 nm source, with FWHM pulse duration of 85 fs assuming $sech^2$ pulses, thus, the time-bandwidth product was 0.42. The peak power of the 807 nm pulse is estimated as 13.4 kW. The M^2 value of the 807 nm source was measured to be 1.1, a diffraction limited beam quality. Figure 7 shows a Gaussian fit of our 807 nm beam shape.

In applications such as THz imaging, the noise property of an ultra-fast laser is a critical parameter. We measured the temporal stability of our source with an 8 µs time-constant system including detector and oscilloscope and measured at a time scale of 10 µs, 100 µs, and 1 ms. The output power fluctuation was less than 0.10 %. These excellent spatial, spectral beam qualities are ascribed to the filtering action caused by nonlinear crystal PPLN.

3. Conclusion

We have demonstrated a compact all-in-fiber (except for the frequency doubler) 85 fs pulsed 810 nm source. The laser provides a stable 60 mW average power with repetition rate of 50 MHz and with extremely good temporal, spectral, and spatial properties. Being all-fiber, this system lends itself for integration into an extremely compact package as an attractive alternative to Ti:Sapphire lasers in many applications.

References

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