High repetition-rate 2 μm ultrafast source for data communication and processing

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Abstract: Spectrally masked phase modulation technique is used to demonstrate a 2 μm picosecond source, with continuously tunable repetition rate up to 6 GHz. Such a source is useful for 2 μm data communication and processing.

OCIS codes:(140.3538) Lasers, pulsed; (140.3600) Lasers, tunable; (060.5060) Phase modulation.

1. Introduction

2 μm pulsed lasers with multi-gigahertz repetition-rates are of increasing importance due to their potential applications in high-speed optical telecommunication, data processing, sensing and metrology. Active mode-locking techniques are frequently used to achieve high repetition ultrashort laser source [1]. Although tens of GHz have been reported at a wavelength of 1.5 μm, to the best of our knowledge, the highest repetition-rate of 2 μm actively mode-locked lasers is limited to ~1.5 GHz [2]. On the other hand, passive mode-locking represents a superior method for enabling extremely short pulses, but the repetition-rate is often limited within hundreds of MHz due to the relatively long cavity lengths for fiber lasers [3]. Engineering high repetition-rate passively mode-locked fiber lasers using highly-doped gain fiber and carbon-based saturable absorbers have achieved remarkable progress, but this has not been achieved in the 2 μm range yet [4-7]. Howe et al. reported an impressive 18 GHz repetition-rate source at 2 μm by using two phase modulators as time-lens. However, the system exhibited relatively poor stability, low SNR and imperfect parabolic phase [8].

Spectrally masked phase modulation (SMPM) is another powerful extra-cavity technique to obtain high repetition (tens of GHz) pulse trains. It was first described by P. V. Mamyshev in 1994 [9]. Compared with other amplitude modulation techniques, this modulation technique does not require a resonant cavity or DC bias [10], resulting in a number of advantages such as robustness of operation and ease of repetition scaling. 10-20 GHz SMPM systems have already been demonstrated at 1 and 1.5 μm [10, 11]. In this paper, we have for the first time developed a high repetition, 2 μm all-fiber ultrafast source by SMPM, with a repetition rate tunable up to 6 GHz.

2. Experimental setup

As shown in Fig. 1, the experimental setup is composed of a RF electric driving circuit and an optical circuit. The RF driving source (up to 10 GHz) is provided by a signal generator (KEYSIGHT N5183) and the signal is then amplified by a RF amplifier (SHF 81) to an output power of 26 dBm. For the optical part, a 2 μm CW diode laser (Eblana Inc.) whose wavelength can be fine controlled by temperature is used as the seed source. To compensate for the insertion loss, the laser is then fed to a thulium-doped fiber amplifier (NPI Lasers Inc.) and amplified to an output power of ~80 mW. Subsequently, a polarization-sensitive lithium niobate phase modulator (LNPM, EOSPACE Inc.) is used for sideband generation. Then, an optical circulator and a FBG with a pass bandwidth of 0.8 nm are used to extract a portion of the modulated laser (with broadened spectra) for further optical diagnosis. In previous SMPM systems, a tunable filter is usually used to align with the sidebands of the broadened spectra after phase modulation. Instead of using a tunable filter which is not widely commercially available at 2 μm, here we combine a fixed passband FBG with a temperature tunable seed source.

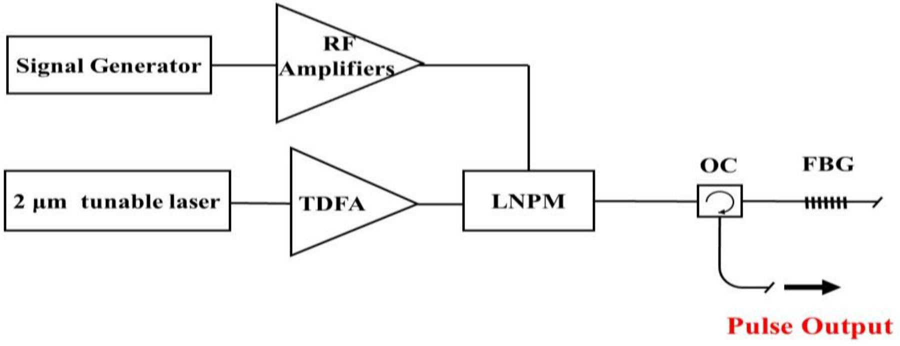

Fig. 1. Schematic setup of the SMPM system. TDFA: thulium-doped fiber amplifier; PC: polarization controller; LNPM: lithium niobate phase modulator; OC: optical circulator; FBG: fiber Bragg grating.

3. Results and discussion

Fig. 2a shows the optical spectra of the source (operating at 6 GHz) before and after the FBG measured by an optical spectrum analyzer (Yokogawa AQ6375). It can be seen that phase modulation produces a comb of new frequency components located on both sides of the center wavelength (~1958.7 nm). The interval between the new frequency components is the same as that of the driving electrical signal. The measured passband of the FBG （1959.6 nm） is also plotted. After the FBG, the short-wavelength portion of the spectrum is seen to be effectively suppressed, which is crucial for obtaining higher SNR of SMPM generated pulses. We note that an effective bandwidth of ~ 0.3 nm (at -10 dB) is achieved for our system. It is estimated that about 12, and 4 side modes participate in the pulse forming process for 2 and 6 GHz. This sets the upper limit for the operating frequency, as a good number of side modes would guarantee high quality pulse forming through in-phase interference [6, 7].

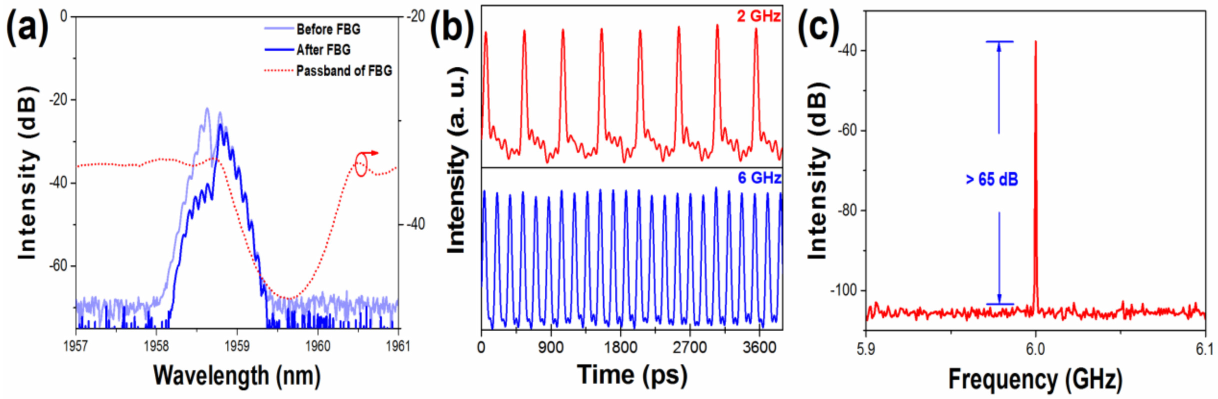

Fig. 2. (a) Optical spectra of phase modulated output before and after the FBG, at an operating frequency of 6 GHz. Dash-dotted line indicates the passband of the FBG; (b) The pulse trains observed by a digital signal analyzer, with repetition rate of 2 GHz and 6 GHz； (c) The RF spectrum over a span of 200 MHz, RBW=3 kHz.

The output is detected by a high-speed photodetector with a nominal bandwidth of 11 GHz (EOT ET-5000F), which is then analyzed by a real-time oscilloscope (KEYSIGHT DSA91304A). The output pulse train with varying repetition rate clearly observed as shown in Fig. 2b. The ratio of pulse width over the modulation period is ~ 1/7, and 1/3, in agreement with the decreasing sideband number. It is clearly observed that more sideband modes result in a better duty cycle pulses. The pulse width achieved with the current setup is 65 ps and 60 ps for the repetition of 2 GHz and 6 GHz, respectively. It is generally true that setting a higher repetition rate will give narrower pulse width, similar to other SMPM reports [28, 29]. Overall, the 2 GHz pulse shows a better performance in terms of pulse quality, probably due to a good balance between effective sideband modes and the stronger spectral modulation at this frequency. Increasing the 3 dB bandwidth of the FBG or passband filter will make optimal results achieved at higher repetition rates. It is observed that the pulse can be well fitted by a Gaussian pulse shape and the TBP of the pulse is ~ 0.45. Fig. 2c depicts the RF spectrum of the pulses at a center frequency of 6 GHz measured with a RBW of 3 kHz in the range of 200 MHz. A rather high signal to noise ratio of 65 dB indicates the good stability in this operation regime.

It should be noted that the incorporation of a tunable fiber laser as the seed in our experimental setup brings significant flexibility in the system and may be employed to enable a wavelength reconfigurable source (with the incorporation of a tunable filter). One advantage of this system is that the repetition rate can be flexibly changed by modifying the driving RF signals. Further experiments are underway for optimizing the system’s performance, a tunable filter with broader bandwidth will be employed to replace the FBG, providing more flexibility for optimizing the system.

4. Conclusion

In summary, we have for the first time demonstrated a stable and highly flexible GHz repetition-rate picosecond pulse sources at 2 μm, employing SMPM technique. A tunable seed diode laser and a FBG can be combined to yield effective pulse curving. By simply adjusting the modulation RF frequency, the repetition rate of the output pulses can be continuously and flexibly controlled up to 6 GHz, making it highly suitable for high speed mid-infrared data communication applications.

5. References

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