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A Stable 40 GHz Pulse Train Generation by Pulse Repetition-Frequency Quadruplication Using a Fiber Fabry-Pérot Interferometer

Wanyong Ruan*, Jae-Hyun Park*, and Dongsun Seo*★

Abstract

We demonstrate a simple method to generate a stable 40 GHz pulse train at 1550 nm by spectral filtering of a 10 GHz mode locked pulse source using a fiber Fabry-Pérot interferometer (FFPI). A high finesse FFPI with a 40 GHz free spectral range blocks successfully unwanted spectral components of a 10 GHz pulse source and passes only 40 GHz spaced spectral lines ensuring pulse repetition-frequency quadruplication of the input pulses.

Key words: Repetition frequency multiplication, Spectral filtering, Optical pulses, Ultrafast optical technology

I. Introduction

Fast pulse sources are very useful for future high capacity optical communications, millimeter-wave photonics, and fast optical signal processing. Active harmonic mode locking of a fiber laser is an effective technique for generating stable picosecond pulses with low timing jitter at several GHz. However, the maximum pulse frequency of a mode-locked fiber laser is practically limited by the bandwidth of an intracavity Mach-Zehnder intensity modulator (MZI). It is, therefore, very challenging to find ways of increasing the repetition-frequency of the output pulses from active mode-locked fiber lasers without increasing the MZI modulation frequency. A rational harmonic mode-locking technique [1,2] was suggested and showed successful generation of optical pulses at several times of MZI driving frequency. However, the output showed serious periodic pulse amplitude fluctuation as the multiplication factor increases. Repetition-frequency multiplication via intracavity filtering or higher-order FM mode-locking using a high finesse Fabry-Pérot (FP) interferometer has been suggested [3,4]. Even though the output showed a good stability comparable with an actively mode-locked fiber laser, the inserted interferometer increases laser cavity loss, leading to broader pulse width and/or unstable laser operation. Without changing anything inside the laser cavity, the repetition frequency multiplication can also be achieved by passing simply the laser output through a multiplication device or apparatus, such as dispersive fibers [5], fiber Bragg gratings [6], time-to-space pulse shapers [7], or AWGs [8], etc. However those methods also showed some drawbacks, such as pulse-to-pulse spectrum change [4,5] and/or relatively large amplitude [6,7] variation.

Most successful technique to get a stable pulse train competing with a conventional actively mode-locked fiber laser output seems like an intracavity filtering using a high finesse FP interferometer. However, as we discussed before, to avoid any additional insertion loss inside the laser cavity, a high finesse FP interferometer can moved

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* Dept. of Electronic Engineering & Semiconductor Process Diagnosis Research Institute, Myongji University

★ Corresponding author, email : sdsphoto@mju.ac.kr

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to outside the laser cavity and do similar spectral filtering for a mode-locked laser output. It passes harmonic spectral lines with spacing corresponding to its FSR. Previously, Gupta [8] used a high finesse FP interferometer for intracavity filtering to multiply, by as much as 4 times, the rate of an 869.284 MHz mode-locked fiber ring laser output. Here we use it at outside the laser cavity and demonstrate repetition-frequency multiplication at much higher repetition rates. In particular, we experimentally demonstrate the repetition rate quadruplication of a 10 GHz pulses to generate 40 GHz pulses at 1550 nm.

II. Experiments

A schematic diagram of our repetition-frequency multiplication method by spectral filtering is shown in Fig. 1. A mode locked output at a repetition-frequency F with period T = 1/F shows discrete spectral combs with frequency spacing F as schematically shown in Fig. 1(a) and (b). If we employ a FP interference filter, we can select periodical spectral lines with frequency spacing mF where m is a positive integer as shown in Fig. 1(c). Then the resultant pulse period will be reduced by T/m as shown in Fig. 1(d). In this way we can achieve m times of the repetition-frequency multiplication of a relatively slow pulse train. Note that the envelope of the spectral lines does not change after the spectral filtering, ensuring the same pulse width after the multiplication.

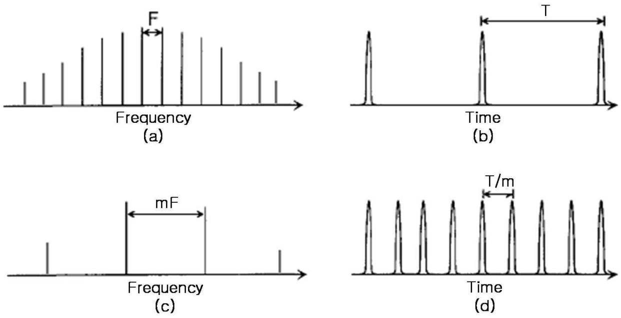


Fig. 1. Basic idea of repetition-frequency multiplication by spectral filtering; (a) optical spectrum and (b) time trace of original pulses, and those (c and d) of the spectral filtered output.

The schematic experimental setup is shown in Fig. 2. The 10 GHz pulse source is an actively mode-locked fiber laser followed by a dispersion decreasing fiber producing 0.7 ps pulses at 10 GHz centered at 1550 nm [9]. A high finesse fiber Fabry-Pérot interferometer (FFPI) with 40 GHz of a free spectral range (FSR) is used for spectral filtering of the 10 GHz pulse source. After passing the FFPI, the filtered output is amplified by EDFA and measured by an autocorrelator (ACR), an optical spectrum analyzer (OSA), and a fast detector coupled with a RF spectrum analyzer (DET/RFSA). The mode-locked output frequency was tuned deliberately to match its harmonics with the FSR of the FFPI.

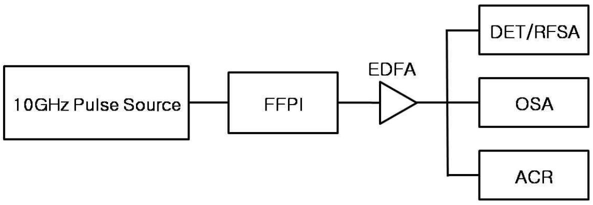


Fig. 2. Schematic diagram of experimental setup.

A pulse compressed mode-locked laser at 10 GHz is characterized by an evenly spaced series of discrete spectral lines (an optical frequency comb) in the frequency domain, of which frequency spacing equals to the pulse repetition-frequency at 10 GHz, as shown in Fig. 3(a). After passing the FFPI, unwanted spectral components of 10 GHz pulses are completely removed to leave the spectral comb with 40 GHz spacing, as shown in Fig. 3(b). This indicates the repetition-frequency quadruplication of 10 GHz pulses by the FFPI spectral filtering. Note that the spectral envelope of the 40 GHz pulses shown in Fig. 3(b) is very similar to that of 10 GHz shown in Fig. 3(a), resulting in the similar pulse shape & width but four times of pulse repetition-frequency. For clear illustration of the spectral filtering, enlarged spectra of Fig. 3 near 1550 nm were shown in Fig. 4.

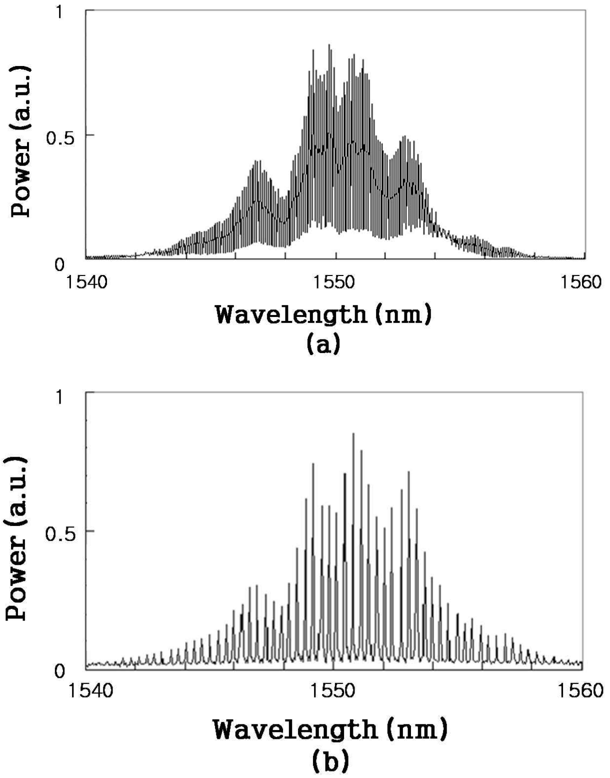


Fig. 3. Optical spectra of the FFPI input and output; (a) input showing 10 GHz frequency comb and (b) output showing 40 GHz frequency comb.

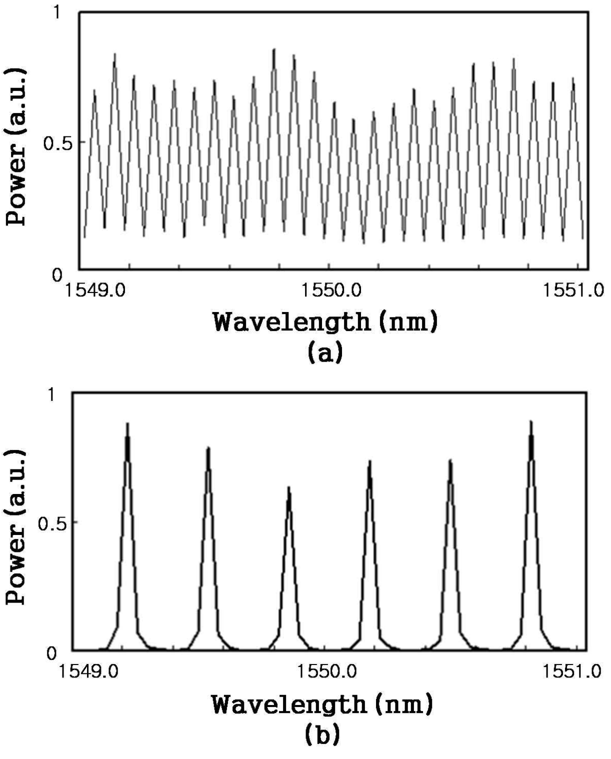
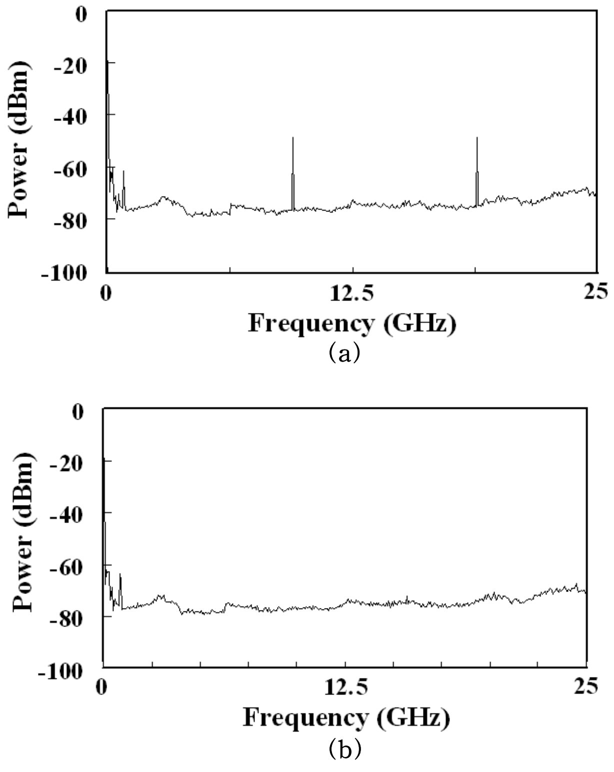


Fig. 4. Enlarged optical spectra of Fig. 3 around 1550 nm region; (a) FFPI input and (b) FFPI filtered output.

Fig. 5(a) and (c) show respectively the RF spectrum of the fast detector output and autocorrelation trace of the 10 GHz pulse train; while Fig. 5(b) and (d) show those of the 40 GHz pulse train. Since the frequency measurement range of our spectrum analyzer was limited to 26 GHz, the 40 GHz harmonic components were not able to be measured. The RF spectrum shown in Fig. 5(b) clearly verify that the 10 GHz and its 2^{nd} harmonic components in Fig. 5(a) are completely suppressed after the spectral filtering. The autocorrelation traces of Fig. 5(c) and (d) show that the pulse period reduced from 100 ps to 25 ps. This also proves that the 4 times of pulse repletion-frequency multiplication has been achieved by the spectral filtering.



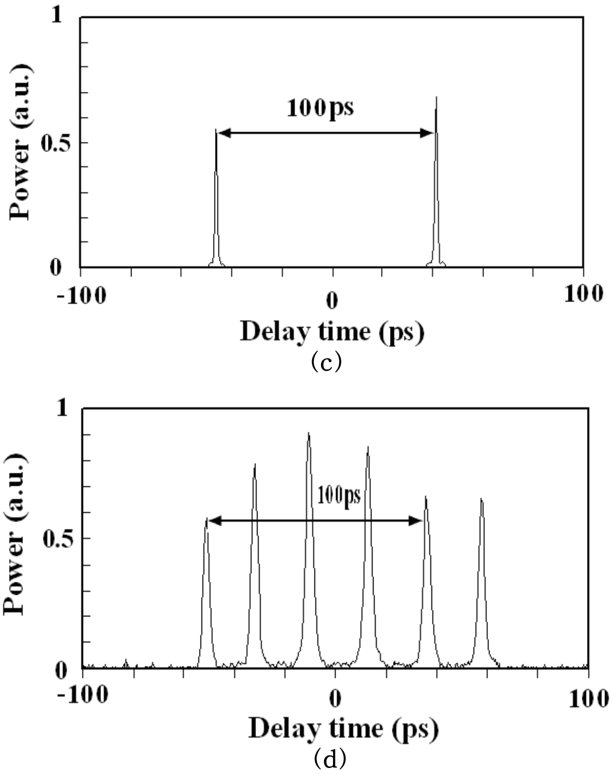


Fig. 5. Measured RF spectra (a & b) and autocorrelation traces (c & d) of 10 GHz (a & c) and 40 GHz (b & d) pulse trains.

III. Conclusion

We presented a simple repetition-frequency multiplication technique of a relatively slow pulse train by spectral filtering based on a high finesse FFPI. The FFPI with 40 GHz FSR selects periodical spectral lines with 40 GHz frequency spacing from a 10 GHz mode-locked laser output to produce a stable 40 GHz pulse train. RF spectrum of the FFPI output detected by a fast photo-detector showed the 10 GHz and its 2nd harmonic components were completely suppressed by the spectral filtering, ensuring again a stable 40 GHz pulse train generation. Autocorrelation traces also showed that the pulse period was reduced from 100 ps to 25 ps, indicating a 40 GHz pulses by repetition-frequency quadruplication of a 10 GHz source. The spectral filtering did not change the spectral envelope of the 10 GHz pulses, ensuring the same pulse shape and width but four times of pulse repetition-frequency. Similar spectral filtering method can be used for higher repletion-frequency multiplication.

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BIOGRAPHY

Wanyong Ruan (Member)
2008 : MS degree in Electronic Engineering, Myongji University.
2008 ~ present : Research Engineer, Nano Chem Tech.

Jae Hyun Park (Member)

1984 : BS degree in Electrical Engineering, Seoul National University.
1986 : MS degree in Electrical Engineering, Polytechnic University.
1993 : PhD degree in Electrical Engineering, Polytechnic University.
1994~1996 : Research Engineer, Samsung Electronics.
1996 ~ Present : Professor, Department of Electronic Engineering, Myongji University.
<Research interests> : Communication theory, Wireless channel modelling, Statistical signal processing.

Dongsun Seo (Member)

1980 : BS degrees in Electronic Engineering, Yonsei University.
1985 : MS degrees in Electronic Engineering, Yonsei University.
1989 : PhD degree in Electrical Engineering, University of New Mexico, USA.
1990 ~ Present : Professor, Department of Electronic Engineering, Myongji University.
<Research interests> : Ultra short pulse technology, optical CDMA, microwave photonics, optical communications, and optical measurements.