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Construction of a Single/multiple Wavelength RZ Optical Pulse Source at 40 GHz by Use of Wavelength Conversion in a High-nonlinearity DSF-NOLM

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Abstract: A single or multiple wavelength RZ optical pulse source at 40 GHz is successfully obtained by using wavelength conversion in a nonlinear optical loop mirror consisting of high nonlinearity-dispersion shifted fiber.

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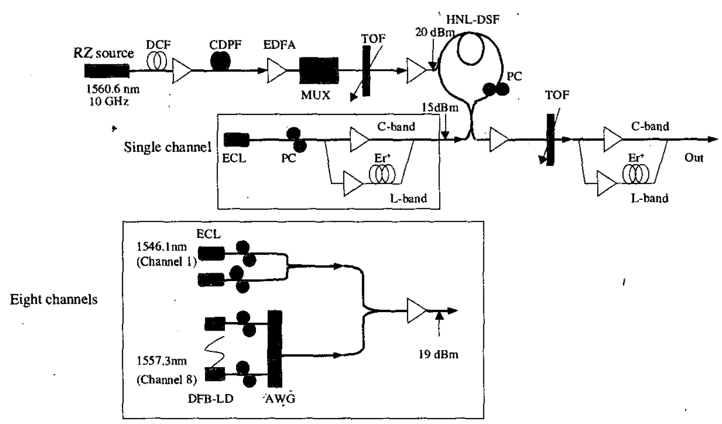
1. Introduction

Recently numerous 40 Gb/s transmission experiments have been demonstrated because electronics at 40 Gb/s has gradually matured. Ref. 1 has shown that for upgrading the existing network to 40 Gb/s, RZ format is attractive compared to conventional NRZ format. So, a stable multi-wavelength RZ pulse source at a repetition rate of 40 GHz is highly desirable for future ultrafast WDM transmission systems [2-6]. We have reported a five-wavelength optical source at 40 GHz realized by use of wavelength conversion in a nonlinear optical loop mirror (NOLM) consisting of 3 km common dispersion shifted fiber (C-DSF) [7]. However, because a C-DSF was used, the nonlinear coefficient was small and therefore a length of 3km was needed along with a wide pulsewidth in order to reduce the dispersion effect [8]. However, the wide pulsewidth is not suitable for high-speed OTDM applications. The wavelength range of the converted pulses with equal pulsewidth was also limited because of a relatively large walkoff between the control pulse and the CW lightwave. In order to increase the wavelength range of pulsewidth maintained wavelength conversion, dispersion and walkoff effects must be reduced. Use of a high-nonlinearity DSF (HNL-DSF) can shorten the DSF length in the NOLM and that leads to reduction of dispersion and walkoff effects. Our new experiment will verify this prediction. To implement practical NOLM wavelength conversion, polarisation independent operation is indispensable. A very simple method to overcome the polarisation sensitivity of the NOLM has been experimentally demonstrated by twisting the fiber to generate circular birefringence [9]. Because all components were fiber-pigtailed, this provided a simple way to generate a 40 GHz multi-wavelength source for WDM transmission systems. Due to the function of NOLM regeneration, the extinction ratio (ER) of the control pulses at 40 GHz can be improved after NOLM wavelength conversion even if the ER of the control pulses is poor [10].

II. Tunable single wavelength RZ optical source

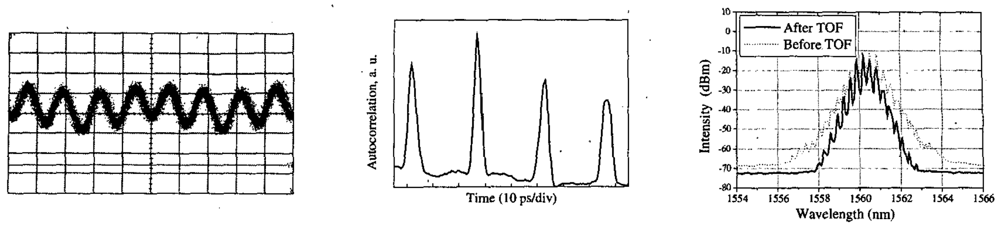
The experimental setup is shown in Fig. 1. The control laser is a 10 GHz, 1560.6 nm gain-switched DFB-LD that generates a 7.9 ps full width at half maximum (FWHM) pulsewidth after compression in a dispersion compensating fiber (DCF). We use a comb-dispersion profiled fiber (CDPF) to further compress the pulsewidth of the control pulses [11]. Then, the 10 GHz control pulses are multiplexed to 40 GHz by a fiber delay-line multiplexer. The CW lightwave is generated from an external cavity laser (ECL). The CW lightwave having a wavelength in the 1530-1568nm range is amplified to an average power of 14 dBm by a conventional C-band EDFA. A CW lightwave between 1570-1580nm was also generated by the ECL but was amplified by erbium-doped fibers that were pumped by a conventional C-band EDFA, giving up to 10dBm of output power. A polarization controller in the loop is used to obtain the best performance of the converted pulses. A TOF at the output of the HNL-NOLM is used to suppress the control pulses. The average power of the control pulses into the 3 dB optical coupler is 20 dBm. The converted RZ pulses at 40 GHz are realized by using wavelength conversion in the HNL-NOLM. The HNL-DSF in the NOLM has a length of 0.5 km, a zero dispersion wavelength of 1552 nm, a dispersion slope of 0.022



TOF: tunable optical filter, PC: polarization controller, MUX: multiplexer from 10GHz to 40GHz, CDPF: comb dispersion profiled fiber, HNL-DSF: high nonlinear dispersion shifted fiber.

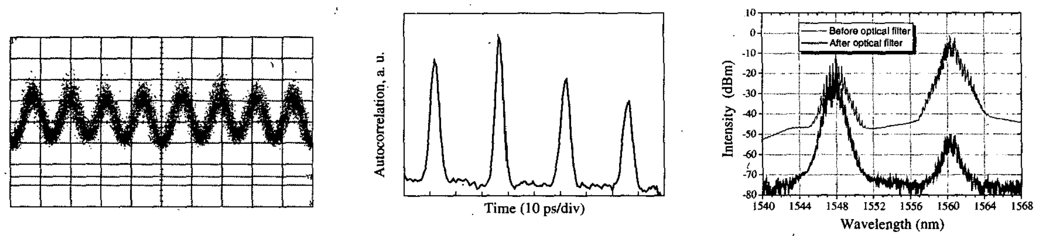
Fig.1. Experimental setup.

ps/$(nm^2 \cdot km)$, and the nonlinear coefficient is 10.9 $W^{-1}km^{-1}$. The control pulse characteristics are shown in Fig. 2. Fig. 2 (a) shows the waveform measured by a sampling oscilloscope. Fig.2 (b) shows the autocorrelator trace; the interval between pulses is 25 ps corresponding to the repetition rate of 40 GHz. The pulsewidth is 2.4ps. Because of the limited performance of the SHG, the measured amplitude of the autocorrelator trace is varying. Fig. 2 (c) shows the optical spectrum. It can be seen that the 3 dB bandwidth of the control pulse is 1.3nm. The time-bandwidth product is 0.441, which is close to the transform-limited product. Fig.2 (c) also shows the optical spectrum after a bandpass tunable optical filter (TOF); the control pulse bandwidth after the TOF is 0.9 nm and the control pulsewidth is broadened to 3.6 ps.



(a) (b) (c)

Fig. 2. Control pulse characteristics. (a) Waveform, (b) autocorrelator trace, (c) optical spectrum.



(a) (b) (c)

Fig.3. Single channel converted pulse characteristics at 1548nm. (a) Waveform, (b) autocorrelator trace, (c) optical spectra.

Fig. 3 shows typical converted pulse characteristics. Fig.3 (a) shows the waveform measured by the sampling oscilloscope. Some noise can be seen and the noise is believed to be partly due to polarization interference noise between adjacent pulses [12]. If the DSF and multiplexer were both made of polarization maintaining fibers, the noise would be reduced. Fig.3 (b) shows the SHG traces of the converted pulses at 40 GHz with a FWHM pulsewidth of 2.8 ps. Fig.3 (c) shows the optical spectra. We can see that the signal-to-noise ratio of the converted pulses is larger than 30 dB (resolution is 0.1 nm, the resolution of the following spectra is the same). After a TOF with 3 dB bandwidth of 1.6 nm, the sidemode suppression ratio is larger than 50 dB. The spectral width is approximately 1.2 nm. The time-bandwidth product is 0.41; this shows that the converted pulses have a small chirp.

Fig. 4 shows FWHM pulsewidth of the converted pulses as a function of CW wavelength. We can see that the pulsewidth is almost maintained in the wavelength range of the whole C-band. The L-band converted pulses are amplified by 120m Er^+ fiber pumped by a conventional C-band EDFA. Because of the nonlinear effect in the long Er^+ fiber, the converted pulsewidth is widened to approximately 5-6ps.

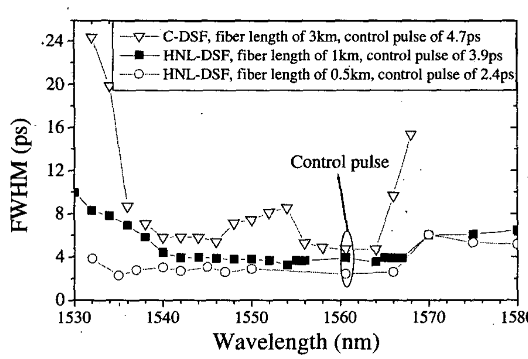


Fig.4. FWHM pulsewidth of the converted pulses as a function of CW wavelength.

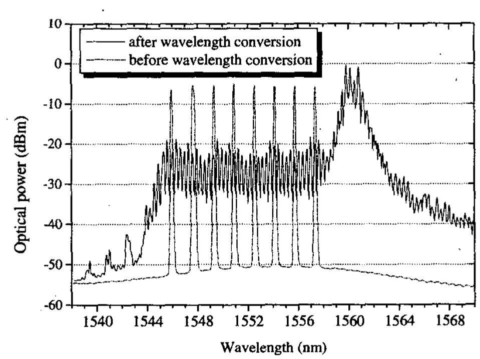
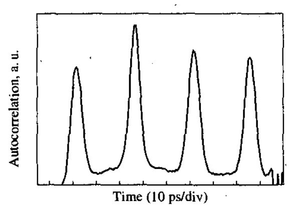


Fig. 5. Optical spectra for simultaneous eight wavelengths before and after conversion.

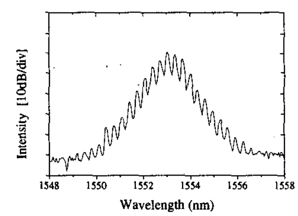
We also measure the converted pulse width by use of NOLMs consisting of either 1km HNL-DSF or 3km C-DSF. When the NOLM consists of the C-DSF with length of 3km, zero dispersion wavelength of 1551nm and dispersion slope of 0.067 ps/$(nm^2 \cdot km)$, we can see that the pulsewidth is almost maintained, but only within 1540-1546 nm and 1556-1564 nm because the walkoff time is small in these wavelength ranges. When the NOLM consists of 1 km HNL-DSF, the parameters are almost the same as that of the HNL-DSF in Fig.1 except that the fiber length is different. We can see that the pulsewidth is maintained when the wavelength of the CW light is chosen in the 1542nm-1568nm range. Comparing the experimental results, it is clearly seen that a short HNL-DSF is useful for pulsewidth maintaining wavelength conversion. However, a short HNL-DSF will need a large input control pulse power.

III. Multiple wavelength RZ optical source

From Fig. 4, we can also see that almost equal pulsewidths at different wavelengths are obtained when the wavelength of the CW lightwave is chosen in the range from 1540 to 1568 nm for the control pulse FWHM of 3.9 ps and HNL-DSF length of 1km. The experimental setup for generation of eight simultaneous channel wavelengths is almost the same as that for generation of a single channel wavelength except that an optical source containing eight CW lightwaves is used instead of one CW lightwave as shown in Fig.1. The outputs of six DFB lasers are combined in an AWG. The laser operating wavelengths are 1549.3, 1550.9, 1552.5, 1554.1, 1555.7 and 1557.3 nm. The other two CW lightwaves are generated by two ECLs; the wavelengths are adjusted to be 1547.7 and 1546.1 nm. The eight CW lightwaves are adjusted to have the same polarization direction. The optical spectra before and after wavelength conversion are shown in Fig. 5. It can be seen that a lightwave in the whole wavelength range from 1545-1559 nm is converted into 40GHz short pulses; it looks like SC generation. The SNR of the converted pulses is larger than 25 dB. We use two cascaded TOFs to filter the optical spectrum after wavelength conversion. At any wavelength from 1545nm to 1559nm, the FWHM of the converted pulses is almost constant at 3.8 ps. As an example, Fig. 6 shows the characteristics of the converted pulses at 1553 nm. Fig. 6 (a) and (b) show the auto-correlator trace and optical spectrum, respectively. Very good SHG trace and optical spectrum are obtained. The spectrum has a symmetric profile and the sidebands stemming from the repetition rate of 40GHz (0.32nm in the wavelength domain) are clearly seen.



(a)



(b)

Fig. 6. The converted pulse characteristics after two cascaded optical filters at 1553 nm. (a) SHG trace, (b) optical spectrum.

IV. Conclusion

We have succeeded in obtaining a single and multiple wavelength optical source with a repetition rate of 40 GHz based on wavelength conversion in an HNL-NOLM. In case of the single wavelength optical source, the converted pulses from 1532 to 1568nm (C-band) or from 1570 to 1580nm (L-band), have almost the same pulsewidth, a small chirp and a large SNR. For the multiple wavelength source, the converted pulses at any wavelength from 1546 to 1559nm have almost the same amplitude and pulsewidth, and the SNR is larger than 25 dB.

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