Armenian Journal of Physics, 2017, vol. 10, issue 3, pp. 108-111

Experimental Techniques of Spectral Compression of Femtosecond Radiation

H. Toneyan[1,2]
[1]*CANDLE Synchrotron Research Institute, Yerevan, Armenia*
[2]*Ultrafast Optics Laboratory, Faculty of Physics, Yerevan State University, Armenia*

E-mail: h.toneyan@gmail.com

Received 12 September 2017

Abstract. In view of applications in ultrafast optics and photonics, few modern schemes of spectral compression technique for femtosecond pulses are experimentally examined in sense of arrangement compactness, high power output and aberration free performance.

Keywords: spectral compression, ultrafast phenomena

1. Introduction

The spectral compression technique, first demonstrated two decades ago [1-4], shows various applications in the large spectrum of contemporary ultrafast optics, photonics and laser physics, based on spatiotemporal analogy and the time lens concept [5,6]. Spectral compression is the spectral analog of pulse temporal compression. The pulses first obtain negative parabolic spectral phase in a dispersive delay line (DDL), and this parabolic phase is then compensated in a nonlinear medium (e.g. fiber), resulting in a spectral narrowing of the signal. The temporal phase, added by the Kerr effect in nonlinear medium, acts like a time lens. This leads to more general feature of Fourier transformation of the signal, i.e. the transferring of the temporal information to the spectral domain, which opens prospective opportunities to solve the problems of signal analysis and synthesis in ultrafast optics. Particularly, spectra-temporal imaging of femtosecond pulses [7,8], fine frequency tuning combined with spectral compression of radiation [8], the femtosecond pulse undistorted delivery [9] are demonstrated. Spectral compression is of interest also for similariton fiber laser architecture instead of usual spectral filtering with high power loses [10]. 8.7× spectral compression was demonstrated, with use of negatively chirped parabolic pulses in [11], resulting in an aberration-free spectral focusing enabled by the optimal parabolic pulse shape. Further developments resulted in 12× spectral compression in an all-fiber configuration for telecommunication wavelengths, with use of kilometer-long fiber [12]. Recently, a 360 fold spectral compression of femtosecond signal has been shown [13]. This setup uses two volume Bragg gratings to chirp two pulses negatively and positively. Afterwards, two beams are focused on a beta barium borate (BBO) crystal, and generate the pulse at second harmonic wavelength, with hugely compressed spectrum.

Urgent problems in contemporary science and technology, specifically in the application of spectral compression methods, motivate in-depth studies of spectral compression aimed at the development of novel, compact, and power-efficient schemes of spectral compression for pico- and femtosecond radiation. Studies in this field attempt to avoid aberrations of the temporal lens [14] for pico- [15] and femtosecond pulses [16,17].

In this work we explore the spectral compression of femtosecond pulses, focusing on practical issues, including compact design, an aberration-free process, and compact all-fiber configuration.

2. Experiment

Three different techniques of femtosecond signal spectral compression have been experimentally examined. A Coherent Verdi 10 + Mira 900F femtosecond laser as source of radiation has been used in the experimental study. It generates near-Gaussian pulses with duration of 100 fs, spectral bandwidth of ~11 nm generated at 800 nm central wavelength. The average power and repetition rate are 1.5 W and 76 MHz, respectively.

For the classical spectral compression technique, an SF11 prism pair based DDL has been used for pulse stretching and chirping. The separation length between the prisms was 3.75 m. The linear negative chirp from the DDL then had to be compensated by nonlinear interaction (Kerr nonlinearity), which was done by coupling the radiation into a single mode fiber. 92 cm of Newport F-SE single mode fiber has been used as the nonlinear medium. The input and output spectral bandwidths were 11.3 nm and 0.92 nm at full width at half maximum (FWHM) (Fig.1). 12-fold spectral compression of the input radiation was observed. The setup had power efficiency of 28 %, with input and output average power of 1.5 W and 0.42 W, respectively. The side lobes of the compressed spectrum are caused by non-parabolic shape of the input pulse. The self-phase modulation (SPM) provides phase similar to the pulse shape, which is not parabolic at the sides, thus not compensating completely the parabolic phase given by the DDL, resulting in the side lobes.

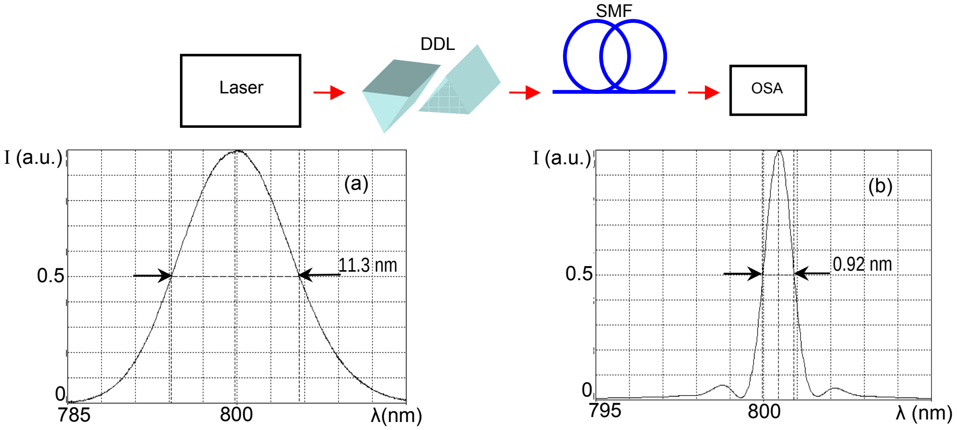

Figure 1. Setup of the classical spectral compressor and the experimental results. Spectra at the entrance (a) and at the output (b) of the spectral compressor, showing 12× spectral compression.

To approach more compact sizes of the setup, a hollow-core fiber (ThorLabs HCF-800) was used. This fiber provides negative dispersion at the wavelength of the laser, and due to the air core, has negligible nonlinear impact on the pulse. This fiber was used as a DDL in the all-fiber setup, replacing the 3.75 m long prism pair base pulse stretcher with 2 m of HCF-800. After this, the radiation was coupled into the same type of single mode fiber, used in the classical setup. As a result, 8.4-fold spectral compression was observed in the all-fiber setup (from 10.9 nm to 1.3 nm) (fig. 2). The input and output radiation had 1.5 W and 0.4 W average power, respectively. The dispersion of hollow-core fiber was controlled by the tuning of central wavelength of laser radiation

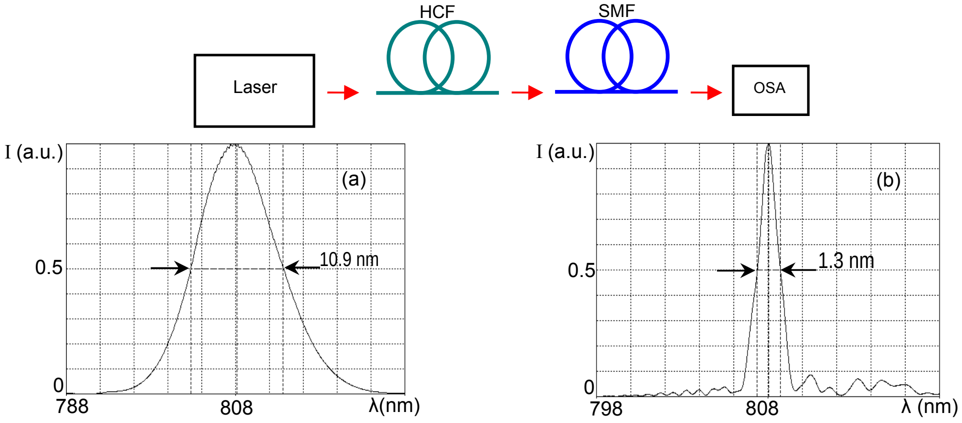

Figure 2. Setup of the all-fiber spectral compressor and the experimental results. Spectra at the entrance (a) and at the output (b) of the spectral compressor, showing 8.4× spectral compression.

to 808 nm. The strong side lobes of the compressed spectrum in figure 2b are formed because of phase given by the high orders of dispersion in hollow-core fiber, which is not compensated in the nonlinear medium.

Thereafter, experiments with the parallel scheme of spectral compressor were carried out. In this technique, a wavelength tunable spectral compression is achieved by phase addition in sum-frequency generation process (SFG). Here the radiation was split into two parts. 20 % of the power passed through a DDL, consisting of pair of prisms with a reverse mirror, with prism separation of 3.5 m. The other 80 % of power was coupled into a single mode fiber (1.65m Newport F-SPF PP@ 820 nm), where nonlinear-dispersive similariton [18,19] with broad spectrum (~100 nm), positive linear chirp and flat central energy carrying part was generated. Thereafter, the two beams were focused in a BBO crystal, where in the nonlinear process of SFG the two pulse temporal shapes were multiplied and the negative and positive linear chirps from the DDL and fiber compensated each other. This resulted in 23.3 fold spectral compression at 394 nm central wavelength (fig. 3b). The compression ratio here is calculated from the spectral width of laser second harmonic, which is 2.8 nm (fig. 3a). The central wavelength of the compressed spectrum can be tuned in a region determined by the similariton bandwidth, by giving time shift to one of the beams. This technique also has the advantage of aberration free spectral compression, allowed by the highly linear chirp of the similariton, which compensate the linear chirp from DDL with high precision.

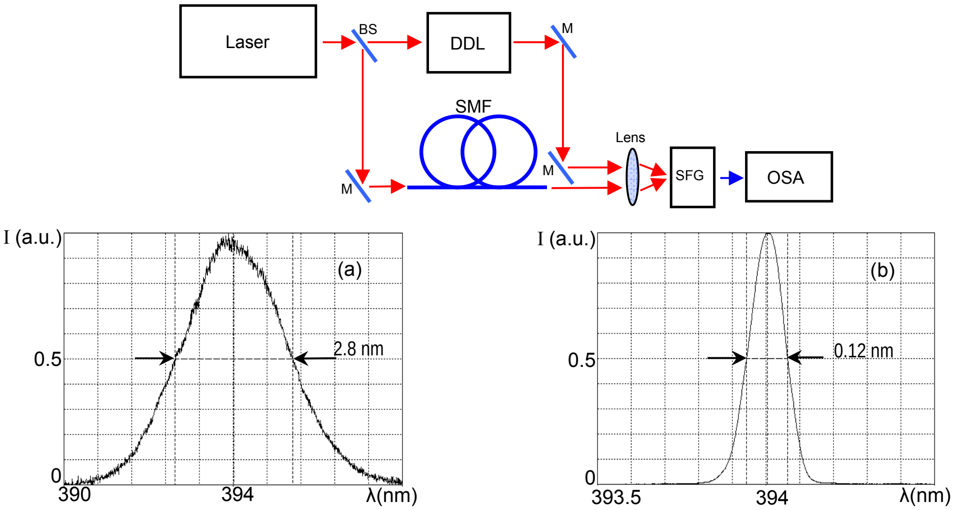

Figure 3. Setup of the similaritonic technique of spectral compressor and the experimental results. Laser spectrum at 394nm (a) and the compressed spectrum (b), showing 23.3× aberration free spectral compression at the second harmonic wavelength.

3. Conclusion

Thus, the spectral compression technique with the classic, all-fiber and similaritonic schemes is experimentally demonstrated for femtosecond pulses. The classic technique provided 12× compression ratio and has the advantage of high power output. The all-fiber technique has more compact arrangement, which can be implemented by splicing the two fibers. Finally, the similaritonic, or parallel technique has provided 23.3 fold spectral compression at the second harmonic wavelength, with opportunity of tunable and aberration free spectral compression.

The author acknowledges his scientific supervisor Levon Kh. Mouradian and the Yerevan State University Ultrafast Optics Laboratory team for helpful discussions during the work.

References

[1] L.Kh.Muradyan, N.L.Markaryan, T.A.Papazyan, A.A.Ohanyan, Conference on Lasers and Electro-Optics, Vol. 7 of 1990 OSA Tech. Digest Series (OSA, 1990), paper CTUH32.

[2] N.L.Margaryan, L.Kh.Mouradian, T.A. Papazyan, Sov. J. Quant. Electron. 21, 783–785 (1991).

[3] M. Oberthaler, R.A. Hopfel, Appl. Phys. Lett. 63, 1017–1019 (1993).

[4] B.R. Washburn, J.A. Buck, S.E. Ralph, Opt. Lett. 25, 445–447 (2000).

[5] L.Kh.Mouradian, A.V.Zohrabyan, A.Villeneuve, A.Yavrian, G.Rousseau, M.Piche, C.Froehly, F.Louradour, A.Barthélémy, CLEO-Europe, Conf. Digest, v. 39 of OSA Trends in Optics and Photonics (OSA 2000), paper CTuH6.

[6] R. Salem, M.A. Foster, A.L. Gaeta, Adv. Opt. Photon. 5, 274–317 (2013).

[7] L.Kh. Mouradian, F. Louradour, V. Messager, A. Barthélémy, C. Froehly, IEEE J. Quantum Electron. 36, 795–801 (2000).

[8] T. Mansuryan, A. Zeytunyan, M. Kalashyan, G. Yesayan, L. Mouradian, F. Louradour, A. Barthélémy, J. Opt. Soc. Am. B 25, A101–A110 (2008).

[9] S.W. Clark, F.Ö. Ilday, F.W. Wise, Lett. 26, 1320–1322 (2001).

[10] S. Boscolo, S.K. Turitsyn, C. Finot, Opt. Lett. 37, 4531-4533 (2012).

[11] E.R. Andresen, J.M. Dudley, D. Oron, C. Finot, H. Rigneault, Opt. Lett. 36, 707–709 (2011).

[12] J. Fatome, B. Kibler, E.R. Andresen, H. Rigneault, C. Finot, Appl. Opt. 51, 4547-4553 (2012).

[13] M. Nejbauer, T. Kardas, Y. Stepanenko, and C. Radzewicz, Opt. Letters, vol. 41/11, 2394 (2016).

[14] S.Boscolo, L.K.Mouradian, and C.Finot, J. Opt. 18 /10, 105504 (2016).

[15] A.A.Kutuzian, Proc. YSU, Natural Sciences, 3, p. 145-149 (2004).

[16] H.Toneyan, A.Zeytunyan, L.Mouradian, V.Tsakanov, F.Louradour, A.Barthelemy, and R.Zadoyan, Frontiers in Optics 2014, FW4D.5 (2014).

[17] H.Toneyan, A.Zeytunyan, R.Zadoyan, and L.Mouradian, J. Physics: Conf. Ser. 672 (2016).

[18] A.Zeytunyan, A. Muradyan, G.Yesayan, L.Mouradian, F.Louradour, A.Barthélémy, Opt. Commun. 284, 3742–3747 (2011).

[19] L. Mouradian and A. Barthelemy, chap. 6, Shaping Light in Nonlinear Optical Fibers, Wiley (2017).