Dispersive Fourier transformation in the 800 nm spectral range

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Abstract: We report the first experimental demonstration of dispersive Fourier transformation in the industrially and biomedically important spectral range of ~800-nm using a chirped fiber Bragg grating and discuss its utility to high throughput biological diagnostics.
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1. Introduction

Dispersive Fourier transformation (DFT) maps the spectrum of an optical pulse into a time stretched waveform whose temporal intensity variation mirrors its spectrum. Fast dynamic phenomena that can be mapped into the optical spectrum can be now acquired and slowed down in time so they can be digitized in real-time. The dispersive optical medium can also be pumped to create Raman amplification of the signal which helps to compensate for reduced number of photons collected during short integration times. These concepts have been exploited to create a range of high throughput real-time instruments, such as analog-to-digital converters, spectrometers and cameras that are making it possible to detect statistically rare but significant rogue events in electronic and optical signals [1].

The key component of DFT is a dispersive element with large group velocity dispersion (GVD) and high dispersion-to-loss ratio. Traditionally, dispersion compensation fibers (DCFs) have successfully been used for DFT in the 1550 nm telecommunication band [2-4]. However, 1550nm band has limited utility in biological applications due to the strong water absorption and poor spatial resolution. On the other hand, the ~800 nm range is particularly useful for a broad range of industrial and biomedical applications. It offers large penetration depths in tissues and better spatial resolution. Also, broadband (femtosecond) Ti:Sapphire lasers are available in this spectral band. However, little progress has been achieved in applying DFT in the 800 nm band due to the lack of low loss dispersive elements such as fibers in this band. For example, optical fibers for shorter wavelengths have a large propagation loss and limited amount of dispersion. While the loss can be circumvented by using a powerful optical source, intense illumination can cause damage to the sample and create unwanted nonlinear signal distortion. Therefore, there is a clear need for low-loss dispersive elements with large GVD in the 800 nm spectral range [5].

Here we demonstrate for the first time DFT using a chirped fiber Bragg grating (CFBG) in the 800 nm band. As a benchmark, previously CFBGs have been widely used for DFT in the 1550 nm band [6]. In this demonstration, we fabricate a CFBG which operates at the center wavelength of 772.5 nm and achieves a very large dispersion of 850 ps/nm, and high reflectivity of 75%. Nonlinear optical effects are also reduced due to the short length of the CFBG. Our results indicate that the CFBG is a good choice as a low-loss dispersive element for DFT in the 800 nm range.

2. Experimental apparatus and results

To demonstrate dispersive Fourier transformation using a CFBG in the ~800 nm band, we constructed the experimental apparatus shown in Fig. 1. A broadband optical pulse train generated from the Ti:Sapphire laser enters the spectral shaper which consists of a Michelson interferometer to produce an interference pattern on the spectrum of the pulses. The inset shows the measured spectral response of the spectral shaper with a free spectral range (FSR) of 0.16 nm. The spectrum-shaped pulse train is then directed to the CFBG via the optical circulator. The CFBG stretches each pulse temporally and hence performs DFT. The dispersed pulse is measured in spectral domain using a conventional optical spectrum analyzer and in time domain using a real-time oscilloscope.

The CFBG was fabricated to meet the specification requirements for DFT. The CFBG was written directly into a photosensitive single-mode fiber (Fibercore PS750) using continuous-wave UV-light at 244 nm [7]. It was apodized ~5% on either end to reduce group-delay ripples which will degrade the performance of DFT. The fabricated CFBG is centered at 772.5 nm and linearly chirped over a bandwidth of 3.5 nm. The length is 30 cm resulting in a GVD of ~850 ps/nm across the bandwidth. The reflectivity of the CFBG is as high as ~75%, corresponding to a low insertion loss of only 1.25 dB. This loss is significantly lower than the loss (18.5 dB) of a commercial silica-core single-mode fiber with the same amount of GVD (~850 ps/nm) in the 800-nm band, validating the CFBG's practical utility.

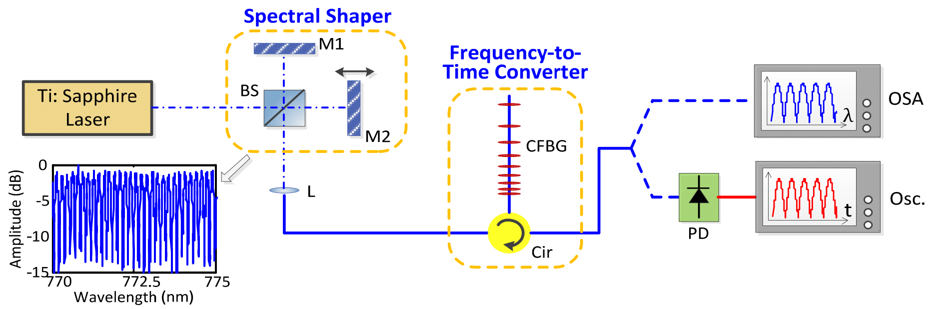

Fig. 1. Experimental setup for dispersive Fourier transformation near 800 nm (BS = beam splitter, M = mirror, L = lens, Cir = circulator, CFBG = chirped fiber Bragg grating, PD = photodetector, OSA = optical spectrum analyzer, Osc = oscilloscope). The inset shows the measured spectral response of the Michelson interferometer.

The performance of the DFT is shown in Fig. 2. The time-domain waveform measured by the high-speed photodetector and the real-time oscilloscope is compared with the spectrum measured by the optical spectrum analyzer [Fig. 2(a) and Fig. 2(b)]. A good agreement between them validates the one-to-one mapping between frequency and time. The fluctuations in the amplitude of the time-domain waveform are mainly attributed to the residual group-delay ripples of the CFBG. By comparing the spectral and temporal patterns, the time-delay response of the CFBG was evaluated and is shown in Fig. 2(c). The mapping relation was also analyzed and plotted in Fig. 2(c), indicating a linear relation with a constant GVD of 843 ps/nm. The normalized reflectivity of the CFBG is also shown in Fig. 2(c).

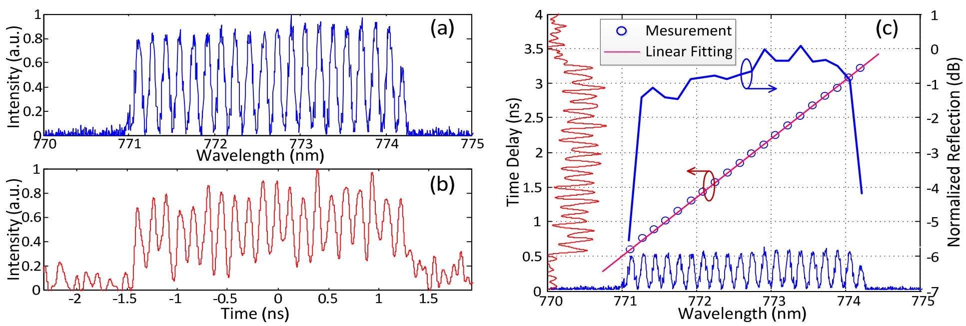

Fig. 2. Experimental demonstration of dispersive Fourier transformation near ~800 nm using a chirped fiber Bragg grating. (a) Spectral fringe pattern measured by a conventional optical spectrum analyzer; (b) Temporal waveform measured by the photodetector and displayed on the real-time oscilloscope; (c) Time delay response and normalized reflectivity of the 800-nm chirped fiber Bragg grating.

3. Conclusions

We have demonstrated DFT in the ~800 nm band using a custom-fabricated CFBG for the first time. Featuring low loss, low cost, and compact footprint, the CFBG is an effective dispersive element for DFT in the industrially and biomedically important spectral range of ~800 nm. This method holds promise for a wide range of applications that require high throughput real-time spectroscopy, sensing, and imaging.

4. References

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