

Time-Wavelength Optical Sampling Based on Laser Cavity Tuning

Lin Yang¹, Shuqin Zhang^{1,2}, Srikamal J. Soundararajan¹ and Lingze Duan^{1*}

¹ Department of Physics, University of Alabama in Huntsville, Alabama, 35899, USA

² Institute of optical & electronic technology, China Jiliang University, Hangzhou, P. R. China

*Corresponding author: ld0003@uah.edu

Abstract: We report a new time-wavelength mapping scheme based on optical sampling by cavity tuning and demonstrate its application in absorption spectroscopy.

OCIS codes: (300.0300) Spectroscopy; (300.1030) Absorption; (320.1590) Chirping

1. Introduction

Wavelength-to-time mapping is a technique that uses a linear dispersive medium (e.g., optical fiber) to stretch ultrashort pulses so that their wavelength components are linearly mapped onto different temporal positions of the stretched pulses. One can then characterize or control the spectral properties of these pulses with time-domain approaches, which are often less complex than comparable frequency-domain methods. Because of its simplicity and elegance, wavelength-to-time mapping has generated much interest in such fields as optical sensing, analog-to-digital conversion, spectroscopy, and arbitrary waveform generation [1-5]. However, conventional wavelength-to-time mapping suffers a key drawback: its need for extra-long pulse stretching and fast photodetection [4]. In order to achieve satisfactory spectral resolutions, ultrashort pulses have to be stretched to hundreds of picoseconds or even nanoseconds, and high-speed detectors such as >10-GHz photodiodes and sampling oscilloscopes, are usually required [1]. The heavy pulse stretching also leads to a reduction of the signal-to-noise ratio on the detector, which in turn adds to the power requirement at the input end.

Here we present a new scheme called *time-wavelength optical sampling* (TWOS), which combines wavelength-to-time mapping with the concept of optical sampling to alleviate the above restrictions. Instead of directly probing the temporal profiles of the stretched pulses with a fast photodetector, our scheme measures the cross-correlation between the stretched pulses and a series of femtosecond reference pulses, with the relative delays between the stretched pulses and the reference pulses being continuously scanned. The reference pulses work as ultrafast gating signals and the relative pulse delay scan allows these gating signals to sample different parts of the stretched pulses to produce a full pulse profile. Measuring cross-correlations improves the signal-to-noise ratio and allows the use of slow photodetectors. It also relaxes the need for severe pulse stretching.

We have demonstrated the application of TWOS in near-infrared spectroscopy by using our existing capability in optical sampling by cavity tuning (OSCAT). OSCAT enables rapid scan of relative pulse delays with large scan depths [6]. It achieves such performances with the combination of laser cavity-length tuning (often by fast PZT actuators on cavity mirrors) and an arm-length mismatched interferometer [7]. It holds a number of advantages over conventional techniques to generate tunable optical delays and hence has been widely applied in many areas such as optical metrology [6,8,9], spectroscopy [10,11], and imaging [12].

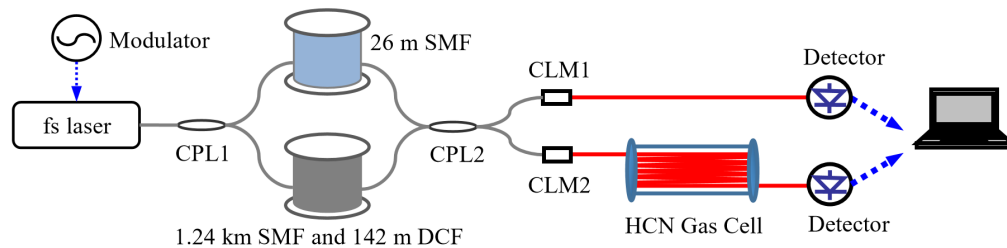


Fig. 1. Schematic of time-wavelength optical sampling system. CPL: optical coupler; CLM: fiber collimator; DCF: dispersion compensating fiber and SMF: single-mode fiber.

2. Experimental Setup

The experimental setup is shown in Fig. 1. Details about the OSCAT system can be found elsewhere [6,12]. The difference of the current system is the addition of a 26-m section of single-mode fiber (Corning SMF-28) in the short interferometer arm. This extra piece of fiber introduces a linear dispersion of 17 ps/(nm·km) and stretches 250-fs

output pulses from the femtosecond fiber laser to 30 ps. On the other hand, the combination of SMF-28 and dispersion compensating fiber in the long interferometer arm results in reference pulses below 500 fs. The pulses are combined at fiber coupler CPL2, where they are evenly split and launched into free space by two collimators. One beam is directly detected to produce the background trace while the other passes through a 50-mm-long Hydrogen Cyanide (HCN) gas cell (300 Torr) multiple times before being collected by a second detector. Crosscorrelation traces between the stretched pulses and the reference pulses are generated on the two detectors when the laser pulse repetition rate is scanned via cavity length tuning. The background trace and the sample trace are collected by a data acquisition system and are subsequently compared to produce the absorption spectrum of HCN.

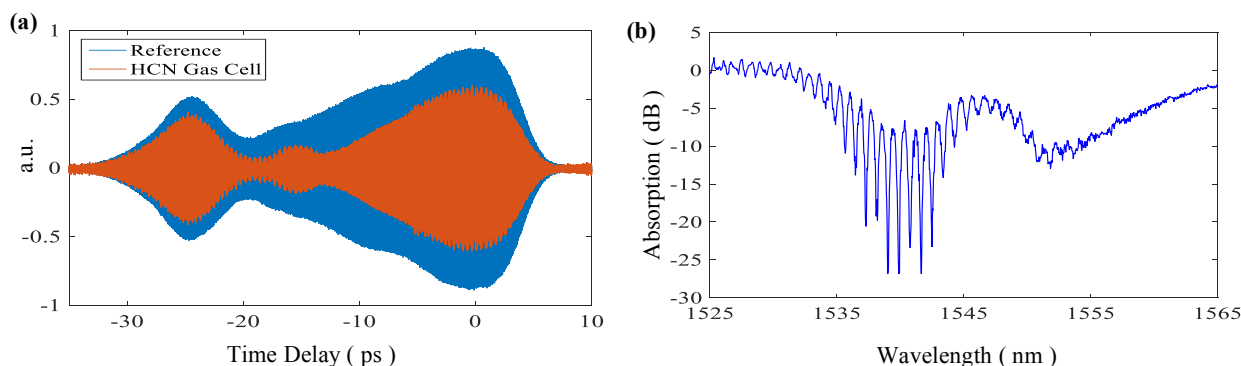


Fig. 2. (a) Time domain crosscorrelation traces collected on both the background (blue) and the sample (orange) detectors. (b) Absorption spectrum of HCN based on the time-domain data shown in (a).

3. Results and Conclusion

The time domain crosscorrelation traces collected on the two detectors are shown in Fig. 2(a). The blue trace is collected from the background path in air and its power envelope reflects the laser spectrum without absorption. The orange trace is collected after multi-pass through the HCN cell and its envelope represents the absorbed spectrum. Significant power loss due to sample absorption is evident in Fig. 2(a). With the help of linear pulse stretching, a number of absorption peaks, located around the envelope of the orange trace, can be clearly resolved. By subtraction between the envelopes of the absorbed trace and the background trace, the absorption spectrum of HCN is obtained, as shown in Fig. 2(b). The spectral fingerprints of HCN between 1535 nm and 1545 nm are clearly resolved.

In conclusion, a new time-wavelength mapping method based on optical sampling is presented. Without heavy pulse stretching and high-speed detectors, OSCAT-based TWOS has demonstrated the ability to perform absorption spectroscopy.

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