Ultrashort Optical Pulse Measurements by Inteferometric Spectrogram

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ABSTRACT

We experimentally demonstrate that an interferometric spectrogram of the signal pulse can be processed differently to obtain the spectral amplitude and(or) phase profile(s). Consistency between the results obtained by frequency-resolved optical gating (FROG) and modified interferometric field autocorrelation (MIFA) methods is confirmed. We also show that the robustness of MIFA technique against measurement noise can be improved if we perform weighted average for the spectral phase profiles retrieved from different parts of the interferometric spectrogram.

Keywords: ultrafast optics, pulse measurement, phase retrieval, interferometry, spectrogram, frequency-resolved optical gating, nonlinear optics, second-harmonic generation.

1. INTRODUCTION

Determination of the spectral phase of ultrafast optical signals is essential in variety of applications, such as coherently controlled nonlinear spectroscopy [1], and signal monitoring in coherent telecommuncations. Frequency-resolved optical gating (FROG) [2] is one of the most widely used techniques, which can retrieve the amplitude and phase profiles by processing the (non-interferometric) spectrogram (power as a function of frequency and time delay) of the signals with an iterative algorithm. In an earlier work [3], FROG using interferometric spectrogram was demonstrated, which permits simpler collinear geometry and enhanced error-checking capability. Further investigation showed that the spectral phase profile can be obtained by processing the interferometric spectrogram without iteration (MEFISTO technique) [4]. However, the enormous data redundancy built-in the spectrogram data makes these pulse measurement techniques complicated and inefficient. Recently we have demonstrated a new technique to analytically retrieve the spectral phase profile by processing two modified interferometric field autocorrelation (MIFA) traces [5], which enables unprecedented measurement sensitivity [6] and has much reduced data redundancy. In this work, we show that MIFA is a technique that makes use of the interferometric spectrogram in a more efficient and straightforward way (compared with [3] and [4], respectively). We will also demonstrate that the robustness against measurement noise of MIFA technique can be improved if we perform weighted average for the spectral phase profiles retrieved from different parts of the interferometric spectrogram.

2. THEORY

The interferometric spectrogram (Fig. 1a) is defined as the collection of second-harmonic power spectra (due to a thin nonlinear crystal) taken at different time delays τ between two pulse replicas from a collinear Michelson interferometer:

$$I^{SHG}(f,\tau)=\left|F_t\left\{\left\{a(t)\exp[i2\pi f_0 t]+a(t-\tau)\exp[i2\pi f_0(t-\tau)]\right\}^2\right\}\right|^2, \tag{1}$$

where $a(t)$ denotes the complex temporal envelope, f_0 denotes the carrier frequency, and F_t is the Fourier transform with respect to time t. The standard FROG trace (non-interferometric spectrogram) can be derived by low-pass filtering $I^{SHG}(f,\tau)$ with respect to delay τ (Fig. 1b, hollowed ellipse) [3]. In MEFISTO, one needs to conduct Fourier transform for $I^{SHG}(f,\tau)$ with respect to delay τ, then sampling at two delay-frequencies around f_0 (Fig. 1b, hollowed rectangle) [4]. To perform MIFA measurement, we directly sample $I^{SHG}(f,\tau)$ at two different optical frequencies around f_0 (Fig. 1a, red dash lines) [5]. The major advantages of MIFA over MEFISTO are twofold: (1) elimination of Fourier transform of $I^{SHG}(f,\tau)$, (2) no need to take the entire $I^{SHG}(f,\tau)$ if some spectral-selective optics (say thick nonlinear crystal) is used. By sampling $I^{SHG}(f,\tau)$ at more optical frequencies (Fig. 1a, black dash lines), one can get more spectral phase profiles. The weighted average of these profiles will give rise to a result with better robustness against measurement noise.

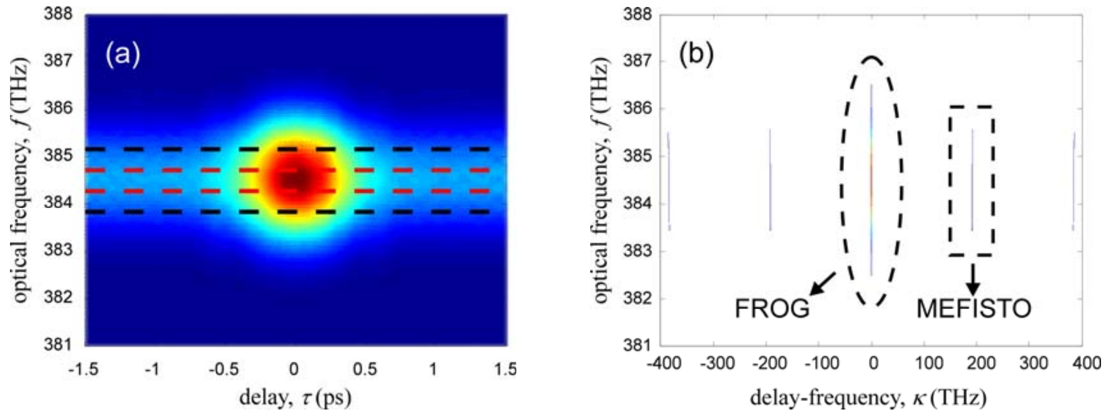

Fig. 1. (a) Experimetnally measured interferometric spectrogram of the signal pulse. (b) The Fourier transform of (a) with respect to delay τ.

3. EXPERIMENTS

Fig. 2a shows that the spectral phase profiles retrieved by FROG (dense dot) and MIFA (dash) at high signal-to-noise ratio (SNR) of 27.5 are in good agreement, proving the reliability of the MIFA method. Fig. 2b illustrates the retrieved spectral phase profiles based on sampling 2 (dash-dot), 8 (dot), and 64 (dash) slices from an interferometric spectrogram with low SNR of 7.91, respectively. The curves show that the more slices we process the more accurate result (closer to the curve derived at high SNR) we can derive.

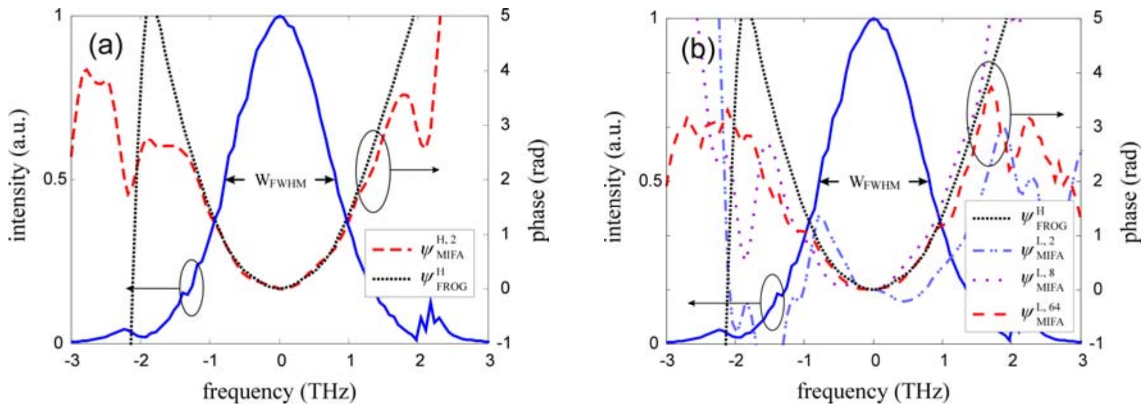

Fig. 2. Power spectrum measured by OSA (solid). The spectral phase profiles retrieved by FROG at high SNR (dense dot), and by MIFA at (a) high SNR using 2 slices (dash), (b) low SNR using 2 (dash-dot), 8 (dot), 64 (dash) slices, respectively.

4. CONCLUSION

We have verified the consistency between the spectral phase profiles measured by FROG and MIFA methods using the same interferometric spectrogram. We have also demonstrated that sampling multiple slices from the interferometric spectrogram in MIFA measurement can effectively reduce the influence of measurement noise.

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