Ultrafast Pulse Characterization by Cross-Phase Modulation in Silicon Waveguide

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Abstract- Based on the high nonlinearity of silicon waveguides, a compact frequency-resolved optical gating (FROG) system has been demonstrated using cross-phase modulation for ultrafast pulse characterization. Amplitude and phase of a 700fs pulse have been measured.

I. Introduction

Frequency-resolved optical gating (FROG) is a powerful tool to measure ultrafast femtosecond pulses. Other than using second harmonics generation (SHG), there are different types of FROG, such as polarization gate FROG, self-diffraction FROG, third harmonic generation FROG and XPM FROG [1-3]. XPM FROG was proposed and has been demonstrated by using bulk silica [4], single mode fiber [5], microstructure optical fiber [6], and a quantum well structure device [7] as the nonlinear medium. The advantage of using XPM FROG is that, SHG FROG has an ambiguity in the direction of time of the retrieved pulse and XPM FROG can provide a comparable sensitivity without ambiguity. The silicon has the inherent advantages of strong optical confinement due to large refractive index difference between silicon core and glass cladding, and large Raman and Kerr nonlinearities which are about 1000 and 200 times higher than those of silica. In addition to these advantages, small walk off make silicon an ideal material for miniaturized nonlinear optical devices for ultrafast applications. Here we show silicon based XPM frog device and phase and amplitude measurement of 700fs optical pulses.

II. Principle

The schematic setup of silicon XPM FROG is shown in Fig. 1. The incident pulses are separated by a polarization beam coupler/splitter (PBC) into two polarization components that are orthogonal to each other. The ratio between two branches can be controlled by the polarization controller at the input. An optical delay line constructed by two fiber collimators and a moving stage is used to produce time delay between two polarizations. After passing the delay line, the two polarization are combined by another PBC and entering a 1.7cm SOI waveguide. The waveguide has 5 μm^2 modal area. Probe pulse is selected by a PBS at the output of the waveguide. We use an optical spectrum analyzer (OSA) to measure the spectrum and generate the spectrogram. The probe signal selected at the output of the PBS can be written as [16]:

$$E_{sig}(t,\tau)=E_p(t)\exp\left[\frac{2}{3}i\gamma\left|E_G(t-\tau)\right|^2\right] \qquad (1)$$

Where $E_p(t)$, $E_G(t)$ is the field in the two polarization branches. Here we assume $E_p(t)$ is much smaller than $E_G(t)$ and thus the self phase modulation can be ignored. The FROG signal measured by the spectrum analyzer is:

$$I(\omega,\tau)=\left|\int_{-\infty}^{\infty}E_{sig}(t,\tau)e^{i\omega t}dt\right|^2 \qquad (2)$$

The spectrogram is generated by measuring spectrum with different delay τ between two signals. The pulse amplitude and phase information then can be retrieved from the spectrogram by using principal component generalized projections (PCGP) algorithm [8]. In the PCGP algorithm some criteria of the probe and gate is required to avoid ambiguous solutions. For example, in SHG FROG the criteria is P(t)=G(t), where P(t) is the probe signal and G(t) is the gate signal of the FROG system. In the XPM FROG we treat the probe field E_P as the input P(t) and the XPM exponential term $\exp(2/3i\gamma|E_G(t-\tau)|^2)$ in (2) as the gate function G(t). Since the

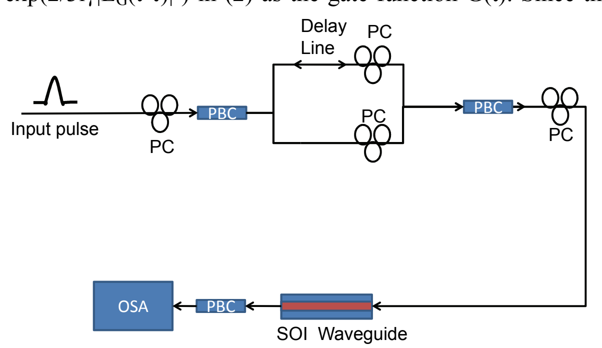

Fig. 1 Schematic setup of XPM FROG in silicon. PC: polarization controller; PBC: polarization beam coupler; OSA: optical spectrum analyzer.

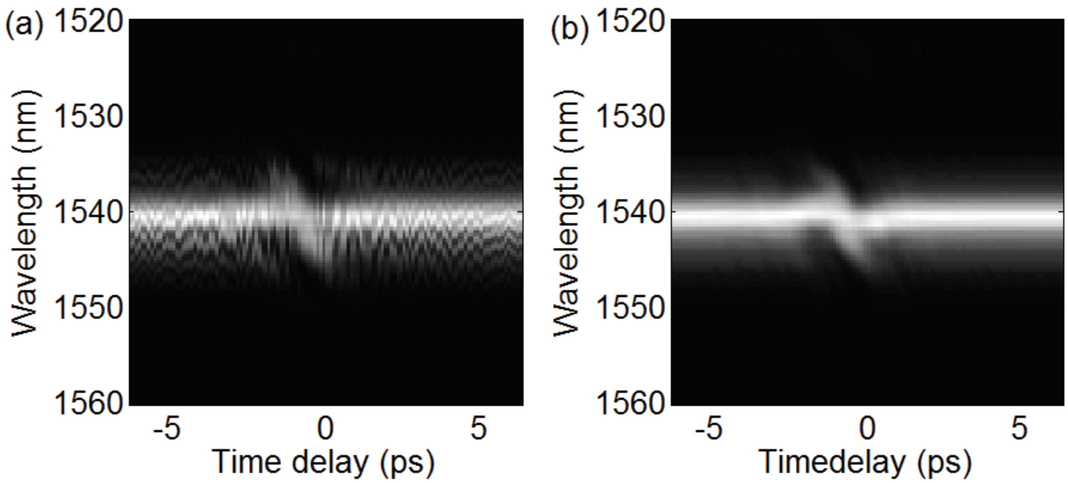

Fig. 2 (a)Measured and (b) retrieved FROG traces

gate is only a phase modulation the amplitude of G(t) is reset to one in each itineration while keeping the phase information.

III. Experimental Results

The experimental result for measuring a femtosecond modelocked fiber laser is shown in Figure 2. The spectrogram is taken within 12.8 ps time delay. The retrieved pulse and the phase are shown in Fig. 3. It reveals that the input pulse has a pulse width ~700fs, which matches the spec of the modelocked laser. The error is 4.5% which is mainly due to noise in the spectrum analyzer. As illustrated in the previous section, the time wavelength mapping can be adapted here for real time characterization of femtosecond optical pulses.

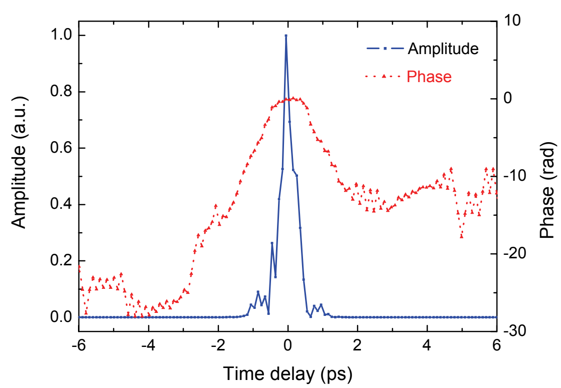

Fig. 3 Retrieved pulse and phase.

IV. Summary

A frequency-resolved optical gating system has been demonstrated by using cross-phase modulation in silicon. A 700fs pulse is measured by this system.

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