Time lens for Sub-picosecond Optical Pulse Measurement on a Chip

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Abstract We demonstrated subpicosecond temporal optical imaging based on four wave mixing temporal to frequency domain conversion in a CMOS compatible, high index glass waveguide.

OCIS codes:(130.2755) Glass waveguides; (190.4380) Nonlinear optics, four-wave mixing ; (160.4330) Nonlinear optical materials;; (130.3130) Integrated optics materials;

1. Introduction

Signal monitoring plays a key role in the development of fiber optics telecommunication systems. The push towards data stream speeds of the order of Tb/s requires a real-time method for imaging optical pulses with subpicosecond resolutions. However electronic-based measurement tools (e.g. photodetection followed by an electronic oscilloscope) are only suitable for characterizing optical signal longer than tens of picoseconds. All-optical approaches based on ultrafast electronic nonlinearities can overcome this severe bandwidth limitation.

A time lens (TL)[1], [2] is a physical mechanism that adds a quadratic chirp to a temporal optical signal. This concept translates into the temporal domain the well known property of a spatial lens, i.e. the capability to add a quadratic curvature to the phase front of a transmitted radiation. A TL can be obtained using a parametric process, such as three or four wave mixing (TWM-FWM), based on the conversion of the signal in an idler using a Gaussian pump conveniently dispersed. The idler results in the product of the signal and the squared pump chirp, being the temporal dimension of the pump the effective temporal aperture of the lens. This approach has been successfully employed in quadratic crystal (via TWM)[1] and in Kerr material (via FWM)[3], being the latter particularly interesting for CMOS compatible photonic systems.

Temporal-to-frequency domain conversion is an interesting application of a TL, which can provide a real time instrument for the measurement of subpicosecond optical waveforms. In the spatial case it is well known that the optical field transmitted by a lens is the Fourier Transform (FT) of the spatial distribution in the lens focus. In the temporal case, when an input signal propagates exactly as much as the TL focal length, i.e. its chirp is exactly compensated by the TL, the output (the generated idler of the parametric interaction) is the signal FT. A measurement of the output spectrum reverse the FT and provides in real-time the input signal temporal image[3-4]. However, the system is extremely sensitive to deviation from the optimal condition, and especially the FWM based approach is prone to self-phase modulation (SPM) and cross-phase modulation (XPM) effects, which can actually prevent the subpicosecond resolution.

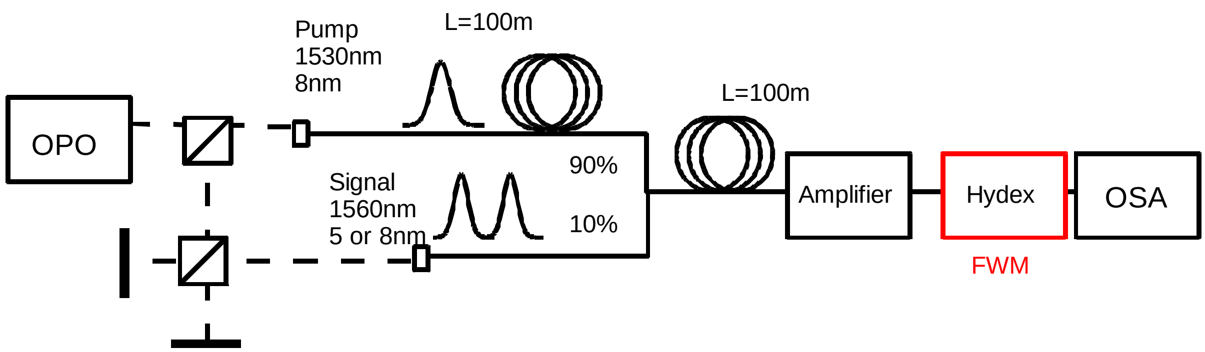

Fig. 1: Experimental Setup

In this work we developed a time to frequency conversion of subpicosecond optical pulses based on FWM on CMOS-fibre technology compatible systems. The nonlinear device consists of a 45cm long spiral waveguide in high-index, doped silica glass (hydex) integrated on a silicon wafer. Our device has very low linear propagation loss (0.06dB/cm), together with a very tight modal field confinement (< 1.5x1.5 μm^2) and narrow bend radii (down to 30 μm)[5,6] . The high nonlinearity enhanced by the high modal confinement, together with the absence of nonlinear losses, makes our structure optimal for FWM based temporal lens applications. The extremely low dispersion of the waveguide guarantees a large FWM bandwidth and a negligible effect on the pulses chirp.

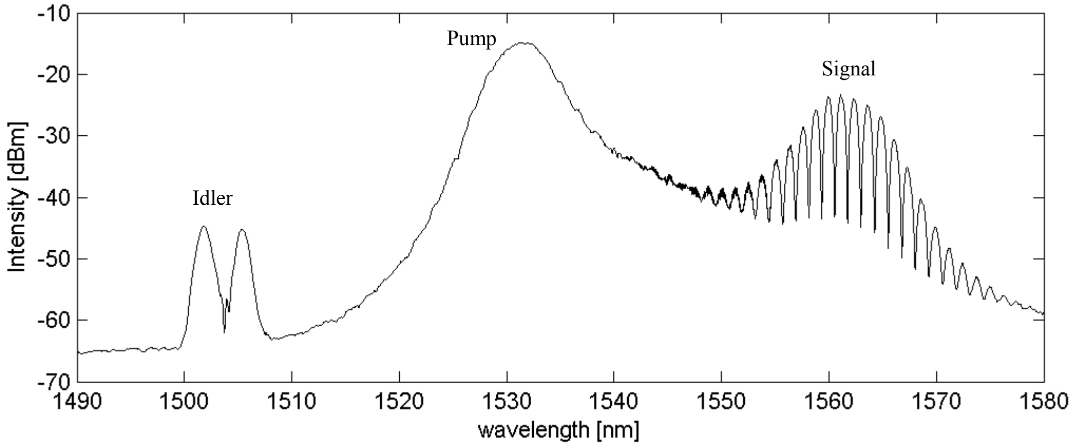

Fig. 2: OSA spectrum: The pump is centered at 1530 nm. The spectrum of the signal under test (consisting in two delayed pulses) is visible at 1560nm. The interference of the two replicas is evident. The FWM idler (around 1502nm) clearly shows an image of the signal under test (double pulse).

2. Experiments

A sketch of the experimental setup is in fig 1. Pump and signal are obtained filtering a 1540nm, 30nm bandwidth OPO pulse at 80MHz rep rate. A Gaussian 8nm bandwidth tunable filter is used for the pump, while a 5 or 8nm bandwidth filter is used for the signal, thus obtaining two new peaks centered at 1530 and 1560nm respectively. An interferometer splits the signal in two pulses (signal under test), and a movable mirror controls the relative delay. The pulses are dispersed with a standard single mode fibre (SMF). The pump is dispersed twice as much as the signal length: hence the signal chirp is exactly compensated by the TL chirp in the FWM process and the idler results in the FT of the input signal [3]. We kept the pulses power in the SFM low enough to avoid SPM. Pulses are first amplified with a standard fibre erbium amplifier providing 25mW total average power, and are then coupled in the 45nm waveguide. An optical spectrum analyzer provides the output spectrum.

A typical result is showed in Fig. 2. The SPM free pump is visible at 1530nm; the signal spectrum centered at 1560 shows clearly interference of the two delayed pulses. The FWM product around 1502nm is the temporal image of the signal under test.

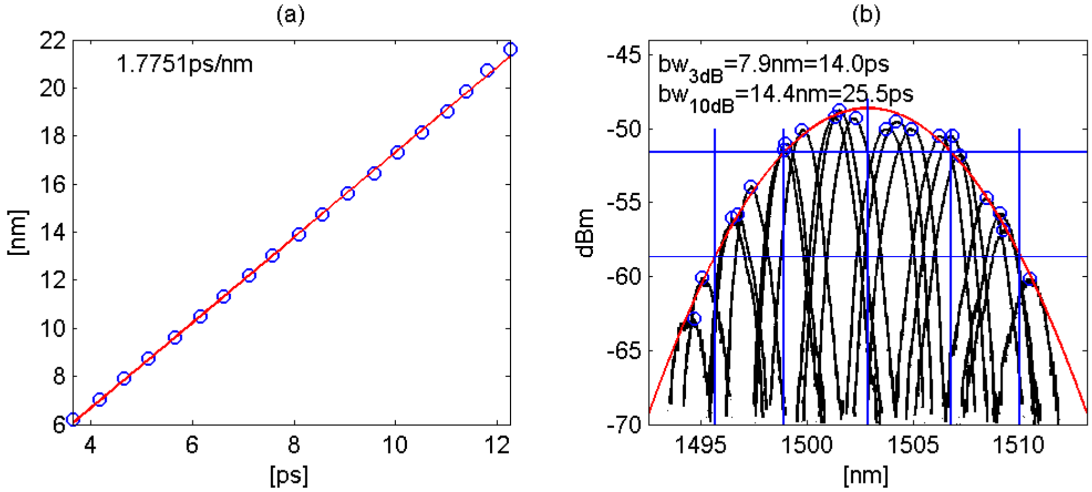

Fig 3. (a)Calibration curve: blue dots experimental, red line linear interpolation. (b) black line: FWM spectrum at different pump-signal delays. Blue dots: maxima. Red curve: parabolic interpolation of the experimental maxima.

The system calibration is obtained by changing the delay between the two signal pulses, while the temporal window is measured by varying the pump-signal delay. We obtain a calibration factor of 1.77ps/nm and a -3dB window of 14ps.
Fig 4 shows the measurement of a subpicosecond detail, namely the destructive interference between two replicas of a Gaussian pulse with 5nm bandwidth.

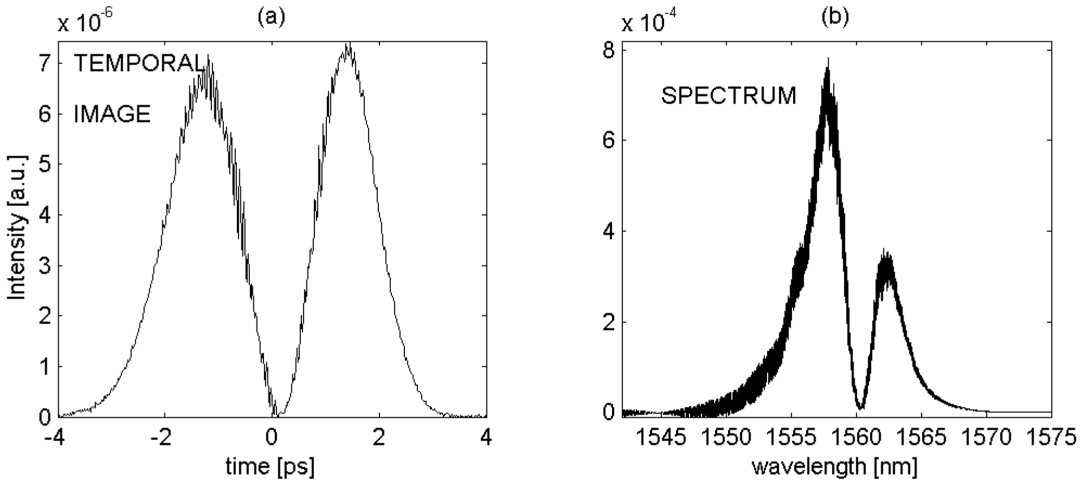

Fig 4. Real time (a) temporal image and (b) spectrum of two 5nm bandwidth Gaussian replicas showing destructive interference.

3. Conclusions

In conclusion, we demonstrated a subpicosecond temporal optical imaging system based on FWM TL implemented in a CMOS-compatible high index doped silica glass platform. Wave mixing is achieved by exploiting the high nonlinearity of a 45cm long waveguide having extremely low dispersion and linear and nonlinear losses. This work may pave the way to the realization of integrated and affordable CMOS compatible optical devices for the temporal imaging of optical signals operating at terabit/s pulse rates and beyond.

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