Highly-Efficient Optical Sampling of a 100Gbit/s OTDM Data Signal via Two-Photon Absorption in a Semiconductor Microcavity

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Abstract By incorporating a semiconductor microcavity device, a highly-efficient Two-Photon Absorption based sampling system, with a system sensitivity of 0.009mW^2 and temporal resolution <500fs is presented.

Introduction

Future high-speed optical networks employing Optical Time Division Multiplexing (OTDM) will require a sensitive and ultra-fast technique for precise optical signal monitoring [1]. Currently high-speed optical signals are characterised using a fast photodetector in conjunction with a high-speed oscilloscope. Unfortunately such a system is limited to a maximum data rate of approximately 40Gbit/s. Optical nonlinearities in optical fibres, crystals and semiconductors, which occur on timescales in the order of a few femtoseconds (10^{-15}s), are thus being considered for the accurate monitoring of data rates in excess of 100Gbit/s. One example of such a nonlinearity is Two-Photon Absorption (TPA) in a semiconductor.

TPA Based Sampling

As TPA is an instantaneous optical nonlinearity, the temporal resolution is limited only by the duration and the jitter of the sampling pulses used [2], making it an ideal candidate for use in a high-speed all-optical sampling scheme. The main difficulty with using TPA is its inherent inefficiency resulting in the need for either high optical intensities, or a very long detector, making them unsuitable for practical applications. One way to overcome this problem is to employ a semiconductor microcavity [3]. This should significantly enhance the TPA response of the device enabling the implementation of practical sampling elements for high-speed optical communications.

The phenomenon of TPA is a nonlinear optical-to-electrical conversion process where two photons are absorbed in the generation of a single electron-hole pair [4]. It occurs when a photon of energy E_{ph} is incident on the active area of a semiconductor device with a bandgap exceeding E_{ph} but less than $2E_{ph}$. The generated photocurrent is proportional to the square of the intensity, and it is this nonlinear response that enables the use of TPA for optical sampling. The semiconductor microcavity used in this work [3] was specifically fabricated for TPA at 1550nm, and greatly enhances the optical intensity by increasing the interaction length in the device [4]. The TPA photocurrent plotted as a function of wavelength around the microcavity resonance is shown in Figure 1. It clearly shows how the cavity response is dependent on the incident wavelength, with a cavity resonance of 1556nm and a measured cavity linewidth of 5nm.

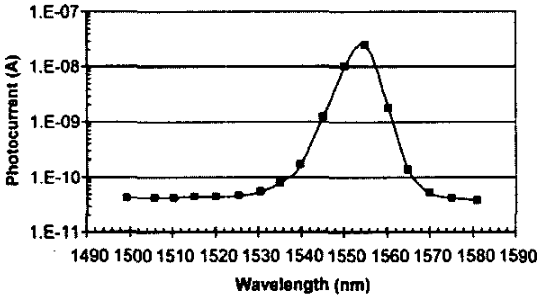

Figure 1: TPA photocurrent as a function of the incident optical wavelength across the microcavity resonance.

In order to use TPA for optical sampling, the duration of the optical sampling pulse $I_{sam}(t-\tau)$ used must be significantly shorter than the optical signal pulses $I_{sig}(t)$ under test. The signal and sampling pulses are then incident on the microcavity device and the electrical signal $i(\tau)$ generated by the TPA process in the device is measured as a function of the sampling delay τ. This results in an intensity cross-correlation measurement between I_{sam} and I_{sig}. For practical implementation, the peak intensity of the sampling pulse is larger and sufficiently shorter than the signal pulse. Therefore the measured signal represents the signal pulse waveform on a constant background [5].

Experimental Set-Up

Figure 2 shows the experimental set-up used. It consists of two tunable pulse sources; a 10GHz u^{2}t TMLL 1550 (pulse duration ~ 2ps with a tuneable range 1480-1580nm) used for the signal pulses and a 10MHz Calmar Optcom Femtosecond Pulse Laser (pulse duration 400fs-1.4ps, jitter < 140fs, tunable range 1448-1558nm) used as the sampling pulse. Both pulse sources were tuned to 1556nm, the resonant wavelength of the microcavity device used during the experiment.

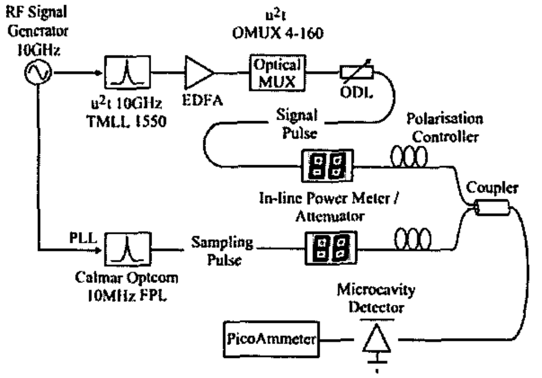

Figure 2: Experimental set-up for TPA Sampling

The signal pulse train from the u^{2}t source was first amplified using a low-noise Erbium Doped Fibre Amplifier (EDFA) before entering a passive delay line multiplexer which consists of a number of independently switch-able stages. Using the passive multiplexer and operating at a data rate of 10GHz, a 100 GHz stream of pulses was obtained at the output of the device. The 100 GHz pulse train then passes through an Optical Delay Line (ODL), which is used to introduce the sampling delay τ.

As mentioned, the sampling pulse was generated using the Calmar Optcom pulse source. This pulse source was locked to the 10GHz clock signal driving the u^{2}t source the using a Phase Locked Loop (PLL), and generated pulses with durations ~500fs at 1556nm. Both the sampling and the signal pulse trains pass through in-line power meters/attenuators and polarisation controllers before being recombined at a coupler. The power meters allow easy measurement and attenuation of both pulse trains, while allowing the system sensitivity to be monitored. The combined signals are then incident on the microcavity with the generated photocurrent recorded on a picoammeter as a function of τ, the sampling delay.

Experimental Results

Figures 3(a) and (b) shows the experimental results of the TPA sampling of a single optical pulse and a 100Gbit/s pulse train. From 3(a), the optical pulse duration was calculated to be ~2.5ps, with the expected pulse width being ~2ps. The deviation between the two can be accounted for by the temporal resolution of the sampling set-up, cavity lifetime of the device and amplification of signal pulse in the EDFA. The peak powers of the signal and sampling pulses were 6.8mW and 1.2W respectively. Figure 3(b) displays the TPA sampling of a 100Gbit/s data signal, as the separation between optical pulses is approximately ~10ps. The peak powers of the signal and sampling pulses were 10.3mW and 1.2W. To calculate the system sensitivity, which is the product of the peak power of the signal pulse and the average power of the sampling pulse [5], we reduced the signal power to levels at which we can just still accurately sample the pulses. In this case the signal peak power was 1.5mW and a sampling peak power was 1.2W, resulting in a system sensitivity of 0.009mW^2.

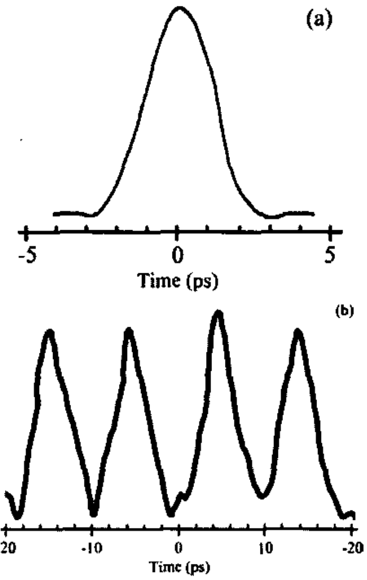

Figure 3: (a) TPA Sampling of a Single Optical Pulse; (b) TPA Sampling of a 100Gbit/s Optical Pulse Train

Conclusions

This papers shows that by employing a microcavity device the TPA efficiency can be improved to a level that allows successful sampling of a 100Gbit/s optical signal with a system sensitivity of 0.009mW^2, corresponding to a signal peak power of 1.5mW, and a temporal resolution <500fs. These represent the most sensitive ultra-fast TPA optical sampling reported. With the addition of a low-noise amplifier after the detector, it is anticipated that further improvement in the system sensitivity can be acheived.

References

1 S.Kawanishi, IEEE J. Quan. Electron., 34 (1998), 2064-2079
2 K.Kikuchi, Electron. Lett., 34 (1998), 1354-1355
3 T.Krug et al. IEEE Photon. Technol. Lett., 16 (2004) 1543-1544
4 H.Folliot et al. J. Opt. Soc. America B, 19 (2002), 2396-2402
5 B.C.Thomsen et al. Electron. Lett., 35 (1999) 1483-1484