Direct Measurement of a High-Speed (>100Gbit/s) OTDM Data Signal Utilising Two-Photon Absorption in a Semiconductor Microcavity

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The future development of high-speed optical data channels, operating at individual data rates in excess of 100Gbit/s, will require a sensitive and ultra-fast method for pulse measurement [1]. Current high-speed signals are usually characterized using a fast photodetector in conjunction with a high-speed oscilloscope, but are limited to maximum data rate of approximately 40Gbit/s. An alternative is to employ all-optical sampling techniques based on ultra-fast optical nonlinearities present in optical fibres, crystals and semiconductors. One such nonlinearity is the optical-to-electrical process of Two-Photon Absorption (TPA) in a semiconductor [2].

TPA is a nonlinear process where two photons are absorbed in the generation of a single electron-hole pair [2]. 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. As TPA is an instantaneous nonlinearity, the temporal resolution is limited only by the duration and jitter of the sampling pulses [3]. However, the main difficulty of employing TPA is its inherent inefficiency, which requires either high optical intensities or a very long detector, making it unsuitable for high-speed telecommunications applications. By incorporating a semiconductor microcavity, the optical intensity, and hence the TPA response, should be greatly enhanced due to the increased interaction length within the device. Therefore it should be possible to use these specially fabricated microcavity devices [2], which are optimized for TPA at 1550nm, in the development of practical sampling and switching elements for high-speed optical communications.

For the practical implementation of optical sampling via TPA, the duration of the sampling pulse [$I_{sam}(t-\tau)$] must be significantly shorter than the optical signal pulse [$I_{sig}(t)$] under test. The signal and sampling pulses are then incident on the microcavity, with the electrical TPA signal generated [$i(\tau)$] measured as a function of the sampling delay τ. This results in an intensity cross-correlation measurement between I_{sam} and I_{sig} [4]. By operating the sampling pulse with a higher peak intensity than the signal pulse, the resulting cross-correlation trace represents the signal pulse waveform on a constant background [4]. Previous TPA sampling experiments [5] involved a manual variation of an Optical Delay Line (ODL) in the sampling arm to provide the sampling delay, resulting in a laborious stepwise measurement of the signal under test. Here the sampling delay between the sampling pulses and the signal under test is generated by operating the frequency of the sampling pulse (f_{sam}) slightly detuned from a sub-harmonic of the signal frequency (f_{sig}) [4]. This allows the sampling pulse to be automatically swept across the signal pulse at a scan frequency that is low enough to be directly detected and displayed on a standard high-impedance oscilloscope without the need for high-speed electronics or a lock-in amplifier [5].

Figure 1 shows the experimental set up of the real-time TPA optical sampling. It consists of two tunable optical pulse sources; a 10GHz u^2t 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. By assuming that the sampling pulse has the same average output power as the signal pulse, the lower repetition rate (10MHz) allows a higher peak power, and hence a higher nonlinear TPA response. The repetition rate of the signal pulse (f_{sig}) was set to 9.998991GHz with the sampling pulse (f_{sam}) operating at 9.998992MHz, which results in a scan frequency of 1KHz [4], which can be easily displayed on the 60MHz high impedance oscilloscope used. The stability of the scan frequency was maintained by feeding the 10MHz reference clock signal from synthesiser 1 to synthesiser 2, and by using a Phase Locked Loop (PLL) to synchronise the 10GHz signal of synthesiser 2 to the 10MHz output optical signal of the sampling pulse source. The u^2t signal pulse train is first amplified using a low-noise Erbium Doped Fibre Amplifier (EDFA) before entering a passive delay line multiplexer (u^2t OMUX 4-160) which consists of a number of independently switch-able stages. Using the passive multiplexer a 100GHz pulse stream was obtained at the output of the device, which was then amplified via a second EDFA to overcome any losses encountered in the OMUX. Next the sampling and

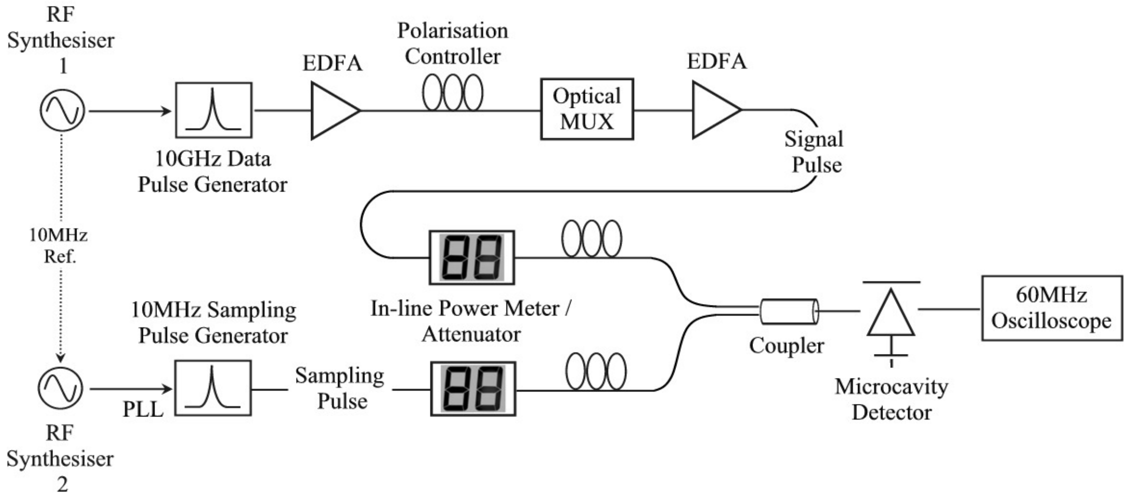

Figure 1: Experimental Set Up for Optical Sampling based on TPA in a Semiconductor Microcavity

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 power 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 TPA photocurrent signal being directly displayed on a standard 60MHz high impedance digital oscilloscope.

Figure 2 (a) shows the real-time measurement of a 10GHz optical pulse as displayed directly on the oscilloscope. The optical pulse duration was measured to be ~2.5ps, with a pulse width of ~2ps expected. This deviation can be accounted for by the temporal resolution of the sampling set up, cavity lifetime of the device and the amplification of the signal pulse in the EDFA's. The peak powers of the signal and sampling pulses used were 11mW and 25W respectively. Figure 2 (b) displays the real-time measurement of a 100Gbit/s (pulse separation ~ 10ps) pulse train, with a signal peak power of 9.6mW and sampling peak power of 32W. The sensitivity of the sampling system, which is defined as being the product of the peak power of the signal pulse and the average power of the sampling pulse [4] was calculated as $0.35mW^2$, with the temporal resolution of the system being < 500fs.

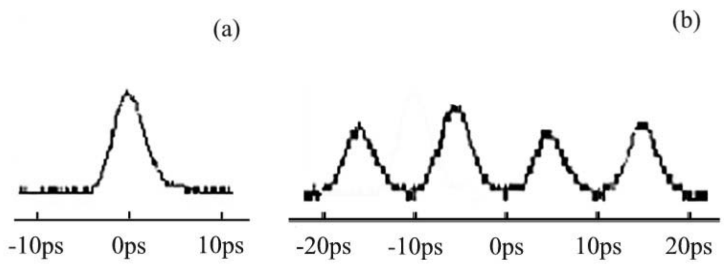

Figure 2:Real-Time TPA Sampling Measurement of (a) 10GHz Optical Pulse; (b) 100Gbit/s Pulse Train

Our results demonstrate that the TPA efficiency is enhanced using the microcavity to a level that allows the successful real-time direct detection of a 100Gbit/s data stream. The system sensitivity is calculated to be $0.35mW^2$, with a signal peak power of 5.6mW, and temporal resolution less than 500fs. This higher temporal resolution, combined with the low sampling rate, allows the direct monitoring of high data rates (>100Gbit/s) without the need for high-speed electronics. By optimising the existing cavity design, it is hoped that the device can be further improved to allow operation at higher data rates approaching 1Tbit/s.

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