Simulation of All-Optical Demultiplexing utilizing Two-Photon Absorption in Semiconductor Devices for High-Speed OTDM Networks

P. J. Maguire, and L.P. Barry
Research Institute for Networks and Communications Engineering, School of Electronic Engineering,
Dublin City University, Dublin 9, IRELAND.
Phone: + 353 1 700 5883, Fax: + 353 1 700 5508, Email: maguirep@eeng.dcu.ie

SUMMARY

A stable and ultra-fast switch for the demltiplexing of a ultra-high bit rate data signal will be vital for the development of future high-capacity Optical Time Division Multiplexed (OTDM) networks [1]. Nonlinear effects present in fibres and semiconductors are used in the majority of all-optical switching techniques for OTDM since they occur in time scales of a few femto-seconds. Current all-optical demultiplexers for OTDM suffer from a number of factors that limits their performance for high-speed switching. An alternative is to use the nonlinear optical-to-electrical process of Two-Photon Absorption (TPA) in a semiconductor, where two photons are absorbed in the generation of a single electron-hole carrier pair [2,] to carry out all-optical switching at data rates above 100Gb/s [3]. 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 switching. Recent work undertaken has been aimed at significantly enhancing the TPA response by using a micro-cavity device [4], which overcomes the inherent inefficiency associated with TPA, and enables the implementation of practical switching and sampling elements of high-speed optical systems. The device that we specially fabricated for TPA at 1550nm is a GaAs/AlAs PIN micro-cavity photodetector grown on a GaAs substrate. It comprises a 0.459µm GaAs active region embedded between two GaAs/AlAs active region embedded between two GaAs/AlAs Bragg mirrors. The front p doped (C~10^{18}cm^{-3}) mirror consists of 9 pairs while the back n (Si~10^{18}cm^{-3}) mirror contains 18 pairs designed for reflectivity at 1550nm. The device studied was a 100µm diameter vertical structure. The characteristics of these devices are shown in Figure 1. The measured photocurrent as a function of incident optical power is shown in Figure 1 (a) and clearly shows the square dependence of the photocurrent on the incident intensity, indicating Two-Photon Absorption. Figure 1 (b) shows how the TPA response is dependent on the incident wavelength, with a cavity resonance of 1554 nm and a measured cavity linewidth of 5nm.

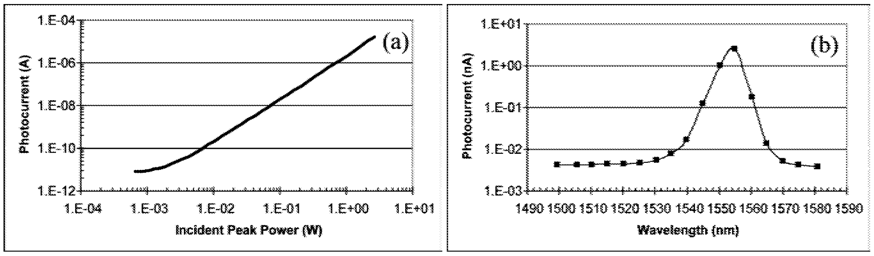

Figure 1: (a) Photocurrent as a function of Incident Optical Peak Power (b) Micro-Cavity Resonance

From these characteristics, the Single-Photon Absorption (SPA) coefficient (α) and the TPA coefficient (β) of 0.01cm^{-1} and 3x10^{-10} m/W were chosen respectively. To use these devices as optical demultiplexers we normally use a setup as shown in Figure 2, in which the TPA device uses optical control pulses to demultiplex a high-speed OTDM channel via TPA in the semiconductor device. The high speed OTDM signal and the control pulses (at the repetition rate of the individual channels) are optically coupled together and are incident on the device with their relative arrival time adjusted via a variable optical delay in the control arm. The nonlinear quadratic nature of the TPA

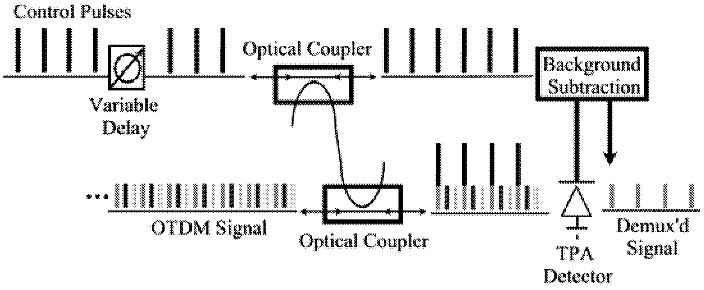

Figure 2: Schematic of TPA Demultiplexing

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response ensures that there is a strong contrast between the electrical TPA signal generated when the control and selected channel pulses overlap, and that generated when the adjacent channels arrive independently. Background subtraction of the constant signal due only to the control pulse can then be conveniently carried out to result in a high contrast demultiplexed signal output.

The purpose of the simulation was to investigate the suitability of using a TPA device to switch a high-speed OTDM signal. System parameters that were examined include: **1)** Number of channels in the OTDM network **2)** Ratio between the peak power of the control signal and data signal **3)** Temporal response of the TPA detector.

The model creates an OTDM data signal by multiplexing together a number of specified channels, each consisting of random data, using short optical pulses. The peak power of the data pulses can be set to a specific value with a fixed level of noise added, which has the effect of limiting the optimum BER achievable. Control pulses are synchronized with one of the OTDM channel and are then incident on the TPA device. The TPA model also takes into account the temporal response of the TPA detector, and this is set to a percentage of the bit slot duration of the individual data channels in the OTDM signal in order to minimize the amount of noise from adjacent channels. The simulation model finally calculates the Bit-Error-Rate (BER) of the demultiplexed and detected signal after the TPA device. The overall goal is to determine the operating characteristics such that BER of the demultiplexed/detected signal (EBER) is the same as the optical BER (OBER) on the signal before the TPA detector (due to noise on the signal pulses), indicating that the demultiplexing process is not introducing additional errors.

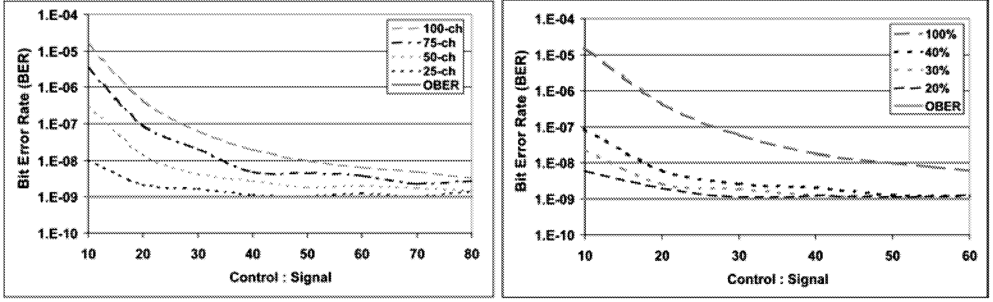

Figure 3: (a) BER Vs. Control-to-Signal Power as the number of channels is varied (b) BER Vs. Control-to-Signal Power as the temporal response is varied.

Figure 3 (a) illustrates the received BER vs. control-to-signal ratio as the number of channels is varied. It can be clearly seen that as the control-to-signal ratio is increased, the EBER approaches the OBER. This results from the fact that as the control-to-signal peak power ratio is increased, the contrast ratio between the data signal synchronised with the control pulse and those not synchronised widens. This reduces the amount of noise due to the detection of all adjacent channels (since the temporal response is set to 100%), which improves the resultant signal-to-noise ratio, and improves the BER of the received signal. We subsequently went on to examine how the temporal response of the TPA detector affected its operation. Figure 3 (b) plots the BER as a function of the control-to-signal ratio as the temporal response of the device is varied from 100% to 10%. The 25-channel system is employed, as this was the only one that gave optimum performance at a reasonable control-to-signal ratio. As the temporal response is reduced (enhancing device bandwidth), the BER of the received signal is improved since the number of adjacent channels that add noise to the detected channel decreases, thus improving the received BER. This allows a smaller control-to-signal ratio to be used to offer the same overall performance. For a 25-channel system, a temporal response of 20% allows us to obtain good performance with a control-to-signal ratio of around 30:1. Assuming a data rate for each channel of 10Gbit/s, and thus a bit period of 100ps, a 20% temporal response (20ps) would correspond to a device bandwidth of approximately 20GHz.

We have modeled the performance of a TPA based demultiplexer in an OTDM communication system. The performance of the demultiplexer was evaluated by comparing the electrical BER of the demultiplexed and detected channel to the optical BER of the signal before the demultiplexer. Using the parameters we have chosen for the TPA device, we have shown that error-free demultiplexing of a 250 Gbit/s OTDM signal (25 x 10 Gbit/s channels), using a 30:1 control-to-signal peak power ratio, with a TPA device with a bandwidth of 20Ghz should be possible.

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[1] D.M.Spirit et al., *IEEE Communications Magazine*, vol. 32, no. 12, pp. 56–62, 1994.

[2] B.C.Thomsen et al., *Electronics Letters*, vol. 34, no. 19, pp. 1871–1872, 1998.

[3] B.C.Thomsen et al., *Conference on Optical Fiber Communications*, vol. 54, no. 3, pp. WO2/1-WO2/3, Anaheim, USA, 2001.

[4] H.Folliot et al., *Journal of Optical Society Of America B*, vol. 19, no. 10, pp. 2396–2402, 2002.