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Design of micro-cavity semiconductor devices for highly efficient optical switching and sampling applications

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SUMMARY

Two Photon Absorption (TPA) in semiconductors has recently been shown to be a serious candidate for optical autocorrelation of short pulses, and all-optical switching and sampling of high speed optical data signals in optical time division multiplexed (OTDM) systems. Experiments using TPA for these applications have been performed at many different wavelengths, and using different types of semiconductor devices [1-4]. However, as TPA is essentially a very inefficient non-linear process, it usually requires high intensity lasers or very long detectors, which could make the TPA non-linearity unsuitable for use in practical autocorrelators, and optical switches and sampling devices for real telecommunication systems. One possible way to overcome the inefficiency of the TPA process is to use a Fabry-Pérot micro-cavity to greatly enhance the optical intensity, and thus exalt the non-linear properties of the embedded material. In this paper we present the design and fabrication of a TPA detector that has been specially designed for TPA with an input wavelength around 880 nm. The device that we have constructed is based on a microcavity structure, which greatly enhances the interaction length in the device. We also demonstrate the use of this non-linear detector for carrying out autocorrelation measurements on picosecond optical pulses.

The device that we have specially fabricated for TPA is a GaAlAs PIN microcavity photodetector grown on a GaAs susbrate. It comprises a 0.27µm $Ga_{0.7}Al_{0.3}As$ active region embedded between two $Ga_{0.5}Al_{0.5}As$/AlAs Bragg mirrors. The front p doped (C~$10^{18}cm^{-3}$) mirror consists of 15.5 pairs while the back n (Si~$10^{18}cm^{-3}$) mirror contains 35.5 pairs designed for reflectivity at 880nm. The device was designed to show significant TPA response (energy bandgap of semiconductor material 1.3 times greater than photon enery at 880 nm). The device studied was a 400µm diameter vertical structure. SiN layer was deposited to passivate the sides of the mesa and thus limit the leakage current.

We have used a tuneable Ti:Sa laser delivering 1.6ps pulses at 82MHz repetition rate to initially characterise the device by employing standard Lock-in techniques to measure the photocurrent. Alignment was achieved by forward biasing the photodiode which then acts as an LED emitting at 700nm. Firstly we performed a photocurrent measurement as a function of the incident power (Fig.1) close to the cavity resonance. The cavity resonance is around 888 nm, and the measured cavity linewidth is 1.12nm, consistent with simulations. As expected, a square dependence of the photocurrent on the incident intensity is clearly observed, evidencing the Two-Photon absorption process. We also show the simulation results, where we took a TPA coefficient of β=0.013cm/MW and a linear absorption of $0.1cm^{-1}$ which is observed at low intensities.

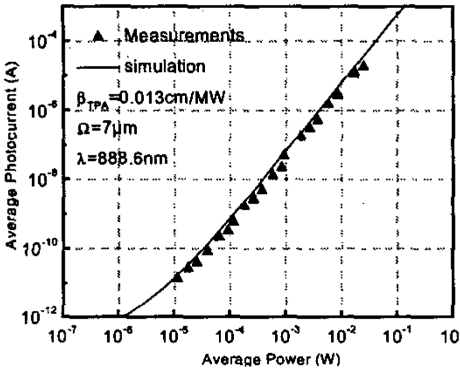

Fig. 1 Measured (triangles) and simulated (straight line) average photocurrent versus average power

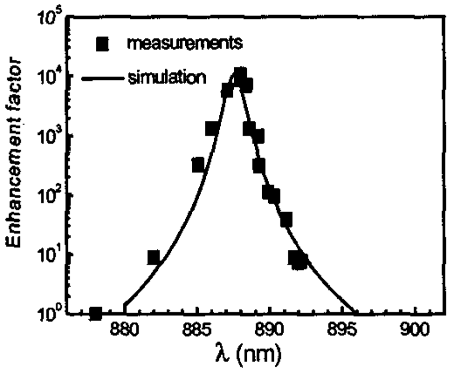

Fig. 2 Photocurrent vs. wavelength across the cavity resonance.

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Then, for a given incident average intensity of 10 mW, we performed a wavelength dependence photocurrent measurement around the resonance, as shown on Fig. 2. An experimental enhancement close of 12000 is reached, which is close to the simulation results that take the spectral dispersion of the pulses into account.

We then examined the use of the microcavity TPA detector for carrying out autocorrelation measurements on the picosecond optical pulses from the Ti:Sa laser. We replaced the BBO crystal in a standard autocorrelator with the TPA detector, and used lock-in techniques to measure the autocorrelation trace of the optical pulses. Fig. 3 displays the measured pulse in addition to the result when the non-linear crystal was used at the output of the autocorrelator's interferometer.

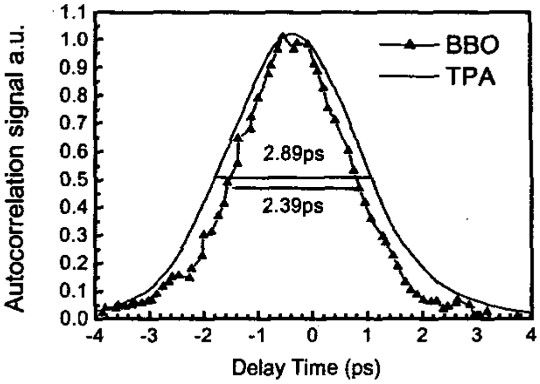

Fig. 3 Autocorrelation signal using BBO crystal (up triangles) and the TPA microcavity device (line).

The impact of the cavity on the dynamic response of the TPA microcavity device is seen from these measurements. The cavity lifetime elongates the measured autocorrelation pulse width. Using a 1.6ps pulse, an autocorrelation pulse width of 2.39ps was recorded for the BBO crystal (as expected for sech^2 pulse shape), compared with 2.89ps for the TPA device. This broadening of the autocorrelation measurement due to the cavity lifetime has been confirmed through simulations, and is clearly a function of the reflectivity of the micro-cavity reflectivity. In order to determine the sensitivity of autocorrelation measurements carried out using our TPA detector we attenuated the power in the optical pulses incident on the TPA detector. The minimum average power in the pulse train that we were able to autocorrelate was 1.27μW, which corresponds to a peak power of 9.8 mW, and a sensitivity of 12.5 x 10^{-3} mW^2. It should be noted that the autocorrelation arrangement using the TPA detector is as sensitive as the usual set-up based on Second Harmonic Generation in a nonlinear crystal.

In conclusion we have shown that by using a semiconductor micro-cavity structure, we are able to fabricate a device in which significant TPA enhancement can be achieved. This enhancement in the TPA efficiency may be extremely important for using this specific non-linearity for constructing high speed optical processing devices for use in future broadband photonic communication systems. Our initial results have shown the use of our TPA micro-cavity structure for autocorrelation measurements on pico-second optical pulses, and we have also discussed the impact of the photon lifetime of the cavity structure on the results from the TPA autocorrelation. In addition, it should be noted that the cavity structure can be optimised for whatever application the device is being designed for, thus allowing us to design high-speed and highly efficient non-linear optical devices for application specific functions. We wish to thank Enterprise Ireland for supporting this project under grant No. SC/00/245.

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