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# Fast nonlinear response in a GaAs photonic crystal waveguide in the picosecond regime

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## Summary

We identify strong and fast refractive index changes that have a time constant of less than 10 ps, whilst studying the propagation of short pulses in GaAs photonic crystal (PC) waveguides on membrane. These measurements also illustrate the nonlinearities enhancement in PC structures and reveal the full potential of GaAs based devices for fast optical signal processing.

## Introduction

Because of the strong transverse confinement in PC waveguides, of about  $10^{-9}$  cm<sup>2</sup>, optical nonlinearities are enhanced. Low operating power optical switches have been conceived and demonstrated in silicon [1], AlGaAs [2], and GaAs [3] PC microcavities. Bandgap engineering in III-V semiconductor-based devices grants access to electronic Kerr effects in order to minimise switching time. However, free carriers generated in nanostructured materials by two-photon absorption (TPA) can reveal fast refractive index changes, similar to optical Kerr effect, because of the short carrier-lifetime in such structures.

In this work, we study free carrier (FC) induced Kerr-like effects in GaAs PC waveguides, because the TPA absorption coefficient  $\beta_{TPA}$  of GaAs is ten times higher than that of silicon [4]. The guides are etched in thin suspended GaAs membranes of 250 nm in thickness. The lattice period of the W1 type guides, consisting of air holes of  $r=0.3a$  in radius, is  $a=410$  nm [5]. To characterise the samples we used an optical parametric oscillator that emits short pulses (10 ps) delivering an average power of 80 mW. Two microscope objectives were used for injection in the TM mode and collection of the light. To analyse the beam, we used an optical spectrum analyser.

## Discussion

In a first step, we measured the transmitted power through the guide as a function of the incident signal power (Fig 1). The theoretical curve for TPA takes the form:

$$P_{out} = K^2 P_{in} / (1 + K f^4 \beta_{TPA} L P_{in} / A_{eff}) \quad (1)$$

where  $P_{in}$  and  $P_{out}$  are the peak-powers at guide input and output,  $A_{eff}$  is the effective mode area,  $L$  is the guide length,  $K$  is the coupling efficiency at input and output and is determined with a linear measurement ( $K = 5.7 \times 10^{-3}$ ),  $f = \sqrt{n_g / n_0}$  is the local field factor with  $n_g$ , the group index inside the guide and  $n_0=3.37$ , the GaAs bulk

index. By exploiting the Fabry-Perot fringes of the guide facets on a linear transmission experiment, we were able to determine  $n_g = 1.84 \times n_0$ , which shows that we are in the presence of a slow mode, thus enhancing  $f$ . Using  $A_{eff} = 10^{-9} \text{ cm}^2$  and  $L = 0.98 \text{ mm}$  and  $\beta_{TPA} = 10^{-8} \text{ cm/W}$  [6], Fig 1 shows the good agreement between theory and experiment. We can thus conclude that TPA has been enhanced as a consequence of the photonic structure.

In a second step, we analysed the transmitted spectrum with a resolution of  $0.05 \text{ nm}$  (Fig 2). The thin ( $P_H$ ) and solid curves ( $P_L$ ) represent the spectra at high and low incident powers, respectively. Fabry-Perot modulations are present on both curves.  $P_L$  is similar to the spectrum of the incident pulse. It is possible to eliminate these spectral oscillations by temporally filtering the signal autocorrelation function at half the round trip inside the guide (dotted curve  $P_F$ ). We observe both a blue and red shift of the pulse after propagation inside the guide, which show a very fast Kerr-like phenomenon induced on both the rising and falling part of the pulse.

The carrier lifetime still needs to be determined, because it will enable us to conclude whether the observed spectra are due to fast FC recombination or both FC and Kerr effect.

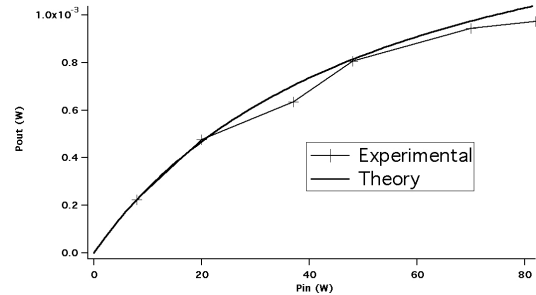


Fig 1.  $P_{out}$  vs  $P_{in}$  showing TPA

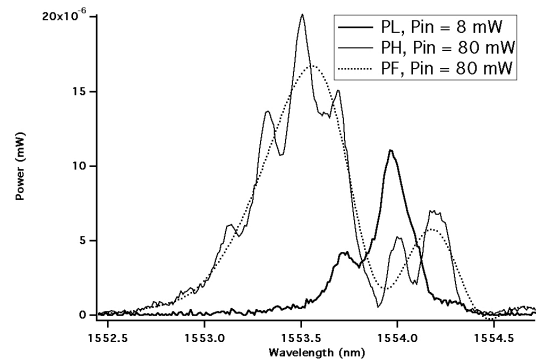


Fig 2. Spectra of transmitted pulse

## Conclusions

By analysing transmission measurements in GaAs based photonic crystal waveguides, we have observed FC induced Kerr-like effects with a very fast time constant, which is on the same order of magnitude as the pulse duration (10 ps). Even though further investigation is necessary to determine the contributions of TPA and Kerr effect, these observations reveal the full potential of very fast nano-structured GaAs based optical devices.

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