

Micro and Nano Structured Materials for Nonlinear Optics

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Abstract.

In this paper we will review recent progress in the use of periodic structures in nonlinear optics with a particular focus on the observation of solitons. In particular we will consider discrete, Bragg and gap solitons.

Summary

There has been a growing interest in the use of periodic structures in nonlinear optics. In particular the use of gratings, coupled waveguide arrays and photonic band gap materials promises a range of novel, nonlinear optical effects. In this paper we will review recent experimental and theoretical results on nonlinear micro- and nano-structured materials, with a particular focus on the use of the half band gap nonlinearity of AlGaAs. We will consider systems of coupled waveguide arrays which support discrete spatial solitons[1], nonlinear gratings and PBG materials which can support Bragg and Gap solitons[2,3] and micro-ring resonators which offer the prospect of low power Gap solitons[4,5].

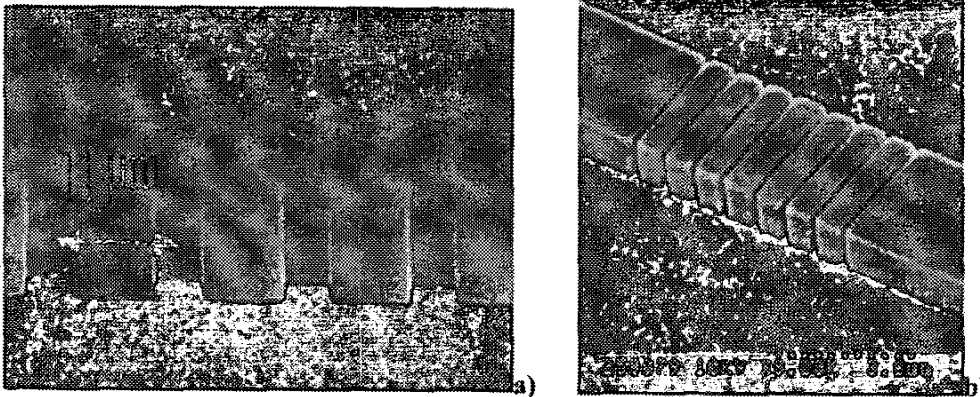


Fig. 1. Shows a scanning electron micrograph of a) an array of coupled waveguides and b) a one dimensional photonic microstructure with a defect state.

Our material of choice is the III-V semiconductor AlGaAs, where the half band gap nonlinearity provides an almost ideal Kerr like response at the 1.55 micron communications wavelength. The typical waveguide structure consists of an 18% Al core region bounded by AlGaAs claddings with a larger Al composition. The nonlinear coefficient, n_2 is $\sim 1.5 \times 10^{-13} \text{ cm}^2\text{W}^{-1}$, the two photon absorption coefficient is essentially

zero and there is minimal three photon absorption in the 1.55 micron telecommunications band. In addition the mature fabrication processes available for this material system allow a range of structures to be realized.

We will start our discussion with coupled systems of waveguides, see fig1a. Here each of the waveguides is coupled to its nearest neighbor and as a result an initial input field coupled into a single waveguide is able to tunnel or “diffract” to the outer waveguides as the mode propagates along the sample. This is an example of a discrete system which exhibits discrete diffraction. At high input power, the coupling between adjacent waveguides is broken, the mode remains confined over a few waveguides and propagates as a discrete spatial soliton. The ability to control the waveguide spacing and size allows more complex arrays of coupled waveguides to be realized, for example: non-uniform arrays, defect states, and diatomic arrays.

We will also consider structures which have a periodic modulation of the refractive index along the propagation direction. The simplest form is a Bragg grating where the modulation leads to a strong reflection at a given wavelength. In this case the modulation is relatively weak and leads to a narrow stop band. This type of structure has been used to observe Bragg and gap solitons. More complex structures result when the modulation in refractive index is stronger see fig 1b, occurs in multiple directions, or is chirped or apodized.

As a final example of how micro and nano-structuring can benefit integrated nonlinear devices we will consider the example of nonlinear micro-ring resonator. These resonators are typically formed from narrow waveguide, ~500 nm which have been deeply etched to provide a strong optical confinement. These waveguides allow a very tight turning radius to be realized and have been used to form micro-ring resonators, with ring diameters of ~10 microns. When produced in a nonlinear material these structures support Gap solitons, can operate as logic gates and have a small effective area which enhances the nonlinear interaction.

In conclusion, we have considered the use of micro and nano-structuring as a mechanism for enhancing the nonlinear response of integrated optical circuit elements. To date these demonstrations have been based on the use of a non-resonant nonlinearity, and have revealed new optical physics. In the longer term such effects have potential applications in all-optical switching, routing and logic operations, particularly when combined with the resonant nonlinearities found in semiconductor optical amplifiers.

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