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Low Voltage Tunable One Dimensional Photonic Crystal with Large Air Defects

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ABSTRACT

A one-dimensional Si/SiO_2 photonic crystal with a large, tunable air defect cavity is fabricated. Multiple resonant modes are observed within the photonic band gap. The free spectral range (FSR) is large compared to other resonant structures, with more than 100nm bandwidth. Simultaneous low voltage tuning around two telecom wavelengths, 1.55µm and 1.3µm, is realized using electrostatic force. The whole process is at low temperature and can be CMOS compatible. Potential applications include switching, modulation, and wavelength conversion devices, particularly WDM devices.

INTRODUCTION

Tunable photonic crystals are key devices for microphotonics, especially for future WDM applications [1,2]. Since the introduction of Photonic Band Gap structures (PBG) [3], also known as photonic crystals, new concepts and designs have been proposed, which could be the building blocks for photonic integrated circuits [4,5]. When defects are introduced into PBG materials, highly localized states, which confine light to within the defects, can be created [6,7]. The confinement of light to distances on the order of one wavelength will lead to large reduction of photonic circuit size and numerous useful devices, especially for Si microphotonics[8,9]. Realization of a tunable photonic crystal makes it an active component, which could play a key role in switching, modulation and wavelength conversion. Here we demonstrate a tunable one-dimensional photonic crystal with a "large" air defect cavity (with a size of several operating wavelengths) in silicon based PBG materials. Multiple localized resonance modes are observed within the photonic band gap at 1.402µm, 1.582µm, 1.792µm and 2.072µm. The observed photonic band gap is from 1.19µm to 2.18µm, which has 1000nm bandwidth. The free spectral range (FSR) is larger than 100nm. Employing electrostatic force, simultaneous low voltage tuning of two localized modes around two telecom wavelengths, 1.3µm and 1.55µm, is achieved. At 10V, a mode shift of almost 60nm is also achieved. This is the lowest we have seen to date.

EXPERIMENTS

The schematic illustration of the tunable PBG device is shown in Fig.1.
We emphasize that, a) the whole process is CMOS compatible. b) low temperature process is preserved. Low temperature process reduces the film stress significantly, which is critical for the optical properties and polymer based materials can be incorporated into the process. Starting with (100) Si substrate(about 500um in thickness), the SiO_2 layer is deposited by Plasma Enhanced Chemical Vapor Deposition(PECVD). Silicon layer is formed via e-beam deposition. After deposition of first several SiO_2/Si pair layers, followed by another oxide layer by PECVD, Polyimide(PI) film is spin coated at various speed for different PI thickness, after postbake, PI film is sent to the furnace for cure at relatively high temperature. Careful treatment is necessary to keep the surface flat, which is important for the final performance. Another oxide film is deposited on the top of PI film via PECVD, followed by several top SiO_2/Si pair layers. Then supporting membranes films are deposited at low temperature. Lithography is utilized to pattern the structure and form the air gap by ashing the PI layer at selected areas.

Figure 1. The Si/SiO_2 tunable PBG device with large air gap.

RESULTS AND DISCUSSION

We utilize the Micro-Electro-Mechanical System (MEMS) method to realize the low voltage tuning of the 1D PBG structure with a large air defect. The top and bottom Si/SiO_2 mirrors form an air gap (cavity) by membrane, which is suspended by supporting beams. Applying a voltage between the membrane and substrate can tune the cavity thickness, i.e., it can shift the multiple resonance modes within the PBG. Here we emphasize that low voltages can be used to tune large shifts in wavelength. We concentrate on the window of wavelengths ranging from 1.2um to 1.7um. The resonance wavelength shift is proportional to the voltage square as follows:

$$\Delta\lambda \sim V^2 \tag{1}$$

We plot the wavelength shift versus the voltage squared for two resonances, one at 1.402μm and another at 1.582μm (with zero applied voltage) in Figs. 2, respectively. These wavelengths are chosen for their proximity to the telecom wavelengths of 1.3 and 1.55μm. The almost perfect linear relationship between the wavelength shift and voltage square confirms the electrostatic tuning of the localized modes. We notice that, for the 1.582μm resonance, a shift of almost 60nm is realized with 10 volts. This is the lowest we have seen to date. Switching and wavelength conversion mechanism can be designed to take advantage of such low voltage.

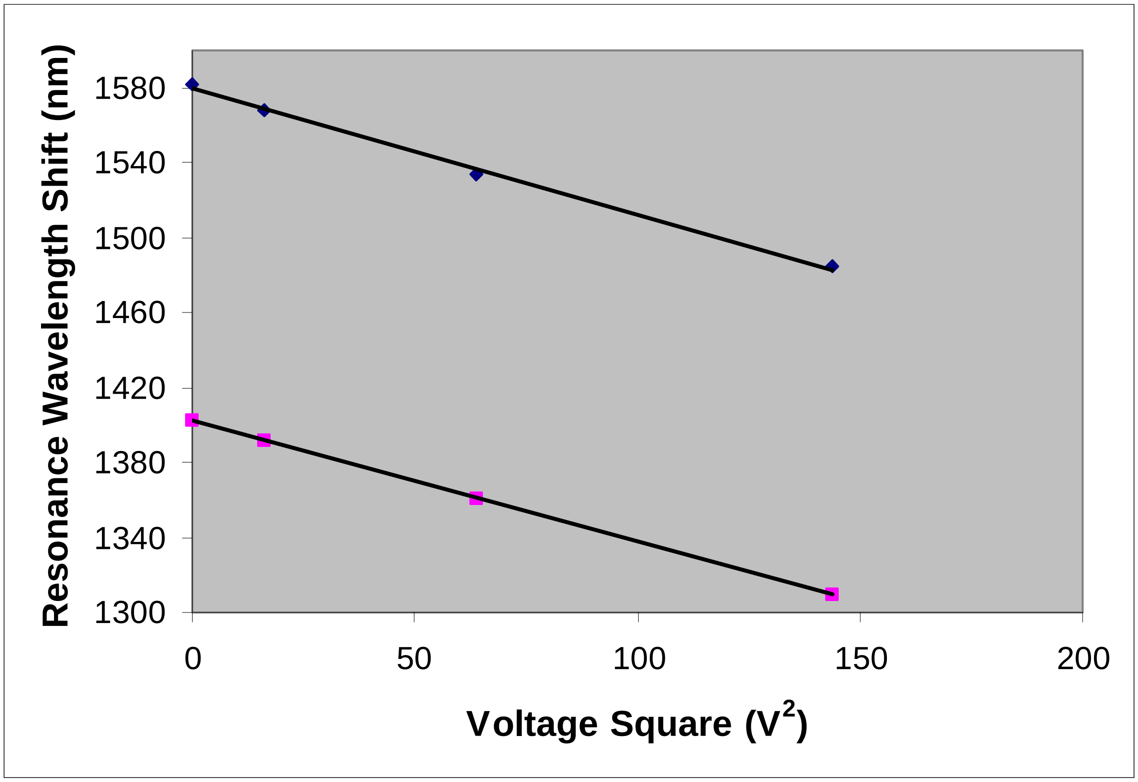

Figure 2. The resonance wavelength shift versus voltage squared at 1.582μm and 1.402μm

CONCLUSION

In conclusion, 1D Si-based and CMOS compatible photonic crystals with “large” air defects are fabricated and measured. This is the first time that multiple resonance modes within a PBG have been realized and studied experimentally. The four modes are at 1.402μm, 1.582μm, 1.792μm and 2.072μm. The Photonic Band Gap range is from 1.19μm-2.18μm with 1000nm bandwidth. Low voltage tuning of the four resonance modes is achieved, with a 60nm shift at 10V of the 1.582μm mode. This is lower than any value cited in the literature. Also, the resonance shift is in perfect linear relationship with V^2, which again confirms our understanding of the electrostatic tuning. Operations can be conducted at two telecom wavelengths, 1.3μm and 1.5μm,with a FSR larger than 100nm. The switching and modulation prototype are realized.

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