Chapter 1 Introduction

1-1 Background

Over the past decade a considerable number of studies have been made on many particular man-made materials called photonic crystals (PhCs) [1-4]. The word “crystals” originated in their structural periodicity, and the word “photonic” indicated their ability to well control the photon. Photonic crystals provide a fascinating platform for a new generation of integrated optical devices and components. The existence of photonic bandgaps (i.e. frequency bands that no electromagnetic (EM) waves can propagate) is a conspicuous character in such materials (also known as photonic bandgap materials). Photonic band gaps were first predicted in 1987 by two physicists working independently. They were Eli Yablonovitch, at Bell Communications Research in Red Bank, New Jersey, and Sajeev John of the University of Toronto. Many scholars believe that the PhCs bring us a possible solutions and unlimited visions of creating large-scale photonic integrated circuits (PICs) in the future [5]. Since people have done more and more studies about photonic crystals, large numbers of reports focusing on the design of PhCs devices in PICs have been published in the last few years, e.g., electro-optical switch [6], Mach-Zehnder interferometer [7], band-dropping devices [8], and multiplexers/demultiplexers [9-10].

The simplest form of a photonic crystal is one-dimensionally periodic structure, such as a multilayer film (a Bragg stack), was first studied by Lord Rayleigh in 1887 (although he didn’t call it “photonic crystal”) [11-12]. Bragg stacks are generally used within laser cavities and for optical coatings to provide either high-reflection or anti-reflection. Besides, many interesting and creative subjects like omnidirectional reflector [13-14] and one-dimension photonic crystal heterostructure [15] have also been studied. Fig. 1-1 shows the variation in transmission spectrum of Bragg stack.

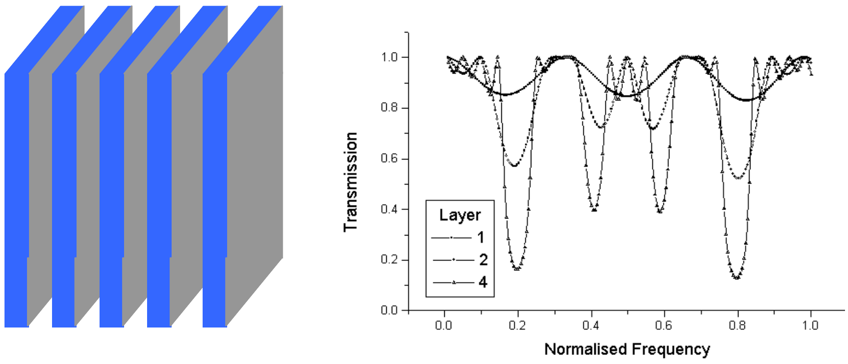

Fig. 1-1.
A rough diagram of 1-D photonic crystal and its variant transmission resulted from different number of layers.

Two-dimension photonic crystals can be regarded as the hottest topic nowadays, because they offer the possibility of fabricating high-Q cavities [16-17] and waveguide devices [18] on the scale of the wavelength in the semiconductor-based structures (i.e. GaAs/AlGaAs or SOI). Circuits of similar integration density so far only known as electronic VLSI (Very Large Scale Integrated Circuits) can be imagined. Two-dimension photonic crystals might finally bring the dream of photonic integration to miniaturization! Photonic crystal waveguides play the quite essential role in the whole photonic systems. As important as the electric wire within the electric equipments, they are the key components of interconnects for optical circuits. In contrast with fibers, PhCs waveguides can still keep well guiding the signal even if they form zigzag waveguides (Fig. 1-2). Another focal point is the microcavities in PhCs. By introducing a small number of holes (not necessary holes), that are slightly smaller or larger than the other holes in the PhCs lattice, we can generate both a microcavity so-called point defect and a narrow defect mode within the photonic band gap. Combining such cavities with light-emitting diodes (LED) will highly enhance the rate of photoemission, and are crucial for the operation of lasers [19]. Other phenomenon of two-dimension PhCs has also been widely discussed, for instance, coupling/decoupling [20], energy flow [21], and extremely low group velocity [22-23]. All of those researches make us getting closer and closer to entirely grasp this new technologies.

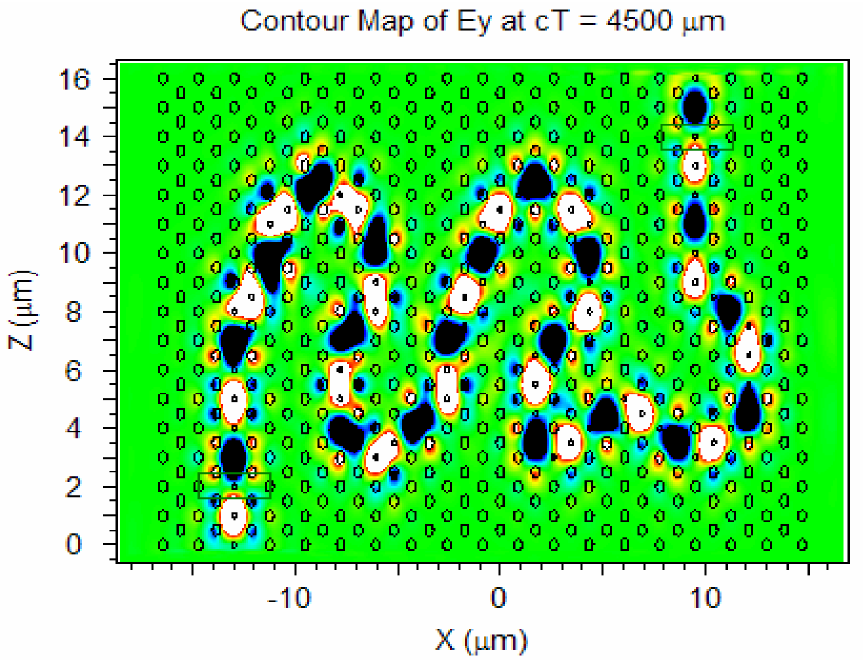

Fig. 1-2. As the diagram indicates, PhCs waveguides can perfectly communicate the signal in an acutely zigzag situation.

Because of the advanced manufacturing technology of semiconductor in the present day, three dimensional photonic crystals can be successful made by several ways, including chemical etching, stacking or electron beam writing and so forth [24-26]. Ho, Chan, and Soukoulis were the first theorists to correctly predict that a particular 3-D photonic crystal, a dielectric that is periodic along three different axes, would have a complete band gap (both TE and TM waves cannot propagate within it). In 3-D photonic crystals we have the additional freedom in three dimensions to create guided linear modes and modes that are localized at a single point and also a perfect photon-confined ability will be obtained. The most common example of the complete band gap is the diamond lattice of spheres, as shown in Fig. 1-3.

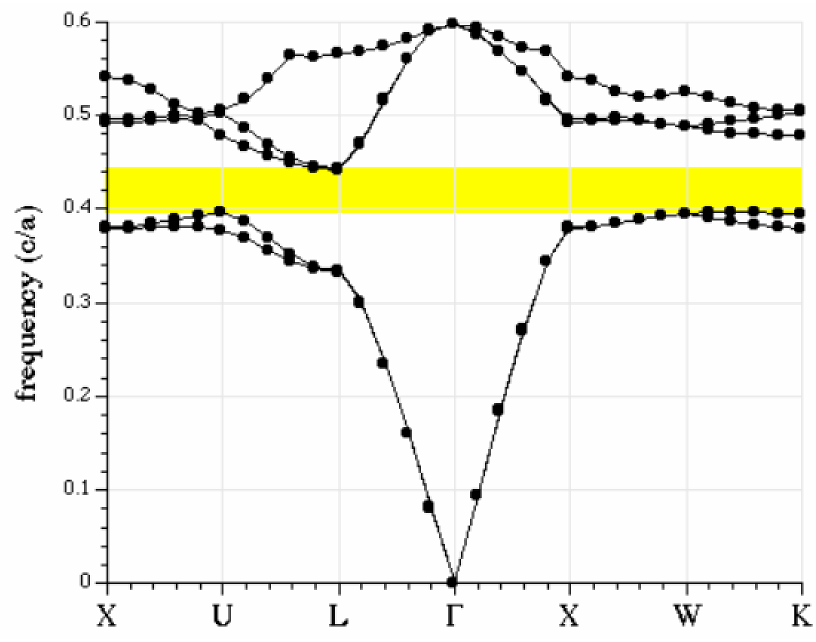

Fig. 1-3. The band gap appears in both TE and TM polarization thus so-called complete band gap. Above dispersion relation is a typical complete band gap appears in diamond lattice.

1-2 Motivation

In order to prepare for arrival of the next-generation optical communication, many scholars endeavor to develop new optical devices which possess tiny scale, high efficiency, integrable and easy fabrication. Fortunately, people found some kinds of man-made material called photonic crystal that make all our imagination realizable. By introducing different defects into perfect photonic crystals, many abilities such as wave-guiding, light-trapping, filtering, slow-light and coupling could all be generated at will. With integrating such devices in a single chip, large photonic integrated circuits (PICs) provide a wide view of future information technology. People even predict the coming of the photonic computer in the next ten years.

In this thesis, the main target we tried to explore is the development of some useful optical devices. With the study to the properties of PhC waveguides, several startling behaviors like coupling/decoupling, ultra-short coupling length and high field localization which all give us large number of ideas to do the design of PhC devices applying in optical communication with micrometer scale. In the following chapter 3, we present four topics focusing on physical discussion in PhC waveguides and optical devices such as wave division multiplexing (WDM), dual wavelengths multiplexer and bidirectional communicator (BIDI) base on photonic crystal with silicon rods array. Each topic is calculated and simulated by plane wave expansion (PWE) and finite-difference time domain (FDTD) method in order to do the eigenmodes-solving and real space wave propagation experiment, respectively.

1-3 Organization of the thesis

In this thesis, we divided the text into four chapters. We have narrated a brief statement to the background and history of the photonic crystal and also our research motivations in this chapter. The main theory we depended will put in chapter 2. After that, the chapter 3 will embrace all our PhC optical devices design and the simulation results. Including four different topics, each topic will have its own brief summaries before the final conclusion. In the end, the final conclusion will be presented in chapter 4.