# 論 文 の 内 容 の 要 旨

論文題目　Design and Fabrication of Three Dimensional Photonic Crystal for Guiding and Localization of Light
(光導波・局在機能を有する三次元フォトニック結晶の設計と作製に関する研究)

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Possessing spatial periodicity in the dielectric constant, photonic crystals (PCs) can strongly modulate light and, with sufficient dielectric contrast and an appropriate geometry, the refractions and reflections of light from all of the various interfaces can produce many of the same phenomena for photons (light modes) that the atomic potential produces for electrons, which may exhibit a photonic bandgap (PBG). Science the conception of photonic crystal was brought into the research field from 1987, many researches had been done to improve the performance of devices based on this type of structure. Photonic crystals with defects have been attracting much interest as a promising platform for guiding and localization of light due to existence of photonic bandgap. Three dimensional PCs could provide complete photonic bandgap, which will offer advantages on manipulating light, but the progress in three dimensional photonic crystal cavities is far behind that in two-dimensional system due to the difficulty in fabrication. So novel designs on functional structures in three dimensional photonic crystals are needed, which should be easily realized in fabrication. In this thesis, original research work on designs, which are mainly done by using the Finite-Difference Time-Domain (FDTD) method and the Plane-Wave Expansion (PWE) method on simulation of Maxwell's equations in photonic crystal structures, and fabrications of high performance structures in three-dimensional photonic crystals are presented.

In Chapter 2, basic principles of photonic crystals that are necessary for understanding the research background and motivation of this thesis are introduced. Three-dimensional woodpile photonic crystal structures are described in details as they are basic building blocks of all the work in this thesis. The influence of cavity geometry and structural parameters on the behavior of characteristics of photonic crystals, such as photonic bandgap, resonant frequencies, is discussed. Finally, defects are introduced by adding dielectric materials to perfect crystals to manipulate light in them.

In Chapter 3, details on computational methods used in this thesis, which are all based on the FDTD and PWE methods, are described. The FDTD simulations are categorized into two classes with different boundary conditions, depending on the types of calculations to obtain efficient and accurate solution of electromagnetic waves. The applications of the 3D FDTD calculations to investigate photonic band structures, equi-frequency contours, resonant frequencies, field distributions, quality factors, mode volumes, and effective refractive indices are shown. On the other hand, The PWE simulations have been introduced in detail on the simulation of photonic band structure, the analysis of eigen-state, eigen-frequency and field distribution.

In Chapter 4, a design of silicon three-dimensional (3D) photonic crystal (PC) waveguides with a combination of acceptor-type and donor-type line defects is reported. Tuning the width of the acceptor-type line defect allows the waveguide to support two guided modes, which enable single-mode propagation over 98.7% of the complete photonic bandgap (cPBG). In addition, we demonstrate that the frequency ranges for single-mode propagation can be extended to the entire range of the cPBG by further tuning the thickness of the layers in which the donor-type line defects are located. The wide ranges of available frequencies for single mode propagation enable flexible design of 3D PC components and will provide a route towards future 3D photonic circuits.

In Chapter 5, a simple design is reported with high quality-factor (*Q*) three-dimensional woodpile photonic crystal nanocavity in vertically mirror-symmetric structure, which can be realized by changing the stacking order of layers above the cavity layer from ordinary woodpile structures. A *Q* of $1.7\times10^5$ in the mirror-symmetric structure was obtained with a relatively small PC size. This is ~3.6 times as high as the maximum *Q* of the same nanocavity embedded in an ordinary woodpile structure of the same PC volume.

In Chapter 6, based on the design of chapter 5, experimental demonstrations of high-*Q* cavities coupled with quantum dots in three-dimensional photonic crystals fabricated by using micromanipulation techniques are presented. The structures are shown to have very small stacking errors, in spite of their large number of the stacked layers. The square-shaped defect cavity in a 25-layer woodpile layer exhibits a cavity mode with a high *Q* factor in mirror-symmetric woodpile structure.

In Chapter 7, conclusions to this thesis are presented. Implications of the results presented in this thesis are discussed. The outlook for future research and development is also given.

The results obtained in this thesis provide one important step towards the acquisition of complete manipulation of guiding and localization of light.