Chapter 9

Summary, Future Work and Some Results

9.1 Summary

In conclusion, we present the analysis and applications of the interaction phenomena between light wave and scatters (e.g. optical fiber, sample and SIL probe system) in the near field zone using 3D finite difference time domain (FDTD) method. The high efficiency coupling techniques between SWG and PPCWGs are also proposed using both plane wave expansion (PWE) and FDTD method. There are three issues are discussed in this thesis. The first issue we studied is a series of using the FDTD method to get more insight in the near field distribution of subwavelength aperture and fiber probes are numerically investigated . Besides, the FDTD design of field enhancing NSOM probe is illustrated and gives a suggestion for fabricating an optimal probe. The second issue is a SIL combined with near field probes which are conic dielectric probe and local metallic coating one are designed for optical recording by means of a 3D FDTD method to gain more insight in the near field distribution. We investigate the optical properties of near field distributions between SIL-probe and recording-layers. A promising idea for fabricating a new type of SIL-probe system was proposed. As regards the third issue, we report high efficiency coupling techniques between SWG and PPCWGs using optimal configurations which can remarkably enhance the coupling efficiency at the entrance and exit terminals of PPCWGs. From simulations, we find that the transmitted probability reaches up to 90%. Moreover, the suggested structures possess other advantages, such as quite short taper, easy fabrication, low cost, etc. It is anticipated that the proposed structures might feasibly apply to the integrated optical circuits compatibility. Also, a comparison between the 2D devise and 3D slab version is given in section 7.4. Besides, we present an efficient mode coupling technique between silica SWGs and a planar photonic crystal heterostructure waveguide (PPCHWG). In the next section of this chapter, we will introduce our future work and some results.

9.2 Future work and some results----------

Near field optics imaging in photonic crystals and a promising device for the near-field scanning optical microscopy

The interaction between the photonic crystals (PCs) and the field near the specimen surface affects the characteristics of the images produced by a near field scanning optical microscope (NSOM) are analysized in some details. The numerical calculation is carried out using the three-dimensional (3-D) Finite-difference time-domain (FDTD) method, and the spherical chains as a extra defect in a PCs that includes a specimen is considered. FDTD analysis of light propagation of photonic band gap (PBG) structures demonstrates that the electric field distribution is localized and rim enhancement in the spherical chains within near-field zone. The subwavelength resolution uses FDTD simulations to be achieved in the near field, revealing efficient formation of an evanescent field at the output of such PBG structure. It is based upon the detection of the static radiation in near field. No diffraction effect happens enable the PBG structure to have ultrahigh resolution in imaging. The influences of the optical field distribution generated by some factors are discussed and possibilities for using such PCs with an extra material embedded into the defect region as a defect lattice in NSOM are also described. It offers a way to control the light field localized in defect modes of such PCs in NSOM giving a new idea of PBG applications in NSOM.

9.2.1 Introduction

It is well known to be a powerful tool for the observation of microstructure beyond the diffraction limit of conventional optical microscopy using the NSOM[1-4]. During the last decade, much attention has been focused on the investigation of photonic structures[5, 6]. This kind of optical information between the specimen area and PCs of nanometric dimensions that can be obtained from an NSOM image has remained unclear, because the NSOM imaging process is quite complicated. The near field electric distribution formed when the incident light passing through the structure of PCs waveguide diffracts to the optical properties of the specimen such as geometrical structure, refractive index and absorptivity distribution. Such periodic structure of transparent dielectric media has characteristic electromagnetic eigenmodes, known as the photonic bands just like the electronic bands for electrons in a crystal. Existence of PBG means that light propagation in the specified rangeis suppressed in a certain direction (a stop band) or in all directions (a complete PBG) [7, 8]. In particular, it was demonstrated that unusual dispersion properties of such structures to control light propagation[9], to create thresholdless microlasers [10] and all-optical transistors [9], to allow compact tunable optical delay lines to be implemented[11], parameter of short laser pulse to be controlled[12], and to increase the coherent time of states in quantum computers[13], etc. The light field localized in two kinds of extra material embedded in the defect region as a extra defect lattice in a PBG structure within areas with near-field zone is never studied within our knowledge in the present time. The field intensity distribution at the output of the PBG structure is also sensitive to the presence of a probe object (dielectric sphere) , offering a way to control the light field localized in defect modes in the PBG structure. In this chapter, we will use FDTD method to studies this object. The FDTD method has been successfully applied to describe optical switching [14] and pulse compression [15] in nonlinear one-dimensional (1-D) PBG structures. We employed the FDTD technique to analyze the propagation of a light beam in a PBG structure and a defect by the 3-D FDTD methods. This analysis reveals several intriguing features of light localization in such PBG structures, which seem to offer much promise for near-field microscopy. In particular, the subwavelength resolution can be achieved with PBG structure when the localization of light within areas whose sizes are less than a wavelength. That provides the information concerning the spatial distribution of the field inside and outside of a PBG structure allowing us in particular to find the throughput of the defect mode quantitatively characterize the areas of field localization inside the PBG structure, and determine the spatial distribution of the electromagnetic field emerging from the PBG structure. In the past, several efficient methods were implemented to overcome the difficulties raised by the complex geometry of such optical systems. Memory requirement is important in particular for calculating the field distribution with PCs. Various methods have been proposed for calculating the band structures, such as the plane wave expansion method[16-18], the translational matrix method [19], the finite element method (FEM)[20], the multiplescattering theory [21] and the finite-difference time-domain (FDTD) method[22],etc. Among these methods, the FDTD method reduces the computer memory amount for the same PCs model than the others, and solves Maxwell's equations without any simplifying approximately other than the discretized grid, the method is well suited to simulating near field configurations. For most of the other numerical methods, the computational time grows in a rate of $N^m (m > 2)$ as N increases, where N is the number of expansion terms or discretization points in a cell, i.e., they are of order N_m, Compared to the plane wave expansion method is of order N^3, As one of the major advantages, the FDTD method is of order N[22]). In this paper, we investigate from a PCs model that we consider is a triangular lattice of finite-height slab, different aspects of this local interaction. Firstly, we will discuss some preliminary results recorded with the near-field distribution of such subwavelength PCs structure for a spherical chains with two kinds of substance as an extra object inside the defect region to construct the foundation of our analysis. Finally, a new near field optical microscopy using a evanescent wave formed in the defect mode in a PCs is proposed, which seem to offering promise of the near-field microscopy.

9.2.2 Photonic crystals model

For our research, we selected a model consisting of a variable number of periods(between five to ten) of cylindrical air pores forming a triangular lattice in silicon matrix (Fig.1). The reason why this type of PCs was selected because silicon technologies are extremely promising for fabricating 1-D[30], 2-D[31], and 3-D[32] PBG structures. We removed one rod of air poles (see the right side of Fig.9.1) in order to form a defect region in the PBG structure described above. For the sake of the complete band gap in the region of air cylinders in silicon, the depth of penetration of the optical field in the skin layer of PC does not exceed a single period of the structure. We solved the problem of light propagation in a superlattice in order to determine the transmission spectrum of a lattice with the defect was introduced periodically (with the period T along the y axis). In the other word, this calculation scheme can also be used to determine the noise level associated with the influence of light localized in neighboring defect which is of interest for applications of these PBG structures in NSOM (For example, optical memory system, optical information processing, near field high density data storage [33] and other applications in biomedical and material science, etc.).

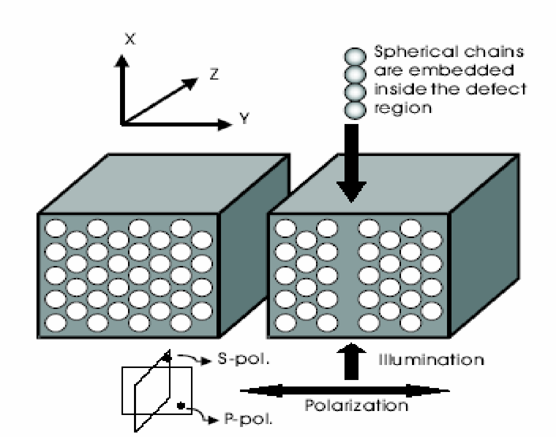
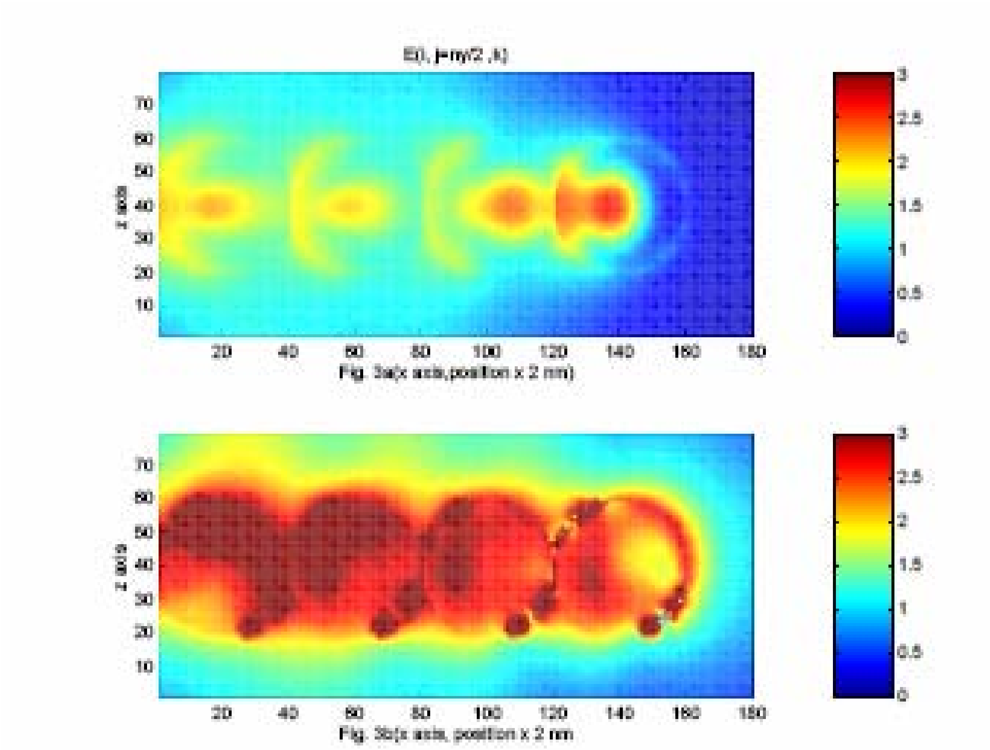


Fig. 9.1 Fragment of a PCs structure with cylindrical air pores forming a triangular lattice in a silicon matrix without (the left side) and with (the right side) a lattice defect.

9.2.3 Comparison of the field distribution of two kinds of spherical chains as an extra defect in the defect region

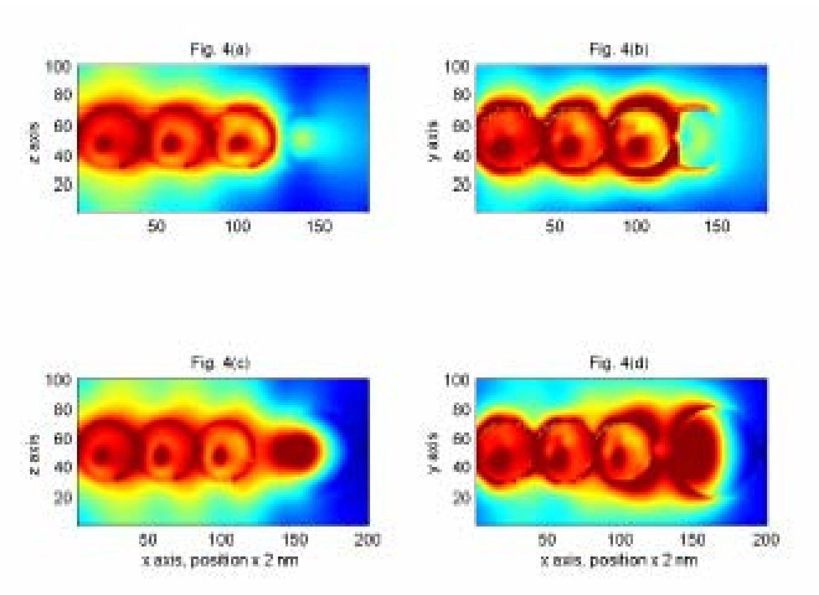
In order to obtain more information of optical properties in the near field zone, we use 3-D FDTD method to evaluate quantitatively the character of the areas field distribution localized inside the PBG structure, and determine the spatial field distribution emerging from the PBG structure. As defect was introduced into such 3-D structure (the fragment see the right side of Fig. 9.1) considered above by removing one of rows of air cylinders periodically with a defect period $T = 10\sqrt{3}\, a$ along the y axis for the lattice constant $a = 0.454\lambda$. The light wave of a certain frequency may propagate in the defect region. We considered two kinds of extra material embedded inside the defect region along the x direction in the central part of defect region. One is single subwavelength spherical chains with pure dielectric material, which refractive index n is 3.4 and the diameter of the spheres is 80 nm (we named it dielectric spheres later),the other is the same contents as described above with some aluminum particles(the dielectric constant were chosen to be $-34.5 + i8.5$[36]) was doped inside the spherical chains randomly(we named it metallic particles sphere later). The numbers of dielectric or metallic particle spheres is the same as the number of the layers along x-axis. The p-polarized incident light is focused onto the central part of the spherical chains direction, located at the bottom face plane shown in Fig.9.1 at normal angle. Results show that the fields to an equilibrium value a short distance from the source plane. Based on our calculation, the field distribution intensity in such a PBG structure with no defect decreases on a spatial scale of the order of wavelength ¸ and has a transmission coefficient of the order of 10^{-3}, in a PBG structure having a defect, the transmission coefficient that was calculated within the range from $0.4398\ \omega a/2\pi c$ to $0.4716\omega a/2\pi c$ for p-polarization increases from 10^{-3} up to 0.5138, The result is similar to reference[37], indicating the appearance of a defect level in the band gap. We first calculated with the FDTD the electromagnetic field near the output of PBG structure without a probe object. Compare the x-z sectional plane map of light localization (field intensity distribution) in a single spherical chains of a PBG structure. Defect are good to mold or control the properties of light and herein lies the exciting potential of PCs. The field associated with the guided mode is strongly confined in the vicinity of the defect and decays exponentially in the PCs. The reason why we treat the spherical shape as an extra material in the defect region since we can obtain the confocal light in the defect region. Fig. 9.2 (a) and (b) shows calculated results for p-polarization illumination of the dielectric spheres and metallic particle spheres, respectively. Although this model is a rotational about chain axis symmetric system, the electric field distributions formed in the two orthogonal cross sections are different from each other due to the different between the boundary conditions in the edge interface. In the color map we used, red signifies higher intensity values. In the sectional image of the dielectric spheres showed in Fig.9.2a, the intensity becomes stronger both in the central part and near the rims of spherical chains (edge enhancement), and the image generated agrees reasonably with the geometrical profile of the same spherical chains. At the edge interface of the spherical chains the electric flux density is conserved so that the electric field amplitude is greater in the outside of the medium where the permittivity is smaller. Fig. 3b shows the same as Fig.3a except that the aluminum particles was doped inside the spherical chains randomly. Note the intensity in the image contrasts relative to the image shown in Fig. 9.2a. The aluminum particles are generated either in the sputtering process or by the reversible chemical reaction, and produce the large nonlinear optical effect. This effect arises from the excitation of the plasmon resonances between the metallic particles (shape-dependence) which are embedded inside the spherical chains by the evanescent photons and leads to propagation mainly in forward direction. In such condition, one also expects the metallic particles to play the role of local source of light if the incident electric field has a vertical component(p polarization). Another significant result from Fig. 9.2b is the influence of the embedded aluminum particles which form much strong scattering centers and increase the evanescent field. The embedded aluminum particles also provide an interpretation for the high scattering property of the PCs structure which further enhances the surface plasmon effect and introduces nonlinear optical properties. It provide strong local field enhancement which may be of the relevance for the near-field optical processing and will be discussed in the latter sections. Observation of localized surface plasmon resonances of metallic particles open the way for many types of nonlinear near-field studies where the signal-to-noise ratio is a critical issue.



9.2 Compare the *x*- *z* sectional plane map of light localization (field intensity distribution) in a single spherical chains as a extra defect in a PCs structure. Fig. 2a shows the calculated results for p-polarization illumination of the spherical chains with constant refractive index. Fig. 9.2b shows the same as Fig. 9.3a but some aluminum particles was doped inside the spheres randomly.

9.2.3 Local excitation of the external probe object at the output of the defect region

As a result, the characteristics of an NSOM image of the surface are quite sensitive to the manner in which the probe is scanned over the specimen surface. We can try to obtain the spatial field distribution of the optical field localization effect in a PCs by controlling the external probe object (in our case a dielectric sphere is used). Figs. 9.3a and 9.3b which show the results of calculated intensity images obtained in x-z and x-y sectional plane for p-polarization illumination, respectively having the parameters described the same as above section (the case of embedded metallic particles inside the spherical chains), when a transparent dielectric sphere with the constant refractive index 1.5 and radius 40 nm (Fig.9.3a,b) and 60 nm (Fig.9.3c,d) is located closed to the output face of the spherical chains, with the center of this sphere being placed at distances d=20 nm (Fig.4a,b) and d=40 nm (Fig.4c,d). The dielectric sphere can look like the local excitation source of particle at the output of the defect region of a PCs. A comparison of Figs.9.3a and 9.3b with Fig.3a shows that the presences of such a dielectric sphere disturbs the field distribution inside the spherical chains, resulting in tunable phenomenon by the potential of spherical probe. We can explain this effect arising from a change of the disturbing source of the dielectric sphere that changes the field distribution in the near field zone. In order to realize the detailed behaviors of the field distribution, the three component field distribution will be discussed here. Fig.4.a-c show the x-z sectional plane map of the three electric field components (E_z,E_x,E_y from top to bottom) the same as the case in Fig.9.4c. Some characteristics can be summarized as follows: The z-component of electric field is distributed symmetrically along the rim of the spherical chains much smaller than the x-component of electric field. The y-component of electric field is also smaller than x-component of electric field, an interesting enhancement occurs at the rim of the spherical chains. The x-component of electric field leads to propagation mainly in forward direction and form the main field distribution of the total electric field emerging from the PCs. The depolarization phenomenon of components is the near-field effect. Recall that under the weak scatter approximation the strongest intensities are found near the center of the tip apex. Another reason can be evidenced from the study of z-component of the electric field: no matter what the light penetrating through or refraction from dielectric sphere, high x-component distributes on the region between dielectric sphere and the output of the defect region in a PCs, where the light wave kept largely its original propagation y-component inside the spherical chains and depolarization x-component outside the PCs along the direction emerging from the PCs. The resultant images for distance between tip and specimen decreases as the d value (the distance between PCs and probe object) increase or the tip gets apart from the specimen surface. This is because the distance apart from the tip decays field distribution exponentially. This can reduce the light surrounding the specimen surface. In the same time, the transmission light from the specimen is weaker. That is to say the light converted in the near-field zone is transmitted less to a photo-detector. Besides, the light between specimen and PCs increases gradually because of the light reflection from the specimen. The physically observable effect in this section gives a better understanding will lead to an unambiguous analysis of an NSOM image and will make the NSOM a more reliable imaging tool for possible applications of light localization effect in PCs or in biomedical and material science.



Figs. 9.3a and 9.3b which show the results of calculated intensity images obtained in x-z and x-y sectional plane for *p*-polarization illumination, respectively when a transparent dielectric sphere with the constant refractive index 1.5 and radius 40 nm (Fig.9.3a,b) and 60 nm (Fig. 9.3c,d) is located closed to the output face of the spherical chains, with the center of this sphere being placed at distances d = 20 nm(Fig.9.3a,b)and d=40 nm (Fig. 9.3c,d).