Chapter 4 Conclusion

In this thesis, we have systematically examined the refractive phenomena of the wave propagating through a two-dimensional (2D) photonic crystal, especially for negative refraction phenomena. In order to realize and define the refractive behaviors, we introduced two kinds of calculation methods which are the finite-difference time-domain (FDTD) method for electromagnetic simulation and plane-wave expansion (PWE) method for band structure, equal frequency surface (EFS), and eigenmode pattern calculations, individually.

We established a model of EFS configuration (reciprocal space) to predict the refractive behaviors in photonic crystal of real space and utilized the concepts of effective refraction index to characterize the direction of refractive wave vectors. Positive refraction, negative refraction, and total internal reflection in photonic crystal prisms (PCP) have been numerically demonstrated; moreover, the right-handed (RH) rule and left-handed (LH) rule are observed at 1^{st} band owing to $\vec{v}_g \bullet \vec{k}_f > 0$ and 2^{nd} band owing to $\vec{v}_g \bullet \vec{k}_f < 0$ respectively. Meanwhile, we can get a pretty well consistence of measuring refractive angles between the infinite case (PWE) and the finite case (FDTD) by using the Snell's law as a result of isotropic-like propagation properties (circular-like frequency contours). In addition we studied the question: dependence of symmetry on excitation of eigenmodes; and further we also confirmed that the uncoupling effect exhibited in a PCP with antisymmetry of eigenmode patterns under the relevant mirror reflection, even if these modes exist within the crystal.

We have also performed that the flat surface focuses light by virtue of the negatively effective refraction index in a photonic crystal slab which can overcome the diffraction limit inherent in conventional lenses. Here the focusing effects are observed inside of the slab (1^{st}

focal point) and at right side of slab (2nd focal point) individually, yet the focal points present energy assembling. Besides we deduce the imaging mechanism of photonic crystal slabs with negative refraction: "the distance of imaging is direct proportional to distance of source by using the center of photonic crystal slab as datum plane", which is different from the imaging mechanism of conventional lenses.

Lately we commented on an interesting opinion that all-angle negative refraction in photonic crystals could be realized at the frequency region without negatively effective refraction index (i.e. 1st band), meanwhile, an imaging-like phenomenon seemed to be observed by Luo *et al.* [11]. We discovered some serious faults in this opinion and gave a new definition by using the "direct-tunneling effect" which is resulted in group velocities directly propagating on the flat band of EFS. Judging by our simulative results, apparently the light is strongly confined in a channel-like around the center of slab, moreover, the wave directly tunnels across the slab and diverges again same as a point source after the light emerging from the slab. In other words, the imaging-like behaviors are not established by a negative refraction law, but preferably by a dominant direct-tunneling effect. The same we can demonstrate it to other periodic structure cases, e.g. the 1st band of the triangular-lattice photonic crystal.