Near-field electromagnetic wave distribution in a two dimensional hexagonal photonic crystal cavity with a negative refractive index

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Abstract

We report here the direct observation of two-dimensional Bloch wave harmonics interferences in a negative index photonic crystal by using optical near-field microscopy techniques. The photonic crystal is formed by a defectless honeycomb lattice of air holes etched in III-V semiconductor slab. The recorded near-field spectra and maps presented here unambiguously demonstrate the Bloch wave harmonics interferences within the photonic crystal. Then, the spectral and spatial evolution of these interferences allows us to recover experimentally the 2D band diagram of the photonic crystal demonstrating that this structure operates in a negative refraction regime and acts as a left-handed cavity.

1. Introduction

Since the pioneering work of Veselago [1], the feasibility of material with simultaneous a negative permitivity and a negative permeability has been extensively studied. Moreover such material may also fin several applications to improve the existing optical systems since the could permit to overcome the diffraction limit [2]. However, achieving a material with a negative refractive index requires artificial materials patterned at a sub-wavelength scale. At optical frequencies, the ability of semiconductor two dimensional photonic crystals to produce a negative refractive index has been demonstrated theoretically [3] as well as experimentally [4].

2. Near field analysis of in the two dimensional hexagonal photonic crystal cavity with an negative refractive index

In this work, we will consider a two dimensional photonic crystal (2DPC) in a defectless honeycomb lattice of air holes etched in an InP slab. The 2DPC structure consists in a hexagon with a 24-period long edge (Fig.1a). Since the structure is spatially limited, two-dimensional Bloch waves will bounce in the 2DPC and thus will allow us to consider the whole structure as a cavity.

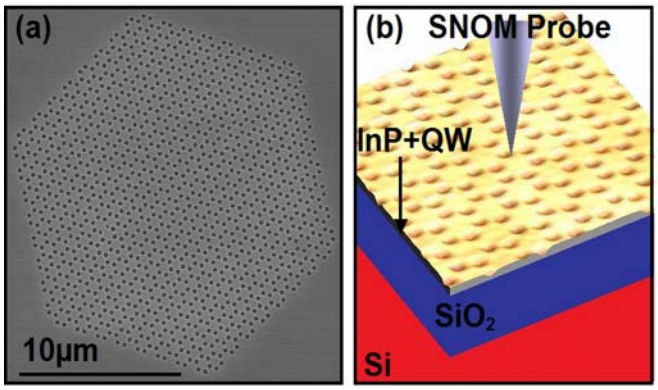

Figure 1: (a) Scanning Electronic Microscope image of the two-dimensional honeycomb photonic crystal structure. (b) Schematic 3D view of the near-field experiment. The figure also shows the layered structure of the sample.

Since few years, several studies have demonstrated the ability of Scanning Near-field Optical Microscopy to directly examine the interactions between light and PC structures [5,6]. Here, by using such a technique, we will evidence that the 2DPC will acts as a Left Handed Cavity with a negative index media supporting several standing Bloch wave (Fig.2c) as predicted by the band diagram of the honeycomb lattice (Fig.2b).

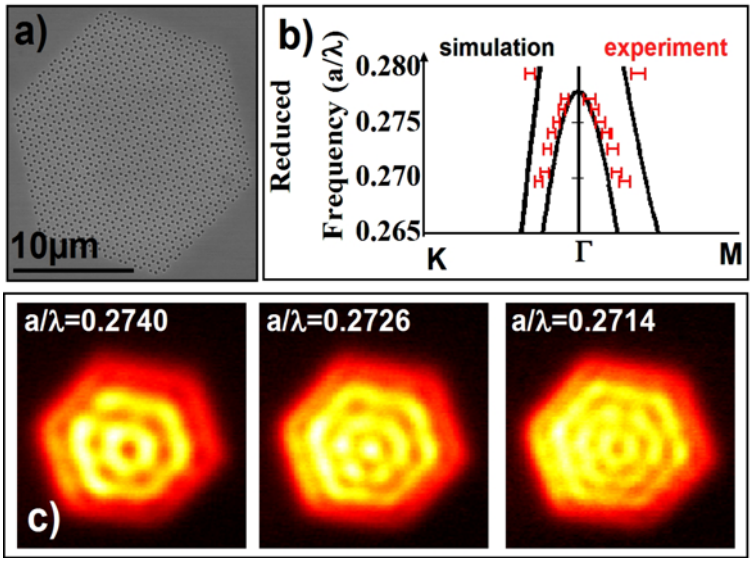

Fig. 2: SEM image of the whole 2DPC Crystal (a) and its second band of the TE band diagram (b). Near-field maps obtained in SNOM for three successive cavity resonant wavelengths (c).

4. Conclusion

In conclusion, we reported the direct visualization, using a Scanning Near-field Optical Microscope, of the spatial and spectral properties of 2D Bloch waves in a negative index photonic crystal. We have shown that the light distribution within the structure is driven by the interferences of the two-dimensional Bloch wave harmonics. Our analysis is supported by a direct comparison between the dispersion curves recovered in light of the experimental observations and the theoretical band diagram of the photonic crystal. At last, we evidenced that the whole two dimensional photonic crystal structure studied in this work acts as a Left-Handed Cavity. This work illustrates the unique properties of negative refractive index media to reverse well known physical effects relying on electromagnetic

waves propagation and may open a new route of investigation towards left handed media applications[Erreur ! Signet non défini.].

5. References

[1] V.G. Veselago, Sov. Phys. Usp. 10, 509 (1968).
[2] J.B. Pendry, Phys. Rev. Lett. 85, 3966-70 (2000).
[3] M. Notomi, Phys. Rev. B 62, 10696 (2000).
[4] A. Berrier et al, Phys. Rev. Letters 93, 073902 (2004).
[5] N. Louvion et al, Phys. Rev. Lett. 94, 113907 (2005).
[6] B. Cluzel et al, J. App. Phys. 98, 86109 (2005).