Chapter 7
Signatures of the Mode Symmetries in Sapphire PhoXonic Cavities

Houda Bentarki
Moulay Ismail University, Morocco

Abdelkader Makhoute
Moulay Ismail University, Morocco

Tőkési Karoly
Institute for Nuclear Research, Hungarian Academy of Sciences, Hungary

ABSTRACT

The acousto-optic couplings mechanisms are investigated theoretically in photonic and phononic crystals with simultaneous band gaps. The authors have focused on the acousto-optic couplings inside a phoXonic cavity by taking into account two coupling mechanisms, the photo elastic effect and effect of movement of the interfaces. They discuss the symmetry of modes to distinguish those that don't interfere in an efficient way. They calculate the modulation of the frequency of the photonic mode during a period of acoustic oscillations with a finite element method (FE) (COMSOL®Multiphysics). The two mechanisms presented in the numerical calculations produce additive or subtractive effects in total acousto-optical coupling while depending on whether they are in phase or out of phase.

1. INTRODUCTION

The study of wave propagation in general, and in periodic media in particular, has aroused great interest in the scientific community for several decades. In order for an extension of the notion of band gaps to electromagnetic waves to emerge, it was not until 1987 that photonic crystals were born.

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Photonic band gap materials or photonic crystals (Joannopoulos et al., 2008; Yablonovitch, 1993) are periodic dielectric structures which have the ability to inhibit the propagation of light in certain directions, for a given frequency range.

In the image of photonic crystals, a composite material whose density and elastic constants are periodic functions of the position, may present, under certain conditions, bands prohibited for acoustic or elastic waves. These are materials with phononic band gaps called phononic crystals (Kushwaha et al., 1993; Pennec, Vasseur, Djafari-Rouhani et al, 2010).

To meet the growing needs to increase the performance of existing components or to propose new components, a new type of periodic structure combining the principle of photonic and phononic crystals which has been named phoXonic crystal (Eichenfield et al., 2009; Maldovan & Thomas, 2006a; Maldovan & Thomas, 2006b; Pennec, Djafari Rouhani, El Boudouti et al, 2010; Pennec et al., 2011; Rolland et al., 2012) was born. It was then expected an improved efficiency with regard to the strong confinement potentially achievable in these structures which present simultaneous photonic and phononic band gaps.

Several applications of these crystals have emerged thanks to these properties, in particular for the production of interesting components in integrated optics such as high quality factor micro cavities, low loss micro guides, laser micro sources, isolation of resonant structures, such as filters and oscillators (El-Kady, 2009), the resolution limited to under-diffraction and acoustic shielding (Lu et al., 2009). The simultaneous existence of photonic and phononic structures has opened a new path in the field of acousto-optic devices (Eichenfield et al., 2009a; Eichenfield et al., 2009b; Gorishny et al., 2005), while seeking to consolidate the principle of photonic and phononic crystal in a single structure called phoXonic crystal. The interest of studying these artificial crystals is to improve the performance of optical devices by controlling the propagation of electromagnetic waves in the presence of elastic waves. During the recent years, the availability of powerful numerical calculation machines has stimulated consider- able interest in the study of acousto-optic couplings mechanisms in phoXonic crystal. In particular, two-dimensional phoXonic crystals have attracted a great deal of attention after publication the pioneering theoretical study of Maldovan and Thomas (Sadat-Saleh, Benchabane, & Baida, 2009; Sadat-Saleh, Benchabane, Baida et al, 2009), which studied theoretically the phononic and photonic band gaps in 2D crystals for a square or hexagonal network of air holes in a silicon matrix. The opening of simultaneous photonic and phononic band gaps in a square periodic array of air holes in a sapphire substrate is studied in this work. The matrix component is chosen to take advantage of the anisotropy of the dielectric tensor in the microwave sapphire regime; the use of anisotropy has the advantage of widening the bandwidth of a cavity, and the reverse is achieved in the case of a cavity intended for a filter design, however, the microwave filters are widely used in radars, satellites, and mobile communication systems. These are typically devices, band pass, or selective bandwidth, with stringent features for insertion losses. The goal is to study the acousto-optic coupling, based on both photo-elastic and opto-mechanical mechanisms, in periodic structures with simultaneous photonic and phononic band gaps. The acousto-optic interaction generates a phonon thanks to the excitation of the cavity by the confinement of the optical wave. The aim in this field being to seek a maximum coupling of this interaction, and this also due to a strong confinement of the waves in the micro cavities. The obtaining of allowed bands in band gaps are also studied in this work, by introducing defects in the periodicity of a super cell, which has led to the propagation of waves appropriate. The frequencies of the localized modes in the first band gap are computed with a finite element method (FE) (*COMSOL®Multiphysics*). However, the Finite Difference Time Domain (FDTD) method was also used in 2010 for the same structure (Bria et al., 2011); the difference with our work is that we have chosen a different network parameter to have localized modes when introducing