Australian Journal of Basic and Applied Sciences
2019 July; 13(7): pages 42-48
DOI: 10.22587/ajbas.2019.13.7.7
Original paper
AENSI Publications
Journal home page: www.ajbasweb.com

Cavity modes Investigation in phononic crystal

Mohamed Lamine Bouchemal [a], Samia Bouhedja [a, b], Nora Boussouf [c, d]

[a] Hyperfrequency and Semiconductor Laboratory, Department of Electronics, Faculty of Science of Technology, University of the Mentouri Brothers Constantine 1, BP 325 Ain El Bey Road, Constantine 25017, Algeria
[b] Department of Medicine, Faculty of Medicine, University of Constantine 3, BP125 Pine Chalet, Constantine 25000, Algeria
[C] University Centre of Mila Abdalhafid Boussouf, Algeria. Institute of Science and Technology. Department of Technical Science.
[d] Material Science and Applications Research Unit, Physics Department, Constantine 1University, Route de Ain-el-Bey 25017 Constantine, Algeria

Correspondence Author: Mohamed Lamine Bouchemal, Department of Electronics, Faculty of Science of Technology, University of Constantine 1, Algeria

Received date: 20 May 2019, Accepted date: 20 July 2019, Online date: 28 July 2019

Abstract

The design of a phononic crystal allows to confine the acoustic energy or the contribution of the bands gap is an essential condition to locate the phononic modes in a defect. The objective of this context is to propose a periodic structure optimized to have a wide absolute bands gap whatever the nature of the excitation (symmetrical or asymmetric) where we could also determine the nature of the resonances modes obtained by using the transmission study where it was impossible by the dispersion study.

Keywords: Phononic crystals, Absolute bandgap, Transmission

INTRODUCTION

Currently, and by their extraordinary properties, the phononic crystals and arouse considerably the interest of the researchers(Capdeville et al., 2015), (Wang et al., 2017). These structures are made by periodic repetition of inclusions in a network (Bergamini et al., 2014), (Jin et al., 2015). The latter presents a periodicity of acoustic impedance to confine the acoustic waves and lead to new applications(Reinhardt et al., 2010), (Gedge and Hill, 2012), (Trigo et al., 2002).

The geometric and physical properties of these crystals, such as the periodicities, the shape of the inclusions and the nature of the material, were chosen in several studies to have wide bands gap used in guiding(Wang et al., 2013), (Mohammadi et al., 2008), filtering and confining elastic waves to localize phononic modes in defects (cavities(Zhang et al., 2012), (He et al., 2013), for the purpose of manipulating the resonance frequencies of phononic modes that may participate in an interaction with an electromagnetic mode(Akimov et al., 2008), (Eichenfield et al., 2009b), (Sadat-Saleh et al., 2009), (Eichenfield et al., 2009a).

In this context, our work is based on the transmission study by tracing the symmetrical and asymmetrical phononic band gap and aiming the investigation on the localization of the phononic modes and their nature, according to the different excitations which were impossible to obtain by the study in the dispersion.

METHODS OF CALCULATION AND GEOMETRY

The proposed structure consists of a two-dimensional square array of air holes in a silicon matrix (Si). $ai = a / 10$, $r = 0.48 * a$ is the radius of the cylinders, referred to the mesh parameter, which corresponds to a filling factor of $f = \pi r^2 / a^2 = 0.72$, *ri* is the internal radius of the structure inserted of silicon (si) in the air holes, in order to improve the performances of the crystal which act on the width of the absolute band gap figure1, a. Table1 groups the acoustic parameters in the case of silicon.

Table 1: Elastic parameters of silicon

Material	Mass Density (Kg/m^3) ρ	Elastic constants(10^{10}N/m^2)		
		C_{11}	C_{12}	C_{44}
Silicon	2331	16.57	6.39	7.962

Citation: Mohamed Lamine Bouchemal *et al.*, Cavity modes Investigation in phononic crystal. Australian Journal of Basic and Applied Sciences, 13(7): 42-48.
DOI: 10.22587/ajbas.2019.13.7.7

Among the methods developed for numerical resolution, we mention the finite element method (*FEM*) (Hou and Wu, 1997), (Certon et al., 1997) that is used for the theoretical calculations involved in the present work. We use COMSOL MULTIPHYSICS software to simulate the results obtained.

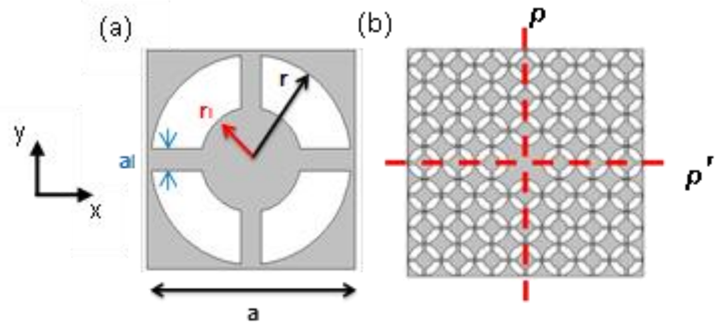


Figure 1.(a) unit cell. (b) L1 cavity in a supercell

RESULTS AND DISCUSSION

The study of the transmission of elastic waves in the periodic structure can show us additional information on the evolution of the band gap width, according to the different polarizations of the elastic excitation wave following the geometric variation which was impossible to observe in dispersion curves.

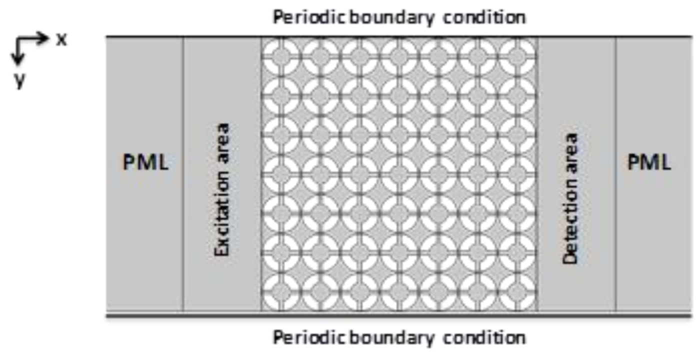
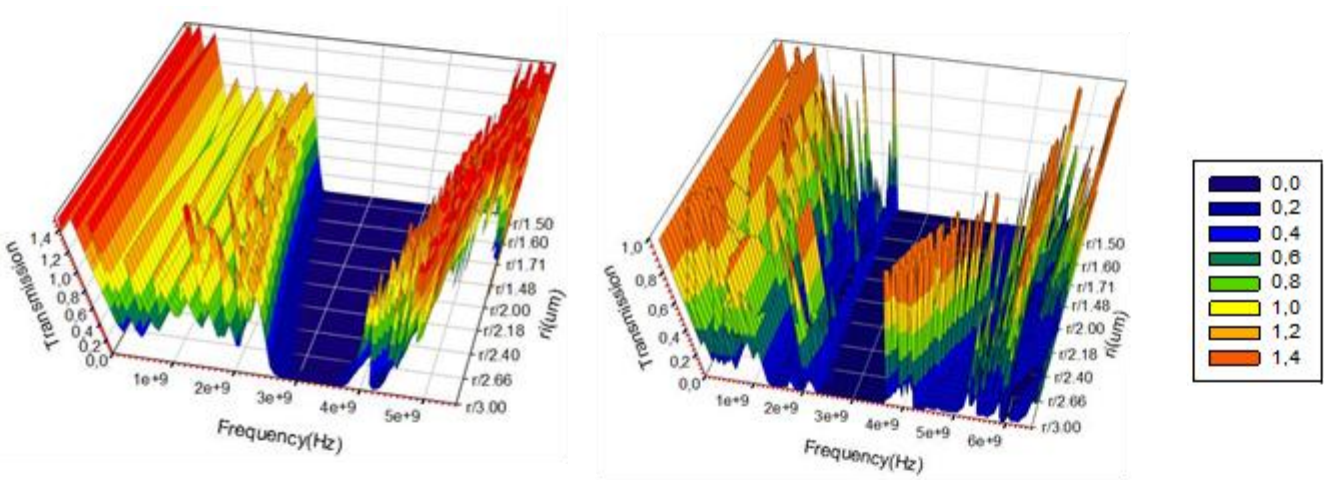


Figure 2. Diagram of a phononic crystal of finite dimension for the calculation of transmission curves.

Figure 2 shows the mechanism of calculation of the transmission in the phononic crystal; the diagram shows two homogeneous zones, an excitation zone located before the crystal is from which a progressive acoustic wave is launched. The x-direction corresponds to the wave propagation direction. A detection zone located after the crystal and where the displacement field is collected as a function of time. The boundary conditions applied in the system are *PML* in the x-direction and periodic boundary conditions in the y-direction. Figure. 3 shows a 3D representation of the transmission curves and which effectively explains the behavior of the band gap with the variation of the internal radius *ri* for the two symmetrical (longitudinal wave) and asymmetric (transverse wave) excitations.



Citation: Mohamed Lamine Bouchemal *et al.*, Cavity modes Investigation in phononic crystal. Australian Journal of Basic and Applied Sciences, 13(7): 42-48.
DOI: 10.22587/ajbas.2019.13.7.7

Figure 3. 3D phononic transmission curves according to the variation of the internal radius *ri* a) symmetric excitation b) asymmetric excitation.

We note from the first moment that the variation of the band gap (*blue color*) is progressive according to *ri:* widths of the narrow band gap are associated with the low values of the ray *ri* and a wide band for higher values of *ri*. The variation of the band gap appears the same for both excitations, we can detail this variation by sampling at *ri* values and plotting the transmission curves associated, as it is defined in Figure 4.

The figure shows transmission curves of different symmetric and asymmetric excitations, and the variation of the apertures of the band gap according to the internal radius *ri* is similar compared to the method of the dispersions curves used before. This figure shows that for each value of *ri*, there are two different bands gap which are bands associated to symmetric and asymmetric excitations

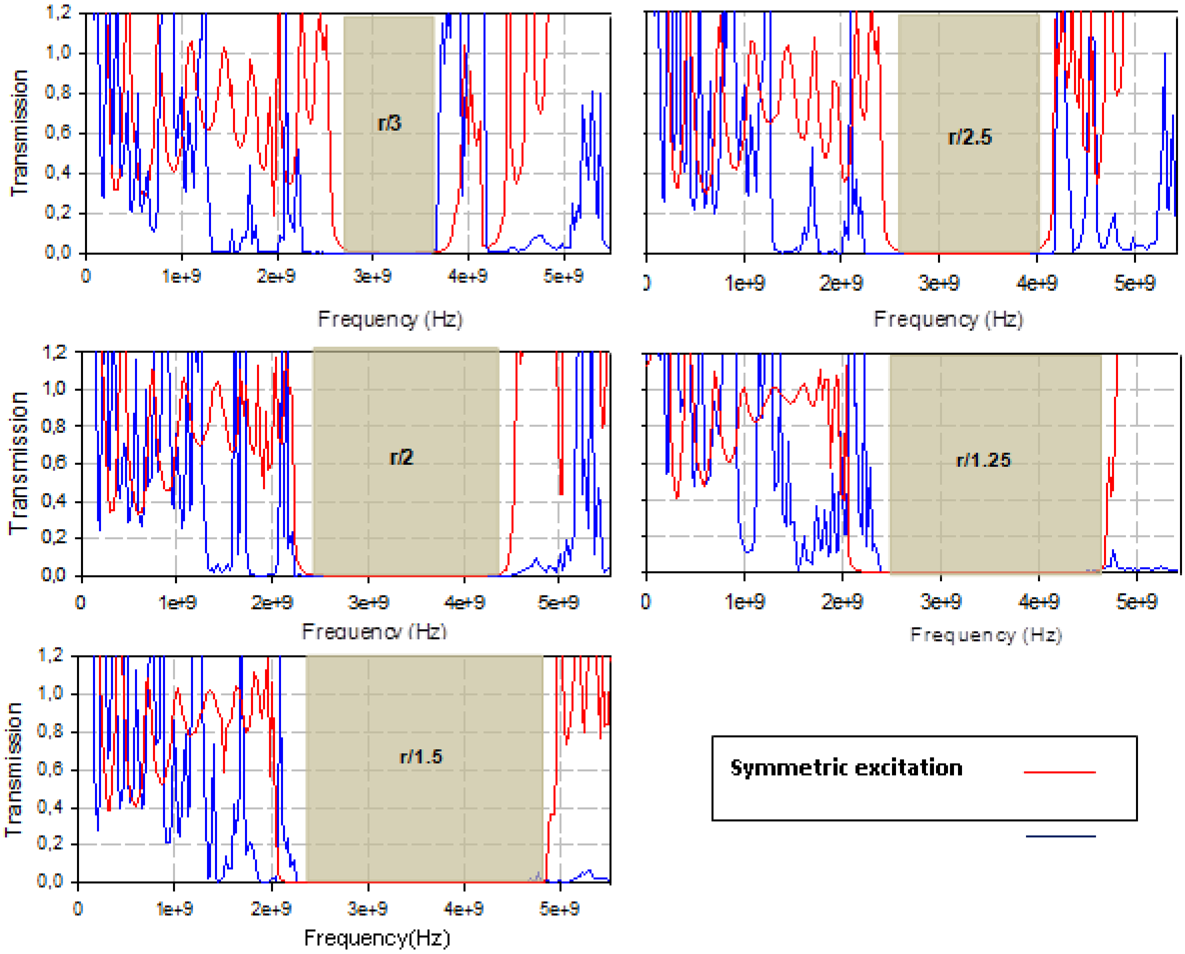


Figure 4. Variation of the phononic transmission curves for the two symmetric and asymmetrical excitations according to the different values of the internal radius *ri*.

The variation of the internal radius *ri* shows a superposition of the symmetric and asymmetric bands gap progressively. This property shows that the structure has the same band gap regardless of the excitation nature. This is beneficial for some applications such as phonic filtering.

THE PHONONIC MODES IN A CAVITY

The introduction of a cavity inside the perfect crystal is done by filling a silicon-air hole figure. 1. b, (p, p') is the symmetry planes of the cavity, the calculation of the transmission curves of the structure containing the cavity is carried in the same way of the preceding structure. The study of the transmission will enable us to investigate the phononic modes, their appearance in the band gap for symmetric or asymmetric excitation. This study is important for choosing the polarization of the elastic wave for the associated internal radius. Figure 5 shows a 3D representation of the phononic band gap a) symmetric excitation, b) asymmetric excitation) and has peaks inside that represent phononic modes for both excitations.

Citation: Mohamed Lamine Bouchemal *et al.*, Cavity modes Investigation in phononic crystal. Australian Journal of Basic and Applied Sciences, 13(7): 42-48.
DOI: 10.22587/ajbas.2019.13.7.7

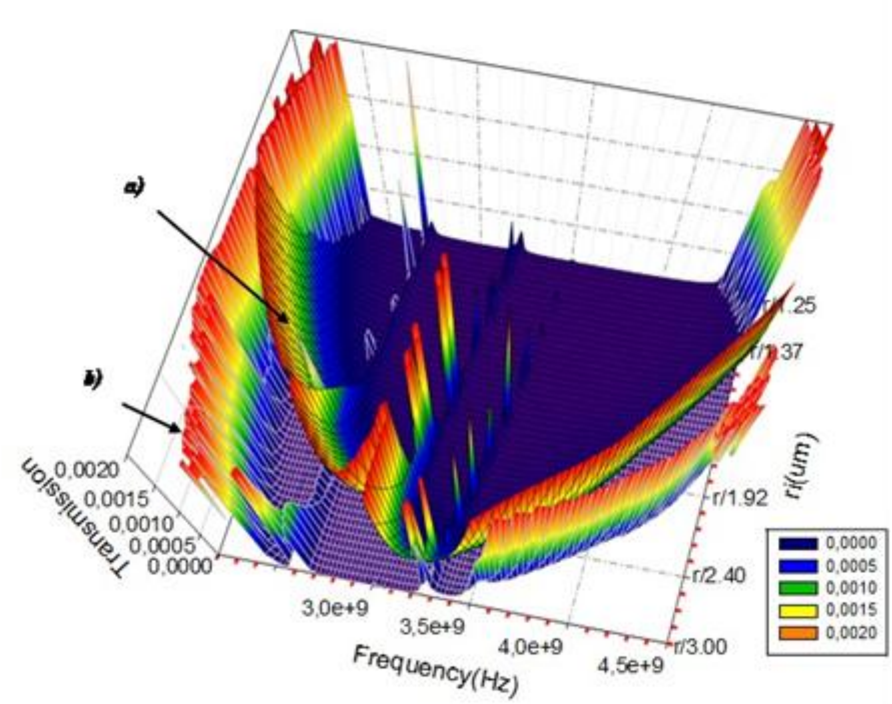


Figure 5. Investigation of phononic modes in the phononic cavity associated with a) Symmetric excitation, b) Asymmetric excitation.

Figure 5 shows a 3D representation of the phononic band gaps a) symmetric excitation, b) asymmetric excitation and has peaks inside that represent phononic modes for both excitations. By making a section of the 3D curve of Figure 5 for the value of the radius *ri = r / 2* as an example, we obtain in detail the phononic modes associated with each excitation figure 6, this figure clearly shows that the appearance of a phononic mode is related to the nature of the polarization of the elastic wave.

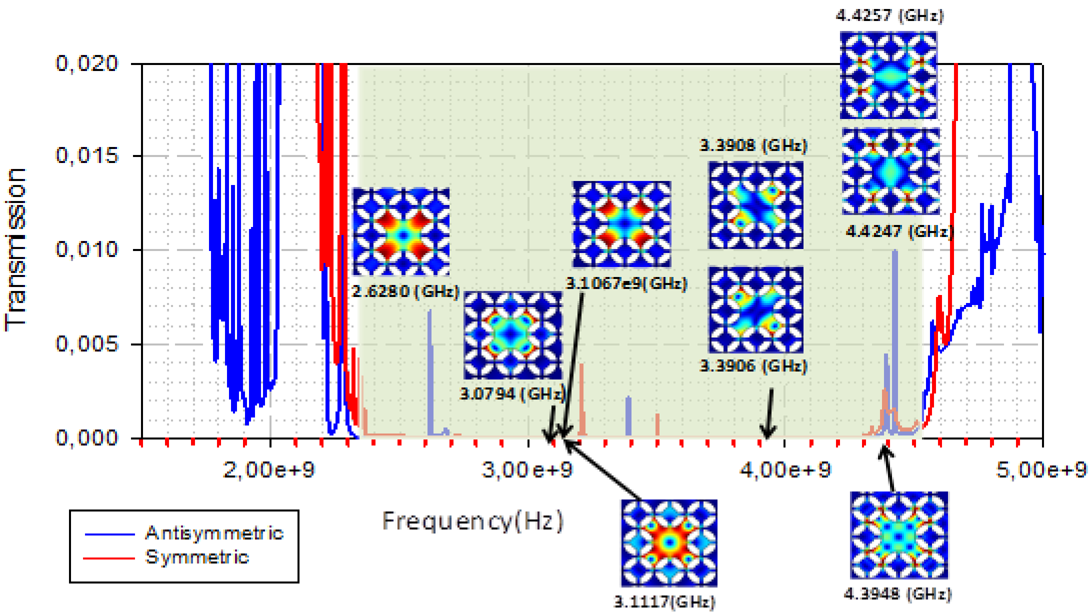


Figure 6. Phononic transmission curves for *ri = r / 2* with both polarizations, the hatched area represents the forbidden band, within the peaks associated with the resonance modes of the phononic cavity.

Figure 7 shows transmission curves of the phononic modes for the value *ri = r / 2*. This representation shows that there are modes that appear in both symmetric and asymmetric excitations.

This means for both polarizations with the same resonant frequency as the modes 1,2,3,4 and 5. There are modes that appear for a single polarization as the case of mode 7 and 8 results of the asymmetric excitation, modes 6 and 9 results from symmetric excitation. So, the choice of polarization is important to choose the targeted mode.

Citation: Mohamed Lamine Bouchemal *et al.*, Cavity modes Investigation in phononic crystal. Australian Journal of Basic and Applied Sciences, 13(7): 42-48.
DOI: 10.22587/ajbas.2019.13.7.7

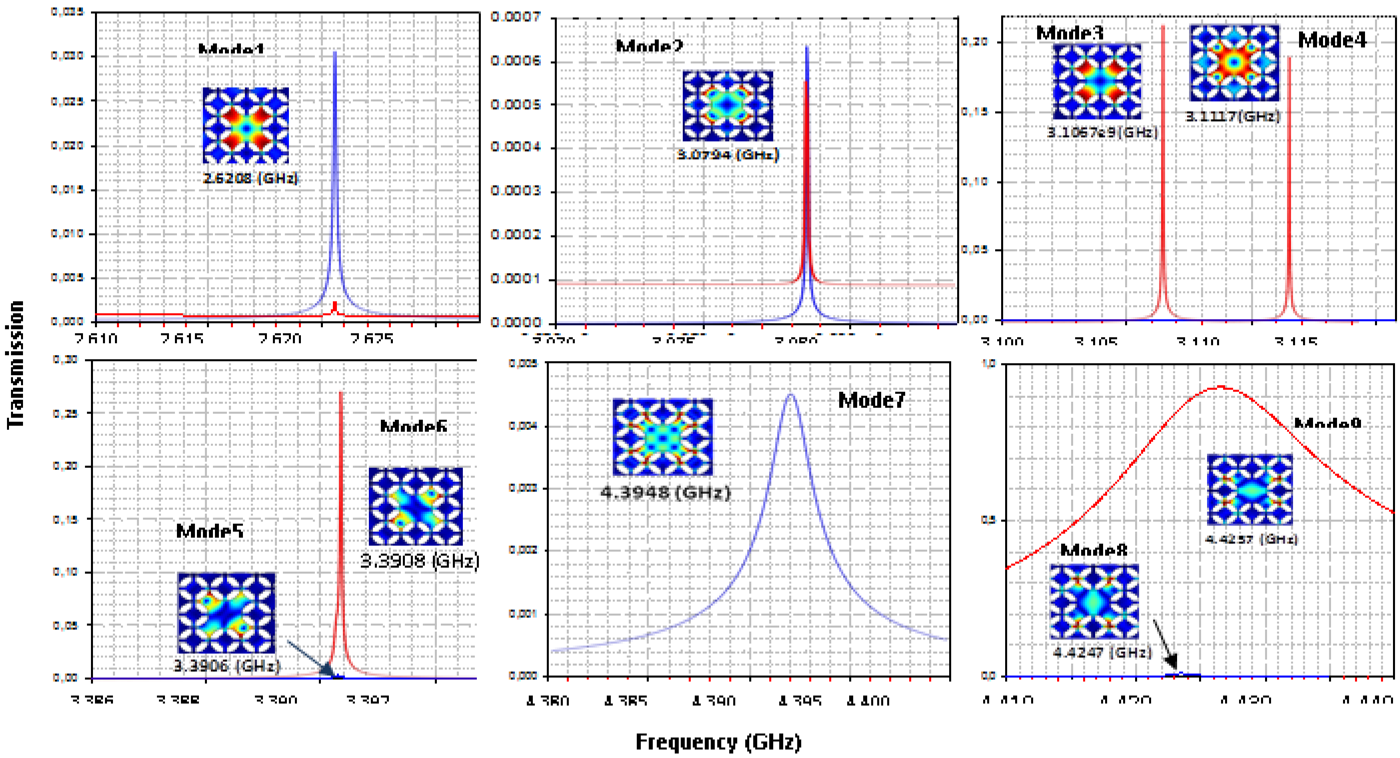


Figure 7. Transmission curves of the phononic modes for *ri* = *r* / 2 with the two polarizations.

Figure 8 shows a clear presentation of the phononic modes for the different values of *ri*. This figure shows that the presence of the mode for certain polarizations (symmetrical or asymmetric) is related to the value of the ray *ri* (There are modes which change their appearances, once in symmetrical excitation and another time in asymmetric and other both times at the same time).

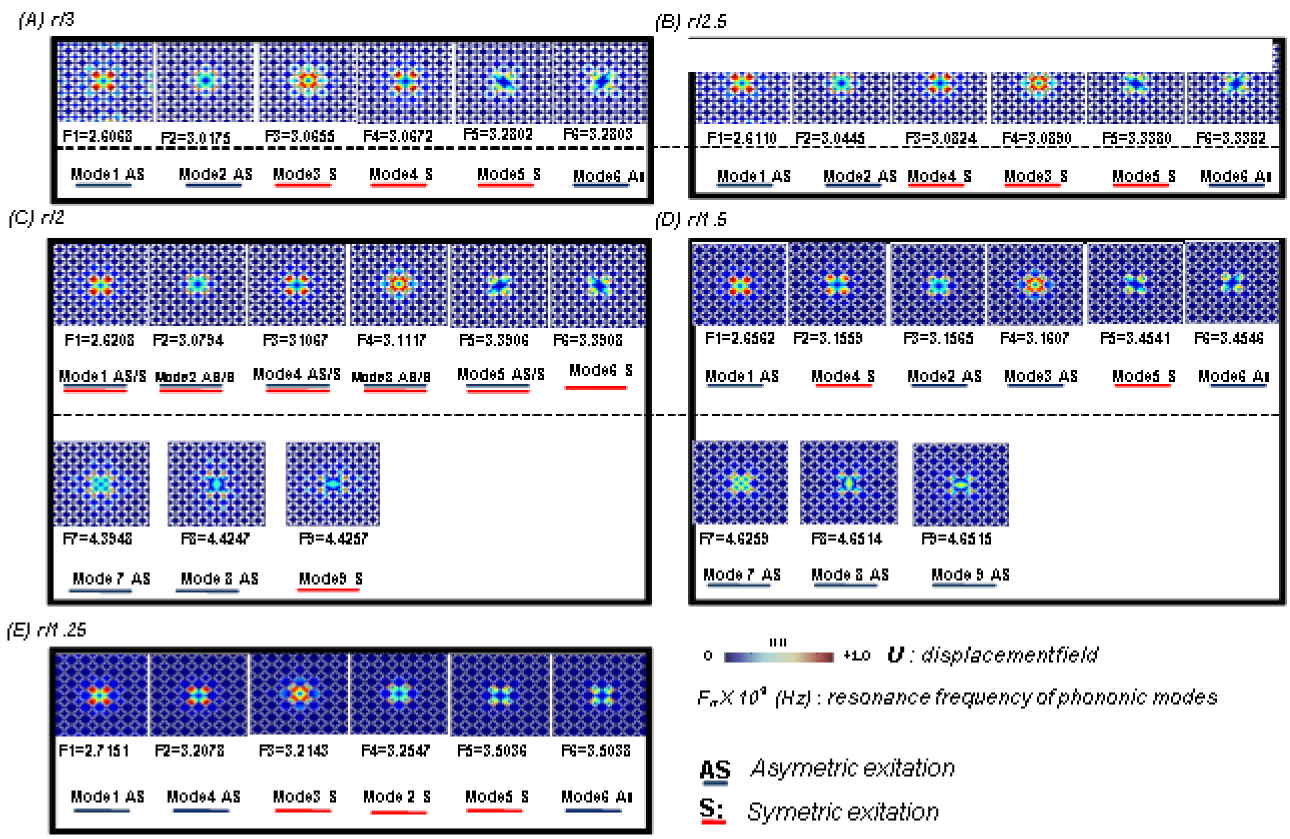


Figure 7. Transmission curves of the phononic modes for *ri* = *r* / 2 with the two polarizations.

Citation: Mohamed Lamine Bouchemal *et al.*, Cavity modes Investigation in phononic crystal. Australian Journal of Basic and Applied Sciences, 13(7): 42-48.
DOI: 10.22587/ajbas.2019.13.7.7

CALCULATION OF DEFORMATION

Figure. 9 shows the normalized displacement curves (*∫u ds*) of the phononic cavity in the absence of the disc (*reference case*) and the presence of disc (*according to the internal radius ri*) for the two phononic modes (Mode 1 and 3) symmetrical with respect to in the plane (*p, p'*) of the cavity.

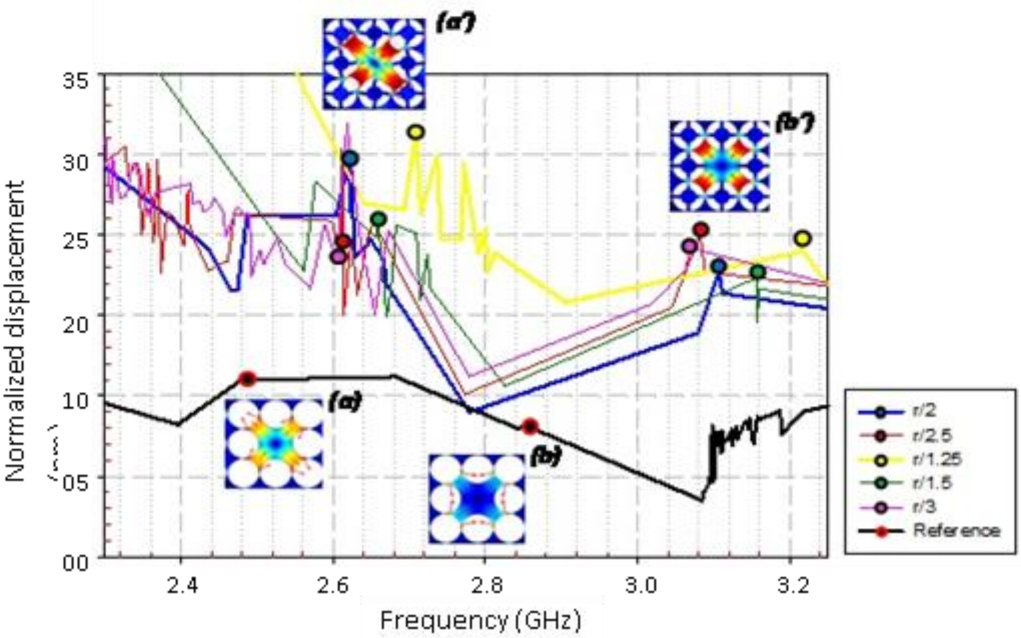


Figure 9. Representation of the normalized deformations in Picometer (*pm*) for Mode 1 and 3 in the absence of the disc (a and b) and presence of the disc (a' and b') respectively.

The representation of the cavity deformations for the reference crystal shows a slight increase from the frequency 2.4 GHz, then stability up to the value 2.7GHz, beyond this frequency, an interesting decrease in the value of the displacement. For the case where the disk is inserted inside the air holes, the values of the displacements are generally more important and different from one ray to another. For *ri = r / 3*, *r / 2.5*, *r / 2* and *ri = r / 1.5* the displacements are very close, a strong decrease starting from the frequency 2.65 GHz where we observe an equality of displacement between the reference case and the presence of the disk case for the radius *ri = r / 2* at the frequency 2.77 GHz.

For *ri = r / 1.25*, we obtain the most important displacement values, beyond the 2.8GHz frequency, a slight decrease by comparing with the other values of the internal radius *ri*. The increase of the cavity deformations increases the displacement of the air / solid interfaces; the intensity of the displacements is related to the nature of the movements of the phononic modes confined in the cavity. The values of the mode 1 displacements in the absence of the disk (a) and the presence of the disk (a ') with a value of (12 and 30) *Pm* respectively, for the mode 3, in the absence of the disk (b) and the presence of the disk (b ') with a value of (7 and 25) *Pm*. From these values of the normalized displacements associated with the phononic mode localized in the cavity, we obtain that in the presence of the disk we will have a multiplication of two to three of the value of the displacement concerning the reference crystal.

CONCLUSION

In this work, we show that a large band gap is obtained by optimizing the geometry of a phononic crystal. The simulation of the band gap according to the geometrical parameters using *COMSOL MULTIPHYSICS* software based on the finite element method. We calculate the width of the band gap by using the transmission curves according to the variation of the internal radius *ri* and according to the different excitations (Symmetric and Asymmetric) of the incident elastic wave where the superimposition of the band gap was observed symmetric and asymmetric for the internal radius *ri = r / 2*. Also, we also study the cavity by studying the phononic modes and by exploiting the transmission curves. The transmission study allows the choice of the nature of the elastic wave excitation (Symmetric or Antisymmetric) to obtain the desired phononic mode associated with the value of the internal radius *ri*. In addition, we have been able to conclude that for the value *ri = r / 2* the appearance of the phononic modes does not depend on the excitations symmetric or asymmetric.

REFERENCES

Akimov, A.V., Tanaka, Y., Pevtsov, A.B., Kaplan, S.F., Golubev, V.G., Tamura, S., Yakovlev, D.R., and Bayer, M. 2008. Hypersonic modulation of light in three-dimensional photonic and phononic band-gap materials. *Physical Review Letters* 101, 033902.

Bergamini, A., Delpero, T., Simoni, L.D., Lillo, L.D., Ruzzene, M., and Ermanni, P. 2014. Phononic crystal with adaptive connectivity. *Advanced Materials* 26, 1343–1347.

Capdeville, Y., Zhao, M., and Cupillard, P. 2015. Fast Fourier homogenization for elastic wave propagation in complex media. *Wave Motion* 54, 170–186.

Certon, D., Patat, F., Levassort, F., Feuillard, G., and Karlsson, B. 1997. Lateral resonances in 1–3 piezoelectric periodic composite: Modeling and experimental results. *The Journal of the Acoustical Society of America* 101, 2043–2051.

Eichenfield, M., Camacho, R., Chan, J., Vahala, K.J., and Painter, O. 2009a. A picogram-and nanometre-scale photonic-crystal optomechanical cavity. *Nature* 459, 550.

Eichenfield, M., Chan, J., Safavi-Naeini, A.H., Vahala, K.J., and Painter, O. 2009b. Modeling dispersive coupling and losses of localized optical and mechanical modes in optomechanical crystals. *Optics Express* 17, 20078–20098.

Gedge, M., and Hill, M. 2012. Acoustofluidics 17: Theory and applications of surface acoustic wave devices for particle manipulation. *Lab on a Chip* 12, 2998–3007.

He, Y., Wu, F., Yao, Y., Zhang, X., Mu, Z., Yan, S., and Cheng, C. 2013. Effect of defect configuration on the localization of phonons in two-dimensional phononic crystals. *Physics Letters* A 377, 889–894.

Hou, T.Y., and Wu, X.-H. 1997. A multiscale finite element method for elliptic problems in composite materials and porous media. *Journal of Computational Physics* 134, 169–189.

Jin, Y., Torrent, D., Pennec, Y., Pan, Y., and Djafari-Rouhani, B. 2015. Simultaneous control of the S 0 and A 0 Lamb modes by graded phononic crystal plates. *Journal of Applied Physics* 117, 244904.

Mohammadi, S., Eftekhar, A.A., Khelif, A., Hunt, W.D., and Adibi, A. 2008. Evidence of large high frequency complete phononic band gaps in silicon phononic crystal plates. *Applied Physics Letters* 92, 221905.

Reinhardt, A., Parat, G., Defaÿ, E., Aïd, M., and Domingue, F. 2010. Acoustic technologies for advanced RF architectures. In Proceedings of the 8th IEEE International NEWCAS Conference 2010, *(IEEE)*, pp. 161–164.

Sadat-Saleh, S., Benchabane, S., Baida, F.I., Bernal, M.-P., and Laude, V. 2009. Tailoring simultaneous photonic and phononic band gaps. *Journal of Applied Physics* 106, 074912.

Trigo, M., Bruchhausen, A., Fainstein, A., Jusserand, B., and Thierry-Mieg, V. 2002. Confinement of acoustical vibrations in a semiconductor planar phonon cavity. *Physical Review Letters* 89, 227402.

Wang, P., Shim, J., and Bertoldi, K. 2013. Effects of geometric and material nonlinearities on tunable band gaps and low-frequency directionality of phononic crystals. *Physical Review* B 88, 014304.

Wang, P., Yi, Q., Zhao, C., Xing, M., and Tang, J. 2017. Wave propagation in periodic track structures: band-gap behaviours and formation mechanisms. *Archive of Applied Mechanics* 87, 503–519.

Zhang, M., Zhong, W., and Zhang, X. 2012. Defect-free localized modes and coupled-resonator acoustic waveguides constructed in two-dimensional phononic quasicrystals. *Journal of Applied Physics* 111, 104314.