PHONONICS 2015: 3rd International Conference on Phononic Crystals/Metamaterials, Phonon Transport and Phonon Coupling

Paris, France, May 31-June 5, 2015

PHONONICS-2015-0380

Ultra-wide acoustic band gaps in silicon-tungsten based phononic crystal strips

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Abstract: The methodology to achieve ultra-wide band gaps with phononic crystal strips is described. One-dimensional silicon based structures with tungsten pillars are used. The influence of geometric parameters on band gaps is studied with the finite element method, leading to a structure with a relative bandwidth close to 90%.

One-dimensional phononic crystals (PC strips) have not received much attention compared to PC in two dimensions. Applications mainly focus on micromechanical resonators using PC strips as anchors[1,2]. Indeed, the achievement of full band gaps in PC strips allows the reduction of resonators' support loss and thus the improvement of their quality factors. As wider band gaps generally mean better performances, many studies try to enlarge the band gaps of strips. For instance, Hsu *et al.* demonstrated the possibility to achieve a band gap with a relative bandwidth of 14.3%, using strips cut from a silicon PC plate with square lattice vacuum cylindrical holes[3]; Yao *et al.* studied the influence of the geometrical parameters on the Lamb wave band gap of an epoxy strip with periodic soft rubber attached[4]; Li *et al.* computed optimal parameters to get the largest band gap of three typical phononic crystal strips[5]; Feng *et al.* obtained, with proper design, a relative bandwidth of 62% using a silicon based PC strip[6].

In this presentation, we sought to achieve ultra-wide band gaps with structures coupling silicon and tungsten. The first structure consists of a silicon strip with periodic tungsten cylinder pillars as shown in Figure 1(a). The lattice constant along the x axis is denoted by a; h_{Si} is defined as the thickness of the silicon plate; b the width of the silicon part of the strip; h_W is the thickness of the tungsten pillar and r_W the radius. The band structure of the strip was calculated using the finite element method (with the commercial software Comsol Multiphysics). Assuming the structure is infinite along the x axis, the numerical study was restrained on a single cell with Bloch-Floquet boundary conditions on the two sides normal to the direction of wave's propagation. The other sides were set as free boundary conditions.

The band diagram of the first PC strip - normalized frequency ($F \times a$ [Hz.m]) as a function of reduced wavevector ($k_x a/2\pi$) - is represented in Figure 1(b). The tungsten pillars induce several full band gaps and the widest band gap has a relative bandwith of 45.0%. In order to widen the band gap, the modes were studied and we found out that, for modes 7, 9 and 10, all the displacements were localized in the corners of the unit-cell as shown in Figure 2. The total displacements of the unit-cells are given for a reduced wavevector $ka/2\pi$ = 0.5. Thus, the displacements of the Bloch-Floquet's boundaries are in opposite phase.

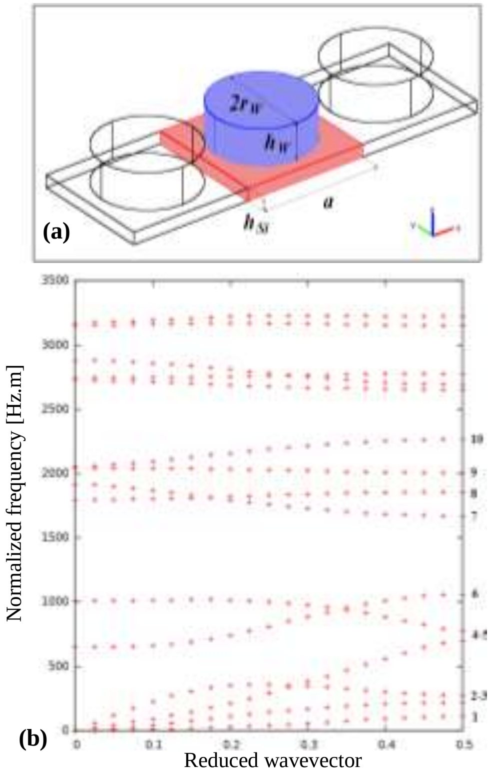

Figure 1 (a) Schematics of the first PC strip. Unit-cell with geometric parameters (blue: tungsten, red: silicon). **(b)** Band diagram of the first PC strip with b/a = 1, h_{Si}/a = 0.1, r_W/a = 0.4 and h_W/a = 0.3.

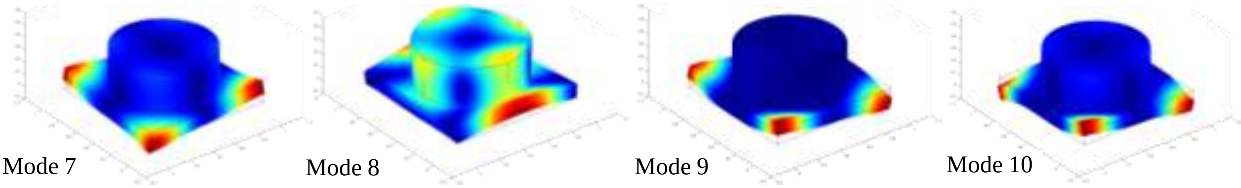

Figure 2 Total displacements of the unit-cell of the first PC strip for modes 7 to 10.

In order to obtain wider band gaps, we removed material where the energy was localized in the previously described modes. The second PC strip, as shown in Figure 3(a), is similar to the first one, except for the holes of radius r_{Si}/a = 0.2 located at the corners of the unit-cell. Using the same parameters, we obtained the band diagram of Figure 3(b). One can observe that previous modes 7-10 are reduced to two flattened modes between $F \times a$ = 1825.5 and 1896.8 Hz.m. The widest band gap has a relative bandwidth equal to 62.3%.

The band gap in this structure can be increased by modifying the height of the tungsten pillar, which enables rising up the frequency band of the two flatten modes. With h_W/a = 0.6, the bandwidth is maximum with a normalized mid-frequency of 1500.0 Hz.m and a relative bandwidth of 89.7%, which constitutes to the authors' knowledge the state of the art for full band gaps in phononic strips.

The propagation of elastic waves through phononic strip was studied with the finite element method. Phononic band gaps were achieved using silicon strip with periodic tungsten pillars. The study of the localization of the modes' energy enabled the design of a second structure, leading to an ultra-wide band gap with a relative bandwidth of 89.7%. These phononic strips can be produced with standard microelectronics techniques for various applications such as wave filtering or energy confinement for MEMS and electronic devices.

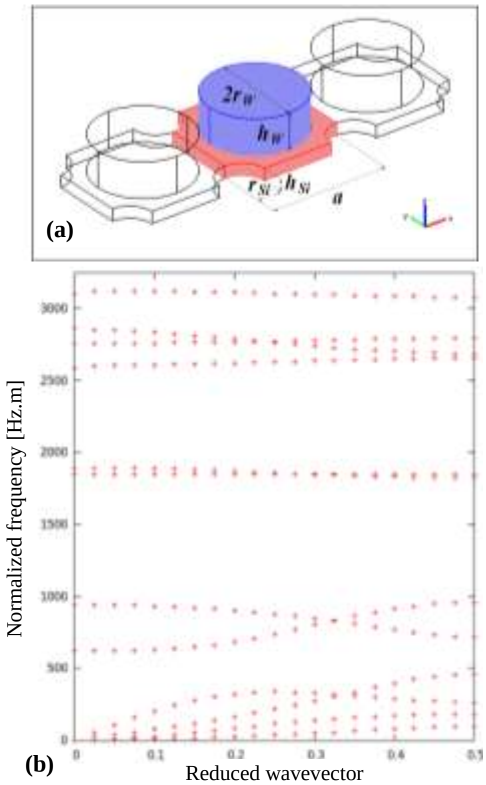

Figure 3 (a) Schematics of the second PC strip. Unit-cell with geometric parameters (blue: tungsten, red: silicon). **(b)** Band diagram of the second PC strip with b/a = 1, h_{Si}/a = 0.1, r_{Si}/a = 0.2 r_W/a = 0.4 and h_W/a = 0.3.

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