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Diffusion of Sound Waves by Sonic Crystals

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Abstract: In this work we report the diffusion of acoustic waves by sonic crystals. We study different configurations of a sonic crystal formed by squared rods in a squared lattice with a finite rigid backing. Several resonances appear related with Fabry-Pérot resonances, the existence of band gaps and the character of diffraction grating of the interface of the crystal.

An extensive literature exists about the transmission properties of phononic crystals, i.e., periodic distribution of scatterers, characterized by the lattice constant *a*, whose physical properties (i.e., elasticity and density) differ from those of the host medium where they are embedded. The result is a periodic modulation of the acoustic properties of the medium at the scale of wavelength. When the host medium is a fluid, they are called Sonic Crystals (SC).

Recently it has been paid attention about how sonic crystals reflect waves[1,2,3]. When an acoustic wave impinges a sonic crystal, the interface between the crystal and the surrounding medium behaves as a diffraction grating but with the particularity that, behind this diffraction grating the wave does not find a homogeneous medium but a periodic medium. The particular dispersion properties of such medium, explicitly given by the band structures, can affect the reflection at the interface. This problem has been studied[1], obtaining that the diffraction on the external surface of a sonic crystal is highly frequency-dependent and has a relation with the Bloch modes[1]. The intensity of the diffraction orders appears influenced because the presence of band gaps. This opens the possibility to combine the knowledge on diffraction gratings and that of the dispersion properties of sonic crystals to have a better control of the reflected waves in such interfaces[2,3].

On the other hand, the theory of sound diffusers is known for a very long time. A sound diffuser is a device that reflects the sound in several directions, i.e. the system diffuses the sound. Sound diffusers provide both spatial and time spreading of the reflected waves[4]. Recently the behaviour as a diffuser of a biperiodic structure based on sonic crystal has been studied[5]. Authors found that designs based on sonic crystal can have a good behaviour as sound diffusers with an important increase in diffusion at low frequencies. Moreover time spreading, provided by sonic crystals is larger than that produced by conventional sound diffusers.

Is in this framework we have extended the study of the performance of sonic crystals as diffusers. Here the sonic crystals have a flat rigid backing placed to certain distance from the end of the crystal, forming a cavity. In certain sense, a similar problem has been previously studied proposing the use of a subwavelength diffraction grating to design open cavities for electromagnetic waves, replacing one of the walls of a cavity by a grating[6].

For characterizing the behaviour of the SC we are going to use the directional diffusion coefficient that is derived from measurements over a semi-circumference surrounding the sample in the far-field conditions, using the following equation:

$$d = \frac{\left(\sum_{i=1}^{n} 10^{SIL_i/10}\right)^2 - \sum_{i=1}^{n} (10^{SIL_i/10})^2}{(n-1)\sum_{i=1}^{n} (10^{SIL_i/10})^2} \qquad (1)$$

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where d is the diffusion coefficient, SIL_i is the is the Sound Intensity Level[4] of the reflected sound at the i-th measurement position, and n is the number of measurement positions. We will use the normalized diffusion coefficient, d_n, that gives the diffusion coefficient of the structure normalized with respect to the rigid flat backing

$$d_n = \frac{d - d_{ref}}{1 - d_{ref}} \tag{2}$$

where d_{ref} is the diffusion coefficient for the rigid backing, calculated both from Eq. (1). The coefficient d_n gives the diffusion coefficient of the structure with respect to a perfectly reflecting flat backing. We are going to considere a sonic crystal formed by squared rods with a side length of 0.7a, being a=0.22m the lattice constant and having 17 columns and different number of rows. The width of the finite rigid backing is the same as that of the SC. Figures 1 (a)-(e) show the scattered far fields of the structures made from 1 to 5 rows over a rigid flat backing placed a distance h=a/2 from the last row of the crystal. In Figures 2 (a)-(d) we show the diffusion coefficient for the cases of a sonic crystal made of 2, 3, 4 and 5 rows respectively. In each plot we evaluate the diffusion coefficient for different distances of the end of the crystal to a rigid flat backing.

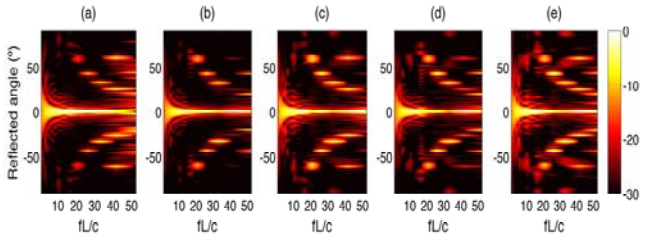


Figure 1. Scattering by a periodic structure over a rigid flat backing. (a)-(e) show the scattered far field for the structures made of 1 to 5 rows respectively

As a general description of all the spectra, at low frequencies (lower than 600 Hz) we are in the homogenization regime and the crystal behaves as an effective medium. The Fabry-Pérot resonances are excited in the system but the presence of the rigid flat backing constrains them to the symmetric ones with respect to the backing. Around 1000 Hz appears a peak of diffusion, which is present for all of them and corresponds to the Band gap of the structure. Finally, around 1700 Hz, we observe a peak of the diffusion related with the periodicity of the first row, i.e., with the diffraction orders due to the grating that represents the interface between the air and the sonic crystal. In Figures 1(a)-(d) we can observe that as we increase the distance h the effect of the periodicity is enhanced and the diffusion coefficient increases in both ranges, at frequencies related with the Band Gap of the periodic structures and at frequencies related with the diffraction at the surface. At low frequencies, the cavity formed between the rigid flat backing and the crystal modifies the frequencies of the Fabry-Pérot resonances because it modifies the effective width of the structures.

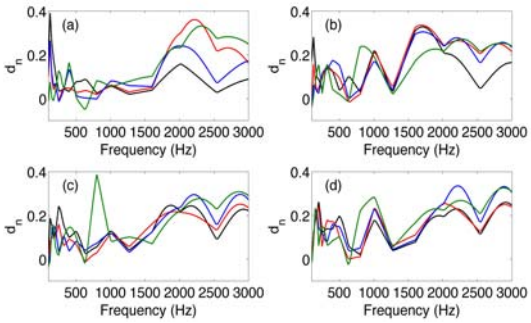


Figure 2. (a)-(d) show the normalized diffusion coefficient of a periodic structure made of 2, 3, 4 and 5 rows by 17 columns. In each plot for distances between the crystal and the rigid flat backing are analyzed: black line, h = $3a/2$; red line, h = $5a/2$; blue line, h = $7a/2$; and green line, h = $9a/2$.

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