Efficient Second Harmonic Generation of Narrow Beams in 2D Sonic Crystals

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Abstract

Sonic crystals (SC) are periodic media that present spatial dispersion. In this work we present a detailed analysis of the efficiency of the second harmonic generation of narrow beams in 2D SC with quadratic nonlinearity. We establish the conditions for that based on self-collimation, phase matching and nonlinear coupling for both the 1st harmonic (FW) and the second harmonic (SH) and its relation with the crystal parameters. The numerical simulations by the nonlinear FDTD method of the proposed structure with tuned parameters show the high conversion efficiency of the second harmonic, as well as the possibility to generate narrow beams of second harmonics and enhancement of sound control.

I. Nonlinear sound beam propagation model

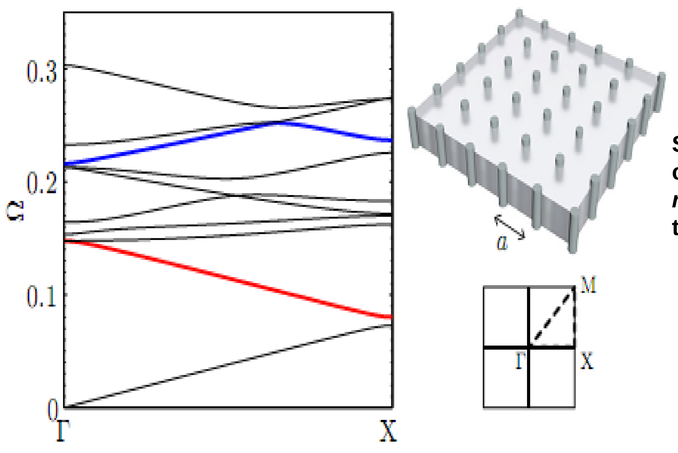
$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathbf{v}) \qquad \text{Mass conservation}$$

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p \qquad \text{Momentum conservation}$$

$$p = c_0^2 \rho + \frac{c_0^2}{\rho_0} \frac{B}{2A} \rho^2 \qquad \text{State equation}$$

p: acoustical pressure, ρ: total density field, ρ_0 : ambient fluid density, B/A: Nonlinearity parameter of host fluid, c_0: sound speed in the fluid.

II. Sonic crystal model: dispersion relation



Square lattice of rigid cylinders with radius $r = 0.11x\ a$, where a is the lattice constant

Fig.1: Band structure obtained by the PWE method

III. SH generation conditions

Self-collimation

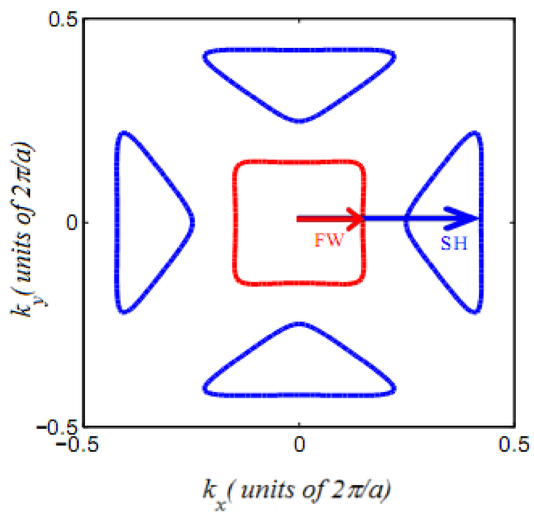


Fig.2: Isofrequency contours for the 2nd (red) and the 8th (bleu) bands

Phase matching

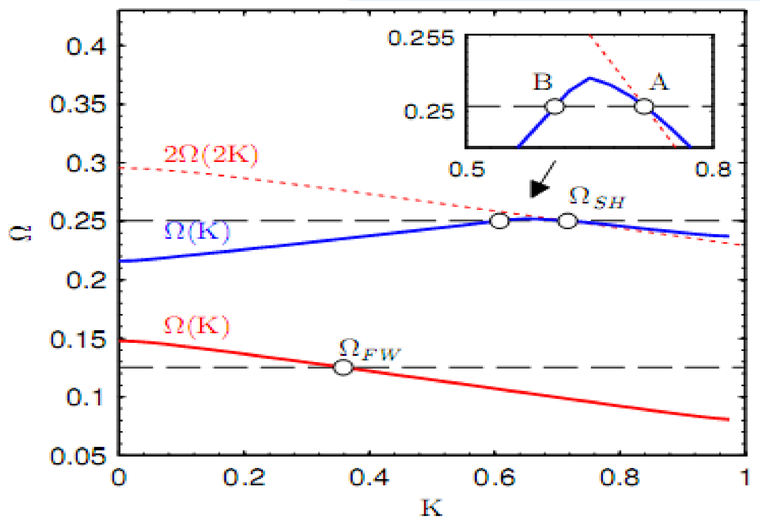


Fig.3: Dispersion curves for simultaneous self-collimation of FW and SH

Nonlinear coupling

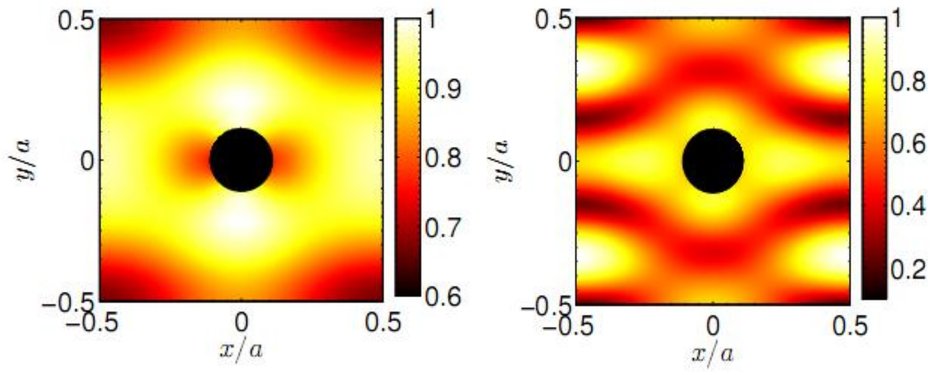


Fig.4:Spatial distribution of the pressure field for the Bloch modes of FW (left) and SH (right). *K = 85%.*

$$\kappa = \frac{\left| \int_M B_1^2 B_2^* \mathrm{d}r \right|}{\sqrt{\int_C |B_1^4| \,\mathrm{d}r \int_C |B_2|^2 \,\mathrm{d}r}}$$

Coupling Coefficient

IV. FDTD numerical simulations

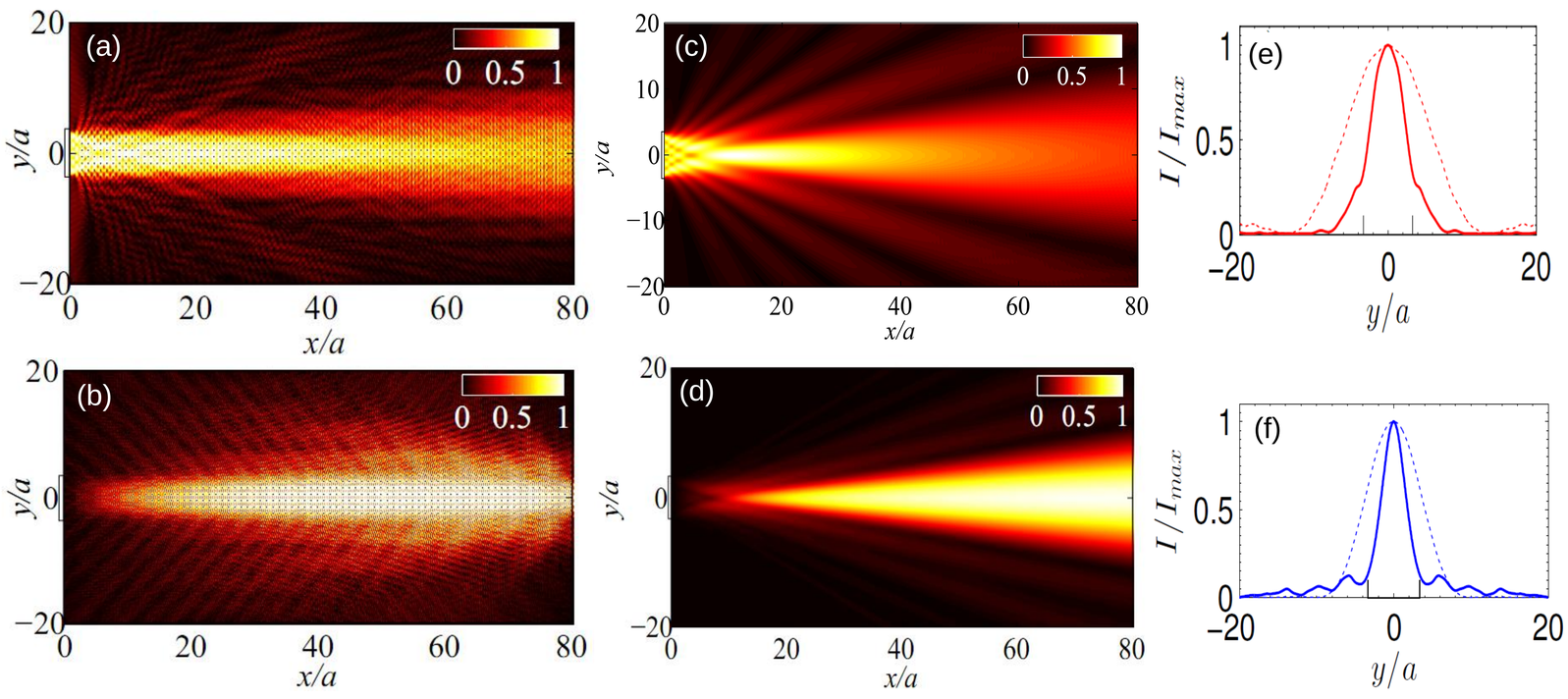


Fig. 5: Pressure distributions obtained by FDTD simulations. *periodicity* = 5.25 mm, *radius* = 0.11 a, frequency = 223 kHz.

(a) and (b) : Beam spatial distribution for simultaneously self-collimated and phase matched FW and SH , respectively, in the sonic crystal	(c) and (d): Beam spatial distribution in homogeneous fluid (water)	(e) and (f): Normalized intensity cross section of FW and SH , respectively, at x = 80*a. Continuous line : propagation in the crystal. Dashed line: propagation in homogeneous fluid.

Conclusion and Remarks

- A periodic structure has been designed and validated to fulfill the three necessary conditions for an efficient SH generation of narrow beams in a 2D SC: 1) self-collimation, 2) phase matching and 3) high spatial coupling of FW and SH fields.
- The sonic crystal parameters can be chosen to fulfill phase matching with the second harmonic, maximizing second harmonic generation due to synchronous cumulative interaction.
- The study show that linear dispersion characteristics can be used to predict the behavior of nonlinear beams propagating in periodic media.
- This opens the possibility of extending the study to other cases of nonlinear propagation of intense acoustic waves.
- Using the strong dispersion properties introduced by the periodicity, sonic crystals structures can be a way to control the sound propagation.
- Future works: crystals with higher filling factors present full frequency bandgaps, that may be used to filter out the propagation of selected higher harmonics.

References

- V. F. Humphrey, Ultrasonics 38, 267 (2000).
- M. F. Hamilton et al., Nonlinear acoustics, Academic Press (1998).
- V. Tournat et al., Europhysics Letters 66, 798 (2004).
- V. Espinosa et al., Physical Review B 76, 140302 (2007).
- E.Soliveres et al., App. Phys. Lett. 99, 151905 (2011).

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