



HAL
open science

Acoustic interaction between 3D fabricated cubic bubbles

Philippe Marmottant, Thomas Combriat, Philippine Rouby-Poizat, Alexander Doinikov, Olivier Stephan, Mariem Boughzala, Benjamin Dollet

► **To cite this version:**

Philippe Marmottant, Thomas Combriat, Philippine Rouby-Poizat, Alexander Doinikov, Olivier Stephan, et al.. Acoustic interaction between 3D fabricated cubic bubbles. Forum Acusticum, Dec 2020, Lyon, France. pp.3461-3462, 10.48465/fa.2020.0181 . hal-03220563

HAL Id: hal-03220563

<https://hal.science/hal-03220563>

Submitted on 9 Jun 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ACOUSTIC INTERACTION BETWEEN 3D FABRICATED CUBIC BUBBLES

Philippe Marmottant¹ Thomas Combriat¹ Philippine Rouby-Poizat¹
Alexander Doinikov¹ Olivier Stephan¹ Mariem Boughzala¹ Benjamin Dollet¹

¹ Laboratoire Interdisciplinaire de Physique, CNRS / Univ. Grenoble-Alpes, France

philippe.marmottant@univ-grenoble-alpes.fr

ABSTRACT

Spherical bubbles are notoriously difficult to hold in specific arrangements in water and tend to dissolve over time. Here, using stereolithographic printing, we built an assembly of millimetric cubic frames overcoming these limitations. Indeed, each of these open frames holds an air bubble when immersed into water, resulting in bubbles that are stable for long times and still able to oscillate acoustically. Several bubbles can be placed in any wanted spatial arrangement thanks to the fabrication process. We show that bubbles are coupled acoustically when disposed along lines, planes or 3D arrangement, and that their collective resonance frequency is shifted to much lower values, especially for 3D arrangements where bubbles have higher number of close neighbours. Considering that these cubic bubbles behave acoustically as spherical bubbles of the same volume, we develop a theory allowing to predict the acoustical emission of any arbitrary group of bubbles, in agreement with experiments.

1. INTRODUCTION

Gas bubbles are good candidates to be sub-wavelength resonators in metamaterials [1, 2]. They feature a remarkable resonance [3], explained by the much greater compressibility the gas they contain compared to the surrounding liquid. Here we introduce gas bubbles trapped in cubic cages [4, 5], that are free to oscillate in water, while maintaining both their position and size.

2. METHODS

We manufacture millimetric cubing frames using stereolithography. Upon immersion bubbles are trapped in the frames by capillary forces, while water invades the space in between the frames, linked by poles forming a scaffold, see Fig. 1. The acoustic response is found by sending waves using an underwater speaker, sweeping frequencies. A signal is recorded by a microphone placed in the vicinity of the assembly, records the acoustic pressure P in the presence and P^0 in the absence of the bubbles. The contribution of the bubble to the spectrum is $A(f) = \frac{\tilde{P} - \tilde{P}^0}{\tilde{P}^0}$ where \tilde{P} and \tilde{P}^0 are the Fourier transforms. We detect resonance frequency by looking at the change of the phase from 0 to π , the resonance being at $\pi/2$, which is more convenient compared to the detection of the peak in amplitude.

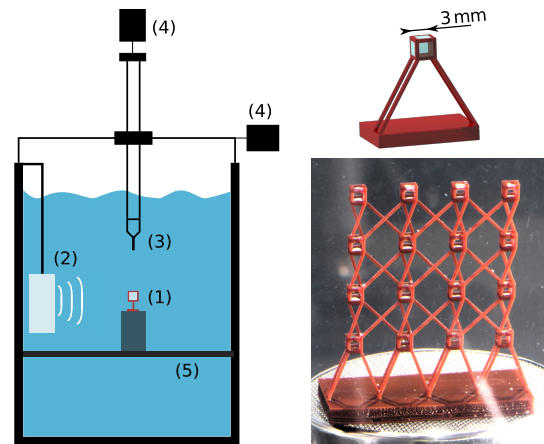


Figure 1. Left: acoustic setup with: (1) the sample, (2) the loudspeaker, (3) the hydrophone and (4) the moving stage. Top right: 3D view of a frame, holding a bubble. Bottom right: photography of a real sample containing a network of 4×4 bubbles.

3. RESULTS

We clearly observe the influence of two bubbles on each other, with a resonance frequency that decreases with the distance decreases, see Fig. 2.

When considering an assembly of many bubbles, the frequency is even more decreased. We have first tested lines, and then matrices of bubbles. The frequency is decreased down to 40% for 6×6 matrices, see Fig. 3.

In finite lines and matrices, bubbles are not identical, since bubbles at the edges have not the same acoustic environment compared to the ones at the center. In order to simplify the physics of the system we found an arrangement with bubbles that are *all* equivalent to each other: rings of bubbles, see Fig. 4.

4. MODEL

We model the behaviour of our cubic bubbles, assuming they behave as spherical bubbles with the same volume. Indeed it was shown that the emitted field by cubic bubbles becomes quasi-spherical very rapidly. The radius of each spherical bubble labeled n oscillates around an equilibrium value R_0 : we write $R_n(t) = R_0 + \xi_n(t)$ with $\xi_n(t)$ the deviation to equilibrium.

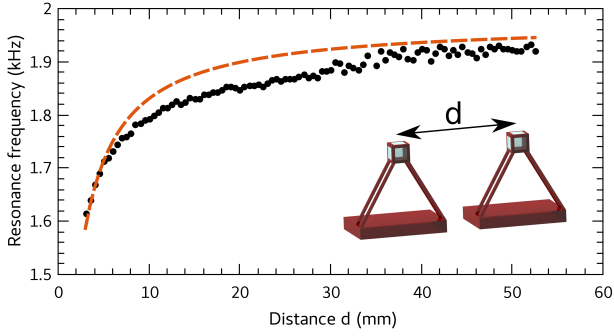


Figure 2. Evolution of the resonance frequency of a group of two bubbles as a function of their spacing d : dots experimental data, orange line: fit using the analytical expression $\omega_0^{\text{ana}} = \omega_0 / \sqrt{1 + \frac{R_0}{d}}$ from Eqn. 2 with $R_0 = 1.65$ mm.

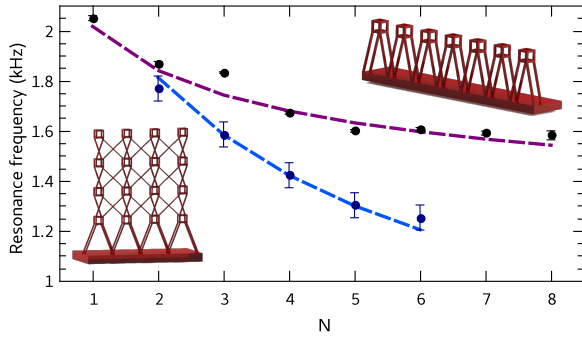


Figure 3. Resonance frequency for lines and matrices with separation $d = 1.8$ mm, as a function of bubbles number. Black and dark blue points are for lines of N bubbles and matrices of $N \times N$ bubbles, respectively. Dashed lines are the numerical resolution of Eqn. 1, taking $R_0 = 1.6$ mm.

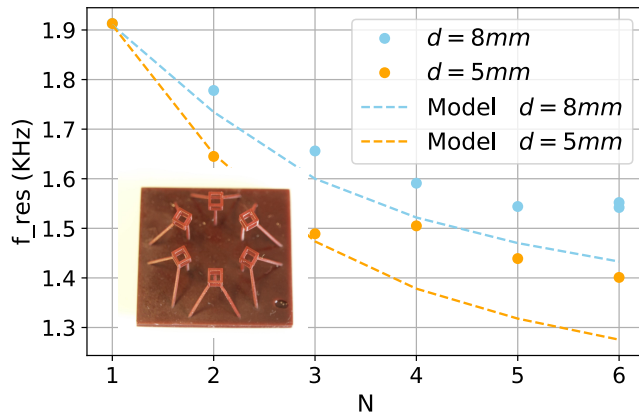


Figure 4. Resonance frequency for a ring of bubbles, for two separation distances. Dashes show predictions using Eqn. 2

It can be shown that each bubble n is equivalent to an harmonic oscillator ruled by:

$$\ddot{\xi}_n + \omega_0 \delta \dot{\xi}_n + \omega_0^2 \xi_n = - \sum_{m \neq n} \frac{R_0}{d_{nm}} \ddot{\xi}_m + \frac{Pa}{\rho_l R_0} e^{i\omega t} \quad (1)$$

where ω_0 is the resonance pulsation, δ ($\simeq 1/20$) the damping factor. The first term on the right hand side is the acoustic coupling with the other neighbour bubbles labeled m , separated by a distance d_{nm} . The last term is the external acoustic forcing. This system can be solved numerically for arbitrary positions of bubbles and provides a first mode where all bubbles oscillate in phase, with a frequency that compares well with experiments.

For the case of a two bubbles or a ring, all bubbles are equivalent and we can have a direct analytical expression of the resonance frequency if we neglect damping:

$$\omega_{\text{res}}^{\text{duo,ring}} = \frac{\omega_0}{\sqrt{1 + \sum_{m \neq n} \frac{R_0}{d_{nm}}}}. \quad (2)$$

5. CONCLUSION AND PERSPECTIVES

Any kind of arrangement of bubbles in space is potentially achieved with the technique of cubic bubbles. Their resonance is well predicted from a model of coupled harmonic oscillators. Perspectives include 3D dispositions of the bubbles. We are also exploring the vibration of non-cubic shapes.

6. REFERENCES

- [1] V. Leroy, A. Strybulevych, M. G. Scanlon, and J. H. Page, "Transmission of ultrasound through a single layer of bubbles," *Eur. Phys. J. E*, vol. 29, pp. 123–130, May 2009.
- [2] V. Leroy, A. Strybulevych, M. Lanoy, F. Lemoult, A. Tourin, and J. H. Page, "Superabsorption of acoustic waves with bubble metascreens," *Phys. Rev. B*, vol. 91, p. 020301, Jan 2015.
- [3] M. Minnaert, "On musical air-bubbles and the sounds of running water," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, vol. 16, no. 104, pp. 235–248, 1933.
- [4] M. Harazi, M. Rupin, O. Stephan, E. Bossy, and P. Marmottant, "Acoustics of cubic bubbles: Six coupled oscillators," *Phys. Rev. Lett.*, vol. 123, p. 254501, Dec 2019.
- [5] T. Combriat, P. Rouby-Poizat, A. A. Doinikov, O. Stephan, and P. Marmottant, "Acoustic interaction between 3d-fabricated cubic bubbles," *Soft Matter*, vol. 16, pp. 2829–2835, 2020.