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A PROTOTYPE FOR VIBRATION ISOLATION AT THE MICROSCALE THROUGH TWO-PHOTON POLYMERIZATION

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Summary The correct functioning of many micro-electromechanical devices requires the isolation from accidental vibration. Metamaterials, presenting band-gaps in the dispersion spectrum, i.e. interval of frequency in which propagating waves are attenuated, can provide an effective solution for isolation at the microscale. In the research work here presented we design, analyse and fabricate a prototype of an isolator made with a metamaterial fabricated through the two-photon polymerization process. The experimental validation is currently under development.

INTRODUCTION

Phononic crystals are periodic structures with properly conceived designs in terms of geometry and elastic properties of the constituent materials, that exhibit exceptional dynamic behaviours, such as frequency bandgaps formation. The presence of bandgaps in these structures, also called metamaterials, makes them very appealing for applications such as vibration shielding at different scales and this demonstrates the increasing interest of the scientific community on the topic. Several examples of macroscale vibration isolators made by phononic crystals are available in the literature [1], no much work has been done so far at the microscale where the complexity of the optimal geometry of the unit cell often makes difficult or impossible the fabrication process.

In the present work, we design through numerical simulations a 3D phononic crystal with a micrometric unit cell able to work as vibration isolator for a micro system. We then exploit the recently developed technique of the two-photon polymerization (2PP) [2, 3] to realize a prototype of the isolated system. Experiments are currently under development.

PHONONIC CRYSTAL: MECHANICAL DESIGN AND SIMULATIONS

The phononic crystal designed in this work is similar to the one proposed in [4]; it is constituted by a periodic repetition of cubic cells with nearly spherical masses suspended by slender beams mutually orthogonal (Figure 1a). This particular arrangement, thanks to an internal resonant mechanism [5], allows obtaining very peculiar dynamic properties (i.e. wide complete bandgap). Two 3D numerical simulations are performed in COMSOL-Multiphysics to demonstrate the dynamic behaviour of the proposed metamaterial and to identify the bandgap frequency interval. In particular, the Bloch-Floquet analysis conducted on the unit cell represented in Figure 1a, shows that the dispersion diagram exhibits very large complete band-gaps: waves of frequencies inside this interval cannot propagate without attenuation. For the case of a cell of 27 μm side, a bandgap from 4.5 MHz and 28 MHz is obtained as shown in Figure 1b.

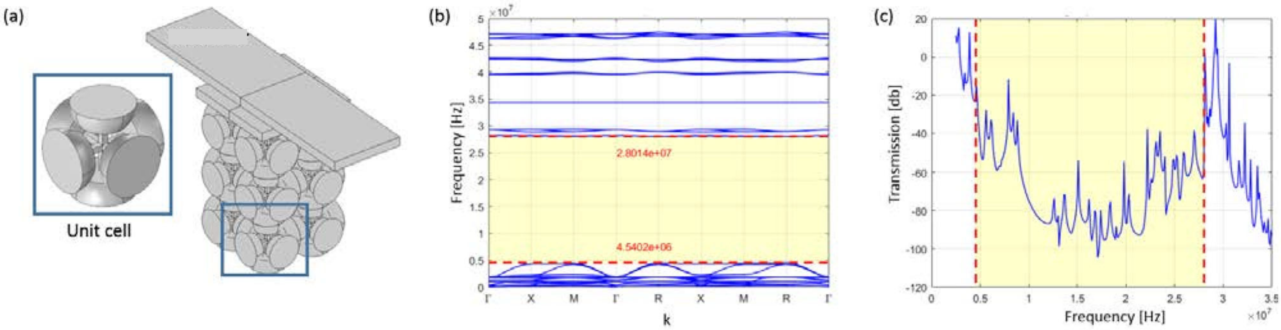

Figure 1. (a) Geometry of the proposed phononic crystal: a close-up view of the unit cell is also shown. (b) Dispersion and (c) transmission diagrams computed in COMSOL-Multiphysics.

In Figure 1c we report the transmission through the system made of the substrate and the 2 x 2 x 3 cells phononic crystal as a function of the frequency of the input waves. A prescribed sinusoidal displacement along the vertical direction is applied on the bottom substrate of the metamaterial and the resultant displacement on the top of the metamaterial is computed to show the attenuation properties of the proposed phononic crystal. From Figure 1c one can observe that, within the bandgap, shaded in the plot, a significant attenuation is obtained with 3 cells only. Note that the transmission diagram is reported only for the vertical direction because of the chosen configuration of the periodic cells (2 x 2 x 3) dictated by the application we want to prove as vibration isolator for the micro-beam.

With the aim of demonstrating the potentiality of this micro-structured material in vibration shielding of micro systems, we consider a beam that can oscillate in bending, and we isolate it from the support through the proposed metamaterial, see Figure 1a. The beam is designed to have the second bending resonant frequency inside the bandgap of the metamaterial.

FABRICATION BY TWO PHOTON POLYMERIZATION

Two-photon polymerization is a direct laser writing technology that allows the fabrication of fully 3D structures with sub-micron resolution. It is a technique based on two processes: two-photon absorption (2PA) and polymerization. The peculiar feature of 2PP with respect to conventional 3D laser printing is the sub-diffraction limit resolution. This feature is obtained thanks to the presence of two competing processes in the focal volume of the laser beam, polymerization and quenching, that tends to stop the polymerization. In fact, only the small region, called voxel, where the density of radicals is higher than a certain threshold value determined by the different quenching channels, is polymerized. The structures fabricated with 2PP strongly depend on the voxel characteristics that in turn depend on many factors, such as wavelength, pulse duration, repetition rate, numerical aperture, laser source polarization, laser power, writing speed and distance between lines.

The photoresist used in this work is called SZ2080 and it is a hybrid organic-inorganic negative sol-gel photoresist specifically developed for 2PP. It is made of two components: methacryloxypropil trimethoxysylane (MAPTMS) and zirconium propoxide (ZPO). A particular photoinitiator, called Irgacure 369 (IRG), is also added to enhance the 2PP effect. Compared to other photoresists, SZ2080 presents excellent mechanical properties [6], it is non-toxic and it shows negligible shrinkage after solvent washing.

To fabricate the structure one has first to prepare a bulky sample by drop-deposition, drop-casting and baking at 105°C, then the complex geometry of the micro-structure is realized within the sample through laser irradiation and finally the development process removes the non-irradiated zones of the drop and makes structures emerge.

In this work, we used a frequency-doubled erbium-doped fiber laser with wavelength of 780 nm, pulse duration of about 100 fs, and repetition rate of 80 MHz. The direct laser fabrication setup used is composed by a laser source, optical and optomechanical components to deliver, control, block, and focus the laser beam, a translation device to move the sample with respect to the laser beam focus, and a machine vision system for real-time monitoring of the fabrication process, as shown in Figure 2a.

Figure 2b shows the SEM image of the fabricated simple microstructure constituted by a beam clamped in the central part to the substrate without the presence of the metamaterial, while Figure 2c shows the prototype for vibration isolation of the micro beam, with a block of 2 x 2 x 3 cells of the metamaterial. The 2PP fabrication technique proved to be suitable to realize the very complex geometry of the metamaterial at the microscale.

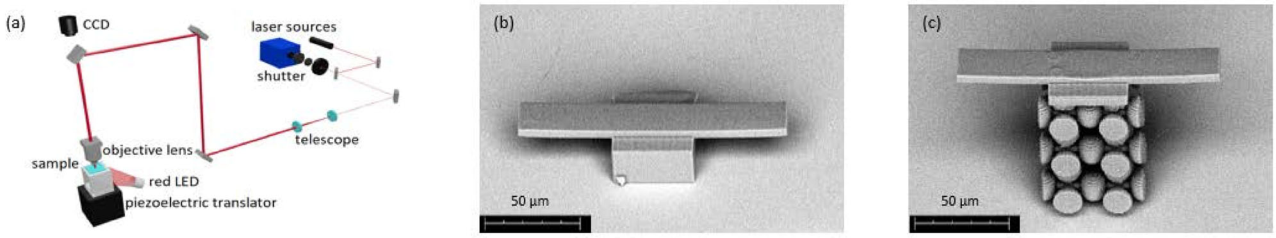

Figure 2. (a) Fabrication set-up. SEM images of the fabricated structures without (b) and with (c) an isolating phononic crystal.

The effectiveness of the proposed isolating system will be experimentally checked. Both structures will be excited at the resonant frequency of the beams by a piezoelectric actuator placed below the substrate. An optical system will allow to detect the oscillation of the beams which is expected to be attenuated by the presence of the metamaterial. This latter experimental apparatus is currently under development.

CONCLUSIONS

A vibration isolator for micro-systems has been designed through numerical simulations and a first prototype has been fabricated through the 2PP process. This represents an important step towards a new class of vibration isolators at the microscale that can be employed for example in microelectromechanical systems.

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