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Nano-particle mass sensing using phononic pillars

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***Abstract*— In this work, we investigate the sensitivity of a pillar based metasurface in order to understand the behavior of the system in real tests conditions where the mass perturbation will not be homogeneous on all the system. The structure we study is composed in stacking alternate layers of Silica and Tungsten and presents a torsional resonant mode which presents a high quality factor and a high mass sensitivity, in a case of a homogeneous perturbation. In a case of a non-homogeneous mass-perturbation over the pillars, each pillar gives a contribution to the signal perturbation under the form of a shifted peak. These results show that each pillar gives a contribution to the output signal and that the high quality factor of the structure allows to distinguishing the different perturbations.**

Keywords— Biosensor, Phononic Crystal, Metamaterial, Mass sensing

I. INTRODUCTION

The development of biosensors is of crucial importance for multiple applications such as food processing, medical diagnosis and military[1]. The surface acoustic waves (SAW) are used in bio-sensing for a long time and are known to be simple to fabricate with low cost [2]–[4]. However, the classical SAW devices reach their limit when used to detect very small number of particles.

However, since the 90's, researchers present periodic structures composed in different materials that have the particularity to prevent the propagation of the waves for some frequencies [5], [6]. These new structures are called phononic crystals (PC). This particularity gives access to new way to manipulate acoustic waves[7]–[10].

This paper presents a study on the sensitivity to explore the non-homogeneous mass-perturbation on the system. This work is following a previous theoretical study that presented a design of PC and a semi analytic model to estimate the frequency shift induced by a mass perturbation[11].

II. PREVIOUS STUDY

In our previous work, we have studied Love waves dispersion by a pillar based meta-surface. It was composed of micro pillars made by stacking alternatively insulators layers (in Silica, SiO2) with metal layers (in Tungsten, W). The dimensions of the PC were 3 µm for the thickness of the layers and 6µm for the diameter of the pillars. We showed that a torsional mode appeared on the top of the pillar. This mode presents a very high theoretical quality factor (around Q = 83000) and is very sensitive to mass perturbation.

We introduced a semi analytic method based on the perturbation theory[12], [13], to estimate the shift in frequency of the modes for a mass loading on the pillar. That leads to the following equation[11] :

$$\frac{\delta f}{f_0} = -\delta_m \frac{\|\boldsymbol{u}(\boldsymbol{r_i})\|^2}{2\int_V \rho\|\boldsymbol{u}\|^2 dV} \qquad (1)$$

In this equation, the parameter $\boldsymbol{u}$ is the displacement fields for the unperturbed pillar, ρ is the density of the material, σ_p is the density of particles homogeneously distributed on the surface of the pillar and δ_m is the mass perturbation added on the pillar. The integral terms are computed with Comsol Multiphysics. We showed that for a punctual mass $\delta_m = 1.15$ *fg* placed on a maximal displacement point (on the circle at the extremity of the top surface of the pillar, Fig1. a), the torsional mode is shifted about $\Delta f = 2.7$ kHZ (Fig 1. b).

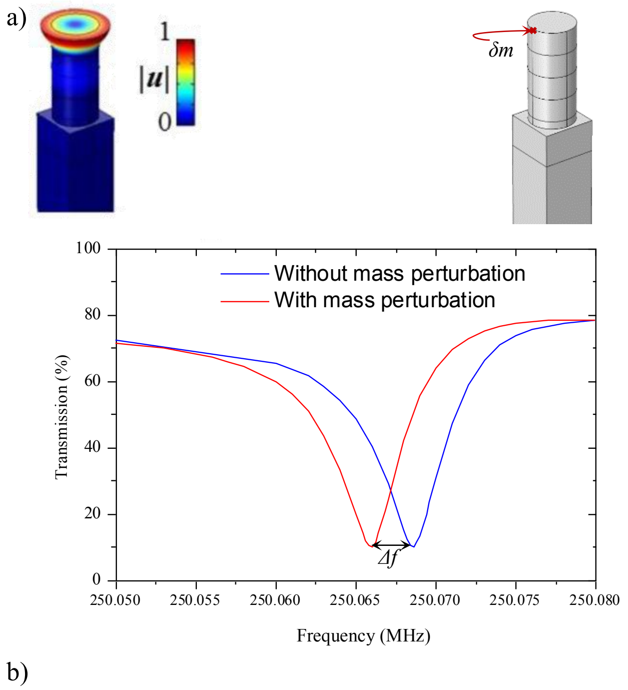

Figure 1. Normalized displacement for the torsion mode of the pillar compute with Comsol Multiphysics (a) and shift of the torsional mode for a mass positioned on a point of maximum displacement (b).

III. Discussion about the sensitivity

However, in these simulations the mass perturbation was the same on each pillar (same mass and same position). All the pillars are making the same contribution to the attenuation of the signal. During an experimental test, the particles will stick progressively on different pillars.

To simulate this phenomenon, we made a simulation on a line of 5 pillars on the delay line with different mass perturbations on each of them. We observe that, as the output signal is received over the entire length of the pillars line, each pillar and therefore each perturbation will contribute to the attenuation of the signal. The output signal will then be the combination of the different attenuations. The output signal is then composed of several peaks, which correspond to the shift we can expect by applying Formula (1) on each perturbation.

As the quality factor of the unperturbed system is very high, we find peaks in the output signal corresponding to different pillars, but the overall attenuation is reduced (Fig. 2).

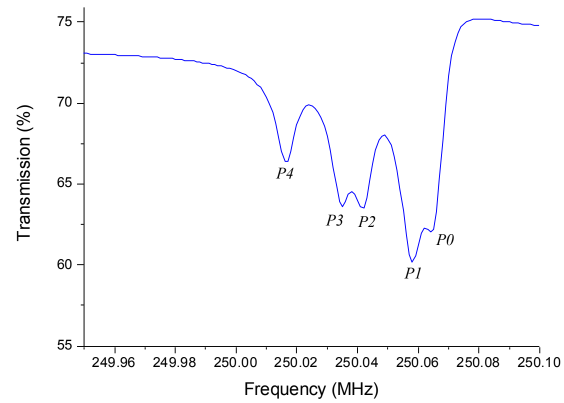

Figure 2. Transmission spectrum with four pillars with different mass perturbations. The pillars contributions are note P0-4. P0 is an unperturbed pillar.

As the number of particles clinging to the pillars increases, the peaks will fuse until only one peak remains, which corresponds to the equilibrium system with approximatively the same number of particles on each pillar.

IV. Conclusion

In this paper, we discuss about the sensitivity of a phononic structure by looking for inhomogeneous mass perturbation. We see that each pillar gives its response to the output signal by shifting its resonance frequency. Thanks to the high quality factor of the structure, each contribution remains visible. The resonance's peak is decoupled, and we can estimate the mass perturbation on each pillar by looking the different frequency shifts.

In an experimental setup, this phenomenon will allow to watch in real time the adhesion of the particles on the pillars and the homogenization of the perturbations along the pillars. However, the amplitude of the peaks will be reduced, leading to a more difficult detection.

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