Design of an Acoustic Transducer Structure for Biosensing

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***Abstract*—In a biomedical context linked to the detection of biological particles in a liquid by a biosensor, we have modeled a piezoelectric transducer based on Gallium Arsenide. The future application will enable to evaluate the mass of biological specific elements present in a complex fluid. The multiphysics simulations of this transducer allowed us to identify a quasi-transverse thickness mode at around 2 MHz. For this mode, the out-of-plane displacement is low, which is a prerequisite to keep the performance when immersed in a liquid medium. In this study, we demonstrated the effect of holes distributed over the structure on the in-plane/out-of-plane displacement ratio and on its resonance frequency.**

Keywords-Gallium Arsenide; Acoustic transducer; Holes numbers.

I. INTRODUCTION

In the medical field, the growing need to provide real-time information on the presence of a specific biological element in a complex environment has motivated the development of a multitude of detection technologies [1][2]. Nevertheless, it is important to mention that many methods of detection still use culture processes before measurement because their limit of detection is too high. The culture of biological elements requires a lot of time and does not allow a real time monitoring of the biological liquid. The objective of this study is to design a transducer whose sensitivity and limit of detection in liquid media are at the state of the art [3][4].

For this purpose, we propose an original acoustic transduction microdevice to detect the immobilization of specific analytes. The challenge of this type of transducer is to maintain its quality factor Q at the value in air when it is immersed in a liquid medium, especially in a viscous medium such as blood. To get close to this result, we must cancel as much as possible the out-of-plane components of the vibration.

Previous works [5][6] on wave propagation in clamped plates have demonstrated the strong attenuation that these embedding could generate on these waves, making measurements difficult when the plate is immersed in a liquid medium. To avoid signal losses when the plate is in contact of a fluid, two alternatives are studied: (1) to clamp the plate along two sides rather than four, and (2) to add holes so as to soften the structure in the plane of the plate.

II. EXPERIMENT

In this study, the considered transducer structure is a rectangular thin plate in the plane (x, y) made of piezoelectric gallium arsenide (GaAs) which size is 3000x2000x50 μm^3 (Figure 1(a)). GaAs was chosen because of its pure crystallinity and its knowledge in terms of microfabrication. The generation of the elastic wave in the structure is ensured by means of three gold electrodes deposited by sputtering on the upper surface. These electrodes are oriented along the plate width and separated equidistantly. The structure is clamped along x direction. All the numeric simulation are performed using COMSOL Multiphysics© software.

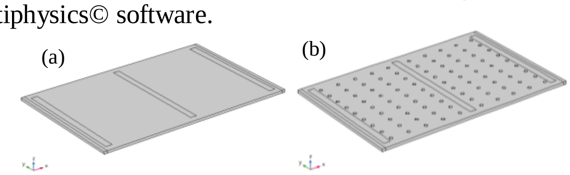

Figure 1. Clamped structure in (100) GaAs crystal (a) without circular holes and (b) with circular holes

The considered mode of vibration (Figure 2) is a quasi-thickness shear mode at a resonance frequency close to 2MHz

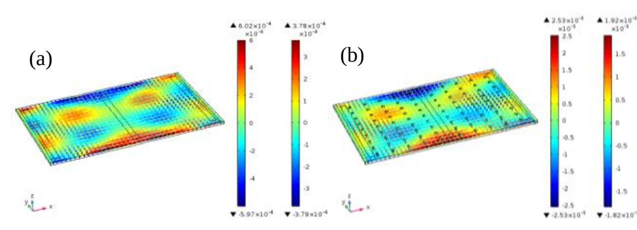

Figure 2. Quasi-thickness shear mode at a resonance frequency of 2 MHz. (a) without circular holes and (b) with circular holes

With this configuration, the attenuation due to the fluid in contact with the membrane is minimized, but not negligible. In order to increase the in-plane amplitude of the acoustic wave in the GaAs crystal**,** we generate several circular holes in the plate (Figure 1(b)). The objective of these holes

 ISBN: 978-1-61208-766-5

distributed over the plate is to increase the elasticity of the plate and then to improve the electrical response of the transducer. In this study, the effect of a circular holes array evenly distributed between each electrode is presented. The simulated results shown in Figure 3(a) and 3(b) highlight the impact of the size and number of holes on the in-plane/out-of plane displacements ratio. As seen in this figure, the displacement ratios X/Z and Y/Z have the same trend. Because of the orientation of electrodes toward Y axis, the ratio X/Z is higher than Y/Z. The most important displacement ratio (in the two directions) is obtained for a holes number equal to 90 and a hole diameter equal to 50 µm. Other recent simulations on equivalent models prove that the frequency step of the model is a significant parameter and impact on the displacement ratios. The apparent plateau observable in displacement ratio of Figure 3(a) is due to a lack of simulation points for a given holes configuration.

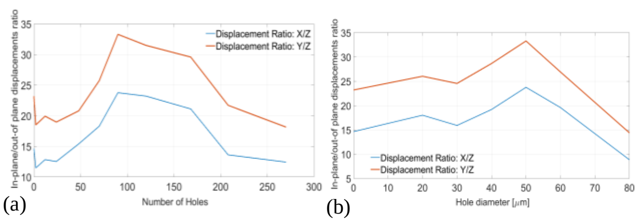

Figure 3. Impact of a) the holes numbers (for a given hole diameter of 50 µm) and b) holes diameters (holes array in the plate considered: 10x9) on the X/Z and Y/Z displacement ratios.

Figure 4(a) displays the resonance frequency evolution with the number of holes for a hole diameter equal to 50 µm. The resonance frequency shift vs the number of holes behaves as a linear curve. Figure 4(b) shows that for two different sizes of holes the behavior of resonance frequency with the hole diameters is non linear.

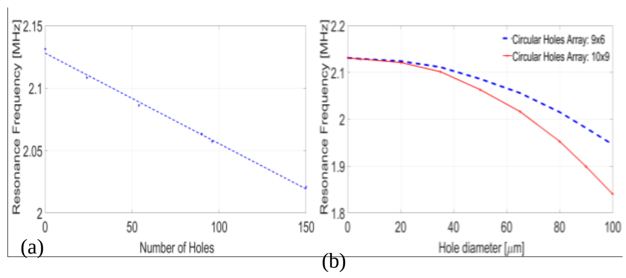

Figure 4. Quasi-thickness shear mode at a resonance frequency of 2 MHz (a) without circular holes and (b) with circular holes.

III. Conclusion

A plate mode (including clamped), with few displacement, depending on the thickness, and, therefore, having small attenuation in contact with the fluid, has been identified around 2 MHz. The addition of holes has the effect of shifting this mode towards lower frequencies. The displacement ratio gives better results for a holes number equal to 90 and a hole diameter equal to 50 µm. Future work will focus on the validation of this model with different fluid media: air, water, ionic solution and a biological fluid. For this purpose**,** several steps will be undertaken:

- Finite Element Method (FEM) simulation of the electrical impedance as a function of the size and the number of holes in the plate.
- Microfabrication of the GaAs / electrode structures by wet chemical etching and measurement of the acoustic impedance at the resonance frequency of the device placed in air and in liquid. The goal is to validate experimentally the previous results. The experimental study will focus on the "solid" structure and then on structures with holes. Some of the different tests that can be performed include:
    - The electrical impedance measurement with impedance analyzer enables to check the resonance frequency value of the mode and provides the quality factor of the resonators.
    - The 3D vibration measurements enable to conclude on the evolution of the out of plane displacement of the structure according to the holes parameters.

These experimental validations aim to conclude on the relevance of these microstructured devices for biosensing in liquid.

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 ISBN: 978-1-61208-766-5