Design of an acoustic transducer structure for biosensing

Emmanuel ATTAL*, Sophie SOK, Thérèse LEBLOIS

FEMTO-ST Institute, UMR 6174 CNRS Université de Bourgogne Franche-Comté Besançon, France

*Corresponding author: emmanuel.attal@outlook.fr

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TL38

Slide 1

TL38 enlève les logos de INRA et Actalia. Ils n'ont rien à faire dans cette présentation.
Thérèse LEBLOIS, 11/10/2020

Short presentation

Emmanuel ATTAL was born in Montpellier, France in 1985. He received the Ph.D. degree in 2016 from the University of Lille in the field of urban acoustics. Since 2018, he is postdoc in the field of ultrasound where he studied the propagation of elastic waves in periodic structures and he is currently working in Acoustics for biomedical engineering.

Outline

1. **Context**

2. Membrane modeling parameters

3. Numerical results

4. Conclusion and Outlook

1. Context

- **Thematic**
  - Ultrasound – Non Destructive Control

- **Scope**
  - Biomedical applications

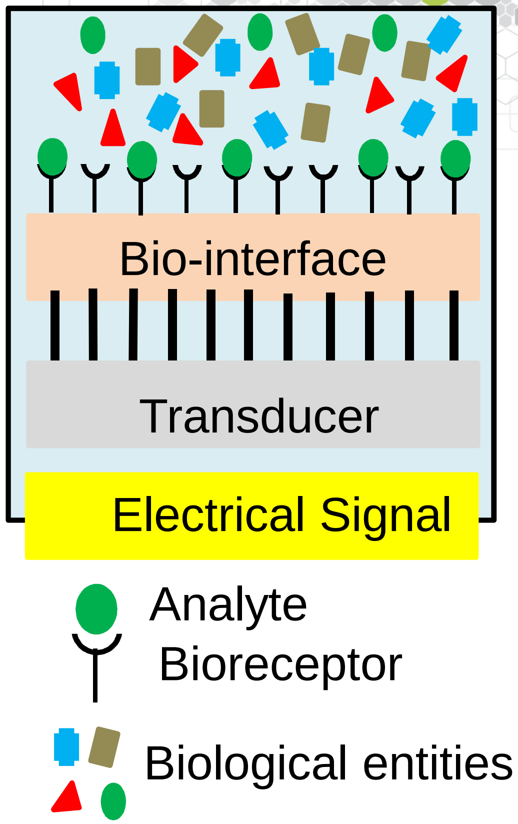
- **Motivation**
  - Cell detection and quantification in a complex fluid

1. Context

- **Acoustic Biosensor**

Definition

- The biosensor is a combination of a bio-interface, a transducer and a signal processing module
- The transducer transforms a biological signal in an electrical signals →The specificity of detection is given by the biointerface



- **Problematic**
  - When immersed into a fluid, the sensitivity of a biosensor allowing the particle mass detection is strongly reduced

Need to avoid signal losses of the biosensor when the transducer is immersed into a complex fluid

1. Context

- **Final Goal**

Design of a biosensor operating in a complex liquid medium with a high mass sensitivity (<ng) and a very low limit of detection

- **Current Goals**

• Search and identify a particular quasi shear mode of a given membrane geometry respecting the following condition*: displacement along Z axis (thickness) small in comparison with the displacement along X and Y axes

• Determine the impact of a structure with holes on the sensitivity of the biosensor is immerged in an ideal fluid and in a real fluid.

**In ideal fluid condition, first for validation*

1. Context

- **Method**

Determine the change in the selected quasi-shear mode of the membrane with:

Number of holes impact	Holes diameter impact

Study of the displacement ratio X/Z and Y/Z

Study of the resonance frequency value positioning of the considered mode versus number of holes and holes diameter

Simulation performed with COMSOL MULTIPHYSICS® **software**

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2. Membrane modeling parameters

Choice of the material: GaAs

- **Piezoelectric material**

- **Pure monocristal material unlike others like PZT**

- **High knowledge of microfabrication processes**

2. Membrane modeling parameters

Dielectric piezo elasto matrix of GaAs

$$\begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \\ D_1 \\ D_2 \\ D_3 \end{bmatrix} = \left[\begin{array}{cccccc|ccc} c_{11} & c_{12} & c_{12} & 0 & 0 & 0 & 0 & 0 & 0 \\ c_{12} & c_{11} & c_{12} & 0 & 0 & 0 & 0 & 0 & 0 \\ c_{12} & c_{12} & c_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & c_{44} & 0 & 0 & e_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{44} & 0 & 0 & e_{14} & 0 \\ 0 & 0 & 0 & 0 & 0 & c_{44} & 0 & 0 & e_{14} \\ \hline 0 & 0 & 0 & e_{14} & 0 & 0 & \varepsilon_{11} & 0 & 0 \\ 0 & 0 & 0 & 0 & e_{14} & 0 & 0 & \varepsilon_{11} & 0 \\ 0 & 0 & 0 & 0 & 0 & e_{14} & 0 & 0 & \varepsilon_{11} \end{array}\right] \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

T_α : Stress
S_β : Strain
E_α : Electrical field strength
D_i : Dielectric charge density displacement

ε_{ij} : permittivity (dielectric constant)

$$\begin{cases} \varepsilon_0 = 8.854 \times 10^{-12} F.m^{-1} \qquad \varepsilon_r = 12.459 \\ \varepsilon_{11} = \varepsilon_r \varepsilon_0 = 11.03 \times 10^{-11} F.m^{-1} \end{cases}$$

$e_{i\alpha}$: piezoelectric coefficients

$$e_{14} = 5.94 \times 10^{10} \, [C.m^{-2}]$$

$c_{\alpha\beta}$: stiffness coefficients

$$\begin{cases} c_{11} = 1.188 \times 10^{11} \, [Pa] \\ c_{12} = 5.38 \times 10^{10} \, [Pa] \\ c_{44} = 5.94 \times 10^{10} \, [Pa] \end{cases}$$

2. Membrane modeling parameters

Studies performed in the case of an ideal configuration (resonator):

- **Eigenfrequency analysis:** to estimate the location of a quasi transverse mode

- **Frequency domain:**

-
  - To determine the exact resonance frequency of this mode
  - To deduce the maximum displacement ratio at the resonance frequency

Choice of the tools for modelling

- **Solid Mechanics (fluidic effect negligeable)**

- **Electrostatics**

2. Membrane modeling parameters

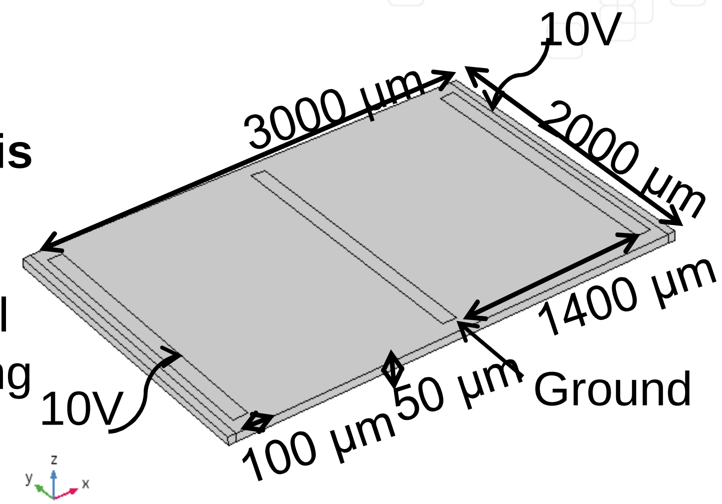
Choice of the geometry

GaAs plate clamped on the 2 edges along the y axis direction with 3 gold electrodes

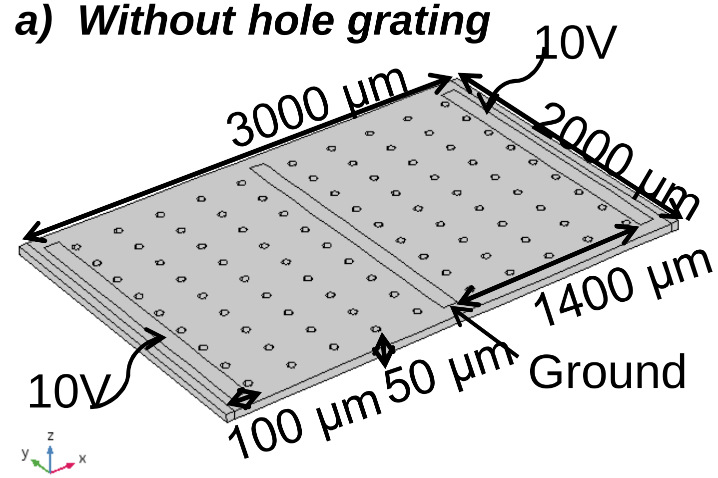
- 3 electrodes placed on the plate to apply a symmetrical voltage of10 V (the earth is in the center) and for doubling the electric field on X axis

- 2 clamps instead of 4 to reduce the damping and the losses

- 2 PML at the recessed end of the structure to simulate the effect of the propagation and absorption of elastic waves at these regions



a) Without hole grating



b) With grating hole: 10 X 9, Ø $_{holes}$: 50 µm

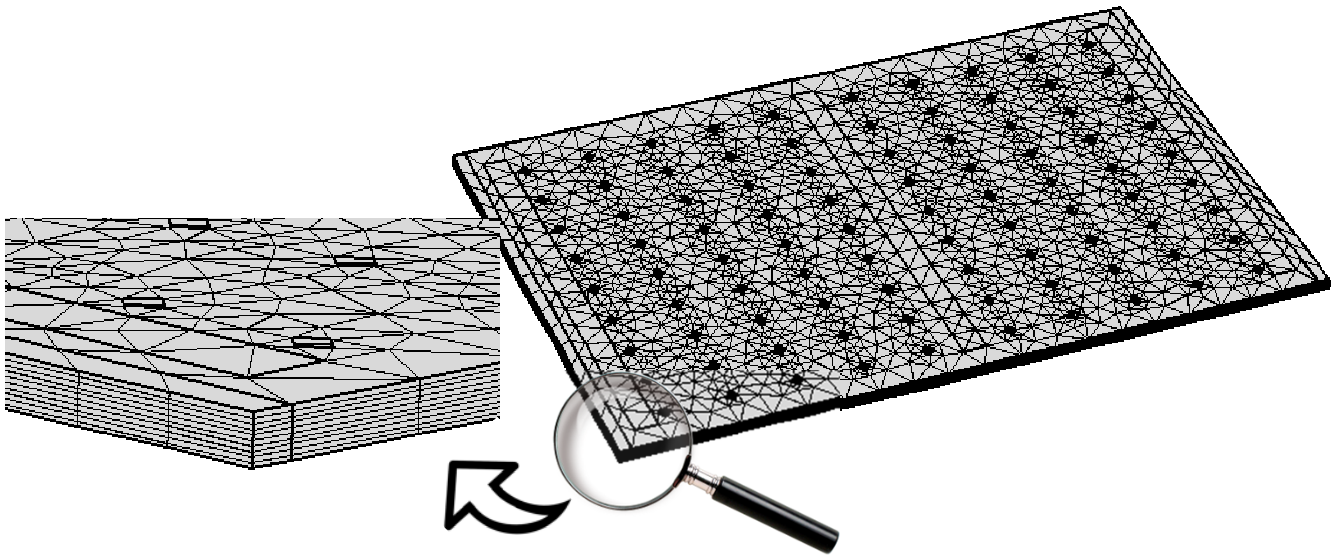
2. Membrane modeling parameters

Meshing

Study of a quasi shear mode at around 2 MHz

• Fine mesh with triangular elements on the plane of the membrane (minimum element size: 0.03mm and maximum element size: 0.24mm)

• Distributed mesh into 10 layers according to the thickness to observe the behavior of the quasi shear mode



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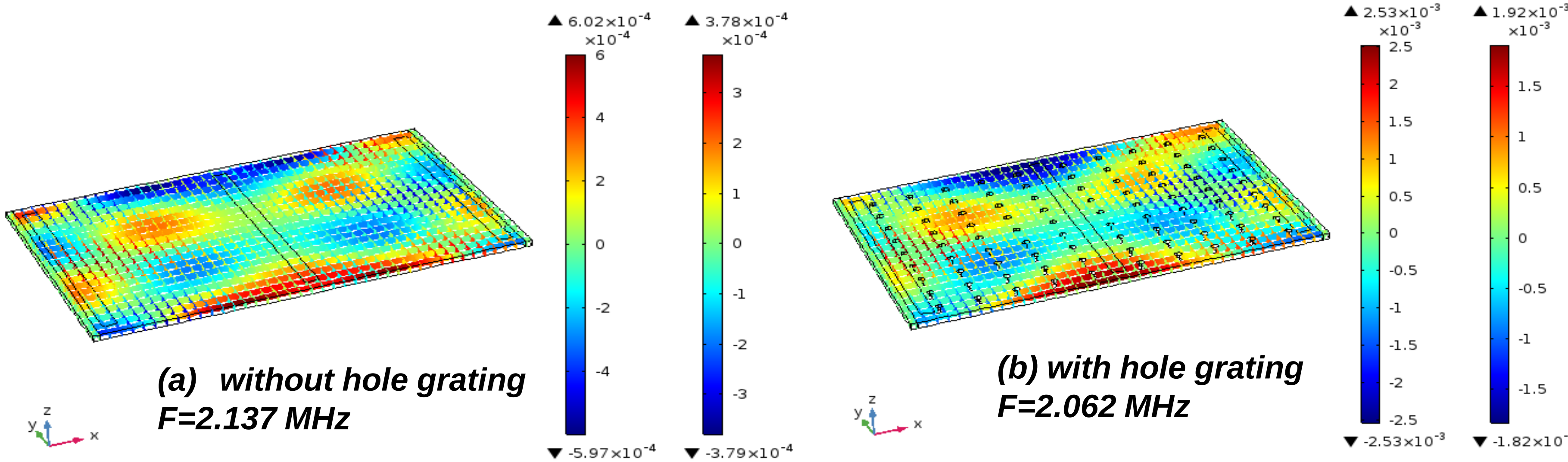
3. Numerical results

Eigenfrequency analysis



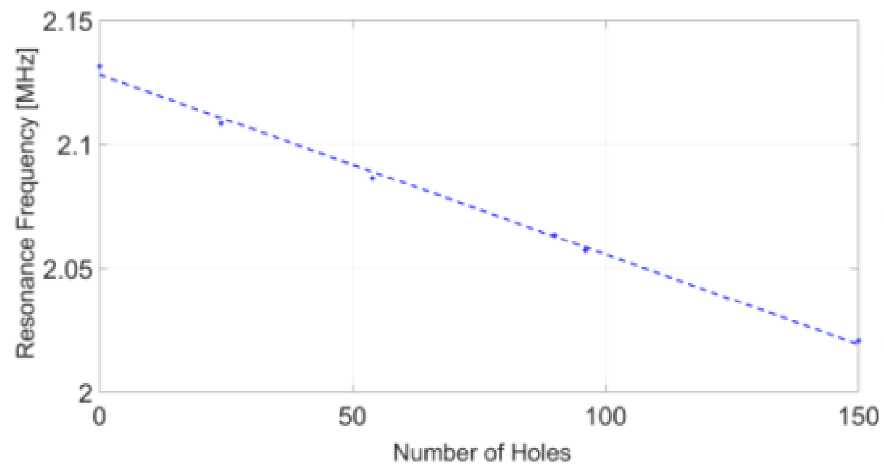
(a) without hole grating F=2.137 MHz

(b) with hole grating F=2.062 MHz

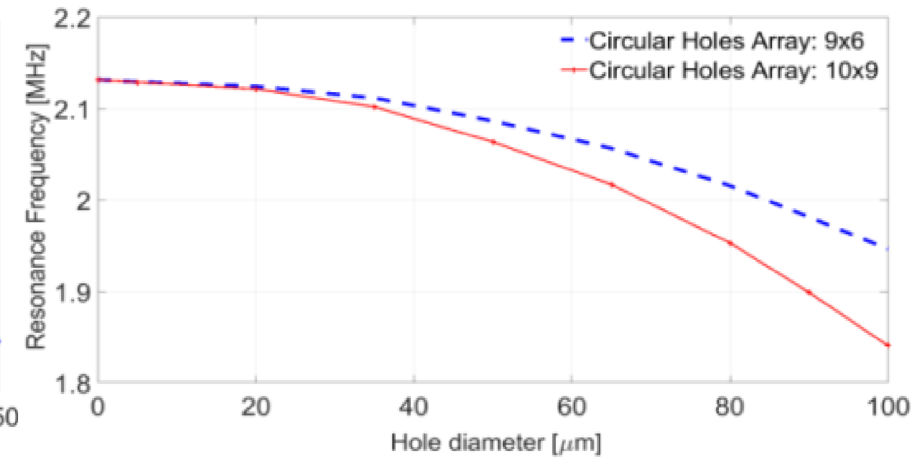
- Resonance frequency of the chosen mode observable at around 2.137 MHz (**without hole grating)** and at 2.062 MHz (**with hole grating**: ***10 X 9, Ø $_{holes}$: 50 µm)***
- Hole grating modifies elasticity of the plate and shifts down the resonance frequency

3. Numerical results

Evolution of the resonance frequency location versus number of the holes



Constant hole diameter (50µm)

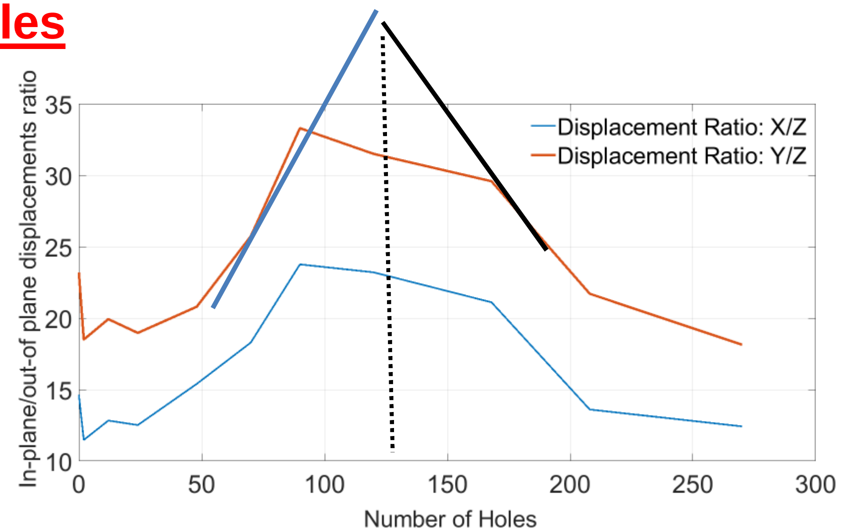


Constant number of holes (2 ≠ configurations)

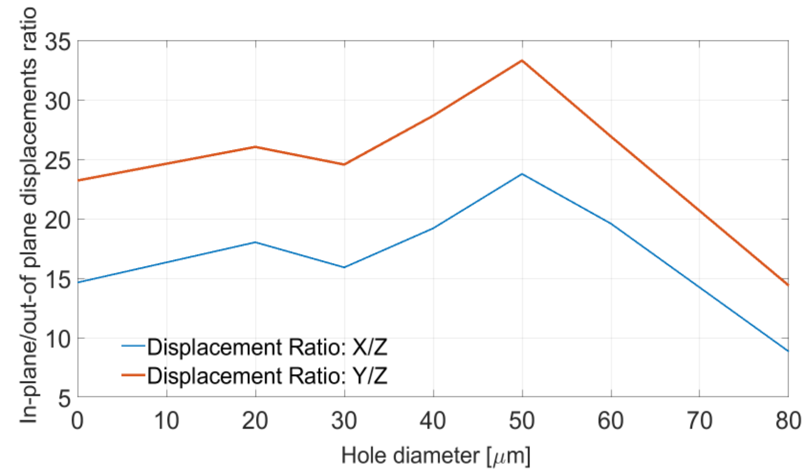
- Linear decrease trend for a constant hole diameter when adding holes
- Below 30 µm hole diameter size → weak change of the resonance frequency, significant effect appears above, according a non linear trend above
- Reduction of the resonance frequency is greater in the case of 10x9 circular array than 9x6 → Therefore diameter change leads to mass decrease and rapprochement between holes modifies the stiffness of the membrane between the holes

3. Numerical results

Evolution of the displacement ratios (X/Z andY/Z) with holes diameter and number of holes



(1) Constant holes diameter (50µm)



(2) Constant number of holes (10x9 circular array)

- Displacement ratios X/Z are larger than Y/Z because of electrodes orientation along Y axis
- An optimal configuration for a better displacement ratio sould be obtained for a number of holes around 130
- Apparent plateau in ***(1)*** due to a lack of simulation points for a given hole configuration

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4. Conclusion and Outlook

Conclusion

- **Several calculations were carried out to determine the optimal frequency step of the simulation**

- **Add of holes shifts the considered mode toward the lower frequencies**

- **Displacement ratios are strongly influenced by the increase of holes number as well as their size**

4. Conclusion and Outlook

Outlook

- **FEM simulation of the electrical impedance versus the size and the number of holes in the plate**
- **Microfabrication of the GaAs/electrode structure by wet chemical etching and measurement of the acoustic impedance at the resonance frequency of the device placed in air and in liquid**
- **Electrical impedance measurement with impedance analyzer to check the resonance frequency value of the mode and provide the quality factor of the resonator**
- **3D vibration measurements of the out of plane displacement with an optical probe for different hole parameters**
- **Comparison between experimental and numerical results**

Thank you for your attention !!!