French Polytech network form for PhD Research Grants from the China Scholarship Council

This document describes one of the PhD subjects proposed by the French Polytech network. The network is composed of engineering schools/universities. The document also provides information about the supervisor.

Supervisor information

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PhD information

Title	**Towards an acoustic wave driven lab on a chip**
Main topics regards to CSC list (3 topics at maximum)	III.7 Biomedical engineering, III.15 Biochips and bio-information VI.6 Micro electromechanical technology

Required skills in science and engineering	Master's degree or Engineering degree in one or more of the following fields: Physics, Acoustics, Materials science, Mechanical engineering, Optics, Scientific Computing, Micro and Nanotechnologies, Biomedical and/or Biotechnology Engineering, or similar.

Subject description (two pages maximum including biblio)

A_Title of the PhD research project: Towards an acoustic wave driven lab on a chip

B_Context

Lab on a Chip (LOC) platforms are one of the most promising approaches to address the important societal challenge of providing quality healthcare at an affordable cost. The scale reduction can lead to lower reagent volume consumption, massive parallelization of experiments, far more rapid outcomes, and better process control [1].

Surface Acoustic Wave (SAW) Technology has become a significant tool in biosensing due to its high sensitivity and versatility. It operates effectively in liquid media, making it suitable for applications involving biological samples. SAW devices generate precise mechanical waves that can interact with biological tissues, offering potential for cell and tissue stimulation. The integration of metamaterials—artificial structures with periodic resonators—can significantly enhance the sensitivity of SAW devices for biodetection and cell characterization.

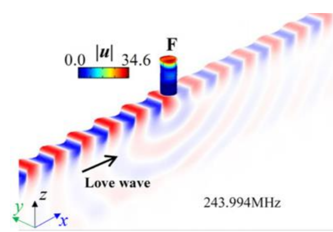

FIG. 1_SCHEMATIC REPRESENTATION OF THE UNIT CELL USED FOR FEM SIMULATION OF THE SYSTEM [6].

Based on work in progress on Ms Monaldi's thesis and previous works, we have shown that the sensitivity could be enhance by using metamaterials which are artificial materials made of periodic distribution of resonators [2] integrated to SAW devices. To obtain an acoustic microscope [3] at the microscale level with the ability to stimulate cells, according to some previous works produced, Sarry et al. [4-7] have simulated through FEM and experimentally tested such structures.

SAW technology may also be used to achieve controllable fusion of human brain organoids, such as forebrain and midbrain organoids, for studying neural circuitry like the mesocortical pathway. By utilizing dynamic acoustic fields in a hexagonal acoustofluidic device, researchers can rotate, transport, and align organoids with high precision. This method ensures reproducibility and minimizes mechanical damage during the fusion process [8]. In cancer research, SAW technology has enabled the controlled alignment and maturation of vascular networks within cancer organoids. This approach improves vascularization speed and directionality, creating more physiologically relevant tumor models for drug testing. For example, co-cultured spheroids with vascular cells showed enhanced interaction and vascular branching when patterned using SAW devices [9].

C_Project and tasks

The aim of this doctoral thesis is the design and optimization of an integrated acoustic system to create a multimodal biosensor having highly sensitivity and stimulation. The idea is to explore the interaction between surface acoustic waves (SAWs) and biological media in a multilayer structure containing spatially-localized functionalization on nanostructured surfaces. The study may identify specific acoustic modes that strongly couple with biological media, leading to significant modulation of physical parameters. This will inevitably require a good understanding of the physics involved, so as to be able to carry out simulation stages before manufacturing and characterization.

The project will be divided in different major tasks:

Task 1: Metamaterial phononic probe for cell characterization and stimulation
Task 2: Modeling & design optimization
Task 3: Fabrication & testing

The project's scientific approach encompasses:

1. **State-of-the-art Review**: Conducting thorough literature reviews at the outset of each project phase.
2. **Fallback Solutions**: Ensuring each approach has a contingency plan to meet project expectations.
3. **Interdisciplinary Collaboration**: Partnering with physiological mechanism specialists to complement the team's expertise.
4. **Sensor and/or actuator Development**: Creating hypersensitive sensors and/or actuator for cellular analysis/stimulating using mechanobiology principles.
5. **System Miniaturization**: Developing a compact testing system for research and biomedical applications.
6. **Translational Research**: Bridging the gap between laboratory findings and clinical applications.

Conclusion

This project aims to develop a LOC platform based on metamaterial phononic device in the field of cellular analysis using a mechanobiology approach. This perspective will provide insight into physiological mechanisms (requiring collaboration with specialists as this is not our core expertise) and contribute to research advancement. The second intended impact is the development of a miniaturized testing system, initially for research purposes and later refined for biomedical applications. The long-term objectives are cost reduction and personalized healthcare.
This comprehensive approach aims to advance both fundamental research and practical medical applications, potentially revolutionizing patient care and medical treatment equity.

References:

[1] Y.C. Lim, et al. “Lab-on-a-chip: a component view,” Microsystem Technologies, vol. 16, no 12, p. 1995-2015, 2010
[2] P.A. Deymier, Introduction to phononic crystals and acoustic metamaterials, Acoustic metamaterials and phononic crystals, Springer, 2013, pp. 1-12.
[3] N. Hozumi et al., Three-dimensional acoustic impedance mapping of cultured biological cells, Ultrasonics, vol. 99, 2019.
[4] Segura Chavez, P.A. et al. Love Wave Sensor with High Penetration Depth for Potential Application in Cell Monitoring. Biosensors 2022, 12(2), 61. https ://doi.org/10.3390/bios12020061
[5] Bonhomme, J. et al. Love waves dispersion by phononic pillars for nano-particle mass sensing. Applied Physics Letters, 114 (1), 013501.
[6] Bonhomme, J. ; Oudich, M. ; Segura Chavez, P. A. ; Bellaredj, M. L. F. ; Bryche, J.-F. ; Beyssen, D. ; Charette, P.G. ; Sarry, F. (2020). Numerical characterization of Love waves dispersion in viscoelastic guiding-layer under viscous fluid. Journal of Applied Physics, 128(15), 154502.
[7] Sarry F., et al., Development of a love-wave biosensor based on an analytical model, Chemosensors, vol. 10, n° 181, 2022.
[8] Controllable Fusion of Human Brain Organoids Using Acoustofluidics https://pmc.ncbi.nlm.nih.gov/articles/PMC8464403/

[9] Abstract 159: Vascularized 3D cancer organoid research platform ...
https://aacrjournals.org/cancerres/article/83/7_Supplement/159/720908/Abstract-159-Vascularized-3D-cancer-organoid