PhD Position Offer

Arrays of resonant MEMS of mechanically coupled membranes-type: Application to biological molecules detection and quantification in a liquid

Deadline for applications: 20 June 2016

Laboratory: FEMTO-ST Institute – Department of Micro Nano Sciences and Systems/ Department of Applied Mechanics

Receiving Institution: University of Bourgogne Franche-Comté (UBFC) – Faculty of Sciences and Techniques - 16 route de Gray 25000 Besançon

Time span: 3 years starting from October or November 2016
Field of research: Engineering science

Keywords: MEMS array, mode localization, biological molecules detection

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Salary: **1 365 euros net/month (grant from Labex Action / Région BFC)**

Context

The final goal of the project is the detection, then the quantification of specific molecules such as pathogenic bacteria or trace amounts of proteins in a biological liquid (plasma, blood) for an early diagnosis of a disease or to follow the evolution of a therapy. This work is carried out with the University of Sherbrooke and the international joint unit LN2 (Canada).

This detection requires a very high sensitivity and selectivity of the sensor. The biofunctionalization drives the selectivity and leads to the adsorption of the molecules from interest. The reliability of the detection and quantification device needs multiple and simultaneous measurements. This implies to have an array of sensors for each device.

The desired sensitivity (a few pg/mm² of active surface) can be reached with two strategies.

The first one consists of reducing the size to the nanometric scales. This miniaturization option needs heavy fabrication equipment and complex processes, difficult to stabilized, leading to fragile devices, with a poor signal to noise ratio.

The second strategy implies to take benefit from a physical principle known as mode localization. The presence of small irregularities in nearly periodic structures may inhibit the propagation of vibration and localize the vibration modes. Under conditions of weak internal coupling, the mode shapes undergo dramatic changes to become strongly localized when small disorder is introduced, thereby confining the energy associated with a given mode to a small geometric region. This phenomenon, referred to as normal mode localization, has excited considerable interest in solid state physics over the years and more recently was rediscovered in the field of structural dynamics. The major advantage of this principle is its high sensitivity, estimated to be two orders of magnitude compared to a classical "noncoupled" device.

This effect offers promising perspectives in terms of sensitivity in the field of biosensors dedicated to biological or environmental measurements.

This project falls within the framework of a collaboration between the MEMS team of the Applied Mechanics Department and the BioMicroDevice team of the Micro Nano Sciences & Systems Department. This collaboration is supported by the Laboratory of excellence ACTION dedicated to the development of Smart systems integrated into matter. It will allow to undertake studies on different geometries of coupled structures and of actuation principles: piezoelectric and electrostatic. The final goal of this studies is the detection and quantification of infinitely small masses.

Previous works carried out at the Departments Microsystems and of Applied Mechanics

The teams involved in the project develop research activities in the field of MEMS, especially on modelling, fabricating and characterizing CMUT transducers or acoustic transducers. The last type of transducers uses piezoelectric materials such as GaAs or ZnO. Several devices using Lamb waves or shear waves in the thickness have been simulated, fabricated and tested [3-4]. This devices have the particular feature to operate in a liquid, which is an additional challenge for the device. Expertise has been developed since 2009 on functionalization and grafting of molecules on vibrating surfaces, allowing to foresee biomedical applications [5].

Project description

The goal of the PhD is to investigate the potential of the mode localization effect in the field of tiny mass detection in a liquid. This work will thus include a part dealing with designing and modeling of a mass detector based on weakly coupled membrane arrays. In this part, innovative architectures will be designed to achieve a mechanical coupling of elementary membranes and to evaluate the interaction with the fluid.

A second part of the work concerns the fabrication of the devices and their experimental characterization. The physical principle referred takes advantage of the property of weakly coupled arrays known as mode localization. This phenomenon appears in weakly coupled systems in which a perturbation is introduced. In the targeted application, the perturbation will be a mass (biological molecule for instance) added on a functionalized surface of the array. This principle has already been partly investigated by Spletzer and al. [1-2] for coupled cantilevers but also by Orgun et al. and Jeong et al. [6-7] for coupled membranes. The major problem raised by the authors is that the manufacturing tolerances introduce initial disorder so that the system is not perfectly symmetric in its initial state.

The goal here is to combine modelling and experimentation for:
- Design and innovative structures based on piezoelectric membranes weakly coupled enable to operate in a liquid
- Fabricate the designed structures using clean room processes [8]
- Carry out the experimental measurements to determine the behavior of the devices, especially the limit in sensitivity

The modelling will be carry out using the equations governing the behavior of the piezoelectric devices. This step will evaluate the best vibration mode to use (thickness shear mode, Lamb waves…) to have an optimal piezoelectric coupling and a sensitivity in mass in a liquid. After this analytical modelling, a design of the devices will be made with numerical simulation (Using software COMSOL Multiphysics®).

The second part of the study is to manufacture devices that allow the validation of the models developed in the first part. This work will use the facilities available at the technology center MIMENTO. It includes the layout mask design, the process flow, and fabrication in the clean room using etching processes developed by previous studies and the characterization of the devices using the equipment of both Research Departments (laser vibrometer, ultrafast camera, impedance analyzers).

The characterization in liquids and especially in biological media will be carried out in the team BioMicrodevices (MN2S) where the functionalization allowing the grafting of molecules of interest on vibrating surfaces will be achieved. The sensitivity tests with biological models targeted for early detection of diseases (cancer for instance) will be performed at the end of the PhD with the devices fabricated during the PhD.

Qualifications

Candidates should have obtained a master's degree in microsystems. Knowledge in piezoelectric materials and/or in fluid structures interaction mechanisms will be appreciated.
Only candidates with very good grades from bachelor and master studies will be considered.
Rigorous and motivated, candidates must have good skills in modeling and numerical simulation in mechanical engineering, as well as a strong taste for experiment and clean room fabrication.

Application procedure

Applications must be submitted as one PDF file containing all materials to be given consideration. The file must include:

- A letter motivating the application (cover letter)
- Curriculum vitae
- Two reference letters
- Grade transcripts and BSc/MSc diploma

Candidates may apply prior to obtaining their MSc degree, but cannot begin before having received it.
The deadline for applications is 20 June 2016.

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Bibliography

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