Design of a Specific Fluidic and Electrical Interface for a Piezoelectric Biosensor

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Abstract

The resonant biosensors are known for their high accuracy, low manufacturing cost and high level of miniaturization. The realization of an integrated sensor device requires the design and fabrication of fluidic and electrical interfaces, satisfying themselves to these requirements. Keeping this aim in mind, we designed fluidic and electrical interfaces easily adjustable to several types of resonant biosensors. Moreover, to characterize our sensor accurately, we developed a testing interface to quantify the influence of external parameters, like temperature and pressure, on the sensor response. The accuracy of measurement would then be strongly improved; real-time corrections on measurements and integration in a portable system would be possible.

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Keywords: piezoelectric biosensor integration, fluidic and electrical interfaces, sensors characterization

1. Introduction

In the field of biosensors, major interests of the resonant piezoelectric device are the high sensitivity, the low cost and the opportunity to obtain wireless and portable devices due to their high miniaturization level. The integration of the sensing part in global biosensor system requires the realization of fluidic and electrical interfaces, satisfying themselves to these requirements. To reach this objective, we developed a specific fluidic and electrical interfaces adapted for a lateral excited gallium arsenide (GaAs) biosensor (Fig. 1.). This integrated system is embedded in a dedicated biosensor test bench that allows control of

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external parameters like temperature or fluid flow. Thanks to this test bench, high accuracy measurement could be realized and compared with commercial devices. The calibration of our sensor is also possible to determine corrective factors for high accuracy real time measurements for nomad outlooks.

Fig. 1. Design of the lateral field excited GaAs structure (A), pictures of the electric circuit (B) and membrane cavity on the opposite face (C); Schematic view of GaAs sensor with 2 active membranes (green see-through part) with the associate flow-cell (grey part).

2. Interfaces design

The design and the microfabrication of a gallium arsenide biosensor being achieved in air [1], we made preliminary tests on the resonant structure with basic electrical interface [2]. These tests confirmed the expected behavior of our sensor with a working frequency of 51.215MHz, a quality factor equal to 2277 and a frequency quality factor product around $1.1 \times 10^{11}$ which proved the potential of this sensor to detect biological interactions with a high sensitivity. During these tests, the basic electrical interface showed its limits and the need to develop a fluidic interface for biological measurement led us to design a new miniaturized and integrated interfaces, composed of opposite fluidic and electric interfaces. For the development of our sensor, we proposed a plug and play (PnP) system (Fig. 2.) where sensor or flow cell could be rapidly and easily removed. The sensor and flow cell are sandwiched and compressed between electric and fluidic support. This compression insures tightness thanks to 4-oring and specific PDMS sealing and is based on the bulk substrate. The counterbore on fluidic support aligns the flow cell with fluidic connections and with the sensor part. The electrical interface is adjusted in front of sensor electrodes through fluidic support, the large connection pads of sensor take into account the positioning default.

Fig. 2. Schematic of the complete system: the electrical interface (1-5), GaAs membranes (6) and the fluidic interface (7-11).

The electrical interface is composed of SMA connectors, a PCB board and elastic pins. Elastic pins ensure a good electrical contact and fix the pressure applied on pads, which are delocalized on the bulk substrate. Large ground planes, transmission lines and compounds are dimensioned to optimize the metrological characterization with a network analyzer in impedance mode. Then, the standards (open and short circuits, 50Ω) necessary for the calibration are mounted with similar electrical interface and
fixation. The fluidic interface is linked to a classical fluidic circuit composed of an injection valve, containing a loading loop, a pump, tanks for solutions and wastes. The inputs or outputs of fluids come in through the standard connectors screwed on fluidic support. This support conveys the fluid to a specific flow-cell especially designed to route homogeneously and regularly the fluid on the two active membranes. This continuous flow was simulated through FEM analyses with COMSOL Multiphysics® and the shape or fluid connection places are optimized.

3. Interfaces for nomad application

The bulky fluidic circuit described above presents the drawback to limit the miniaturization, the portability and the low price of the device, which are key properties for piezoelectric biosensor. We developed a nomad configuration to substitute advantageously this system. This interface used classical needles with Luer connector to inject fluids (Fig. 3.). The fixation of the flow cell, needles and sensors support were simply made by gluing. FEM analyses with COMSOL Multiphysics® helped us to design the shape of the flow cell to ensure a laminar flow on membranes. However, this method of injection leads to a limitation of interaction in static mode which decreases strongly the efficiency of biological interaction comparing to dynamic mode [3]. We imagined a flow cell with a piezoelectric resonant membrane modeled on sensor activation in order to switch to a dynamic regime. The advantages of sensor structure are kept: decoupling fluidic and electric medium, generation of large modes of vibration, fabrication through wet etching process, regenerability of the surface. Another advantage of this structure leads to decrease in fluid volumes (20µL). The electrical connection, located on both sides, required some modifications but the elastic pin connections are conserved for final interface. We planned also implement additional function on this flow cell, for example to introduce microheater [4].

4. Biosensor dedicated test bench

Environmental conditions like temperature or pressure induce a lot of variation on sensor behavior. To control this external parameters influence, we fabricated a box with multiphysical inputs/outputs (Fig. 4.) dedicated to biosensor tests. The external pressure can be modulate from ambient pressure to a primary vacuum level (10⁻³mbar), the temperature vary in the range [-30°C, 150°C] and different fluid flow variations are tested. All data are recorded in computer. We realized a heating / cooling plate by incorporating a fluidic circuit connected to a cryostat inside the bottom of the box. The temperature is measured by a thermocouple glued between the two active membranes, closest to the desired temperature value. With this system, we obtain a precision of 0.1°C in the range of [20° to 37°]. It could be improved by realizing closed loop by introducing a PID regulator on this system. The implementation of an embedded microheater, near to the biosensor, is envisaged to control the temperature more locally. Another factor improving the sensitivity of the sensor is the pressure applied on membranes induced by the flow rate of the fluid. We could evaluate the sensor response in function of pressure by varying the fluidic circuit pressure to the pump. A conjugated analysis of thermal and pressure effect on sensor
response will give us some information about the sensor behavior and corrective factors which will be applied on real-time measurement and/or on nomad application for more accuracy. Vacuum environment is often reached for fine measurements, reducing strongly the attenuation factor induced by air and the ambient noise. The difficulty for biosensor is to conjugate vacuum measurement and fluidic interaction in air without destroying the sensitive membranes. We bypass this problem by alternating fluidic interaction and vacuum measurement, the vacuum is made both inside and outside the fluidic cavity. This method gives also the possibility to dry very efficiently the membrane when we shift on vacuum regime.

Fig. 4. Photography of the multiphysical inputs and outputs box for biosensor tests.

5. Conclusion

The electrical and fluidic interfaces play a key role in the efficiency of a biosensor. We developed specific system adapted for a GaAs biosensor where fluidic and electrical interfaces are situated on opposite sides of the sensor. Thanks to this global system, sensor and interfaces, biological interactions could be measured with a high accuracy level. For nomad outlooks, we designed new interfaces conferring portability and low cost properties which are key properties in this field. A specific test bench was developed to increase the sensibility of measurements and also to calibrate our sensor in order to evaluate correctives factors whose purpose is to provide highly accurate real-time measurements with nomad devices.

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