Design and Fabrication Process for Artificial Lateral Line Flow Sensors

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Introduction

In fish the lateral line is a sensory organ used to perceive water movement in the surrounding environment to localize prey or predators, to avoid obstacles, for schooling and more. The lateral line consists of many mechanoreceptors called neuromast which consist of groups of hair cells covered by a jelly-like cupula. There are two types of neuromasts: superficial neuromasts which are situated on the skin, and canal neuromasts which are located canals that are connected to the water outside of the fish through a series of pores.

We review design aspects for MEMS fabrication of capacitive hair based flow sensor arrays operating in aquatic environments, biomimicking neuromasts. Exploiting information gained from nature building a system that allows the study of hydrodynamic mechanical interactions in complex noisy environments may help to uncover more about nature and how to make reliable artificial systems.

Design

Figure 1 shows the device design evolved from existing constraints. Fluid flow produces a drag force on the hairs resulting in a torque at the base of the hair which deforms the membrane. The main feature is a fully supported membrane that should be flexible enough to deflect with the hair moment and prevents water to enter underneath it, hence avoiding strong damping. Also, by putting electrodes under the membrane, water contact is avoided to eliminate the chance of electrolysis and short-circuiting. The closed membrane structure with the hair in the middle provides the maximum deflection between the center (of the hair base) and the membrane boundaries. Deflection can be determined (figure 2) by the following equation[1].

$$w = \left[A\rho + B\rho^3 + C\rho^{-1} + D\rho \ln \rho\right]\cos\theta$$

in which ρ = r/(membrane radius). Because of the hydrostatic pressure of water the membrane also bends downward increasing the chance of collapse and pull-in. This can be avoided by proper dimensional optimization of the device (figure 3). We have simulated downward deflection and tilting of the membrane simultaneously considering the effect of electrodes on membrane stiffness (figure 4) for various membrane shapes using FEA by COMSOL Multiphysics.

The readout part consists of two separate electrodes under the membrane and a common electrode which is actually the highly doped silicon substrate. Readout mechanism is the same as we use currently for our hair based flow sensors, biomimicking crickets' cerci, to operate in air[2]. The membrane deflection increases the gap between substrate and electrode on one side whilst decreasing the gap on the other side thus enabling differential readout. The process flow is shown briefly in figure 5. The function of the sensor does not allow sacrificial layer etching to be done from front side and requirements for having dense array of hairs rule alkaline etch from backside out. By using etch plugs we overcome this problem without need to High Aspect Ratio Structures (HARS) etching which even hinders diffusion of etch species and makes sacrificial layer etch difficult.

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[1] S. Timoshenko, "Theory of Plates and Shells", McGraw-Hill Education, ISBN13: 9780070858206

[2] M. Dijkstra et al., "Artificial sensory hairs based on the flow sensitive receptor hairs of crickets", J. Micromech. and Microeng, Vol. 15, pp. 132-138, 2005

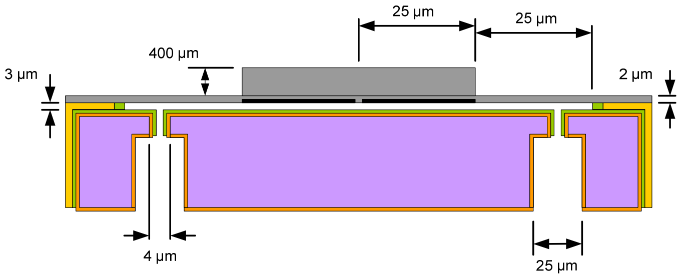

Figure 1. Schematic of the final device

Figure 2. Closed membrane deflection; adopted from [1].

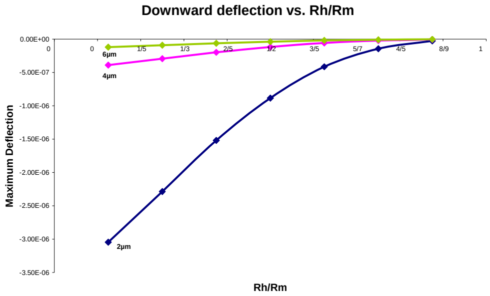

Figure 3. Downward deflection as a function of hair to membrane radius ratio

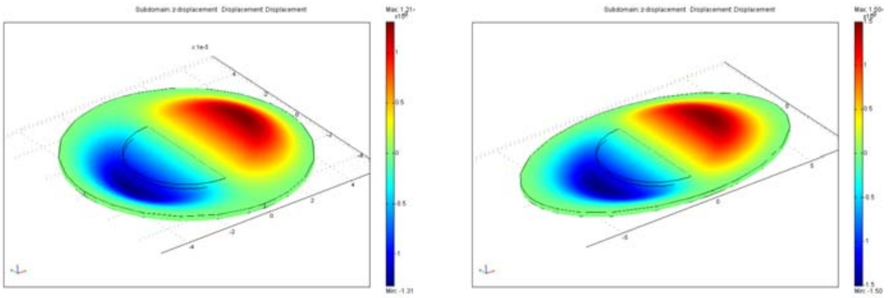

Figure 4. FEM analysis of membrane deflection under static pressure for circular and elliptical shape membranes

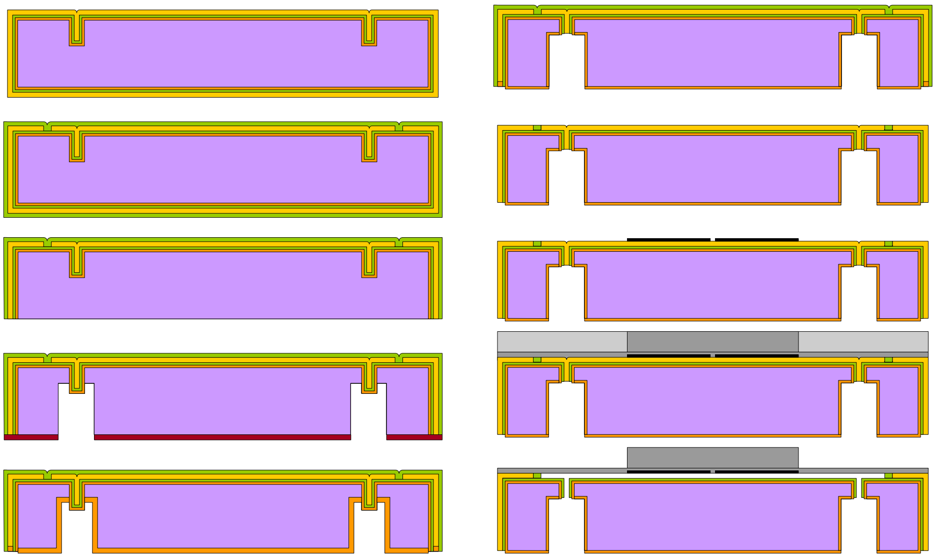

Figure 5. Process flow