DESIGN AND SIMULATION OF A MEMS-BASED COMB-DRIVE PRESSURE SENSOR FOR PEDIATIC POST-OPERATIVE MONITORING APPLICATIONS

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1. INTRODUCTION

Approximately 1% of all children are born with some form of congenital heart disease. At least 10 % of these have complications of the right side of the heart. Surgical repair of right-sided complications is frequently complicated by post-operative infections within catheters used to monitor vascular pressure. To address this problem, we examined the suitability of an implantable MEMS-based pressure sensor for immediate (< 3 months post-operation) monitoring of right sided pressures through a remote telemetry connection. A capacitive pressure sensor was first examined. Based on the specifications of the remote telemetry system, the pressure sensor is required to generate a minimum sensitivity of 1 pF/100 mmHg, provide linear change in capacitance versus pressure, and be capable of registering absolute and gauge pressures. This report provides initial data on the design and simulation of such a sensor.

2. DESIGN

The design was focused on solving various problems that have complicated membrane-type capacitive pressure sensors including: clamp-down of the upper membrane to the base plate at normal blood pressure ranges; sufficient resolution; and sufficient sensitivity to allow integration with a remote-telemetry system. Comparing with other designs [1,2], we believe that a comb-drive capacitor design can solve these problems. The design of comb-drive capacitor unit consists of one top membrane and forty comb-drives. (Figure 1). The workings of this design were compared to those of a conventional membrane-only capacitive pressure sensor (Figure 2).

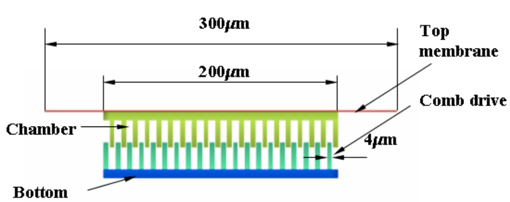


Figure 1. Cross sectional schematic of comb-drive capacitor unit

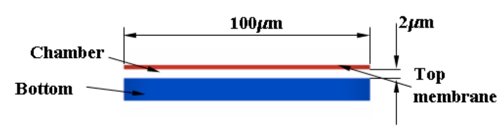


Figure 2. Cross sectional schematic of simple capacitor unit

3. CONCEPT

The comb-drive has an inter-digitated shape as shown in Figure 3, where L is the finger height, x is displacement and g is gap between top and bottom fingers. Application of normal force (pressure) on the top membrane creates a displacement x, which should then change the capacitance C, based on the change in the overlapping area. Therefore, the capacitance generated can be written as

$$C = 2n\frac{\varepsilon(L - x)l}{g} \qquad (1)$$

where ε is the dielectric constant, $\boldsymbol{n}$ is number of fingers, g is gap width, and l is length [3,4].

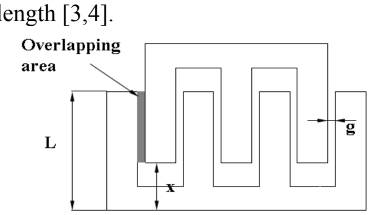


Figure 3. Comb-drive array

4. ANALYSIS AND RESULTS

Several simulations of comb-drive and simple membrane capacitors were implemented using the Coventorware design system. To simulate these capacitors, we assumed that four edges of the top membrane are fixed. Pressure was assumed to be applied on the top membrane. Titanium was used as the main material to achieve high resolution. Vacuum (absolute pressure) and air (gauge pressure) chamber conditions were also simulated to compare the comb-drive design against the simple membrane design.

4.1 Results

To find differences between comb-drive and simple membrane designs, the designs were simulated with static pressures (range: 0 ~ 950 mmHg – absolute) and time dependant pressure ($P(t) = 62.5 \square 32.5\cos \square t$ (0<t<1)). Figure 4 shows capacitance –vs- pressure, and Figure 5 shows sensitivity (capacitance change: Δ**C**) for the two designs.

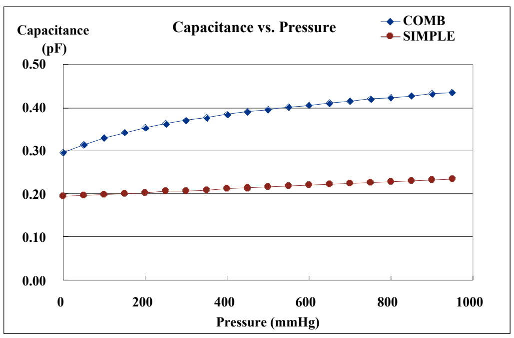


Figure 4. Output capacitance with applied pressure

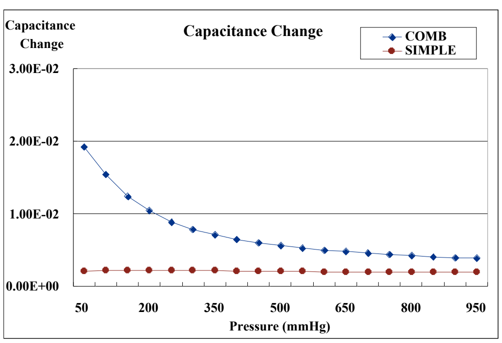


Figure 5. Sensitivity of the two designs

Figure 6 shows the time-dependent change in capacitance as a function of the applied time-varying pressure.

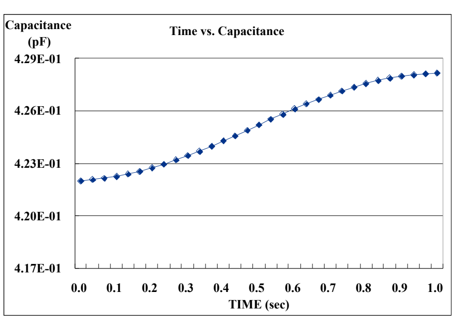
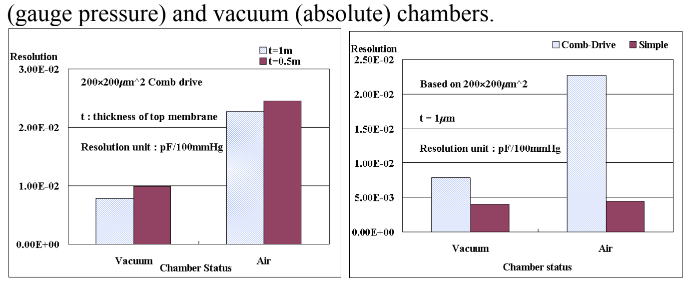


Figure 6. Time dependent change in capacitance for a time-varying pressure for the comb-drive sensor.

4.2 Comparison

Based on a 200x200□m^2 capacitance generating area, Figure 7 shows comparisons of resolution for two different thickness dimensions (left) and for the two sensor designs (right) for air-filled (gauge pressure) and vacuum (absolute) chambers.



(a) (b)

Figure 7. Capacitance resolution (a) depending on thickness (microns) of top membrane and (b) between simple membrane and comb-drive capacitors with air and vacuum chamber status.

5. CONCLUSIONS AND FUTURE WORK

Several conclusions can be drawn from this preliminary work. First, the comb-drive produced increased capacitance for equal applied pressure. Second, the comb-drive provided higher sensitivity ($\Delta C/\Delta P$) than the simple membrane sensor. No bending or other deformation of the upper membrane was found for the comb-drive sensor; this is a frequent problem for membrane sensors. The comb-drive sensor provided better resolution for both absolute and gauge pressure measurements. These data indicate initial promise for the comb-drive sensor as a reasonable design for an implantable pressure sensor that can be coupled with remote telemetry systems for our application. Future work involves fabrication of a number of comb-drive designs and *in vitro* testing with various biocompatible coatings.

References

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