FLUID-STRUCTURE TRAVELING WAVE FILTERS BASED ON THE MAMMALIAN COCHLEA

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ABSTRACT

Micromachined fluid-structure systems capable of acoustic sensing and mechanical frequency analysis are demonstrated. These systems act as passive mechanical acoustic filters. A capacitive sensing scheme is incorporated into the structure to produce 32 channels of filtered output, each sensitive to a particular frequency band. Inspiration for the design is taken from the structure of the mammalian cochlea.

Keywords: acoustic, cochlea, sensor, filter

1. INTRODUCTION

Previously, a number of researchers in cochlear mechanics have reported life-sized cochlear models [2, 3, 4, 5]. These devices demonstrate the ability to achieve passive cochlear-like acoustic filtering in a life-size engineered cochlea. The device described in this paper takes the next step of incorporating sensing elements into the structure to build a cochlear-like acoustic sensor/filter. The system can be applied to the measurement of air- or water-borne sound, with the ability to discriminate different frequencies with low power consumption.

2. THEORY

Mechanically, the system consists of a trapped fluid coupled to a variable width membrane (a diagram is shown in Figure 2). The varying width results in varying membrane compliance, leading to a frequency-position map: high frequencies excite motion close to the narrow end, low frequencies close to the wide end. A thin-film viscous fluid model coupled to a membrane model captures the fluid-structure interaction in a computationally efficient scheme [5, 6]. Model results are shown in Figure 1.

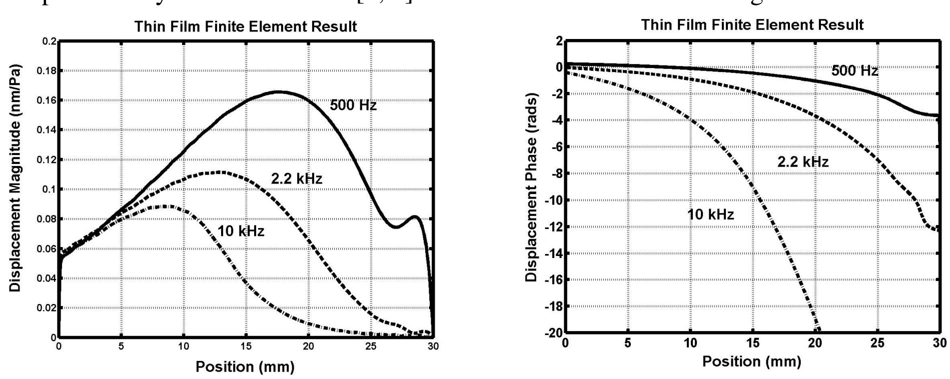

Figure 1. Model results show the predicted magnitude and phase of the centerline oscillation for 3 different driving frequencies. Different frequencies generate amplified motion at different locations. Phase accumulations in the 30 mm length of the device are predicted to be between 4 and 40 radians.

3. EXPERIMENTAL

The membrane is a 3 cm long, 0.1/1.0/0.1 μm thick, LPCVD Si_3N_4/p+ Polysilicon/Si_3N_4 laminate with 40 MPa net tensile stress. The membrane width tapers exponentially from 140 μm to 1.82 mm. A two stage deep reactive ion etch (DRIE) defines both the membrane shape and a 475 μm high fluid chamber behind the membrane. Anodic bonding and Sn-Au fluxless solder bonding are used to bond on two Pyrex glass dies which seal the fluid chamber and provide electrodes for sensing. Silicone oil of 200 cSt viscosity is used to fill the fluid chamber. Figure 2 shows a plan view and two cross-sections of the design.

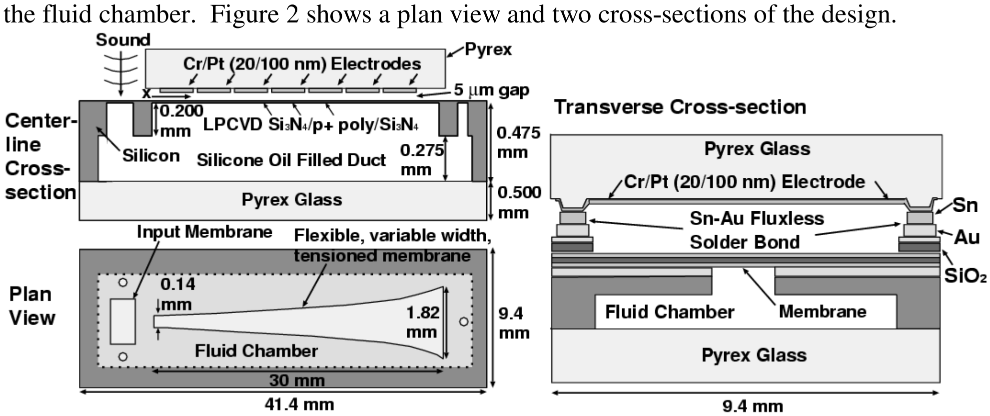

Figure 2. A diagram of the system geometry. The key feature is the exponentially tapered membrane.

Direct measurement of structure motion has been conducted using Laser Doppler Velocimetry (LDV). A baffled piezoelectric tweeter is used to deliver sound to the input membrane. A subsonic traveling fluid-structure wave is set up. Figure 3 shows the measurement results. Each frequency excites amplified membrane motion at a frequency dependent location. The design responds with 0.1-0.2 nm/Pa in the 10-100 kHz band.

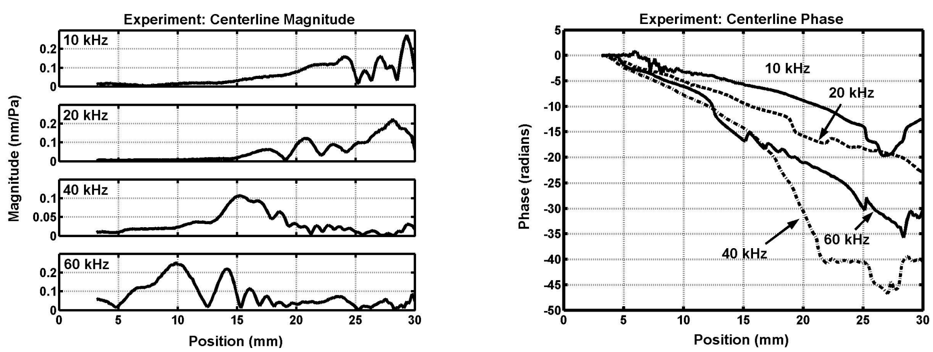

Figure 3: LDV data shows magnitude and phase of the traveling wave along the centerline of the membrane for harmonic excitation. A peak occurs at a frequency-dependant location.

The on-chip capacitive sensing scheme consists of 32 multiplexed channels distributed along the length of the membrane. A DC bias of 9 volts is applied. Membrane vibration generates current which is integrated by an off-chip JFET buffered charge amplifier with 10 V/pC charge gain. Figure 4 shows the output of all 32 channels for 2 driving frequencies. (These results are typical of all frequencies measured from 100 Hz to 70 kHz.)

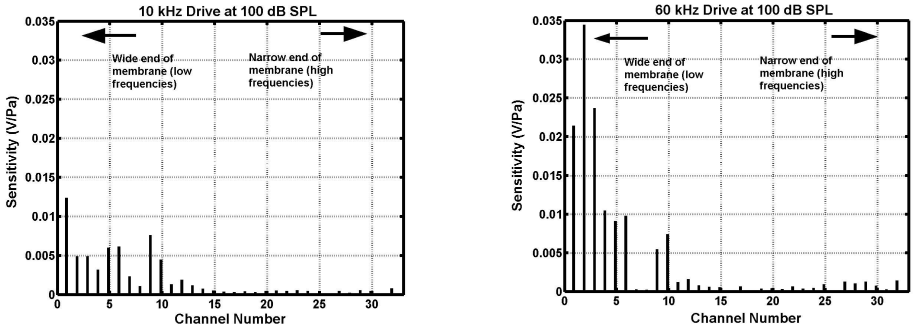

Figure 4. Measured sensitivity of the 32 capacitive sensors at two driving frequencies.

4. CONCLUSIONS

A device which mimics the mechanics of the passive cochlea has been realized. Models predict 0.2 nm/Pa of membrane vibration in the 100 Hz-10 kHz band. LDV measurements show traveling waves with these levels of vibration, but at elevated (10 kHz-100 kHz) frequencies. The discrepancy could be due to membrane stress introduced during anodic bonding or to violation of the thin-film model approximations. An integrated 32-channel capacitive sensing scheme has been included with the device and has been shown to sense membrane vibration. The capacitive sensors do not show the same pattern of membrane vibration measured by LDV. At all frequencies, the channels at the wide end of the membrane show the highest output. This may be due to ineffectiveness of the top glass as a baffle, resulting in direct excitation of the membrane, (during LDV measurement a baffle confines the excitation pressure to the input membrane) or to incomplete Sn-Au bonding.

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