MEMS fabricated cochlea with frequency selectivity and acoustic/electric conversion

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In this paper, we report a novel piezoelectric artificial cochlea which works as an acoustic sensor with frequency selectivity. This system realizes the selectivity with the association of the local resonance of oscillation, the piezoelectric effect and the microfabricated electrode array. The artificial cochlea is composed of a membrane of 40 μm-thick polyvinylidine difluoride (PVDF) which is fixed on a substrate with a trapezoidal channel. The membrane over the channel works as a sensor and is oscillated by the acoustic wave. The width of the sensor is proportionally varied from 2 mm to 4 mm along the 30 mm of longitudinal direction so as to change the local resonance frequency of the sensor with respect to the position. A detecting electrode array with 24-elements is produced by aluminum thin film with 500 μm×1mm rectangle and 1 mm in space, where they are located in a center line of the trapezoidal channel. The measurements of the oscillating amplitude using a laser Doppler vibrometer reveal that the sensor has specific vibration characteristics in response to the frequency from 3 kHz to 15 kHz. As the result of the vibration characteristics, the piezoelectric output from the electrodes show the frequency selectivity. From these findings, the application feasibility of the artificial cochlea is confirmed.

Keywords: fluid-structure interaction, acoustic sensor, cochlea, microelectromechanical systems

1. Introduction

Sensorineural hearing loss is deafness caused by the damage on the hair cells of the cochlea, where the hair cells convert acoustic wave to electrical signals that stimulate the auditory nerve. Recently, the artificial cochlea is used as the medical treatment for the deaf patients. The current artificial cochlea consists of implantable stimulating electrodes and an extracorporeal device, which bypasses the damaged hair cells by generating electric current in response to the acoustic wave. However, there are some essential disadvantages in the current artificial cochlea that extracorporeal device including battery, sound processor, and microphone is indispensable. This situation motivates us to develop a fully self contained artificial cochlea.

The important role of the artificial cochlea is not only conversion of acoustic waves to electrical signals but also the frequency selectivity. In particular, the selectivity is critical to realize the "natural hearing". In order to artificially realize the selectivity, some microscaled devices which mimic the biological cochlea have been reported. Tanaka et al. [1] and Chen et al.[2] fabricated a beam arrays which are fixed over a trapezoidal channel. Despite its frequency selectivity, the mechanical strength of the device is not enough due to its beam bending model.

2. Experimental Method

Schematic of the developed artificial cochlea is shown in Fig.1. The artificial cochlea is composed of a 40 μm thick polyvinylidine difluoride (PVDF) membrane (KUREHA, Japan) and a substrate with a trapezoidal channel. The trapezoidal channel is designed so that the membrane over it is oscillated by the acoustic wave. The width of the channel proportionally changes from 2.0 mm to 4.0 mm along the longitudinal direction with the length of 30 mm. This shape is intended to mimic the passive basilar membrane, that is, the local resonance frequency of the sensor is gradually changing along the longitudinal direction due to the variation of the local mechanical boundary condition. Lower resonance frequency is expected at the wider side, whereas lager one is at narrower one. Applying acoustic wave with a certain frequency, the locally resonating place shows a relatively large

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