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Development of Artificial Cochlea Using Microfabrication Method Based on P(VDF-TrFE)

Harto Tanujaya*, Hirofumi Shintaku*, Toshiya Kanbe*, Yohei Nakamoto*, Satoyuki Kawano*
Takayuki Nakagawa**, and Juichi Ito**
*Department of Mechanical Science and Bioengineering, Graduate School of Engineering Science, Osaka University
Machikaneyama-cho 1-3, Toyonaka, Osaka 560-8531, Japan
**Department of Otolaryngology, Head and Neck Surgery, Kyoto University Hospital
harto@mbox.me.es.osaka-u.ac.jp, shintaku@me.es.osaka-u.ac.jp, kawano@me.es.osaka-u.ac.jp

ABSTRACT

The cochlea in the inner ear is an important organ for hearing. In this work, we develop a novel artificial cochlea using P(VDF-TrFE) to realize the fully implantable system for sensorineural hearing loss by microfabrication and thin films technologies. The device consists of a piezoelectric membrane made of P(VDF-TrFE) fabricated on a silicon substrate and discrete electrodes on the surface. The membrane converts mechanical deformation induced by acoustic waves to electric signals due to the piezoelectric effect. The geometry of the membrane is designed to realize the frequency selectivity at the range of 500 ~ 5,000 Hz. The experiment is carried out to investigate the vibrating characteristics of the membrane. To model the cochlear duct, the device is mounted on a substrate with a fluid channel filled with silicone oil. The results show that the resonant frequency is changed along the position due to the varying local mechanical boundary condition governed by the geometrical configuration. Furthermore, based on the relationship between position and the resonant frequency, it is found that the device can realize the frequency selectivity at the range of 1.45 ~ 10.65 kHz.

Keywords: Artificial cochlea, Frequency selectivity, P (VDF-TrFE), Vibration, Fluid-structure interaction

1. Introduction

Hearing is very important for human to communicate with others. In particular, children who have problem with their hearing get into trouble in their growth and the quality of life. In normal hearing, sound waves are converted into vibrations of basilar membrane (BM) in the inner ear. The hair cells on BM convert the sound wave into electric signals which are transferred to the brain via auditory nerve [1][2]. At present, there are several prostheses, i.e. cochlear implant, to help human who have hearing impairment that caused by malfunction of the hair cells in the cochlea. These cochlear implants consist of two parts; implantable stimulating electrodes (receiver and electrodes) and an extracorporeal device (batteries, processor and microphone). In our research we develop a fully implantable and self contained artificial cochlea using the piezoelectric membrane made of P(VDF-TrFE). The basic vibrating characteristics of the membrane are analyzed by applying sinusoidal acoustic waves to the device.

2. Method

Figure 1 shows the artificial cochlea developed in this work. The artificial cochlea consists of a trapezoidal and piezoelectric membrane and 24 discrete electrodes on it. The membrane, which is named as an artificial basilar membrane, is vibrated by applying acoustic wave. The vibration is converted into the electric signal due to the piezoelectric effect. Because the width of the membrane is varied along the longitudinal direction, the local resonant frequency of the membrane changes as the position. As the result, a certain electrode has a specific frequency, where it gives the relatively large electric signal. Thus, the frequency of the acoustic wave can be detected based on the position of the resonance and the magnitude of the electric signals. To detect the

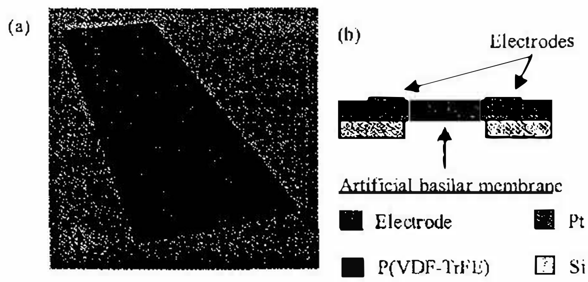

Fig. 1 Schematic of artificial cochlea (a) three dimensional view and (b) cross sectional view

frequency of acoustic wave range from 500 to 5,000 Hz by the device, the width of the membrane is linearly changed from 0.4 to 1.2 mm along x, whereas the length is designed to be 30 mm. The artificial cochlea is fabricated based on MEMS (Microelectromechanical Systems) and thin film technologies. The fabrication is started from the deposition of Pt film with the thickness of 460 nm on Si substrate. The piezoelectric material of P(VDF-TrFE) is formed on the Pt electrode with the thickness of 3.5 μm. The discrete electrodes are fabricated on the surface. To make the membrane flexible, the Si substrate is etched from the backside using Deep-RIE (Reactive Ion Etching).

The vibrating characteristics of the membrane are measured with mounting the device on a substrate with a fluid channel. The fluid channel is a model of cochlea duct and is filled with silicone oil of a model of lymph liquid. The sinusoidal acoustic wave at 75 dBSPL is applied to the artificial cochlea. Distance between speaker and artificial cochlea is 150 mm with tilt angle of 60 deg. The frequency is controlled from f = 1.0 to 15 kHz, where the range is in the human hearing. The vibrating amplitude is measured using Laser Doppler Vibrometer (LDV).

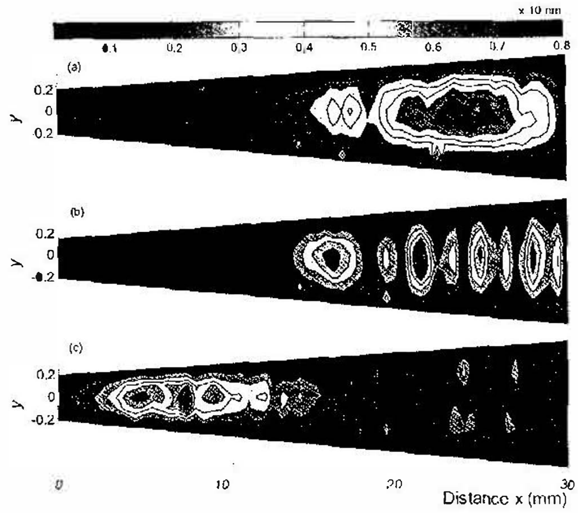

Fig. 2 Contour maps of the vibrating amplitude of artificial basilar membrane at f = (a) 1.45, (b) 3.95, (c) 10.6 kHz.

3. Results and discussion

Figure 2 shows the amplitude distribution at (a) 1.45, (b) 3.95 and (c) 10.6 kHz, respectively. The results show different vibrating behavior at each frequency. The amplitude increases at a certain local place, where the resonance is occurring. The places of the maximum amplitude at each frequency are different. The position x with the maximum amplitudes decreases as the frequency increases. Note that the local maximum amplitudes are considered as the results of the standing waves in x direction.

Figure 3 shows the frequency dependence of the vibrating amplitude at x = (a) 28.5, (b) 13.9 and (c) 5.8 mm, respectively. The amplitudes at different places show clear peaks at different frequencies. The frequency at the peak is considered as the resonant frequency at the local area of the membrane. The value seems higher at smaller x, i.e. the narrower area. This is corresponding to the results in Fig. 2. This feature is owing to the local mechanical boundary condition which is determined by the shape of the membrane. That is, the wavelength of the acoustic wave is affected by the width of the membrane.

Figure 4 shows the resonant frequency at various position x. The resonant frequency is ranged from 1.45 to 10.65 kHz and decrease as x. Compared with the theoretically predicted values of the frequency of 0.5~5 kHz, the measured ones are higher. The further discussion on the underestimation in the frequency should be carried out by increasing the number of the experiments.

4. Concluding remarks

Frequency selectivity of the artificial basilar membrane is confirmed at the range of 1.45 ~ 10.65 kHz. The resonant frequency increases as the width of the membrane decreases. The theoretically predicted value of the frequency is lower than the experimental measurement.

Acknowledgement

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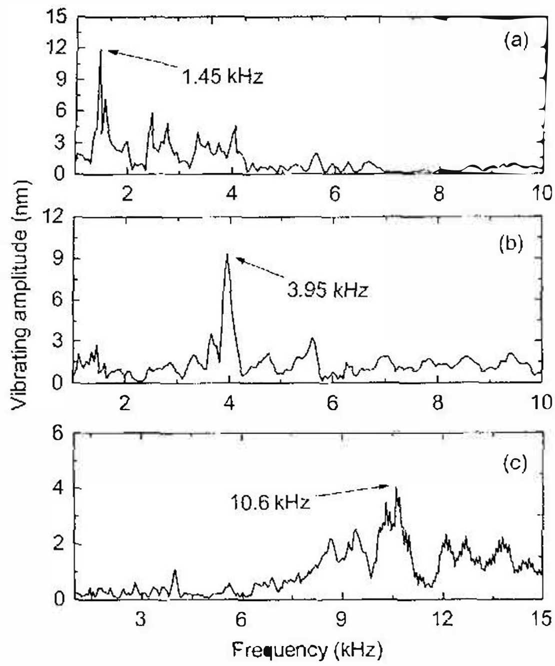

Fig. 3 Frequency dependence of vibrating amplitude of the artificial basilar membrane at x = (a)28.5, (b)13.9, (c)5.8 mm.

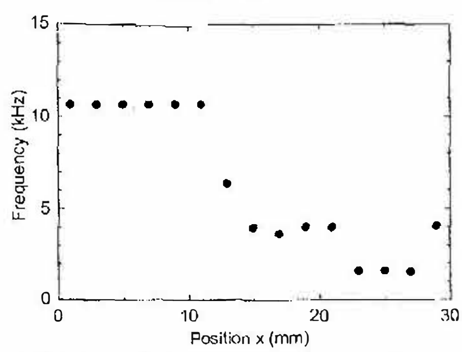

Fig.4 Relationship between position x and resonant frequency.