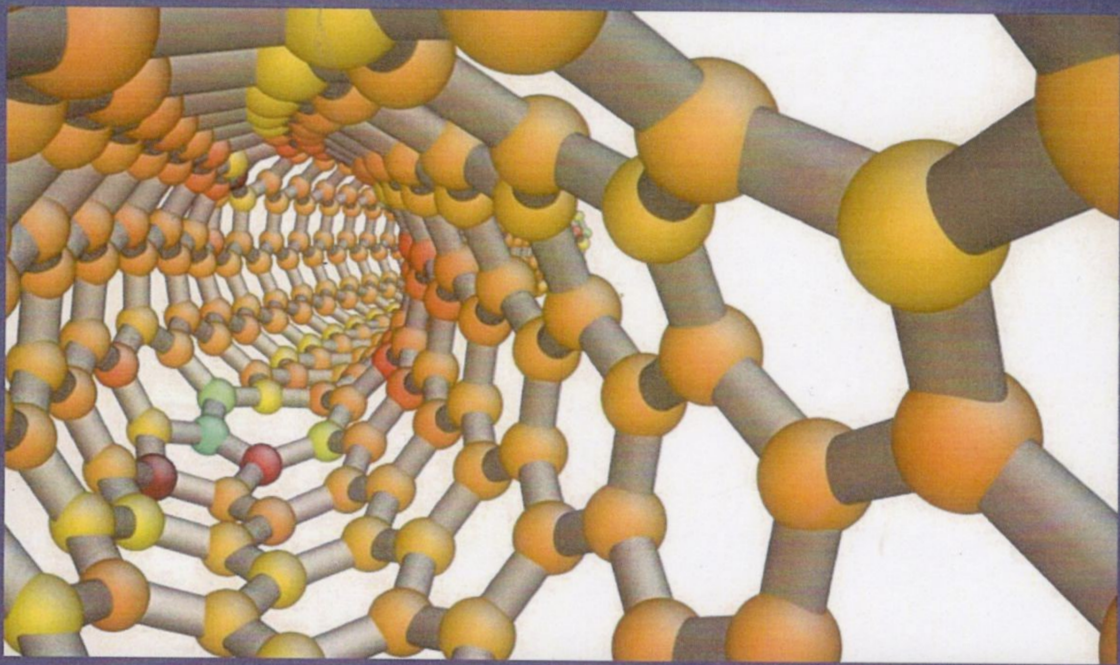
OSAKA UNIVERSITY

第４回非線形テクノサイエンス講演会

NONLINEAR TECHNO-SCIENCE



2009年3月 4日, 6日
基礎工学部大講義室

主催　基礎工学研究科未来研究ラボシステム
「非線形ダイナミクス」

「第４回非線形テクノサイエンス講演会」実行委員会

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（基）基礎工学研究科，（レ）レーザーエネルギー学研究センター

３月６日（金）

9:25 – 11:05 （座長：川野聡恭）

2A-1 Phase Field 法を用いた応力を受ける金属中の水素と欠陥の非線形

森　英喜（基），君塚　肇（基），尾方成信（基）

2A-2 温度成層下の水平平面間クエット乱流の構造 笹倉宗晃（基），河原源太（基）

2A-3 multilinear feedback を用いた結合振動子系の制御法 加納剛史（生），木下修一（生）

2A-4 攪拌槽内の３次元カオス混合の機構

井上義朗（基），橋本俊輔（基），高岡　大（基），岡田文太朗（基）

2A-5 反応拡散モデルを用いた無線センサネットワーク制御 若宮直紀（情），村田正幸（情）

11:05 – 11:15 （休憩）

11:15 – 12:00 【チュートリアル講演】 （座長：井上義朗）

2A - 6 乱流の統計法則と渦力学 河原源太（基）

12:00 – 13:00 （昼休み）

13:00 – 13:45 【チュートリアル講演】 （座長：井上義朗）

2B-1 生物のナノフォトニクス構造 木下修一（生），吉岡伸也（生）

13:45 – 14:30 【チュートリアル講演】 （座長：井上義朗）

2B-2 フィジオーム・システムバイオロジー：

生体機能の数理モデルを基軸とする生命科学の新しい試み 野村泰伸（基）

14:30 – 14:40 （休憩）

14:40 – 16:00 （座長：鈴木　貴）

2B-3 一塩基分解能を有する粗視化 DNA モデルの構築および動力学的考察

土井謙太郎（基），羽賀智章（基），豊北幸弘（基），川野聡恭（基）

2B-4 MEMS fabricated cochlea with frequency selectivity and acoustic/electric conversion

Harto Tanujaya（基）, Hirofumi Shintaku（基）, Dai Kitagawa（基）, Satoyuki Kawano（基）

2B-5 微粒子凝集体の形成と流動に関するＩＢ－ＤＥＭ解析

雪本隆幸（工・院），梶島岳夫（工），中村摩理子（工），竹内伸太郎（東大・工）

2B-6 コンピュータネットワークにおける最小遅延フローの安定化問題

見坂卓郎（基），金澤尚史（基），潮 俊光（基）

16:00 – 17:00 （座長：梶島岳夫）

2B-7 離散状態ニューロンとその応用 橋本　昇（基），鳥飼　弘幸（基）

2B-8 カイネティック理論から導出される臨界指数付き退化放物型方程式 高橋 亮（基）

2B-9 Hesse の３次曲線のトロピカル化と可解カオス写像 野邊 厚（基）

2B-4

MEMS fabricated cochlea with frequency selectivity and acoustic/electric conversion

Harto Tanujaya, Graduate School of Engineering Science
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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 structure. White et al.[3] developed a fully microfabricated cochlear model made of the polyimide membrane with Si_3N_4 beams. However, the frequency range is relatively higher than the audible frequency from 20 Hz to 20 kHz.

In this paper, we report a prototype device for the development of a fully self contained artificial cochlear, where the device realizes the frequency selectivity and generation of electrical output in the range of audible frequency. As a first step, we here focus on the basic characteristics of the device in atmosphere. The device consists of a piezoelectric sensor with a trapezoidal shape so as to generate the frequency-dependent electrical output. The vibration of the sensor is measured using laser Doppler vibrometer (LDV) to measure the frequency-dependence of the oscillation of sensor. The relationship between the oscillation and piezoelectric output is also investigated based on the experimental result. Moreover, the experimental result in terms of the local resonance frequency is compared with theoretical one based on the plate 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

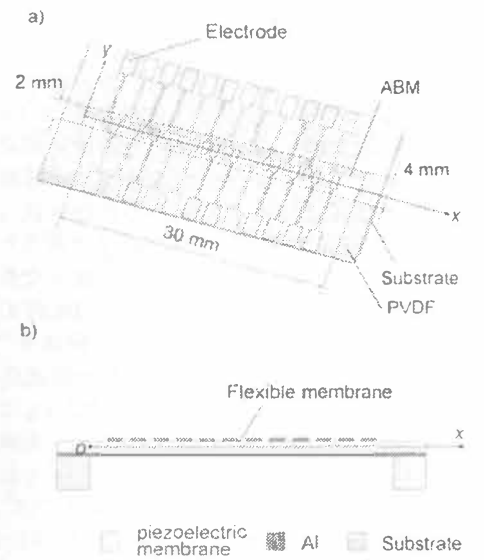

Fig. 1 Schematic of developed artificial cochlea

displacement. This realizes the frequency selectivity of the artificial cochlea with the association of the piezoelectric effect and electrode array. The electrode array with 24 elements made of aluminum thin film is fabricated on the PVDF membrane based on a standard photolithography and etching. The each electrode with the width of 0.5 mm is equally spaced 1.0 mm center to center, resulting in a gap of 0.5 mm between two adjacent electrodes, whereas the bottom electrode is prepared as a common electrode on the backside. The acoustic wave is generated using a speaker (FORTEX, Japan) which locates with 120 mm at a distance and 45 degree at a tilt. The frequency is controlled from 3 kHz to 20 kHz. The vertical velocity due to the acoustic wave is measured by LDV. The displacement which is converted from the velocity data is analyzed by FFT to obtain the amplitude of the oscillation from the spectrum data at the frequency of the applied acoustic wave. At the same time, the piezoelectric output from the electrodes is measured in terms of the voltage.

3. Results and Discussion

The amplitude distribution of the oscillation at 6 kHz, 9 kHz and 12 kHz are shown in Fig.2 (a), (b) and (c), respectively. The results clearly show the dependence of the oscillation on the frequency of the acoustic wave. There are some positions with the local maximum amplitude which are caused by the generation of the standing wave in x direction. Focusing on the global maximum amplitude which may be increased by the resonance, the position changes from right to left with increasing the frequency. This tendency may be induced by the proportionally changing width of the trapezoidal sensor along the x position. Since the curvature in x direction is relatively small compared to it in y direction due to the geometrical shape of the sensor, the local wave length of the oscillation mainly depends on the width at a certain x position. Then, the higher local resonance frequency can be obtained at the place where the width of the sensor is narrower.

The relationships between the x position of the electrodes and piezoelectric output at 5 kHz and 7 kHz are shown in Fig. 3 (a) and (b), respectively. For reference, the distribution of the oscillation amplitude on x axis is plotted by thin line. The piezoelectric output shows the similar dependence with the oscillation, where the shape of the distribution qualitatively agrees well. In addition, the relationship between position x of electrodes and the frequency f_p is obtained as shown in Fig.4, where the piezoelectric output shows the maximum amplitude at f_p. The f_p increases from 3 kHz to 12 kHz with decreasing the position x of electrodes. This result suggests the applicability of the developed device in terms of the frequency selectivity. The f_p is compared with the relationship between the local resonance frequency f_r and the position x in Fig.4. The f_r shows the similar values with f_p. This indicates that the frequency selectivity in the piezoelectric output is induced by the local resonance of the oscillation of the sensor. Furthermore, f_p is compared with the theoretical f_r based on the plate bending theory solved by the WKB (Wentzel-Kramers-Brillouin) asymptotic method[4]. The comparison shows the reasonable agreement between them. and the validity of theoretical analysis is confirmed. Considering the fact that the audible frequency is ranged from 20 Hz to 20 kHz, the developed device covers only a part of it. The theoretical analysis predicts that the frequency range can be reduced by using thinner membranes, for example, it can be reduced from 1 kHz to 3.5 kHz with the 10 μm thick membrane. The optimized device can be easily fabricated by the used of microfabrication technologies and the applicability of it will be discussed in the future work.

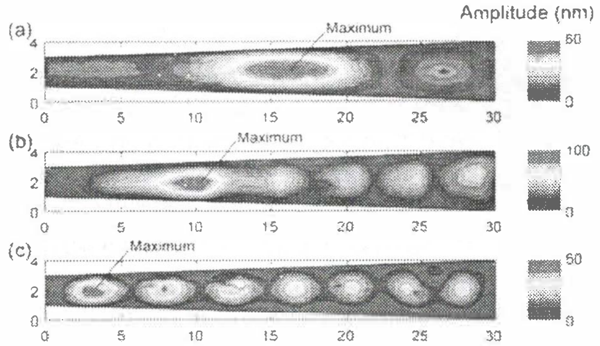

Fig. 2 Contour maps of oscillation amplitude at (a) 6 kHz, (b) 9 kHz and (c) 12 kHz

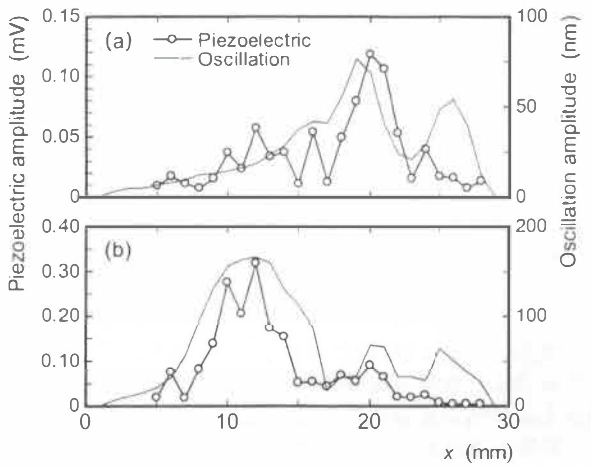

Fig. 3 Oscillation amplitude and piezoelectric one for various position x at (a) 5 kHz and (b) 7 kHz.

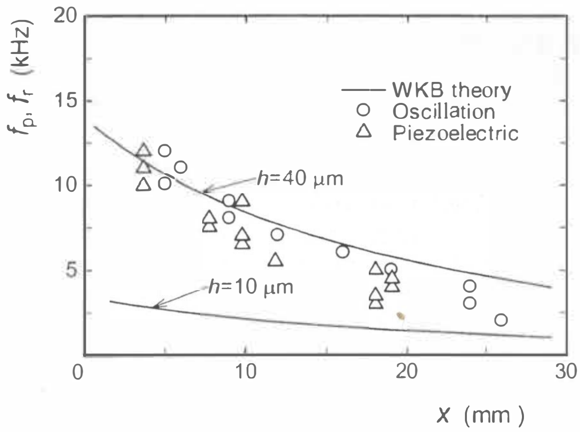

Fig. 4 Dependence of local resonance frequencies of f_p and f_r on the position x for various thickness h of PVDF sensor

References

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