Feasibility Study of Cochlear-like Acoustic Sensor using PMN-PT Single Crystal Cantilever Array

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ABSTRACT

We have fabricated piezoelectric PMN-PT single crystal cantilever array which has the cantilever size of the width of 200 um and the thickness of 10um. The length of cantilever was adjusted with a parameter of resonance frequency. Resonance frequency of PMN-PT cantilevers was measured with laser interferometer and charge sensitivity was measured with charge measuring device. PMN-PT cantilever array was installed on a noise shied case and exposed with sound pressure of specific frequency corresponding to resonance frequency and sensitivity of sound pressure was measured. The experimental results show that the PMN-PT cantilever array exhibits high sensitivity. This implies that the single crystal PMN-PT cantilever array has a potential candidate as cochlear like acoustic sensor.

Keywords: pmn-pt, piezoelectric, cantilever array, resonance, acoustic sensor

1 INTRODUCTION

Researches of artificial sensory system mimicking human and animal senses are increasing with worldwide trend to find the solution from the nature. The mammalian cochlea is an organ that performs the conversion of the incoming mechanical energy into electrical signals in the auditory nerve fibers. Current artificial cochlea has been developed in an effort to restore sensorineural hearing loss of patient. The artificial cochlea, one of the commercialized artificial sensory, consists of microphone for converting sound to electrical signal, signal processor for handling sound signal, inductive coil for transmitting sound signal from outside to inside of body, and electrode array for stimulating nerve cells. Current technologies of the artificial cochlea are difficult to enable the majority of the hearing-impaired people the good benefits due to the expense, inconvenience, frequent recharging requirement due to large power consumption [1, 2]. Piezoelectric materials possess the unique property of being able to generate electric charge when a mechanical force is applied to them, i.e., they are transducers capable of converting mechanical energy into electrical energy. Conceptually speaking, these materials are ideally suited as replacement "organs" for the nonexistent transduction mechanism in patients suffering from profound sensorineural hearing loss [3].

In this paper, we have studied the feasibility of use of PMN-PT($(1\text{-}x)Pb(Mg_{1/3}Nb_{2/3})O_3\text{-}xPbTiO_3$) single-crystal piezoelectric cantilever array as an alternative of conventional artificial cochlea. The PMN-PT material has been shown to possess piezoelectric coefficient and electro-mechanical coupling responses significantly larger than conventional ceramics [3]. We have fabricated piezoelectric PMN-PT cantilever array which has the cantilever size of the width of 200 um and the thickness of 10um. The length of cantilever was adjusted with a parameter of resonance frequency. Resonance frequency of PMN-PT cantilevers was measured with laser interferometer and charge sensitivity was measured with charge measuring device. PMN-PT cantilever array was exposed with sound pressure of specific frequency corresponding to resonance frequency and sensitivity of sound pressure was measured. The experimental results show that the PMN-PT cantilever array exhibits high sensitivity. This implies that the single crystal PMN-PT cantilever array has a potential candidate as cochlear like acoustic sensor.

2 EXPERIMENTAL PROCEDURE

2.1 Fabrication of PMN-PT cantilever

Figure 1 shows the dimensions of PMN-PT single crystal cantilever and interdigitated electrode. The cantilever is designed with width of 200 ㎛, thickness of 13 ㎛ and length of 1500 ㎛. A pair of interdigitated electrodes are designed with comb width of 5 ㎛ and comb gap of 10 ㎛. The interdigitated electrodes are located at supporting position of PMN-PT cantilever. It is good for getting maximum charge output from interdigitated electrodes or large deflection from free end of cantilever.

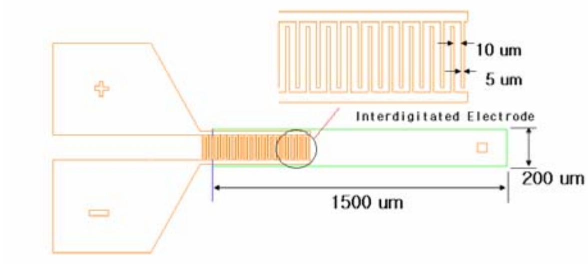


Figure 1: Dimensions of PMN-PT cantilever and interdigitated electrode.

Figure 2 shows the steps required to fabricate a PMN-PT single crystal cantilever type sensor. We use <001>-oriented and poled 20 um-thick PMN-PT single crystal glued on a Si substrate. The sample undergoes a mechanical polishing down to 20~25 µm-thick film. Next, Inductively Coupled Plasma (ICP) etching process is used to thin the film down to 13 µm. For the upper electrode patterning, Au e-beam sputtering is used following the Photo Resistive coating for lift off process. ICP etching process is again applied to define the cantilever shape. As a final step, back side etching with deep RIE etching is used for releasing the cantilever.

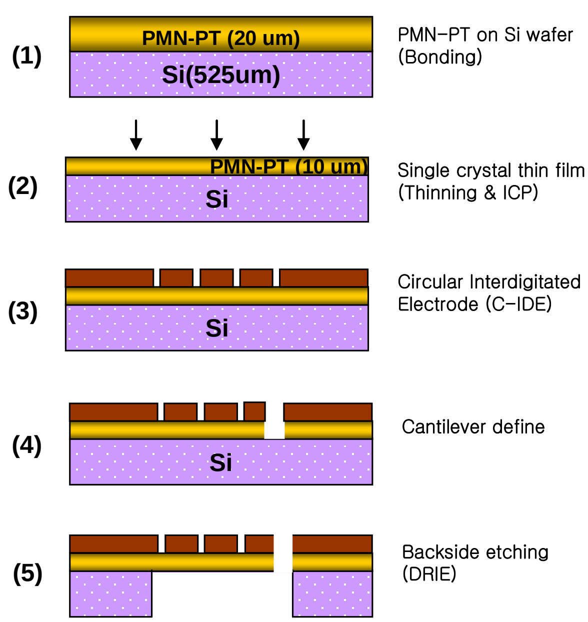
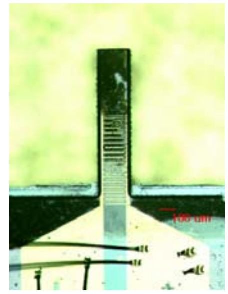
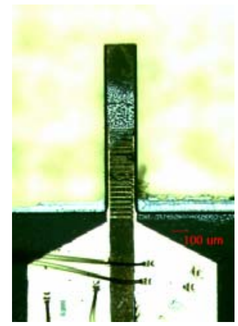


Figure 2: Semiconducting process of PMN-PT single crystal cantilever.

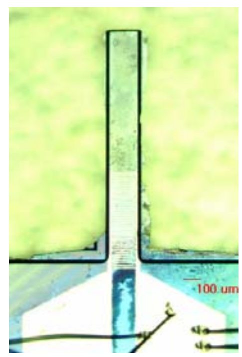
Figure 3 shows the PMN-PT single crystal cantilever fabricated with semiconducting process. Figure 3 (a), (b), (c) and (d) shows length of 900 ㎛, 1000 ㎛, 1300 ㎛ and 1500 ㎛. Wire bonding was performed for each of two cantilevers with same length.



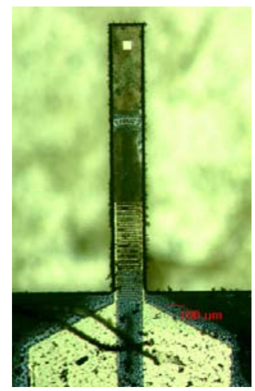
(a) Length= 900 ㎛



(b) Length= 1000 ㎛



(c) Length= 1300 ㎛



(d) Length= 1500 ㎛

Figure 3: The fabricated PMN-PT single crystal cantilever with different length.

2.2 Characterization of PMN-PT cantilever

To measure a resonance frequency of a fabricated PMN-PT single crystal cantilever, the probe was connected with plus and minus electrode of PMN-PT single crystal cantilever. The voltage signal of DC 2.5 V and AC 1.0 V_{p-p} with a sine wave form between 200 Hz and 4000 Hz was provided on the probe. The electric field was generated between the interdigitated electrodes and the deflection of cantilever was generated with sine wave signal. The experimental setup for measuring the deflection of PMN-PT cantilever was consisted of vibrometer controller(Polytec OFV-5000), Fiber interferometer(Polytec OFV-512) and dynamic signal analyzer(Agilent 35670A). The measured deflection of PMN-PT cantilever was about 13 ㎛ p-p. Also we have measured impedance and phase values using HP 4194A impedance analyzer. Figure 4 shows measuring results of impedance and phase value. The resonance frequencies of the same length of two cantilevers were measured with 4.25 kHz and 4.96 kHz respectively.

NSTI-Nanotech 2008, www.nsti.org, ISBN 978-1-4200-8505-1 Vol. 3

Table 1 shows designed and measured values of resonance frequency for PMN-PT single crystal cantilevers using HP 4194A impedance analyzer. It was verified that two cantilevers of the same length has some different resonance frequency. The measured resonance frequency is similar with designed frequency. The density and elastic modulus used for designing PMN-PT single crystal cantilever was 8,200 kg/m^3 and 20.0 GPa.

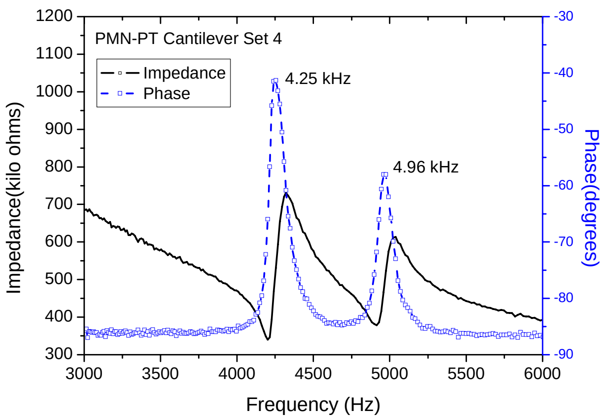


Figure 4: Measurement result of impedance and phase for PMN-PT cantilever set 4 using impedance analyzer.

Cantilever length (㎛)	Resonance frequency (measured) (kHz)	Resonance frequency (designed) (kHz)	Remarks
1500	1.74/1.93	1.46	Cant. Set 1
1300	2.41/2.62	1.94	Cant. Set 2
1000	3.26/3.97	3.28	Cant. Set 3
900	4.25/4.96	4.05	Cant. Set 4

Table 1: Measuring results of resonance frequency for PMN-PT single crystal cantilever.

The mechanism of generating a charge in a piezoelectric PMN-PT cantilever is as follows; as PMN-PT cantilever deflects along the interdigitated electrode, causing stress on the cantilever, the variation of stress in the cantilever produces self-generated charges on the interdigitated electrode. The charges are not generated by the static stress, but by the variation of stress. Figure 5 shows an experimental setup of charge measuring system which can measure piezoelectric charges from PMN-PT single crystal cantilever. Charge measuring system was consisted of differential charge amplifier, laser displacement measuring device and precision displacement actuator. A differential charge amplifier has used feedback capacitance and feedback resistance of 5 pF and 22 MΩ. The generated charge signal is amplified by 10 times with instrumental amplifier.

To reduce a measuring noise, the PMN-PT single crystal cantilever was directly installed on the circuit board of charge amplifier. Precise piezoelectric actuator was used to test PMN-PT single crystal cantilever with displacement range of 40 nm to 330 nm using a square wave of 10 Hz. Piezoelectric charge was measured with charge measuring system as the piezo actuator moves up and down while the tip of cantilever just is contacted with piezo actuator. The deflection was measured with laser diode and photo sensitive detector.

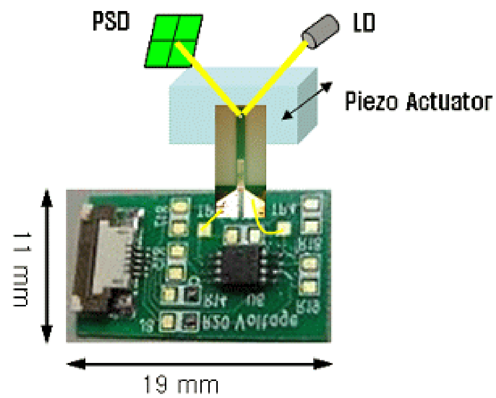


Figure 5: Experimental setup for charge measurement of PMN-PT single crystal cantilever.

3 RESULTS AND DISCUSSIONS

Figure 6 shows a measuring result of charge sensitivity due to a deflection of PMN-PT single crystal cantilever. We measured two samples of PMN-PT single crystal cantilever. The charge signals were linearly proportional to the cantilever deflection. The charge sensitivity of two samples was measured with 2.1 fC/nm and 2.2 fC/nm respectively.

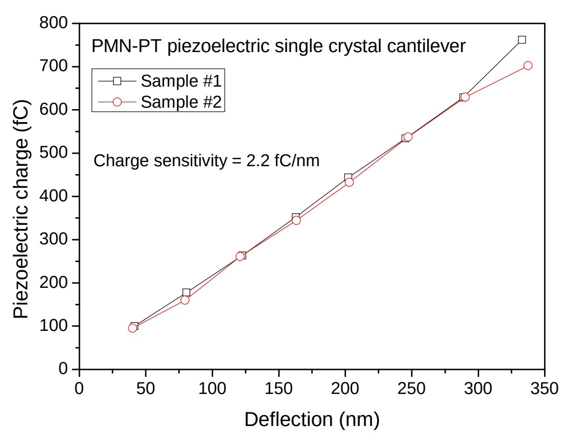


Figure 6: Piezoelectric charge output as a function of PMN-PT cantilever deflection.

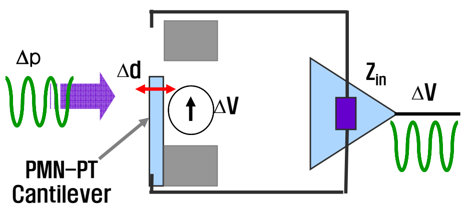


Figure 7: The schematic diagram of acoustic sensitivity measurement for PMN-PT cantilever.

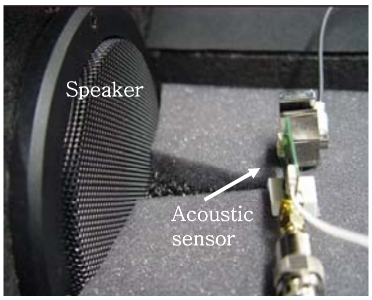


Figure 8: The experimental setup for acoustic sensitivity measurement of PMN-PT cantilever.

Figure 7 shows schematic diagram of acoustic sensitivity measurement for PMN-PT cantilever. When the sound pressure is applied to the cantilever, it is resonated at a specific frequency. It generates the charge signal with the piezoelectric property and is amplified to the output voltage signal. Figure 8 shows the experimental setup for acoustic sensitivity measurement. The PMN-PT cantilever, charge amplifier and reference microphone are installed at 4 cm distance from speaker. This experimental setup was inserted into anechoic test box(type 4232 B&K) to reduce a surrounding noise. Speaker makes the equalized sound pressure of 1 Pa from 1 kHz to 6 kHz with sound signal sweep. The charge signal generated from PMN-PT cantilever was processed with sound processing software.

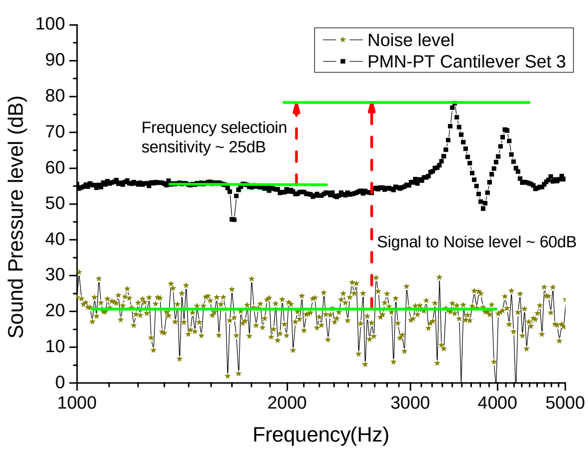


Figure 9: The acoustic sensitivity of cantilever set 3.

Figure 9 shows the acoustic sensitivity and its signal to noise ratio of PMN-PT cantilever set 3. This PMN-PT cantilever can detect the signal with 1000 times of signal to noise ratio and can selectively detect the specific frequency with 18 times higher signal level. Figure 10 shows the experimental results of the acoustic sensitivity for each set of PMN-PT cantilever. The resonance frequencies from 1,741 Hz to 4,960 Hz are obtained from four set of PMN-PT cantilever.

From this study, it was verified that the fabricated PMN-PT cantilever can detect the signal with 1000 times of signal to noise ratio and can selectively detect the specific frequency. In conclusion there is quite a possibility that PMN-PT single crystal cantilever may use as cochlear-like acoustic sensor.

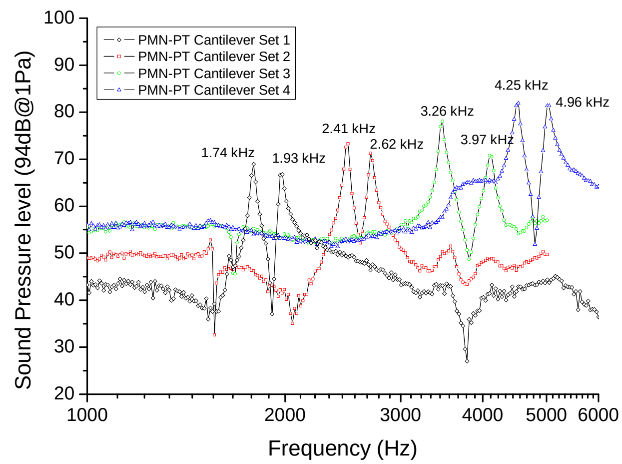


Figure 10: The experimental results of acoustic sensitivity for each PMN-PT cantilever.

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