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Temporary Packaging of PZT Thin-Film Microactuators

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ABSTRACT

This paper is to demonstrate a temporary encapsulating technique that uses photoresist to package PZT thin-film microactuators for an experimental inner ear implant. The microactuator consists of a diaphragm suspension, a bottom electrode, a PZT thin film, and a top electrode. The dimensions of the microactuator and the diaphragm suspension are 3 m × 3 m × 400 μm and 900 μm × 900 μm × 0.95 μm, respectively. A layer of photoresist (AZ1512) with a thickness around 4–16 μm is brushed over the diaphragm suspension as the packaging material. The advantage of this temporary packaging technique is twofold. First, it does not substantially increase the size of the PZT thin-film microactuators. Second, it is waterproof thus allowing the microactuators to function in aqueous environments. To evaluate how the temporary package affects the performance of the microactuator, a function generator drives the microactuator at 1, 3, 5, and 10 kHz and a laser vibrometer measures the vibration of the diaphragm suspension before and after the microactuator is packaged. Experimental measurements show that the presence of the package reduces the gain of the microactuator from 0.33 nm/V to 0.15 nm/V. Also, an impedance analyzer measures the impedance of the packaged microactuator, while it is driven in air and in water. The measured impedance shows no difference in air and in water. This indicates that the temporary package is waterproof and the actuator is strong enough to function in an aqueous environment.

Keywords: PZT thin films, microactuators, photoresist, packaging, laser vibrometer, impedance

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INTRODUCTION

Lead Zirconate Titanate Oxide ($PbZr_{1-x}Ti_xO_3$ or PZT) thin-film actuators have received increasing attention in the last decade because of their wide applications, such as atomic force microscopes (AFM) [1, 2], ultrasonic micromotors [3–6], one- or two-dimensional scanners [7–9], microswitches [10], resonators [11, 12], and dual-stage actuators/sliders for next-generation computer hard disk drives [13–15]. Advantages of PZT thin-film microactuators include large actuation strength and high frequency bandwidth.

In real applications, PZT thin-film microactuators need to be packaged in order to function properly. As an example, recent development of hybrid cochlear implants (HCI) demonstrates the needs for proper packaging of PZT thin-film microactuators [16]. HCI consists of an electrode array and a piezoelectric microactuator; see Fig. 1. The electrode array emits electrical signals to restore high-frequency hearing as in traditional cochlear implants. An intracochlear piezoelectric microactuator delivers a pressure wave directly to the perilymph fluid in the cochlea to augment the response of hair cells to auditory stimuli in the low-frequency range. According to [17–19], the combination of electrical and acoustical stimulation could outperform traditional hearing aids or cochlear implants in terms of word recognition in environments with significant background noise.

The PZT thin-film microactuator in HCI must meet several stringent requirements. First, the size of the microactuator must be less than 800 μm × 1200 μm × 400 μm to fit into the cochlea. Second, the displacement of the microactuator must be large enough (e.g., 300 nm) to generate the pressure wave for hearing rehabilitation. Third, the microactuator must remain functional in aqueous environments, because the cochlea is filled with perilymph fluid.

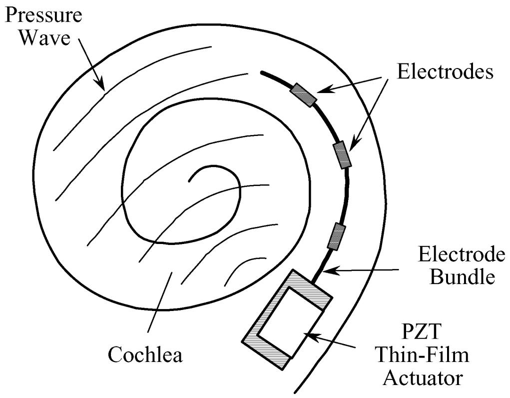


Figure 1. Concept of hybrid cochlear implants.

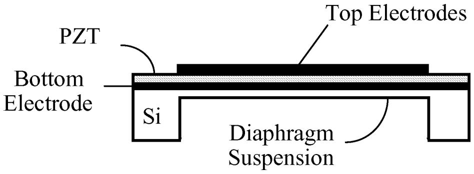


Figure 2. Design of PZT thin-film microactuator for HCI.

Figure 2 shows the design of a PZT thin-film microactuator being developed for HCI. The microactuator consists of a diaphragm suspension, a bottom electrode, a PZT thin film, and a top electrode. The diaphragm suspension is to facilitate localized vibration of the microactuator, which in turns generates the pressure waves. The thickness of the diaphragm suspension is usually on the order of 1–2 μm. Such a design can be realized using sol-gel processes as shown in Fig. 3. The first step is to deposit the bottom electrode on a silicon substrate (Fig. 3(a)). The second step is to dip-coat or spin-coat PZT sol onto the substrate; see Fig. 3(b). Third, the PZT/silicon structure is sintered at 650°C to densify the PZT film (Fig. 3(c)). Then, the top electrode is deposited; see Fig. 3(d). Finally, the backside of the silicon is etched via deep reactive ion etch (DRIE) to form a diaphragm (Fig. 3(e)). Finally, the microactuator is diced off the silicon wafer.

The fabricated microactuator, however, needs to be packaged before it can be used. The microactuator must have lead wires for the bottom and top electrodes. Also, the microactuator must have a protective layer over the electrodes. Otherwise, the top and bottom electrodes will get shorted once the microactuator is immersed in the perilymph fluid inside the cochlea. Note that the presence of the packaging (i.e., the lead wires and the protective layers) cannot substantially increase the size of the microactuator. Otherwise, the

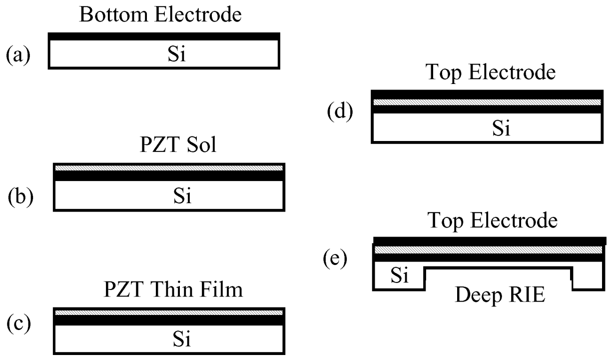


Figure 3. Sol-gel process for PZT thin films.

microactuator may not fit in the cochlea. Also, the presence of the packaging cannot substantially degrade the performance of the microactuator (i.e., 300 nm displacement gain).

The purpose of this paper is to develop temporary packaging for PZT thin-film microactuator and to evaluate the effect of the temporary packaging on the performance of the microactuator. The temporary packaging is a thin layer of photoresist over the diaphragm suspension and around the electrodes and lead wires. This temporary packaging has several advantages. First, it does not substantially increase the size of the PZT thin-film microactuators. Second, it is waterproof thus allowing the microactuators to function in aqueous environments. Third, it is very easy to implement; therefore, it is suitable for short-term uses, such as animal trials.

For the rest of the paper, we first explain the temporary packaging in detail, such as lead wire arrangements and photoresist insulation layer. To evaluate the effect of the packaging, we conduct vibration experiments on the microactuators with and without the packaging. Finally, the packaged microactuator is tested in air and in water to evaluate the functionality of the packaging.

TEMPORARY PACKAGING

Packaging of PZT thin-film microactuators can be permanent or temporary. Permanent packaging is designed for long-term use, such as implants. In the case of hybrid cochlear implants, permanent packaging will require impermeable and biocompatible encapsulation of the PZT thin-film microactuators. Possible encapsulation materials thus include glass and platinum for example. Due to these requirements, development of decent permanent packaging for PZT thin-film microactuators is extremely time-consuming and costly. In contrast, temporary packaging is a low-cost solution designed only for short-term use. Moreover, biocompatibility is less a consideration than the functionality for temporary packaging. In the case of hybrid cochlear implants, temporary packaging is particularly useful for animal trials that take several weeks or a month to complete.

The focus of this paper is temporary packaging of PZT thin-film microactuators. Fig. 4 shows a temporary packaging developed at the University of Washington. The temporary packaging consists of lead wires to bottom and top electrodes and photoresist package. A lead wire is attached to the side of the bottom electrode using silver paste in order not to substantially increase the dimension of the microactuator. A second lead wire is attached to a corner of the top electrode in order not to substantially decrease the amplitude of the microactuator. A layer of photoresist (AZ1512), with thickness in the range of 4–16 μm, is brushed over the diaphragm suspension to protect the electrodes and the lead wire. Although the photoresist is 10 times thicker than

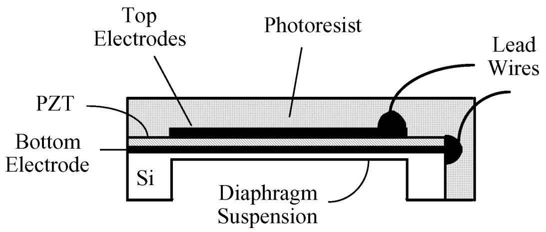


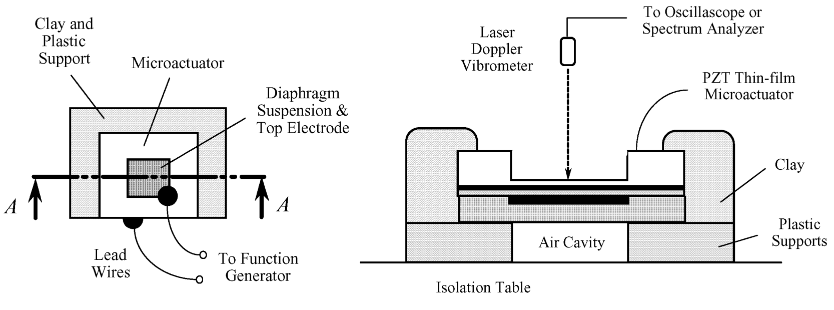
Figure 4. Temporary packaging of PZT thin-film microactuators.

the diaphragm suspension, the presence of the photoresist package will not substantially reduce the actuator gain, because photoresist is much softer than the diaphragm suspension.

EXPERIMENTAL SETUP AND RESULTS

In the experiment, the microactuator to be packaged has a size of 3 mm × 3 mm × 400 μm. Also, the dimensions of the diaphragm suspension are 900 μm × 900 μm × 0.95 μm. A layer of photoresist with a thickness of 4–16 μm is coated over and around the diaphragm suspension as the packaging material.

Figure 5 shows the experimental setup to evaluate the performance of the PZT thin-film microactuator with and without the packaging; see Fig. 5(a) for the bottom view and Fig. 5(b) for the section view from Section *AA*. The microactuator (without photoresist) is first mounted on a plastic support with clay in an up-side-down manner so that the lead wires can come out of the plastic support through the air cavity. A laser Doppler vibrometer measures the vibration of the microactuator, which is driven by a function generator and an



(a) Bottom View (b) *AA* Section View

Figure 5. Experimental setup; (a) bottom view and (b) view from section AA.

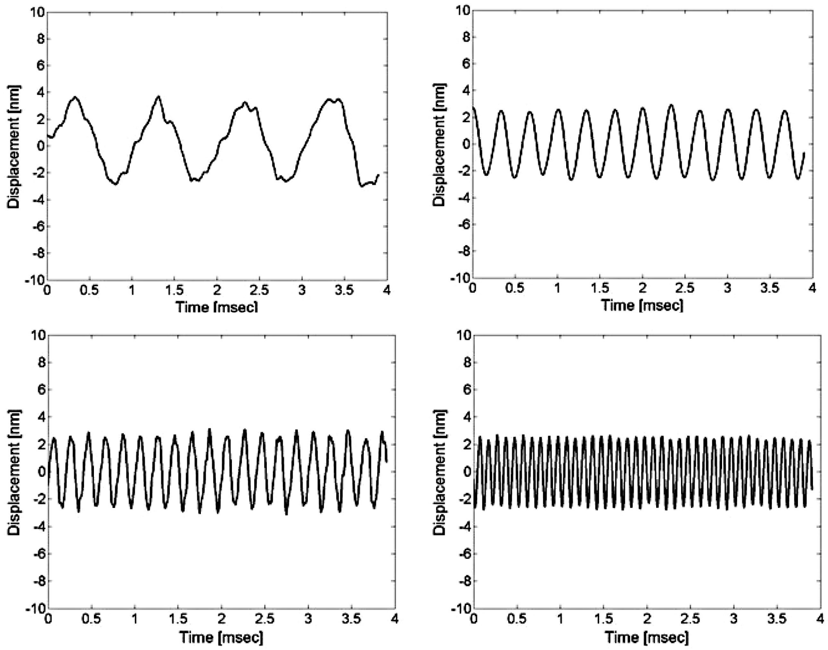


Figure 6. Time response of a microactuator without photoresist driven at 1, 3, 5, and 10 kHz.

amplifier. The microactuator is then removed from the test stand and coated with a layer of photoresist. Again, the microactuator (now with photoresist) is mounted on the plastic support with clay, and its vibration is measured for comparison.

Figure 6 shows the time response measured from the laser vibrometer, when an unpackaged microactuator (without photoresist) is driven sinusoidally at 1, 3, 5, and 10 kHz with amplitude of 7.5 Volts. In this measurement, the laser aims at the center of the diaphragm suspension. The measured response is consistently around 2.5 nm. Figure 7 shows the frequency response measured from the laser vibrometer. The measurement indicates that the response is very much independent of frequency and is roughly 0.33 nm/V.

Fig. 8 shows the time response measured from the laser vibrometer, when the microactuator is fully packaged. The actuator is driven sinusoidally at 1, 3, 5, and 10 kHz with amplitude of 7.5 Volts. Again, the laser aims at the center of the diaphragm suspension. The measured response is consistently around 1 nm. Fig. 9 shows the frequency response measured from the laser vibrometer. The measurement indicates that the response is very much independent of frequency and is roughly 0.15 nm/V. Obviously, the presence of the photoresist as a packaging material has reduced the amplitude of the microactuator.

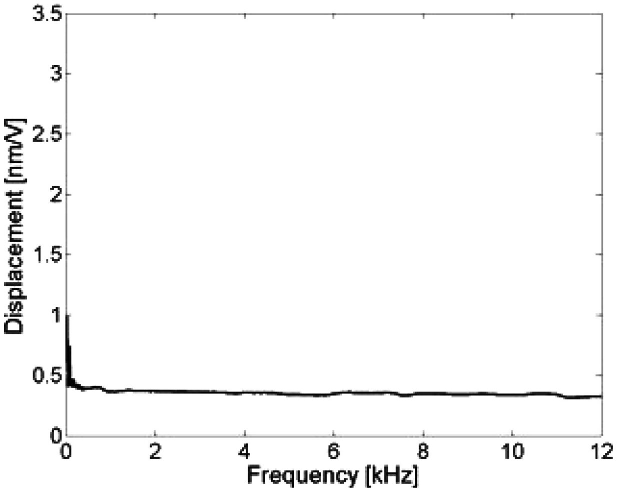


Figure 7. Frequency response of PZT thin-film microactuator without photoresist.

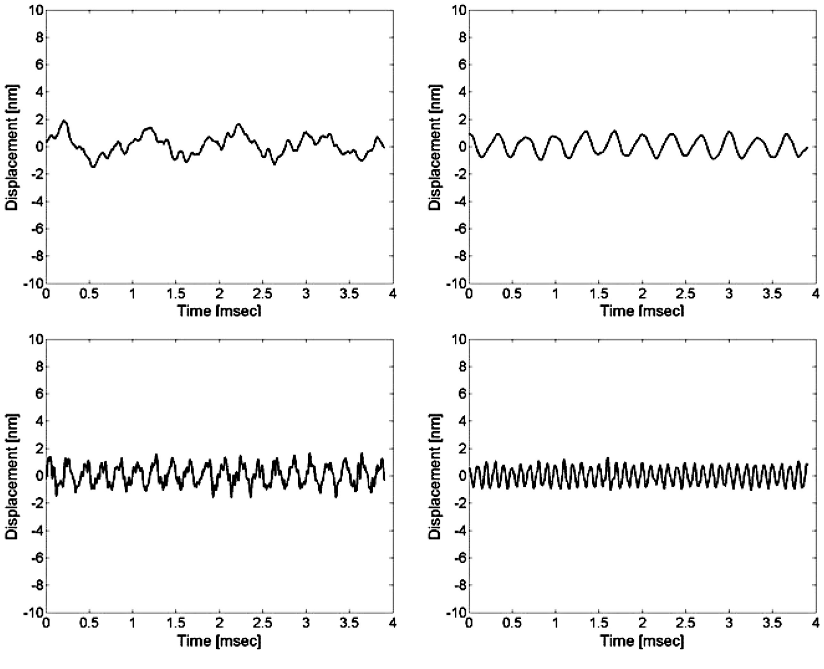


Figure 8. Time response of a microactuator with photoresist driven at 1, 3, 5, and 10 kHz.

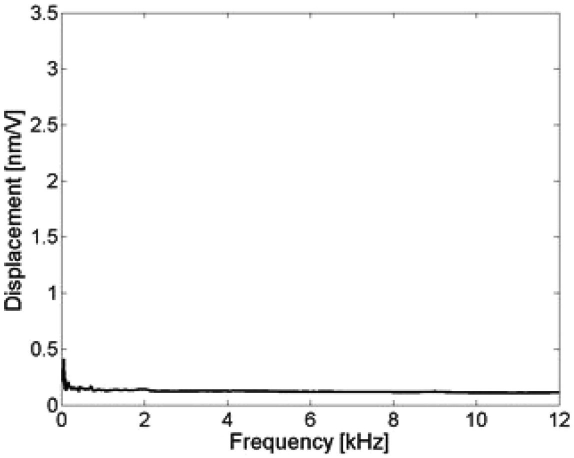


Figure 9. Frequency response of PZT thin-film microactuator with photoresist.

AQUAEOUS ENVIRONMENTS

After the microactuator is packaged, it is necessary to test the microactuator in an aqueous environment. The purpose of the test is twofold. First, the test is to find out if the temporary package is waterproof. If it is, the microactuator will remain functional in the aqueous environment (i.e., no short circuits). Second, the test is to find out if the aqueous environment will serve as a significant load and affect the performance of the PZT thin-film microactuator.

Since the laser vibrometer cannot measure vibration of an object in aqueous environments, the experimental setup shown in Fig. 5 needs to be modified. Instead of using laser vibrometer, we use an impedance analyzer to measure the impedance of the PZT thin-film microactuator. If the aqueous environment causes the microactuator to short-circuit or impose a significant load to the microactuator, the measured impedance will change significantly. The experiment consists of two parts. The first part is to measure the impedance using the setup in Fig. 5, while the packaged microactuator is in the air. In the second part, the packaged microactuator along with the experimental setup is submerged in water while the impedance is measured.

Figure 10 shows the measured impedance in air (Fig. 10(a)) and in water (Fig. 10(b)) as the frequency varies from 10 Hz to 100 kHz. Note that the impedance, plotted in a log-log scale, is a straight line with a negative slope. This indicates that the PZT thin film behaves like a capacitor in this frequency range. The impedance in air and in water is almost identical. This implies that the packaging material is waterproof and the surrounding water does not impose a significant load to the PZT thin-film microactuator.

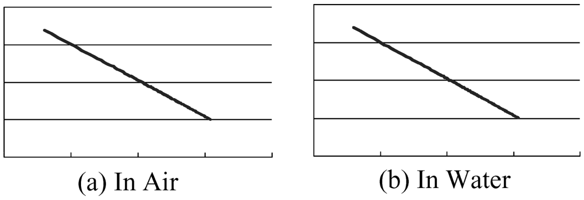

(a) In Air
(b) In Water

Figure 10. Measured impedance; (a) in air and (b) in water.

CONCLUSIONS

In this paper, we demonstrated a simple method to achieve temporary packaging of PZT thin-film microactuators. The temporary packaging includes lead wires for the top and bottom electrodes on the side via silver paste and a photoresist layer around the electrodes. Experiments were conducted using a laser vibrometer and an impedance analyzer to evaluate the performance of the PZT thin-film microactuators and the effect of the temporary package. Experimental results show that the presence of photoresist package reduces vibration amplitude of the PZT thin-film microactuator from 0.33 nm/V to 0.15 nm/V. Impedance measurements indicate that the package is waterproof and the PZT thin-film microactuator remains functional in an aqueous environment.

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