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Temporary Packaging of PZT Thin-Film Microactuators

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ABSTRACT

14 This paper is to demonstrate a temporary encapsulating technique that uses photoresist 15 to package PZT thin-film microactuators for an experimental inner ear implant. The 16 microactuator consists of a diaphragm suspension, a bottom electrode, a PZT thin 17 film, and a top electrode. The dimensions of the microactuator and the diaphragm 18 suspension are 3 m \times 3 m \times 400 μ m and 900 μ m \times 900 μ m \times 0.95 μ m, respectively. 19 A layer of photoresist (AZ1512) with a thickness around 4–16 μ m is brushed over 20 the diaphragm suspension as the packaging material. The advantage of this temporary 21 packaging technique is twofold. First, it does not substantially increase the size of the 22 PZT thin-film microactuators. Second, it is waterproof thus allowing the microactuators 23 to function in aqueous environments. To evaluate how the temporary package affects the 24 performance of the microactuator, a function generator drives the microactuator at 1, 3, 25 5, and 10 kHz and a laser vibrometer measures the vibration of the diaphragm suspension 26 before and after the microactuator is packaged. Experimental measurements show that 27 the presence of the package reduces the gain of the microactuator from 0.33 nm/V 28 to 0.15 nm/V. Also, an impedance analyzer measures the impedance of the packaged 29 microactuator, while it is driven in air and in water. The measured impedance shows no 30 difference in air and in water. This indicates that the temporary package is waterproof 31 and the actuator is strong enough to function in an aqueous environment.

32 Keywords: PZT thin films, microactuators, photoresist, packaging, laser vibrometer,33 impedance

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INTRODUCTION

Lead Zirconate Titanate Oxide (PbZr_{1-x} Ti_xO_3 or PZT) thin-film actuators have 35 received increasing attention in the last decade because of their wide applications, such as atomic force microscopes (AFM) [1, 2], ultrasonic micromotors 37 [3–6], one- or two-dimensional scanners [7–9], microswitches [10], resonators 38 [11, 12], and dual-stage actuators/sliders for next-generation computer hard 39 disk drives [13–15]. Advantages of PZT thin-film microactuators include large 40 actuation strength and high frequency bandwidth. 41

In real applications, PZT thin-film microactuators need to be packaged 42 in order to function properly. As an example, recent development of hybrid 43 cochlear implants (HCI) demonstrates the needs for proper packaging of PZT 44 thin-film microactuators [16]. HCI consists of an electrode array and a piezo-45 electric microactuator; see Fig. 1. The electrode array emits electrical signals 46 to restore high-frequency hearing as in traditional cochlear implants. An intra-47 cochlear piezoelectric microactuator delivers a pressure wave directly to the 48 perilymph fluid in the cochlea to augment the response of hair cells to auditory 49 stimuli in the low-frequency range. According to [17–19], the combination 50 of electrical and acoustical stimulation could outperform traditional hearing 51 aids or cochlear implants in terms of word recognition in environments with 52 significant background noise. 53

The PZT thin-film microactuator in HCI must meet several stringent requirements. First, the size of the microactuator must be less than 800 μ m × 55 1200 μ m × 400 μ m 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. 59



Figure 1. Concept of hybrid cochlear implants.





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

60 Figure 2 shows the design of a PZT thin-film microactuator being devel-61 oped for HCI. The microactuator consists of a diaphragm suspension, a bottom electrode, a PZT thin film, and a top electrode. The diaphragm suspension is 62 to facilitate localized vibration of the microactuator, which in turns generates 63 the pressure waves. The thickness of the diaphragm suspension is usually on 64 the order of $1-2 \mu m$. Such a design can be realized using sol-gel processes as 65 shown in Fig. 3. The first step is to deposit the bottom electrode on a silicon 66 67 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 68 69 to densify the PZT film (Fig. 3(c)). Then, the top electrode is deposited; see 70 Fig. 3(d). Finally, the backside of the silicon is etched via deep reactive ion etch 71 (DRIE) to form a diaphragm (Fig. 3(e)). Finally, the microactuator is diced off 72 the silicon wafer. 73 The fabricated microactuator, however, needs to be packaged before it 74 can be used. The microactuator must have lead wires for the bottom and 75 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)

79 cannot substantially increase the size of the microactuator. Otherwise, the



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

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microactuator may not fit in the cochlea. Also, the presence of the packaging 80 cannot substantially degrade the performance of the microactuator (i.e., 300 nm 81 displacement gain). 82

The purpose of this paper is to develop temporary packaging for PZT 83 thin-film microactuator and to evaluate the effect of the temporary packaging 84 on the performance of the microactuator. The temporary packaging is a thin 85 layer of photoresist over the diaphragm suspension and around the electrodes 86 and lead wires. This temporary packaging has several advantages. First, it 87 does not substantially increase the size of the PZT thin-film microactuators. 88 Second, it is waterproof thus allowing the microactuators to function in aqueous 89 environments. Third, it is very easy to implement; therefore, it is suitable for 90 91 short-term uses, such as animal trials.

For the rest of the paper, we first explain the temporary packaging in 92 detail, such as lead wire arrangements and photoresist insulation layer. To 93 evaluate the effect of the packaging, we conduct vibration experiments on 94 the microactuators with and without the packaging. Finally, the packaged microactuator is tested in air and in water to evaluate the functionality of the 96 packaging. 97

TEMPORARY PACKAGING

Packaging of PZT thin-film microactuators can be permanent or temporary. 99 Permanent packaging is designed for long-term use, such as implants. In the 100 case of hybrid cochlear implants, permanent packaging will require imper-101 meable and biocompatible encapsulation of the PZT thin-film microactuators. 102Possible encapsulation materials thus include glass and platinum for example. 103 Due to these requirements, development of decent permanent packaging for 104 PZT thin-film microactuators is extremely time-consuming and costly. In con-105 trast, temporary packaging is a low-cost solution designed only for short-term 106 use. Moreover, biocompatibility is less a consideration than the functionality 107 for temporary packaging. In the case of hybrid cochlear implants, temporary 108 packaging is particularly useful for animal trials that take several weeks or a 109 month to complete. 110

The focus of this paper is temporary packaging of PZT thin-film microac-111 tuators. Fig. 4 shows a temporary packaging developed at the University of 112 Washington. The temporary packaging consists of lead wires to bottom and 113 top electrodes and photoresist package. A lead wire is attached to the side of 114 the bottom electrode using silver paste in order not to substantially increase 115 the dimension of the microactuator. A second lead wire is attached to a corner 116 of the top electrode in order not to substantially decrease the amplitude of the 117 microactuator. A layer of photoresist (AZ1512), with thickness in the range 118 of 4–16 μ m, is brushed over the diaphragm suspension to protect the elec-119 trodes and the lead wire. Although the photoresist is 10 times thicker than 120

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

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

124 EXPERIMENTAL SETUP AND RESULTS

125 In the experiment, the microactuator to be packaged has a size of 3 mm \times 126 3 mm \times 400 μ m. Also, the dimensions of the diaphragm suspension are 900 127 μ m \times 900 μ m \times 0.95 μ m. A layer of photoresist with a thickness of 4–16 128 μ m is coated over and around the diaphragm suspension as the packaging 129 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



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 137 with a layer of photoresist. Again, the microactuator (now with photoresist) 138 is mounted on the plastic support with clay, and its vibration is measured for 139 comparison. 140

Figure 6 shows the time response measured from the laser vibrometer, 141 when an unpackaged microactuator (without photoresist) is driven sinusoidally 142 at 1, 3, 5, and 10 kHz with amplitude of 7.5 Volts. In this measurement, the 143 laser aims at the center of the diaphragm suspension. The measured response is 144 consistently around 2.5 nm. Figure 7 shows the frequency response measured 145 from the laser vibrometer. The measurement indicates that the response is very 146 much independent of frequency and is roughly 0.33 nm/V.

Fig. 8 shows the time response measured from the laser vibrometer, when 148 the microactuator is fully packaged. The actuator is driven sinusoidally at 1, 3, 149 5, and 10 kHz with amplitude of 7.5 Volts. Again, the laser aims at the center 150 of the diaphragm suspension. The measured response is consistently around 1 151 nm. Fig. 9 shows the frequency response measured from the laser vibrometer. 152 The measurement indicates that the response is very much independent of 153 frequency and is roughly 0.15 nm/V. Obviously, the presence of the photoresist 154 as a packaging material has reduced the amplitude of the microactuator. 155



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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.

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

AQUAEOUS ENVIRONMENTS

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After the microactuator is packaged, it is necessary to test the microactuator in an aqueous environment. The purpose of the test is twofold. First, 158 the test is to find out if the temporary package is waterproof. If it is, the 159 microactuator will remain functional in the aqueous environment (i.e., no 160 short circuits). Second, the test is to find out if the aqueous environment will 161 serve as a significant load and affect the performance of the PZT thin-film 162 microactuator. 163

Since the laser vibrometer cannot measure vibration of an object in aqueous environments, the experimental setup shown in Fig. 5 needs to be modified. 165 Instead of using laser vibrometer, we use an impedance analyzer to measure 166 the impedance of the PZT thin-film microactuator. If the aqueous environment 167 causes the microactuator to short-circuit or impose a significant load to the miconsists of two parts. The first part is to measure the impedance using the setup 170 in Fig. 5, while the packaged microactuator is in the air. In the second part, 171 the packaged microactuator along with the experimental setup is submerged in water while the impedance is measured. 173

Figure 10 shows the measured impedance in air (Fig. 10(a)) and in water 174 (Fig. 10(b)) as the frequency varies from 10 Hz to 100 kHz. Note that the 175 impedance, plotted in a log-log scale, is a straight line with a negative slope. 176 This indicates that the PZT thin film behaves like a capacitor in this frequency 177 range. The impedance in air and in water is almost identical. This implies 178 that the packaging material is waterproof and the surrounding water does not 179 impose a significant load to the PZT thin-film microactuator. 180

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

CONCLUSIONS

182 In this paper, we demonstrated a simple method to achieve temporary packaging of PZT thin-film microactuators. The temporary packaging includes lead 183 184 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 185 186 laser vibrometer and an impedance analyzer to evaluate the performance of the 187 PZT thin-film microactuators and the effect of the temporary package. Experimental results show that the presence of photoresist package reduces vibration 188 189 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 190 191 thin-film microactuator remains functional in an aqueous environment.

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