Fabrication and Analysis of High Sensitivity Biochemical Sensors Using PMN-PT Single Crystal Thin Membranes

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ABSTRACT

In this poster, we report the results of the Hydrochloric Acid (HCl) wet etching process to fabricate a PMN-PT single crystal piezoelectric thin membrane. A piezoelectric thin membrane can offer the ability to passively sense vibrations without power requirements. Furthermore, the new generation oxide material exhibits extraordinary piezoelectric properties. The material, the single-crystal solid-solutions (1-x)PbMg1/3Nb2/3O3-xPbTiO3 (PMN-PT), has been shown to process piezoelectric coefficients and electromechanical coupling responses significantly larger than conventional ceramics. A four-fold enhancement in piezoelectric coefficients and much higher efficiencies in electrical to mechanical energy conversions have been found. Use of a PMN-PT sensor to detect, with high sensitivity, minute amounts of waterborne pathogenic bacteria such as E. coli O157:H7 is one promising direct application. Design of a compact and portable PMN-PT sensor device used in produce packaging facilities and grocery stores is a primary focus. In this paper, we present the research results produced from the experimental work for the PMN-PT wet etching in HCl solution.

INTRODUCTION

PMN-PT is a piezoelectric transducer which can be used with a biochemical sensing element (gold) to measure the effect of surface mass change on the resonant frequency of the sensor. Resonant frequency changes are directly proportional to mass changes on the sensor, such that an increase in the mass of the sensor results in a decrease in the resonant frequency. The physics for this relationship is based upon Sauerbrey’s formula (listed in the box below).

Possible uses for PMN-PT are widespread because of its high sensitivity, high quality value, high dielectric constant, low dielectric loss, high electromechanical coupling coefficient, and high piezoelectric coefficient. Piezoelectric single crystals of PMN-PT have shown superior properties to piezoelectric ceramics and piezoelectric films in device applications. The wet etch rate of PMN-PT with concentrated HCl at 80°C to form a thin PMN-PT membrane (5nm) is determined.

Table 1: Etching Rate of PMN-PT in Conc. HCl at 80°C

<table>
<thead>
<tr>
<th>Time Etch (in minutes)</th>
<th>Total Thickness Etched in Conc. HCl (in μm)</th>
<th>Total Etch Rate (in μm/min)</th>
<th>Per Side Etch Rate (in μm/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>12</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.5</td>
<td>0.25</td>
</tr>
<tr>
<td>180</td>
<td>100</td>
<td>0.566</td>
<td>0.278</td>
</tr>
</tbody>
</table>

Figure 1: PMN-PT Surface After 3 hours of etching in Conc. HCl at 80°C

A) Magnification – X500
B) Magnification – X1,500
C) Magnification – X10,000

Equation from Sauerbrey’s Formula

\[ \Delta f = \frac{2f_b^3 \Delta m}{\rho A f_b^2 \mu} = -2.26 \times 10^4 \frac{f_b^3}{A} \Delta m \]

\( f_b \) – Resonant frequency (Hz)
\( f \) – Frequency change (Hz)
\( \rho \) – Density (quartz = 2.64 g/cm³)
\( \mu \) – Shear modulus (quartz = 2.947 × 10¹¹ g/cm²/s²)
\( A \) – Piezoelectrically active area between electrodes (m²)
\( \Delta m \) – Mass change (g)

Figure 2: Exploded view of various layers of PMN-PT microbalance system with PMN-PT chip and PDMS

PDMS
Gold Coating
PMN-PT
Gold and Palladium Coating
Chromium Coating in the Grooves
Plastic Substrate

Figure 3: Cross-section of Various Layers of PMN-PT Microbalance System with PMN-PT Chip and PDMS

PDMS r=10 nm, d=13.7 nm
Gold r=100 nm, J=0.2–0.4 nm
PMN-PT r=10 μm, J=0–2.4 nm
Gold and palladium r=100 nm
Plastic Substrate r=6.39 nm, d=13.69 nm
Wire Bonding
Image Not to Scale

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REFERENCES