Flexible Thin-Film PZT Ultrasonic Transducers

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We recently reported a transfer process that provides large area PZT ($Pb(Zr_{0.52},Ti_{0.48})_{0.98}O_3$) thin films released from a high temperature growth substrate to few micron thick flexible polyimide substrates [1]. The released films have superior piezoelectric properties compared to as-grown films due to declamping from the rigid substrate. In this work, we demonstrate ultrasonic transducers fabricated using released PZT films.

For the ultrasonic transducer fabrication, a silicon wafer with 100 nm silicon oxide was used as a convenient thermally robust substrate. A 100 nm ZnO sacrificial layer was deposited at 200 °C by plasma enhanced atomic layer deposition (PEALD). Next, a 10 nm thick layer of Al_2O_3 was deposited by PEALD to serve as a diffusion barrier between ZnO and PZT. Pt electrodes were then deposited on the Al_2O_3 layer and patterned by lift-off to form transducer electrodes. Next, a 1 µm thick solution-derived PZT film with 2% niobium doping was deposited and crystallized at 700 ºC. A blanket Pt layer was then added to form second electrodes for the transducers. A 10 nm thick layer of Al_2O_3 was then deposited by PEALD and a 5 µm thick polyimide layer was formed by spin-coating and curing a polyamic acid precursor (PI-2600); the Al_2O_3 layer prevents degradation of the PZT by hydrogen evolved during the polyimide curing. Finally, the PZT-polymer combination was released by etching the ZnO layer in acetic acid. The fabrication process is summarized in Figure 1(a) and additional detail is available in reference 1.

For convenience, we often make electrical contacts to the flexible polyimide substrate PZT devices using anisotropic conductive film bonding. This provides a simple method to provide electrical connections while avoiding difficulties that can be related to probing or wire bonding thin polymeric substrates. Released PZT films have superior electrical properties compared to films on rigid substrates due to substrate declamping. Figure 2 shows a ~40% increase in the remanent polarization for thin films after release. No significant changes are observed by removing the polyimide under devices, suggesting that that the clamping effect of the polyimide is negligible.

The released PZT process provides flexibility in device design as well as mechanical flexibility. For example, Figure 3 shows released transducers with patterned PZT and with the polyimide thinned below the PZT diaphragm to reduce stiffness. This structure mimics that of piezoelectric micromachined ultrasonic transducers (pMUT) [2, 3], but provides additional design freedom and improved piezoelectric characteristics. The P-E hysteresis loops in Figure 2 labeled "window" have the polyimide beneath the PZT removed by oxygen plasma etching of the polyimide.

The ultrasonic transducer impedance versus frequency was characterized. Transducers with 400 µm diameter circular Pt electrodes, but unpatterned PZT, resonated at 36.8 kHz (Figure 4). For the unpatterned PZT the resonant frequency results from motion of an area of PZT larger than the electrode, resulting in a lower frequency than for a 400 µm patterned PZT transducer. These results demonstrate that the released PZT process can provide a path to high quality piezoelectric devices on flexible polymeric substrates.

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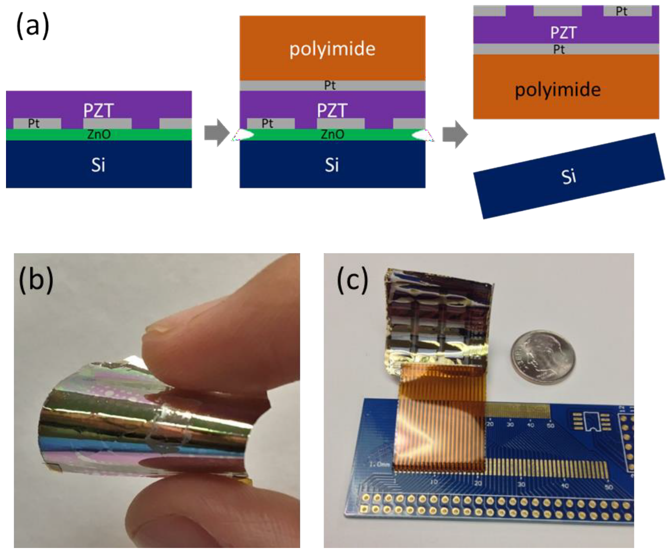

Figure 1. (a) PZT release process, (b) Released PZT film on polyimide being flexed. (c) Released PZT film on polyimide with anisotropic conductive film (ACF) connections.

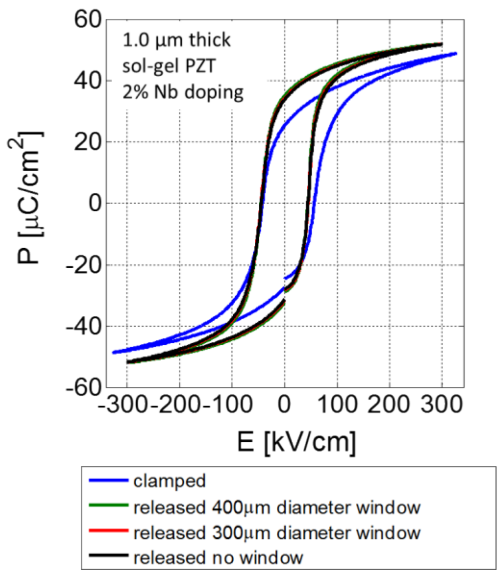

Figure 2. Released and clamped PZT P-E hysteresis loops. The released PZT film has 40% increased switchable polarization due to substrate declamping.

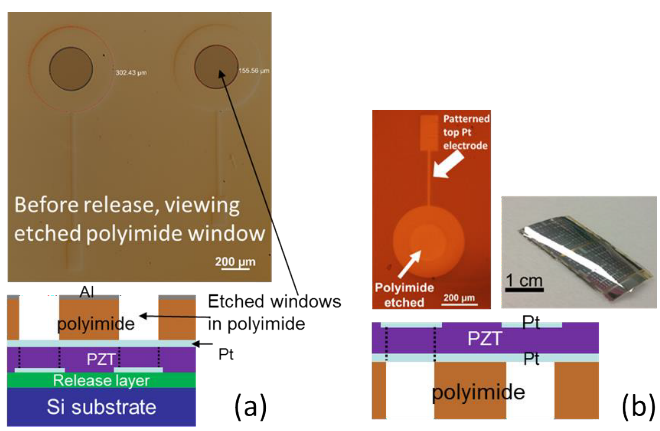

Figure 3. pMUT-like released PZT diaphragm devices via etching of the polyimide layer from the back side by O_2 plasma RIE.

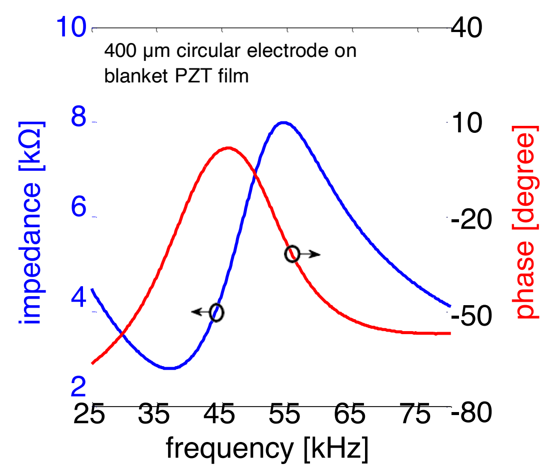

Figure 4. Impedance and phase characteristics for released blanket PZT film with 400 µm circular Pt electrodes with 36.8 kHz resonant frequency.