Piezoelectric Microelectromechanical Systems (PiezoMEMS) for Adjustable X-ray Optics

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Exploring the furthest reaches of the universe requires the development of new telescopes with improved resolution. Thin film piezoelectric actuator adjustors are being considered for NASA's proposed next generation X-ray telescope (Lynx) to achieve a target resolution of < 0.5 arc seconds coupled with a large collecting area. The approach being taken to achieve this is the optimization of piezoelectric $Pb(Zr_{0.52}Ti_{0.48})O_3$-1%Nb (PZT) thin film integration on curved *Corning Eagle* glass substrates with pixel like arrays of Pt top electrodes and thin film transistors to modulate the voltage control using a row-column address scheme. Essentially this is a liquid crystal-like display design, where electric fields are individually modulated across the array to control individual electromechanical responses which fine tune the curvature of the mirror for precise resolution control.

High yield piezoMEMS arrays using PZT films were achieved on glass with a 220 mm radius of curvature. Prior to deposition of the Ti/Pt bottom electrode, the glass was cleaned with a Cr containing sulfuric acid solution and acetone/isopropanol, followed by an oxygen plasma ash. PZT was then deposited in three 0.5 µm layers by room temperature RF magnetron sputtering at 4 mTorr pressure followed by low temperature rapid thermal annealing (RTA) at 650°C for 60 seconds. After the three PZT layers were deposited a 100 nm thick capping layer was deposited at 5 mTorr and crystallized by RTA to remove surface pyrochlore. This layered deposition increased yield by reducing the probability of defect propagation across the film.

In previous work, the transistor array was deposited on a flat substrate, which simplified the alignment process and enabled tight dimensional tolerance. To achieve a comparable resolution of 50 µm features on the curved substrate, a double layer lithography approach was adopted with both spin and spray coating techniques. While spray coating proved to be difficult to optimize, a customized sample holder was utilized for spin coating at 4000 RPM, which minimized the edge bead and produced uniform photoresist coatings. Flexible photolithography masks manually aligned before UV exposure and development, resulted in well-defined lithography pattern with sufficient undercut and vertical side walls. The ensuing Pt deposition and lift off procedure produced 5 × 10 mm electrode arrays of 112 electrodes per 102 × 102 mm glass piece. For proof of concept testing, the individual electrodes were connected to contact pads at the edge of the mirror via lithographically defined Pt line patterns. The resulting mirror pieces exhibit a consistent high yield of ~95%, with typical PZT dielectric loss values of 0.05 and permittivity of ~1270.

The stresses induced by the PZT actuator layer need to be stress balanced by the X-ray reflective coating. The approach taken to achieve this is to use Cr/Ir bilayer films and calibrate the stresses of each metal film to determine the optimal chamber pressures. The thickness of both metals is then adjusted in order to balance the mirror within a micron of its original curvature.