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ZnO Thin Film Based MEMS Piezoelectric Resonator on Silicon

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Abstract: Zinc Oxide thin film based piezoelectric resonator has been realized using silicon bulk micromachining technique. Highly c-axis oriented ZnO films have utilized for resonator fabrication. Low cost micromachining process developed which utilize single side wafer protection holder during TMAH etching. This wafer holder allows active devices protection on single side of wafer and TMAH etching on the other side. The used process is cost effective and can be used alternative to deep reactive ion etching process. Dynamic study of resonator studied using laser Doppler vibrometer. Square electrode shape resonator has resonance frequency 1.596 MHz whereas pentagonal has 0.615 MHz. The square and pentagon shaped resonator have shown quality factor was ~95 and ~173 respectively. The resonator was piezoelectrically actuated by applying ac signal across the top and bottom electrodes. Novel low lost fabrication process developed to realize piezoelectric resonators.

Keywords: ZnO, Piezoelectric, MEMS, Resonator

1. INTRODUCTION

Piezoelectric resonators are essential components of MEMS piezoelectric devices. The piezoelectric material converts electrical energy into mechanical energy and vice-versa. Moreover, piezoelectric thin films can be configured in variety of devices for sensing and actuation applications. These devices have various applications in energy harvesters, acoustic filters, micropumps, microphones and resonant sensors etc. Self-actuation of device is possible by application of electric field on piezoelectric layer. With the exception of acoustic wave resonators, micromachined piezoelectric resonators have received only a limited attention, primarily due to the relative complexity of integrated circuits (IC) integration and complex device fabrication process. Future advances in micromachined piezoelectric resonators will require proven and established MEMS process for potential applications. Piezoelectric resonators have key advantages like small size, light weight; low power consumption and ability to integrate with IC make them promising candidates for future technology. These resonators are becoming practical in communication filters and systems. Sensing and actuation is possible using bulk micromachined piezoelectric resonators.

2. EXPERIMENTAL PROCEDURE

The MEMS piezoelectric resonator structures were fabricated from a 3-inch diameter double side polished Si (100) wafers. The processing of piezoelectric resonator consists of three major steps: 1) integration of ZnO layer, 2) fabrication of Silicon diaphragm, and 3) release of structure. The complete fabrication sequence is shown in figure 1.

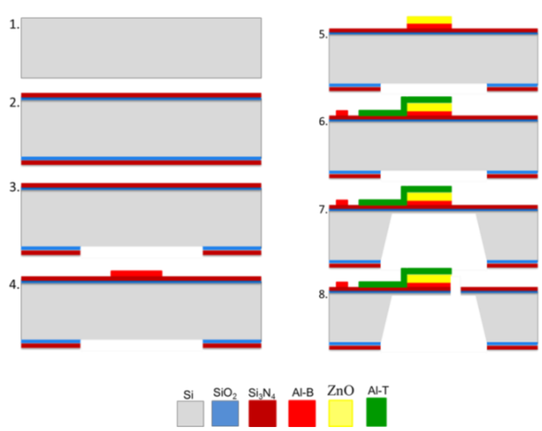

Figure 1: Fabrication process flow of ZnO piezoelectric resonator.

3. RESULTS AND DISCUSSION

High piezoelectric ZnO thin films are the primary requirement for MEMS piezoelectric resonators. Piezoelectric quality of ZnO film depends on its crystalline orientation of ZnO films. X-ray diffraction result of ZnO thin film shown in figure 2 indicates that film has single phase (002) orientation with substrate peak corresponding to Si (004). Film peak position observed at 34.42˚ that is corresponding to bulk phase of ZnO. The full width half maxima (FWHM) of diffraction peak was 0.26˚, indicate films have good crystal quality.

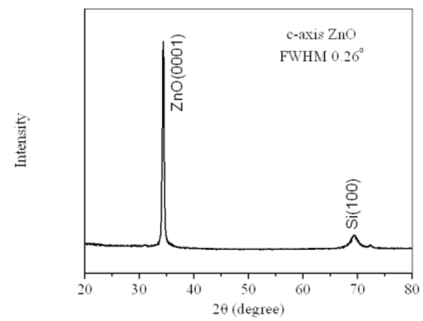

Figure 2: X-ray diffraction of ZnO thin film.

Stress relaxed ZnO films are highly desirable from fabrication point of view. In-plane stress primarily produced in ZnO thin films due to conditions imposed by underlying substrate and deposition parameters. Stressed devices exhibit poor performance, low reliability and poor yield. Figure 3(a) shows the wafer curvature of un-deposited films. Subsequently, ZnO layer deposited and wafer curvature was measured shown in 3(b). Difference in curvature is direct measure of film stress. ZnO film measured stress was ~20MPa that is considered minimal. Utilization of minimal stress ZnO film deposition was one of the motivations here.

We have used aqueous hydrochloric acid (0.25 % HCl) etchant and positive photoresist S1813 as masking layer to pattern the ZnO films. Figure 4(a) shows the SEM etching profile of ZnO layer on Si/SiO_2 wafer after removal of masking photoresist layer. It is noticed that ZnO layer is smooth and defect free.

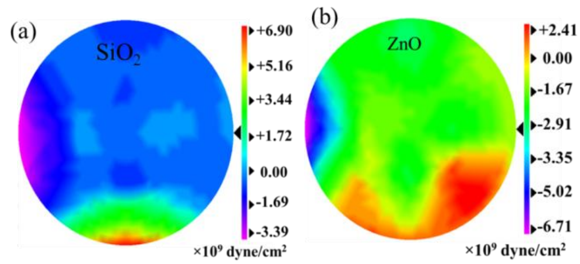

Figure 3: (a) Stress profile of un-deposited wafer, and (b) ZnO deposited wafer.

Figure 4(b) shows the enlarged image for etch profile analysis. Negative step coverage was observed and angle measured between substrate surface and side wall etch front was found to be 59.36˚ shown in figure 4(c). The edge profile also shows negative step profile shown in 4(d). At later stage top electrode metal layer was deposited and after lift-off metal patches are clearly visible in figure 4(e). Further, experiments are executed to improve step coverage and improved profile shown figure 4(f).

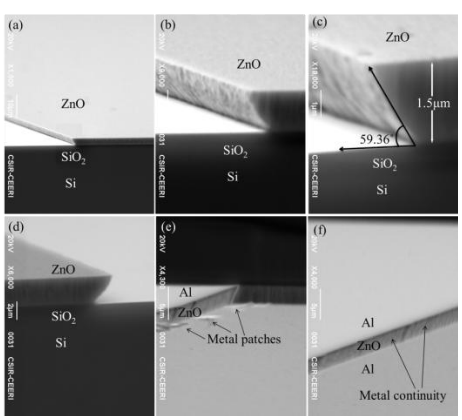

Figure 4: (a) Cross-section SEM image of ZnO layer, (b) patterned image at higher magnification, (c) etching profile angle measured, (d) corner edge of ZnO thin film shows negative step profile, (e) Metal discontinuity at ZnO step (f) improved step and proper step coverage.

Figure 5(a) shows the SEM image of a released square shaped and pentagon shaped piezoelectric resonator respectively. After bulk micromachining from back side of Si wafer, structured are released by dry etching process. First, SiO_2/Si_3N_4 layer was etched by reactive ion etching process and then Si was etched in SF6 gas chemistry. The released structures are ready for electrical and mechanical testing.

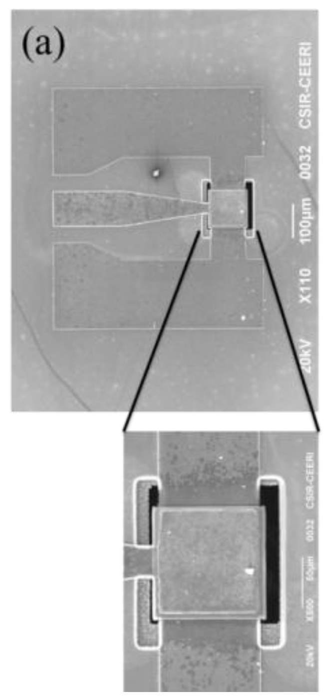

Figure 5: (a) released square shaped resonator and (b) pentagonal shaped resonator.

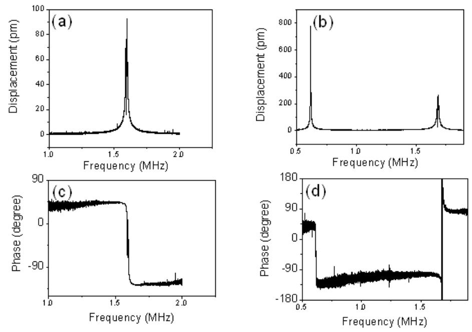

Figure 6: (a) magnitude of square resonator, (b) magnitude of pentagonal resonator, (c) Phase of square resonator, (d) phase of pentagonal resonator.

Electric field induced out-of-plane displacements were measured using MSA Polytec laser Doppler vibrometer. The square resonator was piezoelectrically actuated by applying driving voltage across the ZnO layer. Figure 6(a) shows the displacement magnitude for square resonator. The laser beam was position at the centre of resonator and displacement was measured at the centre. The bending displacement was ~90.28µm measured at the resonant frequency of 1.596 MHz. The first harmonics was only observed for the square shaped resonator. The ZnO resonator was actuated with 0.5V oscillation level sinusoidal signal with varying frequencies in the 1-2 MHz range.

Figure 6(b) shows the displacement magnitude for pentagonal shaped resonator. First and second harmonic resonances were observed at 0.615 MHz and 1.685 MHz respectively. For first fundamental mode displacement magnitude was 777µm. It is noted that for first mode, pentagonal shape has higher deflection compared to square shape and that results to higher quality factor.

4. CONCLUSIONS: Zinc Oxide thin film based piezoelectric resonator has been fabricated and tested. Highly c-axis oriented ZnO films have utilized for resonator fabrication. Low cost micromachining process developed which utilize single side wafer protection holder during TMAH etching. This wafer holder allows active devices protection on single side of wafer and TMAH etching on the other side. The used process is cost effective and can be used alternative method to deep reactive ion etching. Pentagon shaped resonator have shown quality factor. The resonator was piezoelectrically actuated by applying ac signal across the top and bottom electrodes. Low lost fabrication process developed to realize the piezoelectric resonator.

REFERENCES:

[1] Shen D, Park J H, Ajitsaria J, Choe S Y, Wikle H C III and Kim D J 2008 The design, fabrication and evaluation of a MEMS PZT cantilever with an integrated Si proof mass for vibration energy harvesting *J. Micromech. Microeng.* **18** 055017

[2] Jackson N, O'Keeffe R, Waldron F, O'Neill M and Mathewson A 2013 Influence of aluminum nitride crystal orientation on MEMS energy harvesting device performance *J. Micromech. Microeng.* **23** 075014

[3] Doll J C, Petzold B C, Ninan B, Mullapudi R and Beth L Pruitt 2010 Aluminum nitride on titanium for CMOS compatible piezoelectric transducers *J. Micromech. Microeng.* **20** 025008

[4] Lu F,Lee H P and Lim S P 2004 Modeling and analysis of micro piezoelectric power generators for micro-electromechanical-systems applications *Smart Mater. Struct.* **13** 57–63

[5] Ajitsaria J, Choe S Y, Shen D and Kim D J 2007 Modeling and analysis of a bimorph piezoelectric cantilever beam for voltage generation *Smart Mater. Struct.* **16** 447–454

[6] Singh J, Ranwa S, Akhtar J, and Kumar M 2015 Growth of residual stress-free ZnO films on

SiO2/Si substrate at room temperature for
MEMS devices *AIP Adv.* **5** 067140