A HIGH D_{33} CMOS COMPATIBLE PROCESS FOR ALUMINUM NITRIDE ON TITANIUM

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We report process conditions for sputtered aluminum nitride (AlN) on a Ti electrode which yields an x-ray diffraction (XRD) rocking curve full-width at half-maximum (FWHM) of less than 3 degrees for a 1 micron thick film, compared with 7 degrees in prior work [1]. In-situ substrate precleaning and sequential deposition of films under vacuum prevents TiO_2 formation and improves AlN alignment. We characterized the films with XRD and LDV on whole wafers and released cantilevers, achieving d_{33} (3.0 pm/V) and d_{31} (1.3 pm/V) values comparable with Pt [2], but with a low-temperature, CMOS compatible process.

High-speed, low-power actuators find numerous applications in microelectromechanical systems. Although electrostatic parallel plate and comb drives are widely used for their simplicity, piezoelectric actuators have excellent properties for high frequency, low voltage applications. While zinc oxide (ZnO) and lead zirconium titanate (PZT) are typically used for MEMS actuators, aluminum nitride (AlN) offers several advantages for high frequency applications. Although AlN is CMOS compatible, non-standard metal electrodes such as molybdenum and platinum are commonly used due to the poor performance of Ti electrodes to date.

Films were deposited in a Tango Systems pulsed DC reactive sputter deposition system (Tango Systems, San Jose, CA). Power, pressure and substrate temperature for AlN deposition were held constant at 5 kW, 5 mtorr and 200C, respectively. The pressure was chosen to minimize instrinsic stress [2]. Target-substrate distance was fixed at 45 mm. All Ti films were sputtered at 3 kW with 40 sccm Ar for 150 seconds to yield a thickness of 100 nm. System base pressure was 10^{-8} torr. Flow rates were set at 10 sccm and 40 sccm for Ar and N_2. The deposition rate was 13.6 nm/min.

Films were characterized using three techniques: x-ray diffraction two-theta and rocking curves (Philips X'Pert Pro, 45 kV, 40mA), and measurement of the d_{33} coefficient at the wafer scale and d_{31} at the device scale using laser doppler velocimetry (LDV) (Polytec OFV-2500). Although double-beam interferometry is typically used to measure d_{33} directly, LDV was recently demonstrated [3]. However, wafer bending during measurement complicates data interpretation and a comparison between wafer and device data using LDV has not been made to date. We also fabricated unimorph AlN actuators on SOI wafers and compared the measured d_{31} values with LDV measurements on unpatterned wafers.

In contrast with previous work, we deposited all films in a single vacuum run, preventing the formation of oxide interfaces. We also used a 100nm aluminum nitride interlayer below the bottom metal electrode as in reference [4], both to improve growth alignment and to reduce cross-talk in future devices which will combine sensors and actuators onto the same die for high speed force sensing and actuation.

We first investigated the effect of the Si substrate surface condition on the AlN microstructure. Removing the native SiO_2 by in-situ inductively coupled plasma (ICP) resulted in better AlN alignment than presputtering or untreated Si substrates (Figure 1). Several AlN thicknesses and RF induced biases were investigated and the FWHM was found to depend inversely upon film thickness and directly with bias (Figure 2). A fabricated cantilever and its frequency response (Q=293) are shown in Figure 3. The measured d_{33} and d_{31} coefficients for several AlN thicknesses are plotted in Figure 4.

Word Count: 544

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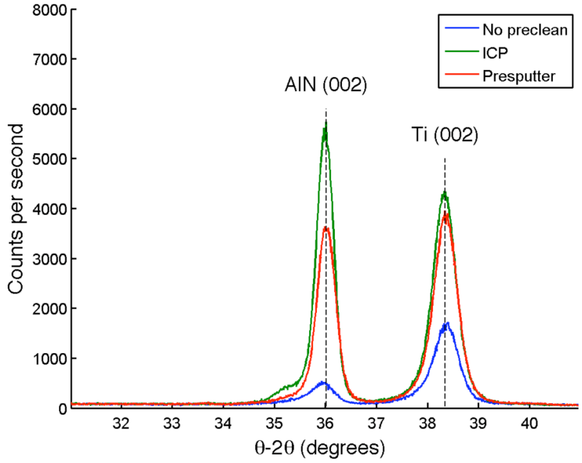

Figure 1: Effect of precleaning upon XRD intensity of AlN (002) and Ti (002) peaks. 100nm of Ti and 500nm of AlN were deposited on a Si (100) substrate in order to investigate the effect of removing the native SiO_2. Significantly improved AlN and Ti alignment resulted from precleaning. All cleaning and depositions were performed in a single vacuum run to prevent the formation of SiO_2 or TiO_2. AlN alignment was further improved by increasing the RF induced bias and adding an AlN interlayer below the bottom Ti electrode.

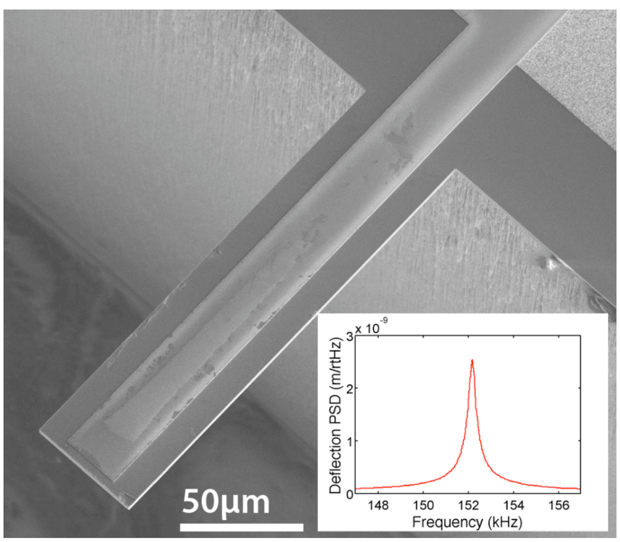

Figure 3. Scanning electron micrograph of a fabricated piezoelectric unimorph actuator. Cantilever is 5um thick x 50 µm wide x 200 µm long and the actuator is 30 µm wide x 196 µm long. Beginning with an SOI (5um device layer, 500nm BOX, 500um handle), AlN was patterned with room temperature TMAH (25%) and the Ti was patterned with room temperature 5:1:1 H_2O:H_2O_2:NH_4OH, using the patterned titanium above each layer as a hard mask for the subsequent AlN patterning. Cantilevers were patterned from the front and back using DRIE and the BOX was released with a CHF3/O2 RIE. Inset: Cantilever frequency response to white noise at 1 V_{pk} for an aluminum nitride film thickness of 100nm. A quality factor of 293 was measured.

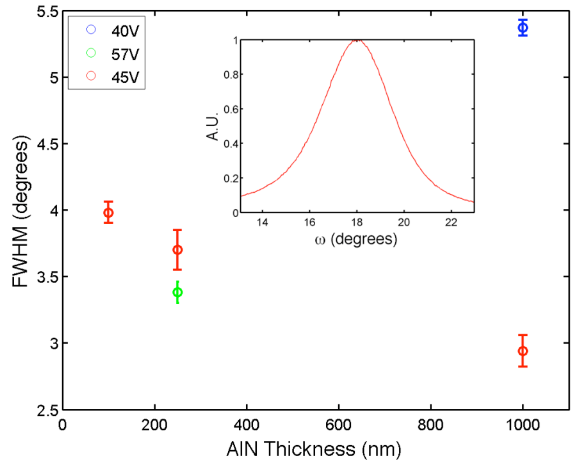

Figure 2. Variation in with aluminum nitride actuator thickness and RF induced bias. All samples were sputtered with a 100 nm AlN interlayer and 100 nm Ti electrodes on top and bottom and varying RF induced bias. RF induced bias increases structural alignment, particularly for thicker films. A typical rocking curve is inset.

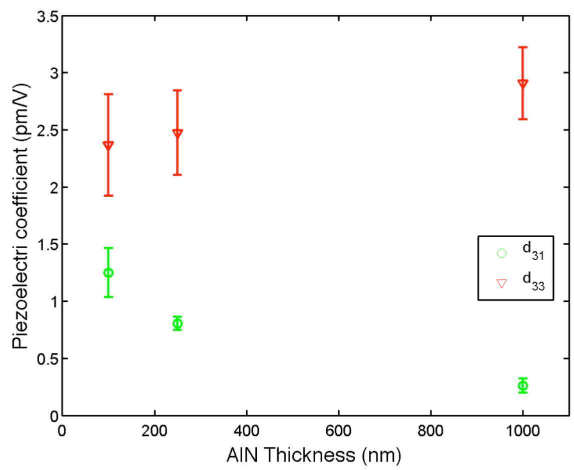

Figure 4: The d_{31} coefficient was extracted by driving the cantilevers below resonance and measuring the tip deflection using LDV. A linear system, taking into account the bending rigidity of the Ti electrodes and AlN film as in [5], was solved to extract the d_{31} coefficient for each measurement. The d_{33} coefficient was extracted by firmly attaching wafers with AlN/Ti/AlN/Ti on the frontside and Ti on the backside to an air isolation table with double-stick tape to suppress wafer bending modes. An AC bias was applied across the wafer thickness, driving them between 700kHz and 1.4 MHz, and reading out deflection with LDV. The actual drive voltage across the wafer was measured with separate electrical contacts. d_{33} varies inversely with FWHM as expected, however d_{31} decreases for thicker films. One possible explanation is that increased film porosity reduces lateral strain coupling. Further study is ongoing, however the thin films offer better actuator performance regardless of the outcome.