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Procedia Engineering 25 (2011) 673 – 676

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXV, September 4-7, 2011, Athens, Greece

Fabrication of AlN slender piezoelectric cantilevers for high-speed MEMS actuations

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Abstract

Very thin piezoelectric cantilevers based on AlN layers using titanium Ti thin film electrodes are fabricated and characterized. By optimizing the Ti sputtering parameters, a very low stress (156MPa) layers stack with high crystallinity and strong (002) orientation of the AlN films is obtained. Finally, a simple fabrication process, fully CMOS compatible, is developed to realize slender (900 nm) piezoelectric microcantilevers. A resonant frequency of 19.3 kHz is measured for 200 µm long cantilevers. The deflection of cantilever is 6 nm/V and 189 nm/V for quasi-statics and resonant frequency actuation, respectively. This makes the fabricated cantilevers attractive for high-speed MEMS actuators.

Key words: AlN; Ti electrode; piezoelectric cantilevers; high-speed MEMS actuation.

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1. Introduction

High-speed actuators based on cantilevers have been recently developed to fabricate micro pumps [1], and a new generation of AFM tools [2] targeting advanced application for bio-medical technology. Piezoelectric actuators, compared to capacitive and magnetomotive actuators present the considerable advantage of miniaturization and low power consumption. Recently, aluminum nitride (AlN) has been considered as an attractive piezoelectric material for MEMS and NEMS devices [3]. AlN piezoelectric cantilever structures often contain a thick layer (5-30µm) of silicon [4,5] to increase the resonant frequency and reduce the severe initial bending caused by the high residual stress of sputtered AlN layers

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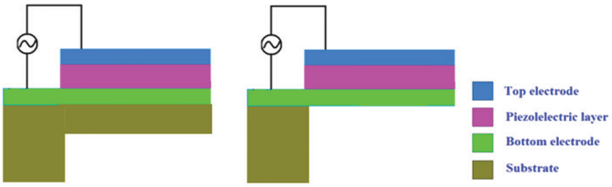
1877-7058 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2011.12.166

(figure 1a). In addition, these thick devices lead to higher actuating power consumption causing lower deflection and difficulty in thickness control of the devices is often encountered.

In this paper, we present the fabrication and characterization of AlN slender piezoelectric cantilevers (figure 1a) indicating a potential candidate for high-speed MEMS actuators. By using a good crystallinity, high (002) orientation and low surface roughness Ti layer as bottom electrode, the high quality of the AlN deposited on it is enabled. Furthermore, the complete film stack (AlN and electrode layers) is optimized to reduce the stress, thus allowing the preparation of slender cantilevers.



a) b)

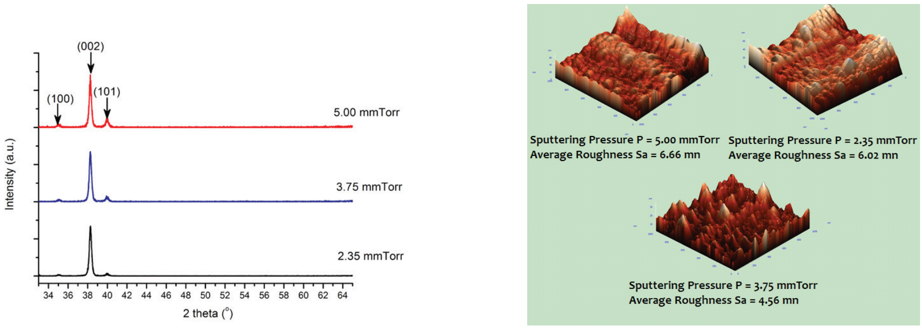
Fig 1: (a) Schematic drawing of (a) AlN piezoelectric cantilever with a thick supporting layer of silicon and (b) AlN slender piezoelectric cantilever.

2. Ti/AlN/Ti stack deposition

In general, the surface roughness of the bottom electrode (see figure 1) strongly influences the crystallinity and the crystalline orientation of the AlN thin-films. It has been shown that a low surface roughness is more favorable to obtain high quality AlN films [6]. It is also known that the crystalline structure of the AlN films can be enhanced when deposited on a highly crystalline layer with a specific orientation [7]. In this work we optimize both surface roughness and crystallinity of the Ti bottom electrodes, by tuning the sputtering pressure during deposition. This methodology was previously successfully applied to AlN deposited on Mo [7].

Figure 2 shows the X-Ray diffraction patterns of a 200 nm Ti films deposited at various sputtering pressures with 2kW power, and the AFM images of its surface. The lowest roughness, obtained for the Ti layer sputtered at 3.75 mmTorr, is 4.56 nm. The high crystallinity and preferred (002) orientation are preserved.

For a good piezoelectric response, a high (002) orientation of the AlN thin-films is required. This was achieved by pulsed DC sputtering technique using an SPTS Sigma 204 DC magnetron PVD system [8]. The 500nm thick AlN layers were deposited at 300 °C. Figure 3 indicates that the deposition of AlN on Ti layer resulted in the high (002) orientation similarly to the layers deposition on bare silicon (100).



a) b)

Fig. 2: XRD patterns of Ti layers sputtered at different pressures (a) and AFM images of the corresponding Ti surfaces (b).

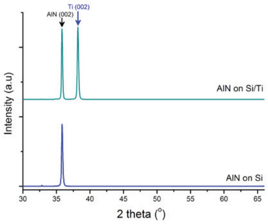


Fig 3: XRD patterns of AlN thin films deposited on bare silicon and on silicon coated with 200nm Ti.

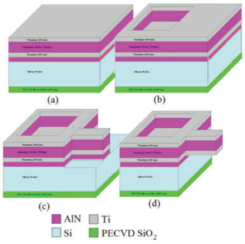


Fig 4: The fabrication process of the AlN slender cantilevers, (a) layers stack (AlN/Ti/AlN/Ti) and backside mask depositions, (b) bottom electrode contact opening, (c) cantilever definition, (d) cantilever release and AlN stop layer removal.

The stack consisting of 200 nm Ti and 500 nm AlN has a tensile stress of 450 MPa. To reduce this stress we developed a compressively stressed Ti films to be used as a top electrode, thus compensating for the high stress in the AlN. The complete stack (Ti/AlN/Ti) has a (total) very low tensile stress of 156 MPa and is only 900 nm in thickness.

3. MEMS fabrication

Figure 4 depicts the process developed to fabricate the AlN piezoelectric cantilevers based on this Ti/AlN/Ti stack. First a thin 100 nm AlN layer was deposited to be used as an etch stop layer for backside bulk silicon etching. Then the optimized Ti/AlN/Ti stack was sputtered. To contact the bottom Ti electrode the top Ti layer was dry etched using a photoresist mask and the exposed AlN layer was subsequently removed by wet etching in MF322 developer at 35 °C. Then, the Ti/AlN/Ti stack was defined by dry etching all three layers in a single step with photoresist as masking layer. The structures were released by etching the silicon substrate from the backside using the DRIE Bosch process with 6 µm of PECVD SiO_2 as mask and the first AlN as stop layer. Finally, the AlN bottom layer was removed by MF322 developer.

4. Device characterization

The SEM pictures in figure 5 show the cross-session of the Ti/AlN/Ti stack and the top view of 50 µm wide released cantilevers without cracking and deformations. The deflection depending on frequency (figure 6a) was measured using a Polytec OFV 5000 vibrometer for a 50 µm wide and 200 µm long cantilever actuated at 10 V. The first resonant frequency is at 19.3 kHz and the second resonant frequency at 119.9 kHz. In addition, the deflection of the cantilever at first resonant frequency generated by changing the amplitude of the input signal was detected. The measured deflection (up to 7.3µm for 40V actuation) linearly increases with the amplitude (Figure 6b).

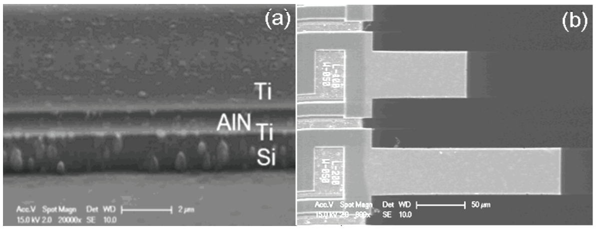


Fig 5: SEM cross session images (a) Ti/AlN/Ti stack and (b) cantilevers with 50µm width and 100µm and 200 µm length.

a) b)

Fig 6: First and second resonant frequencies of the slender 50 μm wide and 200 μm long cantilever (a) and dependence of the measured deflection on input amplitude at first resonant frequency (b).

The deflection for quasi-static and the resonant frequency actuation calculated from data in our case are 6 nm/V and 189 nm/V, respectively. These results indicate the presented slender AlN cantilevers are suitable for high-speed MEMS actuating devices.

5. Conclusion

In summary, we presented slender cantilevers based on a Ti/AlN/Ti layers stack. The bottom electrode was optimized with respect to orientation and surface roughness to obtain high quality AlN layers sputtered on it. The top electrode was optimized to significantly reduce the stress of the total stack. The deflection of the fabricated slender cantilevers actuated by an AC-signal was measured to indicate the potential of these devices for high-speed MEMS actuation applications.

Acknowledgements

The authors would like to thank to the staffs of the DIMES-ICP group for technical help and Dr. M. D. Nguyen from University of Twente for assistance in XRD measurements. This work is funded by MicroNed (SMACT 2-D), as well as the Vietnam International Education Development (VIED).

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