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T. Polster / A. Albrecht / S. Weinberger / M. Hoffmann

# Aluminium nitride a smart multifunctional material for MEMS

## Introduction

Aluminium nitride (AlN) in thin film configuration and its fabrication possibilities are well investigated. [1] Sputter deposited AlN thin films can be used in highly integrated systems as piezoelectric element or to generate structural elements with a high degree of mechanical stability. Another interesting aspect of using AlN thin films is the masking of silicon for plasma etching processes. This report wants to show the multifunctional use of AlN as smart material on the basis of these different fields of application.

## AlN as piezoelectric material

Structural premise to realize piezoelectric material properties in AlN thin films is a special crystal structure in combination with insulating behavior. Investigation of crystalline film structure is done by means of X-ray diffraction (XRD). If the phase analysis shows a pure (002)-orientation the films exhibit the crystalline condition for piezoelectricity. Within the executed investigations (002)-orientation with a good figure for quality had been achieved resulting in 3° full-width-of-half-maximum of XRD rocking curves. This is in good agreement with literature. [2] Fig 1 and Fig 2 display the results of XRD-analysis. Fig 1 shows the desired pure (002)-orientation as results of the phase analysis. The good crystalline structure can be achieved over a wide range of sputtering gas composition. Nitrogen content (NC) stands for the relation between argon and nitrogen in sputtering atmosphere. As one example for the equal film quality the rocking curve of a sample deposited at 65% nitrogen is displayed in Fig 2.

Additionally to the structural analysis, measurements of insulation film properties show satisfying results. Breakdown voltages of 1.6 MV/cm and specific film resistance of some $10^9$ $\Omega$cm has been realized. Piezo-response-force microscopy measurements were carried out to determine the value of the piezoelectric coefficient $d_{33eff}$. For analyzed samples this value is around 3.5 pm/V.

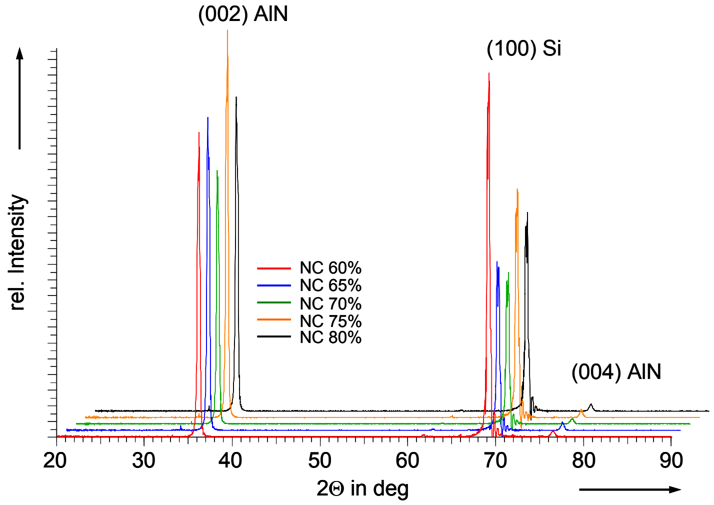

**Fig 1. XRD data for different AlN thin films providing pure (002)-orientation, sputtering parameter 1000 W, 300°C, $4\cdot10^{-3}$ mbar, 60% - 80% nitrogen content in sputtering atmosphere**

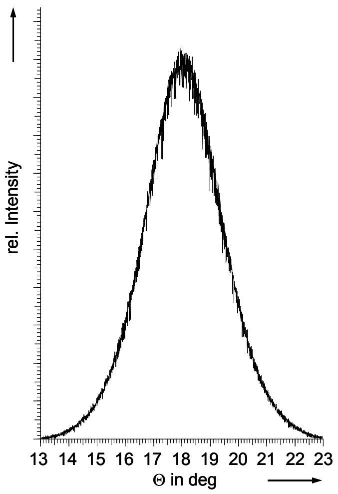

**Fig 2. Rocking curve of one selected sample representing the achieved quality of 3° FWHM**

## Highly stable, thin AlN membranes

Fabrication of free-standing structures based on 300 nm thin, sputter deposited AlN film is realized by bulk micromachining. Therefore the silicon bulk is etched from the wafer backside by means of DRIE processing with $SF_6$. Within the processing the AlN membrane layer serves as secure etch stop. The resulting structures exhibit a high aspect ratio up to 10,000 (diameter vs. thickness).

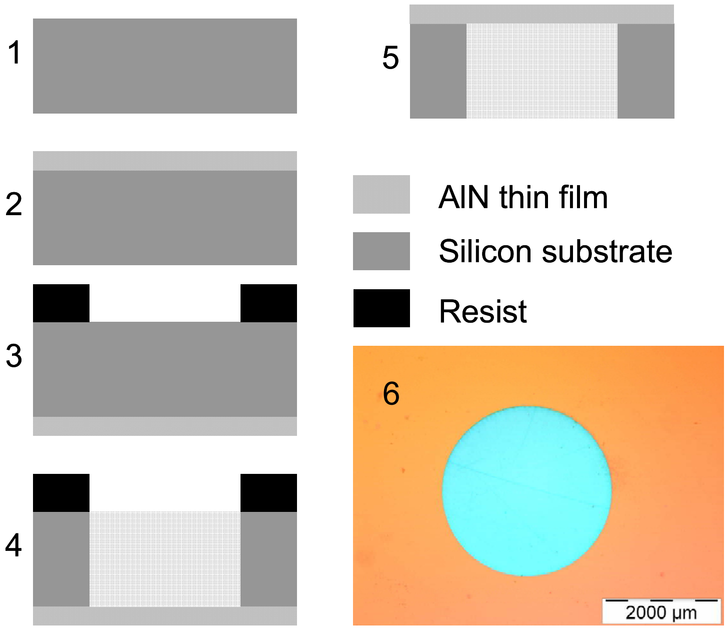

**Fig 3. Process steps for fabrication of free-standing AlN membranes, (1) blank silicon wafer (2) AlN thin film deposition (3) pattern transfer on wafer backside via photolithography (4) DRIE process to structure the silicon bulk (5) resulting free-standing membrane structure after stripping resist mask (6) picture of membrane with 3 mm in diameter**

Fig 3 displays the fabrication process from blank silicon substrate to resulting free-standing membrane. Membrane fabrication is an easy to apply 4-step process. During the fabrication process the membranes suggest their high mechanical stability. This observation has been confirmed by bulge-tests and burst-tests. For bulge-tests different scaled membranes were deflected by static differential pressure and the resulting maximum displacement was measured by optical profilometer. For burst-tests in contrast the pressure was raised until the membrane brakes

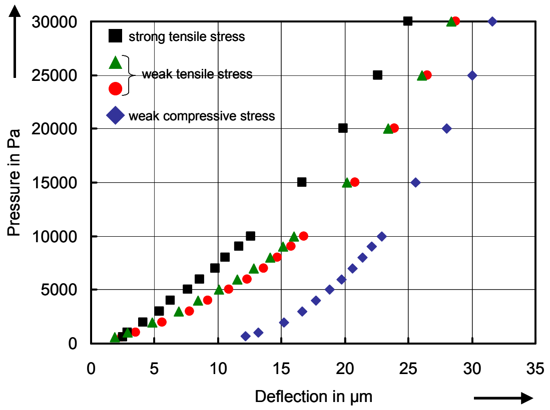

**Fig 4. Relationship between applied pressure and membrane deflection for different stressed membrane structures (diameter ~ 1500 µm, thickness ~ 300 nm)**

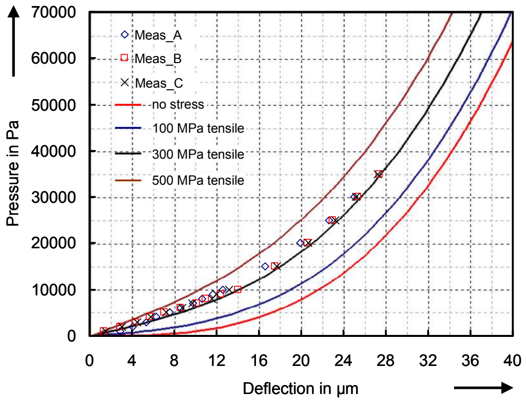

**Fig 5. Fit of measured data with analytic correlation for a membrane sample with 1590 µm in diameter and 275 nm in thickness, determination of stress possible at 300 MPa**

In Fig 4 the measurement results of the bulge test are presented. Therefore different stressed samples were analyzed. Fig 5 points out one sample and fits the measured results with analytic relationship (1). Set of curves is generated by varying the residual stress $\sigma_0$. With this method a determination of film stress in thin membrane structures is possible.

$$P = \frac{C_1 \cdot t}{a^2} \cdot \sigma_0 \cdot d + \frac{C_2 f(\nu)}{a^4} \cdot \frac{E}{1-\nu} \cdot d^3 \qquad (1)$$

Results of the bulge test fit well with the analytic relationship for thin membranes [3]. Deflections of several 10th of micrometer have been reached by a medium pressure load. It has been demonstrated that the deflection for equal pressure loads can be adjusted over the tunable stress in the AlN thin films.

Additionally to this investigation, the burst test demonstrates a high degree of pressure tolerated by the thin membranes. Measurements show that membranes with 1 mm in diameter can withstand 100,000 Pa of static differential pressure.

## AlN as masking material

As secondary result of the membrane fabrication process the high resistance of AlN thin films to fluorine gases can be used in masking technology for silicon etching. Investigations show a very high selectivity between AlN and silicon. The value has been fitted at 10,000. In consequence it is possible to structure silicon from several 100 µm till some mm in depth with a sputtered thin AlN film of only 100 till 300 nm.

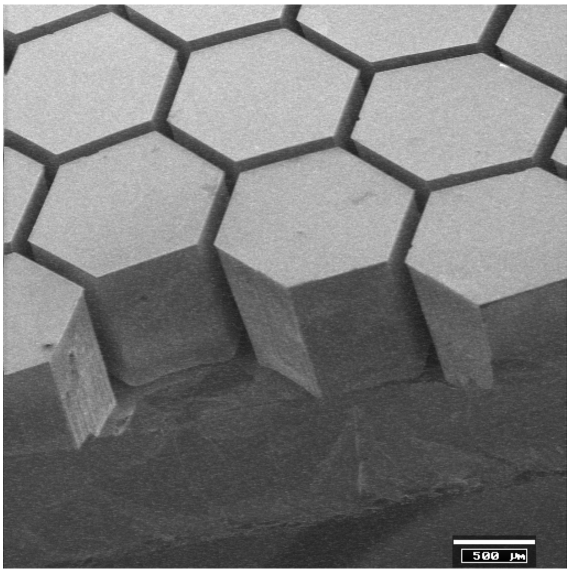

**Fig 6. Silicon structuring for 1000 µm in depth**

**Fig 7. Systematically tests for AlN as masking material for plasma etching of silicon, etch depth several 100 µm**

The Fig 6 and Fig 7 show exemplary two different resulting structures of plasma etched silicon. It is possible to fabricate deep trenches without great loss in shape of the structures. AlN thin films can serve for high rate processes as ideal masking material because of their high chemical and thermal stability in combination with a great thermal conductivity. The mask stands stable in the etching process even at high processing temperatures.

## Conclusion

This report shows the wide field of application for sputter deposited AlN thin films in polycrystalline textured configuration. It is worth to apply this material for other applications than sensing approaches by utilizing the piezoelectric effect. The two last mentioned aspects are outstanding examples for alternative using of this smart material.

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