ResearchGate

See discussions, stats, and author profiles for this publication at:
https://www.researchgate.net/publication/272380857

Impact of C-axis Orientation of Aluminium Nitride Thin Films on the Long-term Stability and Mechanical Properties of Resonantly Excited MEMS Cantilevers

ARTICLE *in* PROCEDIA ENGINEERING · DECEMBER 2014

DOI: 10.1016/j.proeng.2014.11.581

READS

15

4 AUTHORS, INCLUDING:

Michael Schneider

TU Wien

27 PUBLICATIONS **61** CITATIONS

SEE PROFILE

All in-text references underlined in blue are linked to publications on ResearchGate, letting you access and read them immediately.

Available from: Michael Schneider

Retrieved on: 16 January 2016

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 87 (2014) 1493 – 1496

Procedia Engineering

www.elsevier.com/locate/procedia

EUROSENSORS 2014, the XXVIII edition of the conference series

Impact of c-axis orientation of aluminium nitride thin films on the long-term stability and mechanical properties of resonantly excited MEMS cantilevers

M. Schneider*, A. Bittner, P. Schmid, U. Schmid

Institute of Sensor and Actuator Systems, Vienna University of Technology, Floragasse 7/2/MST-366, 1040 Vienna, Austria

Abstract

In this work, the influence of c-axis orientation of sputter-deposited aluminium nitride thin films on the mechanical properties and long-term stability of resonantly excited, Si-based MEMS cantilevers is investigated. Two AlN films are synthesized at different deposition parameters yielding a strong difference in the degrees of c-axis orientation. It is demonstrated, that the temperature and pressure dependency of the mechanical behaviour is independent of the c-axis orientation of the AlN films. However, a substantial impact of this film parameter on the long-term stability of the devices is observed.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the scientific committee of Eurosensors 2014

Keywords: aluminum nitride, cantilever, mechanical properties, resonantly excited, mechanical resonance, long-term stability

1. Introduction

Micro beams and mechanical resonators are used in the field of micro electro-mechanical systems (MEMS) as biological sensors [1], chemical sensors [2, 3] or mass detectors [4], to name a few. A lot of these approaches exploit specific properties of the micro beams in resonance. In order to excite such a device, an active layer of piezoelectric aluminum nitride (AlN) can be utilized [5]. In this work, the influence of different types of aluminum nitride on the mechanical behavior and the long-term stability of a resonantly excited AlN-based cantilever is investigated.

* Corresponding author. Tel.: +43-1-58801-76636; fax: +43-1-58801-36698.
E-mail address: michael.schneider@tuwien.ac.at

1877-7058 © 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).
Peer-review under responsibility of the scientific committee of Eurosensors 2014
doi:10.1016/j.proeng.2014.11.581

2. Experimental Details

In the case of a piezoelectrically excited cantilever, the resonance and Q-factor can be determined by measuring the frequency dependence of the electrical admittance $Y = G(\omega) + iB(\omega)$ of the active film. Using the Butterworth-Van-Dyke model [5, 6], the Q-factor is calculated according to

$$Q = \frac{1}{R_m}\sqrt{\frac{L_m}{C_m}} \tag{1}$$

The parameters R_m, L_m and C_m can be extracted from the conductance $G(\omega)$ and the susceptance $B(\omega)$. Further details are described in [5].

For the fabrication of the devices investigated in this work, a 4” silicon-on-oxide (SOI) wafer was used with a device layer thickness of 2 µm and a buried oxide (BOX) thickness of 800 nm. Electrical isolation of the device layer is achieved by a stress compensated bi-layer of 250 nm thermally grown silicon oxide and an 80 nm thick layer of silicon nitride, as provided by the manufacturer. Using equation (1), the device geometry was fixed at L = 371 µm and W = 100 µm in order to achieve a resonance frequency of the first bending mode of $f_{R,1}$ = 30 kHz. The bottom electrode stack of the device consists of a 50 nm thick chromium film serving as adhesion promoter followed by a 150 nm thick platinum film. The metals were deposited using an evaporation system and patterned by a standard lift-off approach.

In order to analyze the influence of different orientations of aluminum nitride as active material, two sets of deposition parameters were used. The AlN was deposited in a production type DC magnetron sputtering machine by “Von Ardenne” (LS 730). Before deposition, the 150 mm aluminum target (purity 5N) at a distance of 65 mm from the substrate was pre-sputtered at closed shutter position for 10 min for purification purposes. For AlN deposition, pure nitrogen (purity 6N) was introduced into the chamber at a constant flow rate of 50 sccm. Back pressure and power during deposition for the two AlN types were set to p = 2 µbar and P = 800 W for *lp*-AlN (*low pressure*) and p = 6 µbar and P = 500 W for *mp*-AlN (*medium pressure*), respectively. The patterning of the AlN films was done using both a wet-chemical etch step (i.e. phosphoric acid at 75°C) and an additional 100 nm thick titanium film serving as sacrificial layer in an subsequent lift-off step.

The 200 nm thick aluminum top electrode is deposited by sputter deposition and patterned by a wet-chemical etch using phosphoric acid at room temperature. The device layer itself is structured by deep reactive ion etching (DRIE), using the BOX layer as etch stop. Subsequently, the handle of the SOI wafer is also structured by DRIE and the remaining BOX layer removed using hydrofluoric acid, thereby releasing the devices.

The admittance was measured using an Agilent 4294A precision impedance analyzer. The samples were placed in a vacuum chamber by Linkham. The chamber pressure p_m was changed between 20 and 500 mbar using nitrogen as inert gas and the sample temperature T_m was changed between -150 and 150°C. The long-term measurements were performed under high vacuum at T_m = 300°C and the cantilever was stressed by driving it into resonance once per second using a sinusoidal linear chirp. A cycle refers to the duration of one complete chirp. A PANalytical X’Pert PRO Bragg-Brentano X-ray powder diffractometer was used for the XRD analysis equipped with a long fine focus type Cu-tube operated at 40 kV and 40 mA (λ = 1.5406 Å ($CuK_{\alpha 1}$) and λ = 1.5444 Å ($CuK_{\alpha 2}$)).

3. Results and Discussion

The conductance $G(\omega)$ of the mp-AlN sample is depicted in Fig. 1(a) for varying p_m at T_m = 50°C. Due to increasing damping based on the rising chamber pressure, the resonance frequency as well as the peak intensity decrease at higher pressure levels. This behavior is identical for both types of AlN films, as shown in Fig. 1(b) for T_m = 0°C. The f_R-axes are scaled identically. The offset is attributed to manufacturing intolerances, predominantly caused by thickness variations of the device layer.

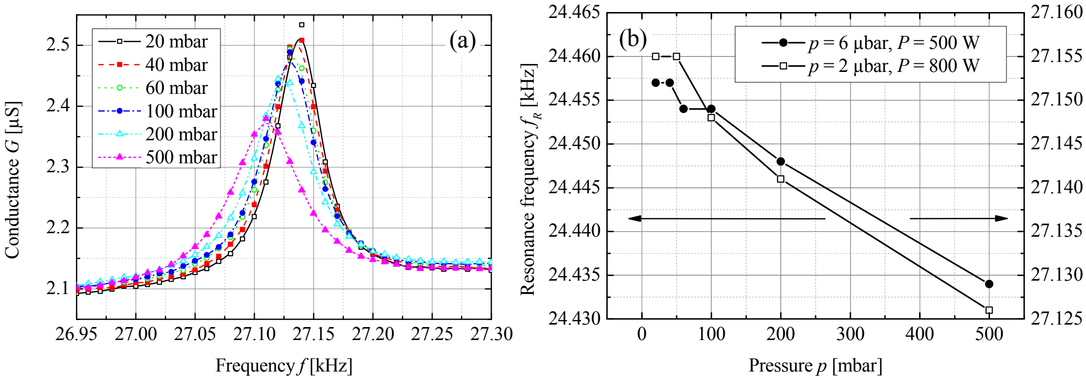

Fig. 1. (a) $G(\omega)$ for mp-AlN at different back pressure levels p_m and $T = 50°C$; (b) Back pressure level vs. resonance frequency f_R.

Fig. 2(a) yields the change of f_R with the sample temperature T_m at the lowest pressure $p_m = 20$ mbar. For $T_m \geq 50°C$, a slight decrease of f_R with increasing T_m is detected, which is mainly due to a decrease of the Young's modulus of the silicon at higher T_m [7]. The significant lowering of f_R for $T_m \leq -50°C$ is caused by a freeze out of residual gaseous constituents, especially water. Since the chamber was not designed for ultralow vacuum levels, this effect is not avoidable, but could also proof useful in light of sensor applications. Basically, the change of the resonance frequency with temperature is independent of the AlN-type.

Both samples show a similar decrease of the Q-factor with increasing temperature, as illustrated in Fig. 2(b). Using a straightforward approach, the temperature dependence of Q can be described as $Q \propto 1/T_m^{\gamma}$ with the temperature coefficient of the Q-factor, γ. It should be noted, that $\gamma \approx 0.5$ relates to damping predominantly by the surrounding atmosphere, whilst a value of $\gamma \approx 3.5$ relates to thermo-elastic damping mechanisms. As shown in Fig. 2(b), the dominating effect in this case is the damping by the surrounding gas, indicating a good agreement between theory and the expected measurement results.

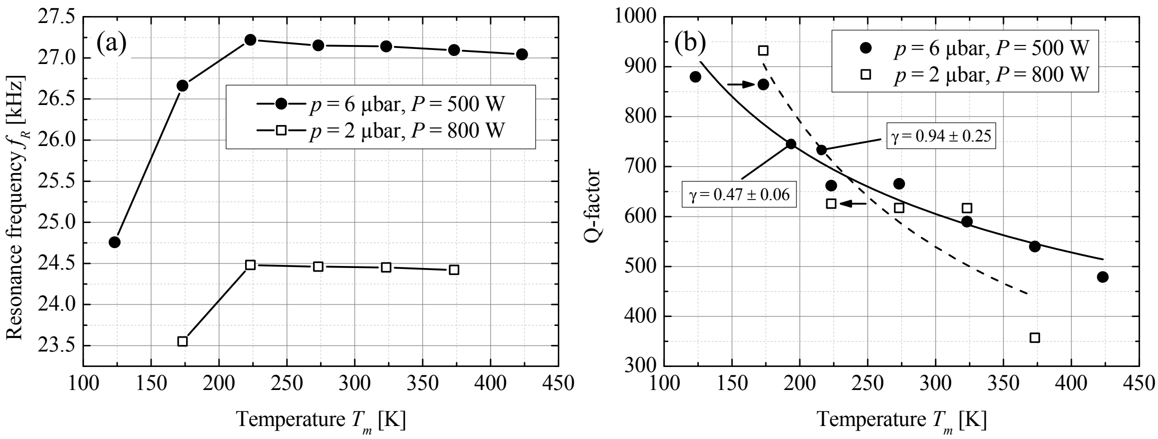

Fig. 2. (a) Temperature dependence of the resonance frequency f_R; (b) Temperature dependence of the Q-factor of the first bending mode.

Fig. 3(a) shows the results of the long-term measurements gained from the sample with lp-AlN. The change in f_R with an increasing number of stress cycles is relatively small (about 1%) and can be attributed to aging effects within the material. The increase of Q correlates to a decrease of R_m in accordance with Eq. 1. In addition, a decrease in R_p together with R_m is observed, suggesting a weakening of the electrical isolating properties of the aluminum nitride thin film due to the continuous mechanical stressing. The sample with mp-AlN is not shown here, since it failed already between 62000 and 87000 cycles, demonstrating a six times shorter time to failure than that with lp-AlN. The difference between the two AlN types is revealed by XRD measurement, yielded in Fig. 3(b). The lp-AlN shows a significantly higher degree of c-axis orientation compared to the mp-AlN sample. It is believed, that this enhancement in microstructure-related film quality is primarily responsible for the increased long-term stability of lp-AlN. Additional investigations, however, will be necessary to give more confidence in this assumption.

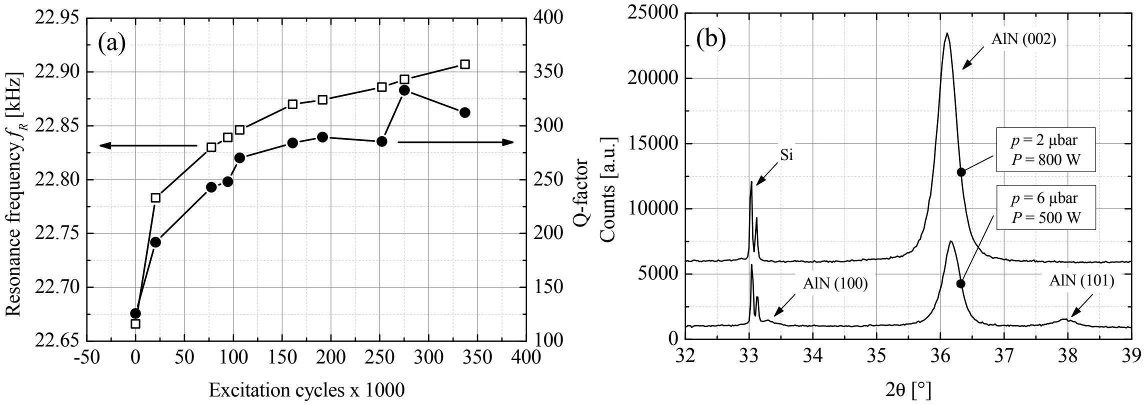

Fig. 3. (a) Shift in resonance frequency and Q-factor in response to mechanical stressing of the cantilever structures with lp-AlN; (b) XRD measurements of the two different AlN types used in the cantilever-type resonators.

4. Conclusion

In this work, the impact of two different AlN-types applied as active layer in resonantly excited cantilevers on their mechanical behavior was observed. It was demonstrated, that the AlN-type had no influence on the measured characteristics of the resonance frequency f_R and the Q-factor with respect to variations in the surrounding pressure levels p_m and the sample temperature T_m. A significant impact was observed when measuring the long-term stability of the devices. It was shown, that the time to failure of the sample with lp-AlN was about six times longer compared to that excited with mp-AlN. This effect can be attributed to the different degrees of c-axis orientation present in the two AlN-types. A higher degree of c-axis orientation results in a longer life time of the device under given mechanical stress conditions.

References

[1] C. Ziegler, Cantilever-based biosensors, Analytical and Bioanalytical Chemistry, 379(2004), 946-959.

[2] K. M. Goeders, J. S. Colton, and L. A. Bottomley, Microcantilevers: Sensing Chemical Interactions via Mechanical Motion, Chemical Reviews, 108(2008), 522-542.

[3] C. Hagleitner, A. Hierlemann, D. Lange *et al.*, Smart single-chip gas sensor microsystem, Nature, 414(2001), 293-296.

[4] J. F. Vignola, J. A. Judge, J. Jarzynski *et al.*, Effect of viscous loss on mechanical resonators designed for mass detection, Applied Physics Letters, 88(2006), -.

[5] M. Kucera, T. Manzaneque, J. L. Sánchez-Rojas *et al.*, Q -factor enhancement for self-actuated self-sensing piezoelectric MEMS resonators applying a lock-in driven feedback loop, Journal of Micromechanics and Microengineering, 23(2013), 085009.

[6] O. T. L. Jordan, and Z., [Piezoelectric ceramics characterization] Institute for Computer Applications in Science and Engineering (ICASE), (2001).

[7] W. Jing, H. Qing-An, and Y. Hong, Size and temperature dependence of Young's modulus of a silicon nano-plate, Journal of Physics D: Applied Physics, 41(2008), 165406.