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50. Internationales Wissenschaftliches Kolloquium
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Estimation of the piezoelectric properties of thin AlN layers for MEMS applications

ABSTRACT

Piezoelectric properties of aluminium nitride thin films were measured using both, the piezoresponse force microscopy and an interferometric technique. Wurtzite AlN thin films were prepared on Si (111) substrates by reactive DC-sputtering and by metalorganic chemical vapor deposition (MOCVD). Direct measurements of the inverse piezoelectric effect in the picometer range showed that the acceptable tolerance in the crystal orientation is much larger for MEMS applications than expected previously. The value of the piezoelectric coefficient d_{33} for the prepared AlN thin films was determined to be 5.36 ± 0.25 pm/V for highly textured as well as for polycrystalline thin films with a (002) preferential orientation.

Micromechanical resonators show significant promise for many sensor applications, including chemical and biological sensing, electrometry, and scanning probe techniques. In these applications, a change in mass, temperature, charge, or any other applied force induces a small shift in the resonance frequency of the oscillator [1]. Typically, resonators require both an actuation and a detection of the resonance frequency. Such responses can be observed through a variety of physical detection methods including electronic and optical effects, i.e. changes in resistance (piezoresistivity), changes in capacitance, and changes in charge (piezoelectricity) [2]. On the other hand, microactuators are usually based on electrostatic, piezoelectric, magnetic, thermal, and pneumatic forces. Although each application of MEMS requires a specific design to satisfy many constraints and conditions, piezoelectric-based MEMS are generally attractive due to their high sensitivity and low electrical noise in sensing applications and high-force output in actuation applications.

The exceptional properties of wide-bandgap III-V nitride semiconductors are promising for such applications. Among the nitrides AlN has the highest thermal conductivity at low temperature, good mechanical strength, high resistivity and corrosion resistance, and the largest piezoelectric coefficients [3]. Thus, AlN resonators are attractive building blocks for electromechanical devices on the micro- and nano scale. Usually, based on surface acoustic wave measurements, a strong c-axis orientation of the AlN is crucial for a high piezoelectric response of the thin film and all process optimization has been performed to achieve such structures. Unfortunately, epitaxial growth of AlN only occurs at high temperatures which makes the epitaxial deposition incompatible for the integration in CMOS or other technologies sensitive to heat. Therefore much effort has been made to grow highly textured polycrystalline films with low temperature processes like reactive sputtering. In this work we will show by direct measurement of the piezoresponse in the picometer range that the acceptable tolerance in the crystal orientation is much larger than expected, which opens the way for low temperature integration of piezoelectric thin films into MEMS and NEMS. AlN thin films of different structural quality have been prepared on conductive (111) silicon wafers by both, metal organic chemical vapor deposition (MOCVD) and reactive sputtering. The resulting layers have been polycrystalline with different degree of texture in the case of MOCVD and nanocrystalline in the case of reactive sputtering. The layer thickness was between 100 and 250 nm.

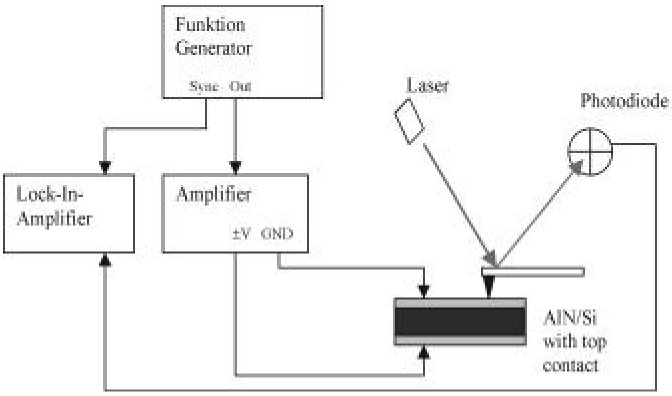

Fig. 1: Piezoelectric Force Microscopy set up to detect thin film expansion of about 10 pm.

For the measurements sputtered Ti/Au contacts were used as top electrodes, while silver glue served as back contact. The estimation of the piezoelectric constants has been performed by piezoelectric response force microscopy (PFM) and by optical interferometry. A modulation voltage is applied between the top electrode and the substrate, which causes the piezoelectric film to oscillate at the same frequency as the applied voltage. In PFM this bias-induced deformation is detected by a common silicon AFM-tip which is brought into contact with the surface of the metallic top electrode [4, 5]. When a modulation voltage is applied to the piezoelectric film, the vertical displacement of the tip follows accurately the piezoelectric motion of the sample surface. The piezoresponse is then detected as the first harmonic component of the deflection signal. Thus, the piezoelectric coefficient can be calculated as the ration between tip displacement Δt and applied voltage V:

$$d_{33} = \frac{\Delta S_3}{E_3} = \frac{\Delta t}{V},$$

were ΔS_3 = Δt/t is the change of strain along the c-axis and E_3 = V/t the electric field along the c-axis. PFM measurements were performed with a commercial AFM (ATOS Solver), a function generator (Agilent 33220 A) and a lock-in amplifier (Stanford Research Systems GS). A schematic of the experimental set up is shown in figure 1. A homodyne Michelson laser interferometer was used to complement the AFM technique [6].

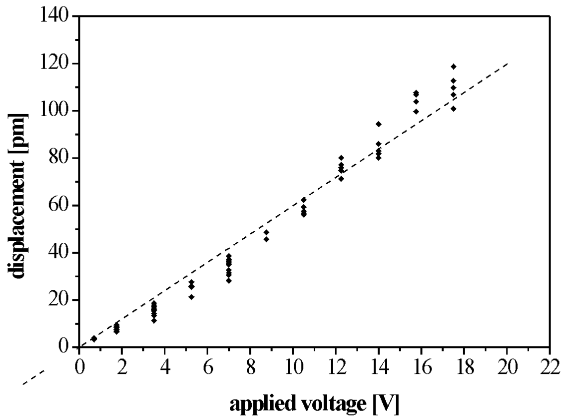

Fig. 2: Typical piezoelectric displacement vs. applied voltage estimated by PFM.

Figure 2 shows the linear dependence of the displacement of the sample surface from the applied voltage measured at a sputtered aluminium nitride film. The calculation of the displacement versus applied voltage results in a piezoelectric coefficient of 5.36 ± 0.25 pm/V for AlN thin films prepared by both reactive sputtering and by MOCVD, and is in good accordance to reported values [5, 7].

Additional measurements using a homodyne Michelson interferometer supported the above obtained results. Here an integrated spectrum ranging from 5,5 to 22 kHz was recorded. An extract of the spectra for (a) a sputtered and (b) for a MOCVD-grown AlN film ranging from 17,5 to 19 kHz is provided in figure 3 and shows the vertical displacement of the sample surface due to the applied voltage of 14 V at a modulation frequency of 18,3 kHz.

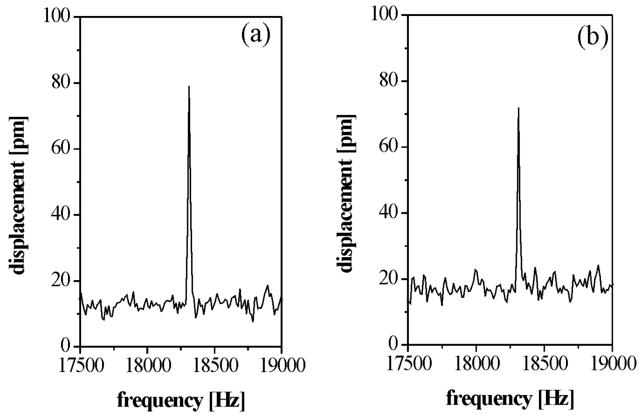

Fig. 3: Typical piezoelectric displacement vs. frequency estimated by optical interferometry for (a) sputtered AlN and (b) MOCVD-grown AlN.

The value of the measured piezoelectric coefficient was less affected by the structural quality than expected by other authors [8] which makes AlN thin films grown at low temperatures suitable for many kinds of MEMS applications.

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