

Characterization of Aluminum Nitride on vertical side walls

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Summary:

AlN is used for actuation of vertical sidewalls e.g. for a MEMS speaker with a high aspect ratio membrane. This actuation of vertical sidewalls by a sputtered AlN layer generates new challenges regarding the characterization of piezoelectric quality along the vertical sidewalls. This work utilizes Fourier transform infrared (FT-IR) microscopy to measure crystallinity and crystal orientation of the layers. FT-IR spectroscopy was found to be a suitable method to characterize vertical AlN sidewalls. Results for crystallinity and crystal orientation of AlN are discussed and compared to surface measurements.

Keywords: piezoelectric AlN, sputter deposition, FT-IR spectroscopy, MEMS, 3D membranes

Background, Motivation and Objective

A novel 3D MEMS speaker concept with high aspect ratio is used to maximize the active surface area [1]. Piezoelectric aluminum nitride (AlN) thin films are used for actuation. In this work, conformal deposited AlN by atomic layer deposition (ALD) is replaced by more crystalline sputtered AlN-layer with higher piezoelectric performance [2] with the drawback of tapered film thickness. As sputtering is a directional process, film properties on vertical side walls will differ from surface properties. This raises the necessity of a reliable characterization method of piezoelectric, structural and mechanical properties at the side wall. The objective of this work is to utilize the high spatial resolution of FT-IR microscopy to characterize the crystallinity, crystal orientation, and residual stress level of AlN layers at vertical side walls.

Description of the new method or system

There are few works on AlN characterization using FT-IR spectroscopy to measure the crystal orientation of AlN films [3]. This work utilizes a Bruker Invenio FT-IR spectroscope coupled with a Hyperion 2000 FT-IR microscope. The high spatial resolution of FT-IR microscopy enables the adjustment on single side-walls of the lamella structure. Side walls were separated by dicing through a trench and aligned horizontally with a mini-vice. The measurement is applied on a side wall sample and results are discussed and compared with surface measurements. Peak positions and widths are extracted using Voigt fitting.

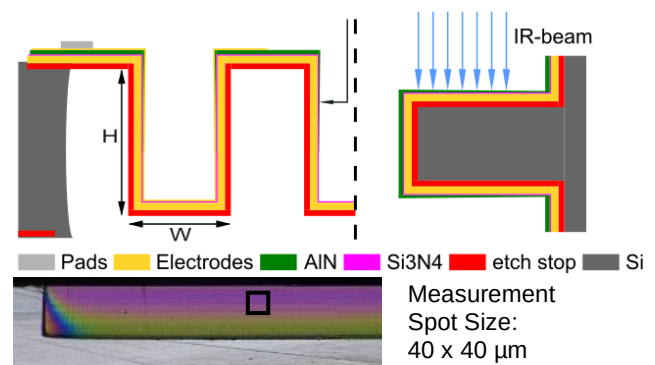


Fig. 1. a) Concept of the MEMS speaker with a high aspect ratio trenches and vertical sidewalls b) alignment for FT-IR measurements; c) LSCOM image of the side wall & measurement spot

Results

AlN thin films were deposited using different sputter conditions on a Si<100> wafer and characterized by FT-IR microscopy. Results are compared with established characterization methods as XRD for crystal orientation and crystallinity, and wafer bow for residual stress measurement. Four different AlN layers were analyzed: two sputtered AlN films with high c-axis orientation and low FWHM (good crystallinity) having different stress states, one sputtered AlN film with crystalline, but not textured crystal structure and one ALD-deposited AlN thin film showing c-axis orientation, but low crystallinity.

FT-IR spectra are shown in Fig. 2a-c. Due to the interaction of the IR beam with AlN, excited phonon modes are dependent on the crystal orientation [3]. If the c-axis is parallel to the incident IR-beam, only the E1 (TO) appears and the A1

(TO) peak vanishes. This can be seen in Fig. 2a. The low FWHM indicates a good crystallinity of AlN. If the crystal structure deviates from an ideal c-axis orientation, the A1 (TO) peak can be detected. This can be due to an additional occurring crystal orientation (Fig. 2b) or due to a lack of crystallinity (Fig. 2c). As excitation of phonon modes is not bound to crystalline materials, also not ordered crystal bonds contribute to the absorption spectrum. The trend in FWHM is similar to the trend detected with XRD. Lowest FWHM was detected in crystalline & c-axis oriented layers (Fig. 2a). A slightly higher FWHM was detected in randomly oriented layers (Fig. 2b) and the highest FWHM was measured in purely crystalline ALD-AlN layers (Fig. 2c). To make an estimation of the residual stress state of AlN-layers, FT-IR peak positions were compared and opposed to wafer bow measurements. A matching trend was not detected. In conclusion, it is possible to conclude on c-axis orientation and crystallinity of AlN by FT-IR measurements.

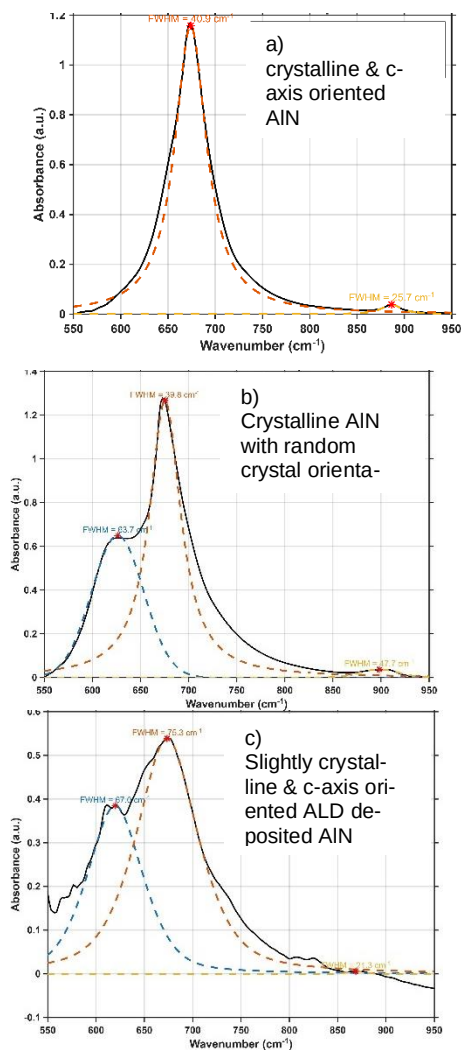


Fig. 2.: FT- IR absorbance spectra of different layers: a) crystalline and c-axis oriented sputtered AlN; b) crystalline, randomly oriented sputtered AlN and c) purely crystalline, c-axis oriented ALD-AlN

The FT-IR measurement of a sidewall coated by AlN is shown in Fig. 3. AlN was grown on a Poly-silicon layer, thus measurements were taken in transmission mode. The aperture size was set to $40 \times 40 \mu\text{m}$ (Fig. 1c) to represent a largest possible part of the side wall with a sufficient AlN film thickness.

Both peaks E1(TO) and A1(TO) were detected in the FT-IR spectrum at the side wall. This indicates a deviation from ideal c-axis orientation. As stated in the literature, the c-axis orientation is not perpendicular to the substrate at vertical side walls [4]. Additionally, as also grains are tilted at the side wall, amorphous grain boundaries also contribute to the intensity of the A1 (TO) peak and promote a large FWHM of the E1 (TO) peak.

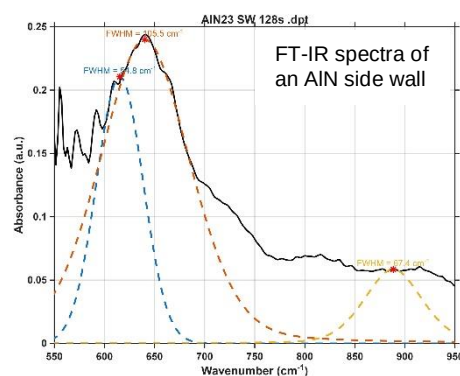


Fig. 3.: FT-IR spectrum of a crystalline AlN layer at the side wall of a trench

In conclusion, FT-IR microscopy can be utilized to measure crystal orientation and crystallinity on trench side walls. Next, it is planned to measure locally resolved at different trench depth to detect the difference occurring with it. Prospectively, FT-IR spectroscopy can be used to optimize AlN for 3D structures.

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