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Sputter deposited aluminum nitride for an efficient manufacturing of piezoelectric folded MEMS membranes

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Summary:
Folded membranes with high aspect ratio features and vertical sidewalls utilize conformal aluminium nitride (AlN) layers to maximize the active area of MEMS transducer chips [1,2]. This work studies the possibilities and limitations of efficient sputtering to replace the currently used atomic layer deposition (ALD) by a denser, crystalline and faster deposited thin film. Scanning electron microscopy (SEM) analysis of test structures shows a successful coverage of features with aspect ratios of up to 12:1 by variation of process parameters such as the working distance and the nitrogen to argon gas flow ratio.

Keywords: 3D membranes; high aspect ratio features; piezoelectric aluminum nitride; reactive magnetron sputtering; MEMS transducer

Introduction

In terms of miniaturization of MEMS devices, a MEMS transducer design with a folded membrane structure was introduced [1,2]. Chip area is used efficiently by lateral actuation of the vertical side walls (SW) of high aspect ratio features. For manufacturing, conformal CVD-processes were used to deposit the mechanical carrier layers, as well as the electrodes and the piezoelectric aluminum nitride (AlN) thin film. The latter is currently deposited by atomic layer deposition (ALD) as it can cover high aspect ratio (AR) trenches with constant film thicknesses [2]. Compared to sputtering, ALD-AlN exhibits a different microstructure leading to less dense and less crystalline films [3,4]. The piezoelectric response of aluminum nitride depends on the crystallinity of the layer [5] and the deposition rate of ALD-ALN is very low [6], this work aims to replace the ALD layer by a more efficient sputtered aluminum nitride. AlN sputtering on vertical SWs has been discussed in literature for free standing structures or edges [7]. In this work sputtering into deep features with high ARs is investigated.

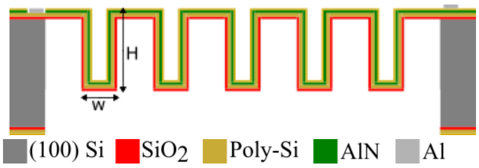

Fig. 1. Folded membrane structure with a conformal piezoelectric layer [2];

Experimental details

For the experimental analysis, trenches with different aspect ratios (AR) from AR1:1 to AR 12:1 are etched into the silicon (Si) (100) substrates with deep reactive ion etching (DRIE). The AR is defined by the height (H) to width (w) of a trench (*Figure 1*). The structure is covered with 1 µm of n-doped Poly-Silicon (Poly-Si) via low-pressure chemical vapor deposition (LPCVD). AlN layers are deposited in the sputtering device CS730S from von Ardenne. Sputtering parameters for the sputter clean and the deposition process are summarized in Table 1. For the scanning electron microscopy (SEM) analysis, samples are cleaved and film thicknesses at different positions are measured with a Zeiss Crossbeam 550L Scanning electron microscope.

Tab. 1: Sputtering parameters, constant parameters: power = 800 W, pressure = 4 µbar; ISE Sputter Clean at same conditions but in pure Argon

Sample	Working distance in mm	Nitrogen content in %
AlN 1	71	22.2
AlN 2	78	22.2
AlN 3	85	22.2
AlN 4	71	47.2
AlN 5	71	73.6

Results and discussion

This work evaluates the possibilities of a conventional sputtering system to cover the sidewalls of high aspect ratio features with AlN. Process parameters from Tab.1 are chosen to find the main trends and levers to achieve that. Figure 2(a) and Figure 2(b) show the dependency of the WD and the nitrogen to argon gas flow ratio on the film thickness at the bottom of the horizontal side wall relative to the film thickness at the top of the SW. The main levers for enhanced sidewall coverage are found to be maximizing the working distance (WD) and minimizing the nitrogen to argon gas flow ratio. This matches the expectation from literature, as both parameters are increasing the amount of ionized sputter atoms within the plasma [8].

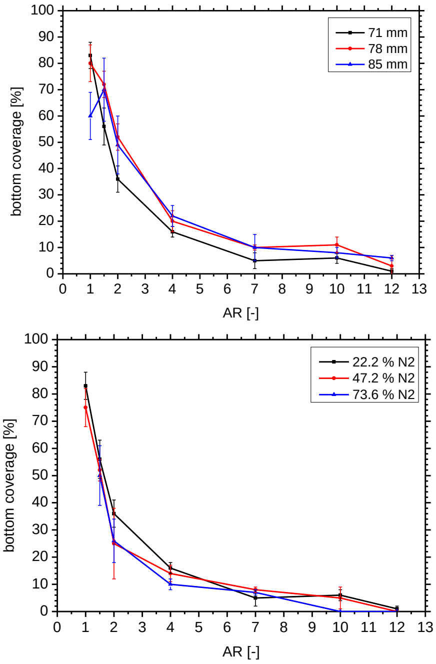

Fig. 2. Dependence of the WD (a) and the nitrogen content (b) on the AR-dependent SW coverage

A maximum AR of 12:1 was covered at the highest WD and lowest nitrogen content. SEM images also reveal the grain structure tilt at the SW. *Figure 3* shows the tilting of the grains across the edge of a trench by 56°. Independent from the AR, the film thickness at the surface is approximately three times the film thickness at the top of the vertical SW. Along the SW, it decreases until the bottom of the trench is reached or no layer is left.

Summary and Outlook

In this work the possibilities and limitations of a conventional sputtering system were evaluated and it was achieved to cover structures with a maximum AR of 12:1 with AlN. The main levers for an enhanced SW coverage of high aspect ratio features are maximizing the working distance and minimizing the nitrogen to argon gas flow ratio. The final paper will investigate the grain structures at the SW and thinning profiles for different aspect ratios and parameter combinations. Influences on the microstructure will be analyzed e.g. through XRD analysis. Prospectively, influences on the behavior of a folded MEMS membrane will be investigated and discussed.

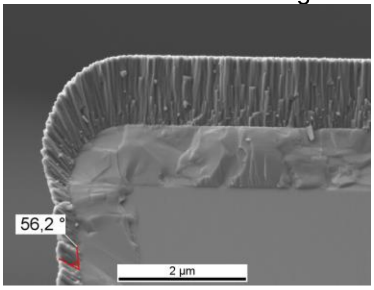

Fig. 3. SEM image of the edge of an AR with elongated grains perpendicular to the surface at the horizontal surface, and tilted grains at the vertical SW.

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