A High d_{33} CMOS Compatible Process For Aluminum Nitride on Titanium

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Introduction

High-speed, low-power actuators find numerous applications in MEMS. Although electrostatic actuation is widely used, piezoelectric actuators are ideal for high frequency, low voltage, out-of-plane applications such as atomic force microscopy.

Commonly used piezoelectric materials include zinc oxide (ZnO) and lead zirconium titanate (PZT), but they both pose a contamination risk in equipment shared with CMOS fabrication processes and require careful processing. Aluminum nitride (AlN) is an alternative with excellent material properties, but AlN must typically be deposited on non-CMOS standard metals such as platinum (Pt) or molybdenum (Mo) in order to achieve good piezoelectric properties.

In this work we characterize the piezoelectric properties of AlN on Ti and present a fabrication process for piezoelectric transducers using only standard CMOS materials.

Experimental Setup
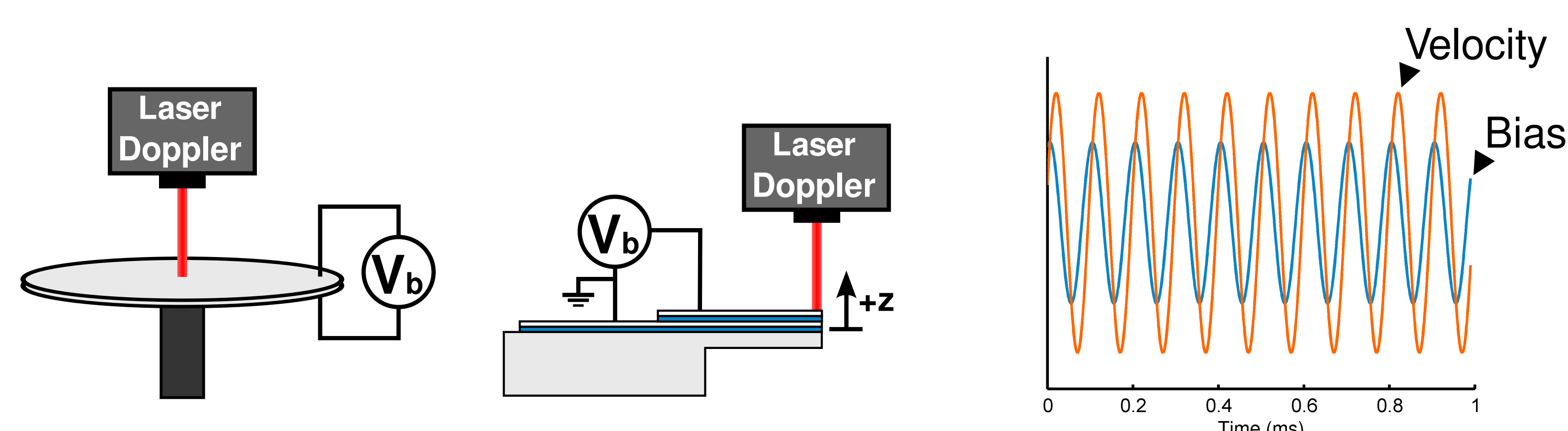
The piezoelectric response of the AlN film was measured at the wafer scale (d_{33f}) and at the device scale (d_{31}). Laser doppler vibrometry was used to measure displacement induced by an AC bias voltage.

The polycrystalline AlN film texture was characterized using x-ray diffraction (XRD) rocking curves. Film thicknesses were measured with scanning electron microscopy.

Device Fabrication
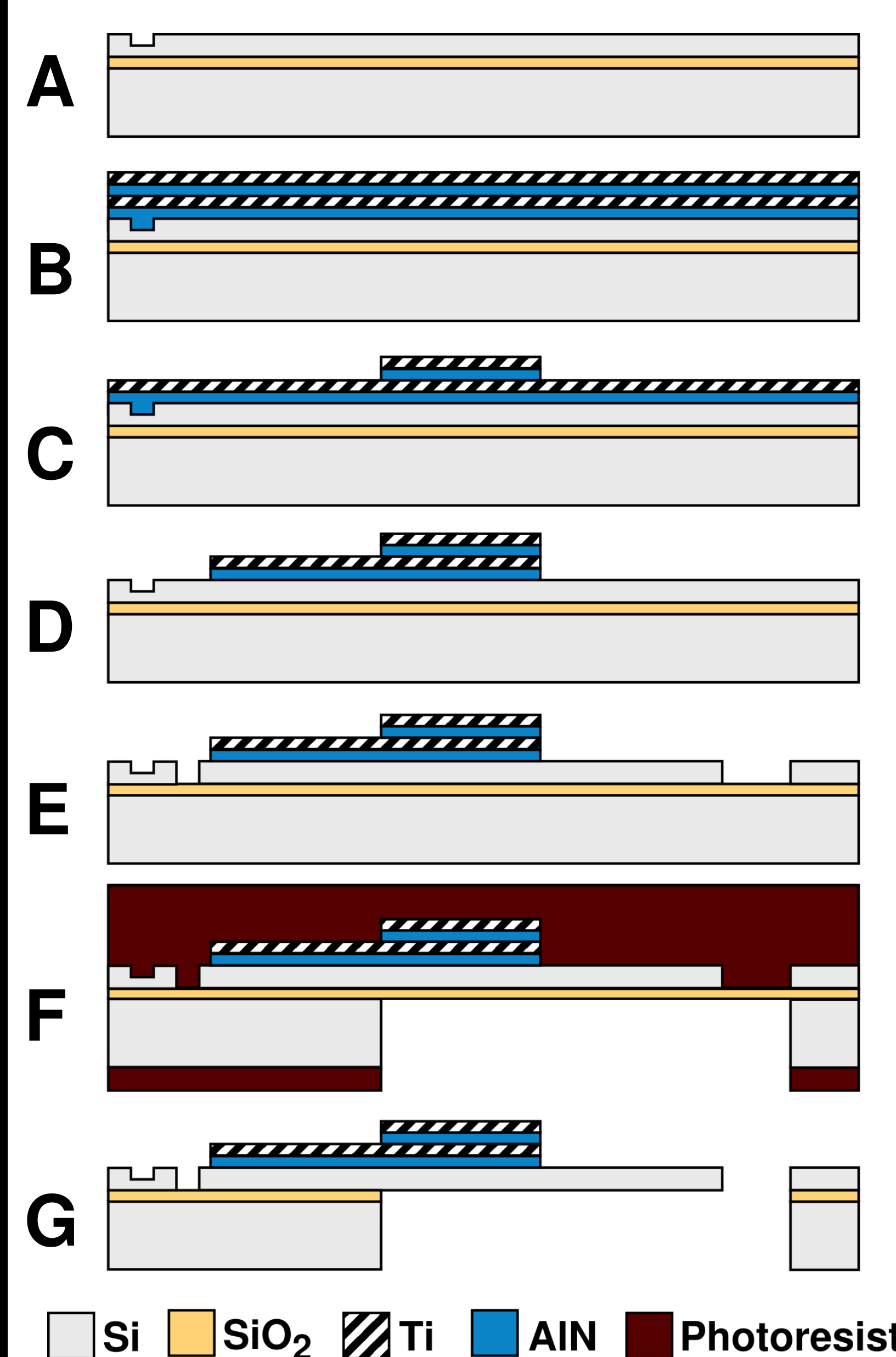
(a) Starting from an SOI wafer (5 micron device layer. 500 nm buried oxide), define the alignment marks.
(b) Deposit the piezoelectric stack.
(c) Pattern the top Ti electrode (50:1 HF) and use as a hard mask to etch the AlN actuation layer (25% TMAH, room temp).
(d) Repeat the same process for the bottom Ti and AlN interlayer.
(e) Define the cantilever by RIE.
(f) Protect the frontside and etch the wafer from the backside by DRIE.
(g) Remove the photoresist protection and etch the buried oxide by RIE to release the cantilevers.

The AlN is deposited by pulsed DC reactive sputtering (5kW, 5mTorr, 200C). The AlN/Ti/AlN/Ti stack is deposited sequentially under vacuum after the wafer is cleaned in-situ by inductively coupled plasma. An AlN interlayer is included to improve film orientation.

Legend: Si | SiO2 | Ti | AlN | Photoresist
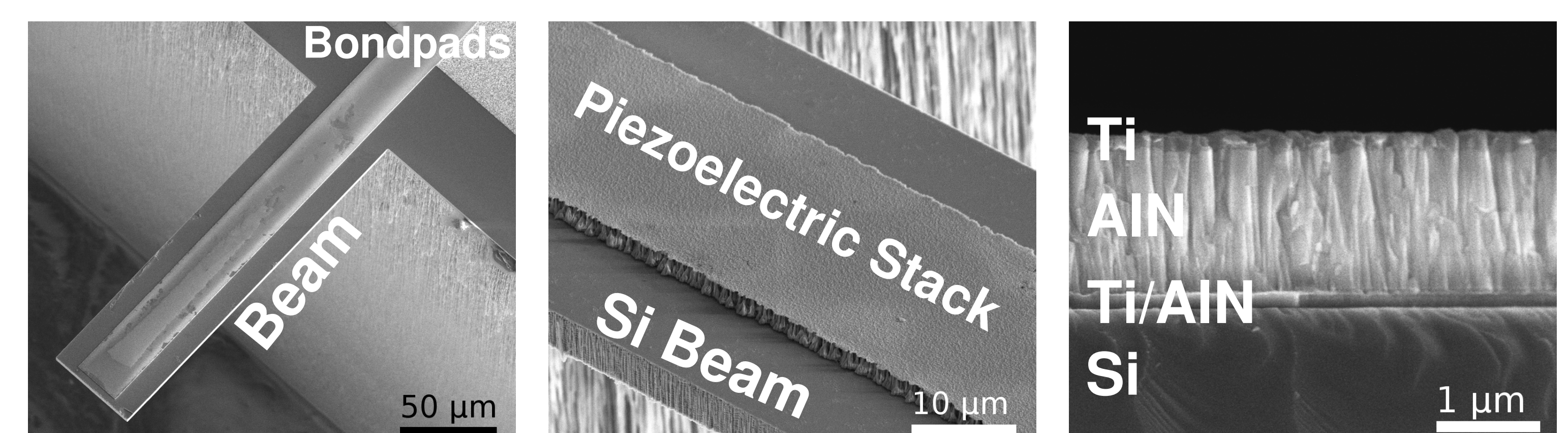
Results and Discussion
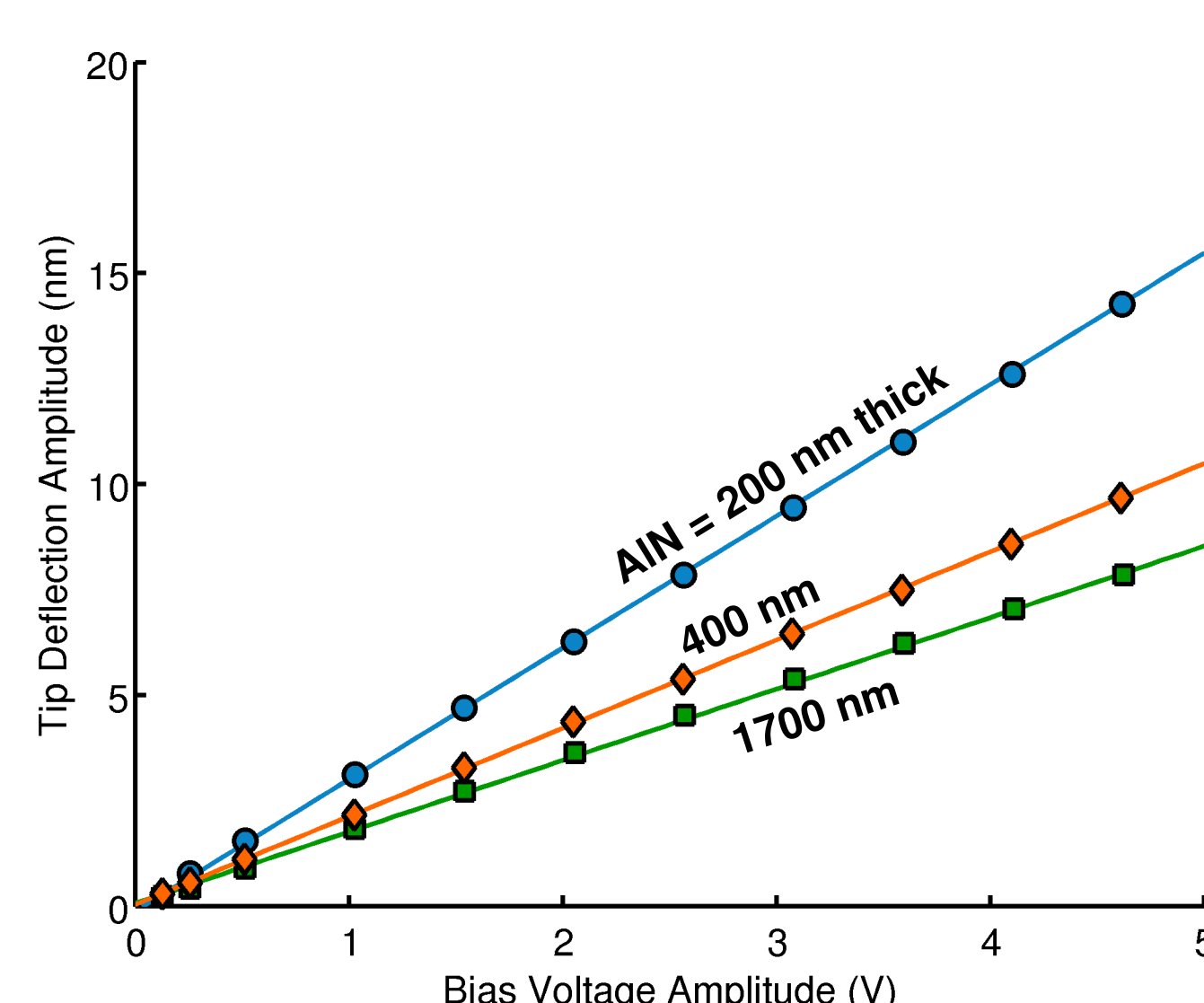
The d_{31} coefficient of the AlN was inferred from the cantilever tip deflection. Tip deflection was measured by LDV while biasing the cantilevers at low frequency (1 - 10 kHz).
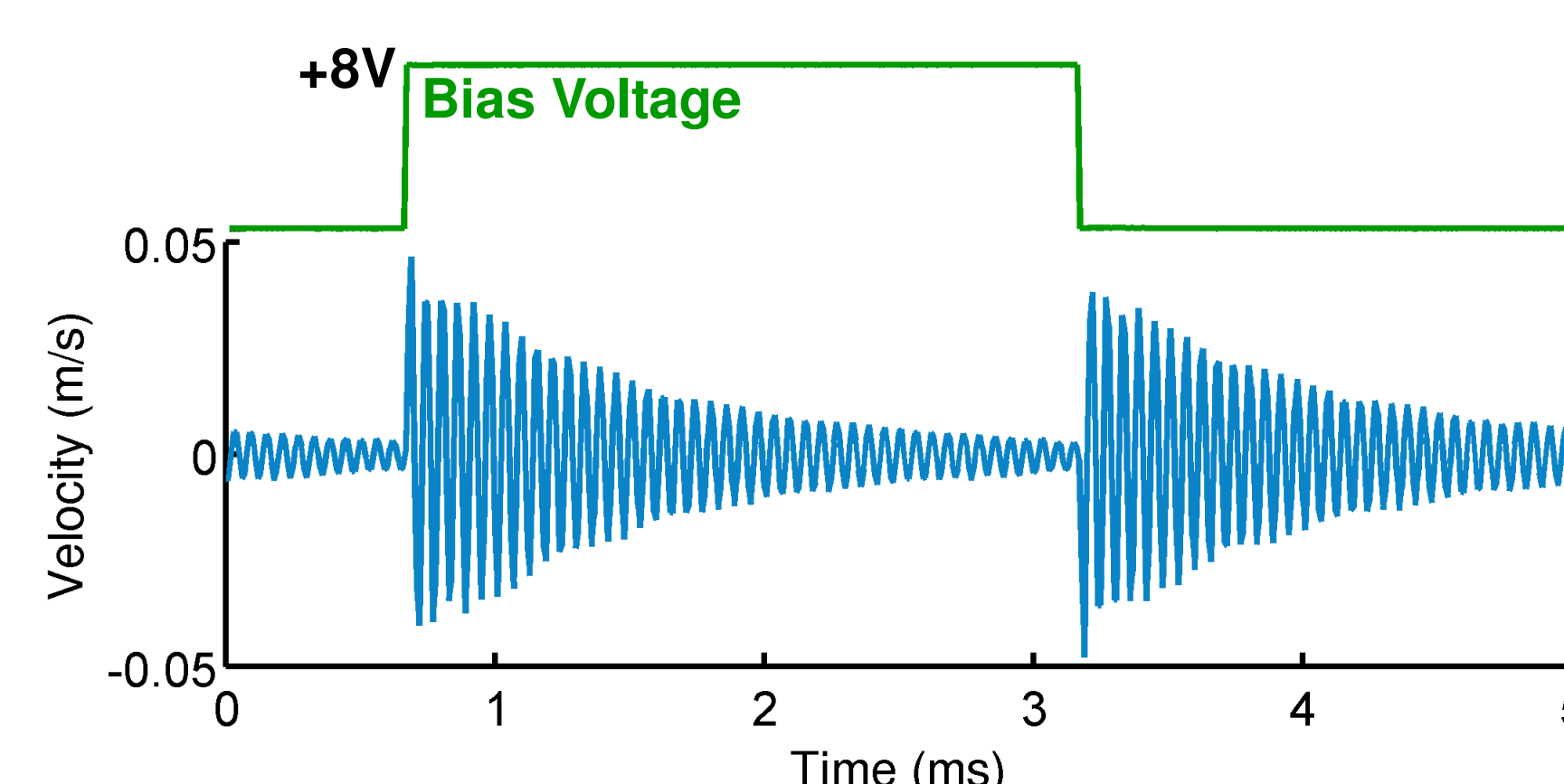
The cantilever step response indicates the polarity of the AlN film ($d_{33} > 0$) as well as the resonant frequency (within 10% of theoretical) and quality factor (300 - 600).
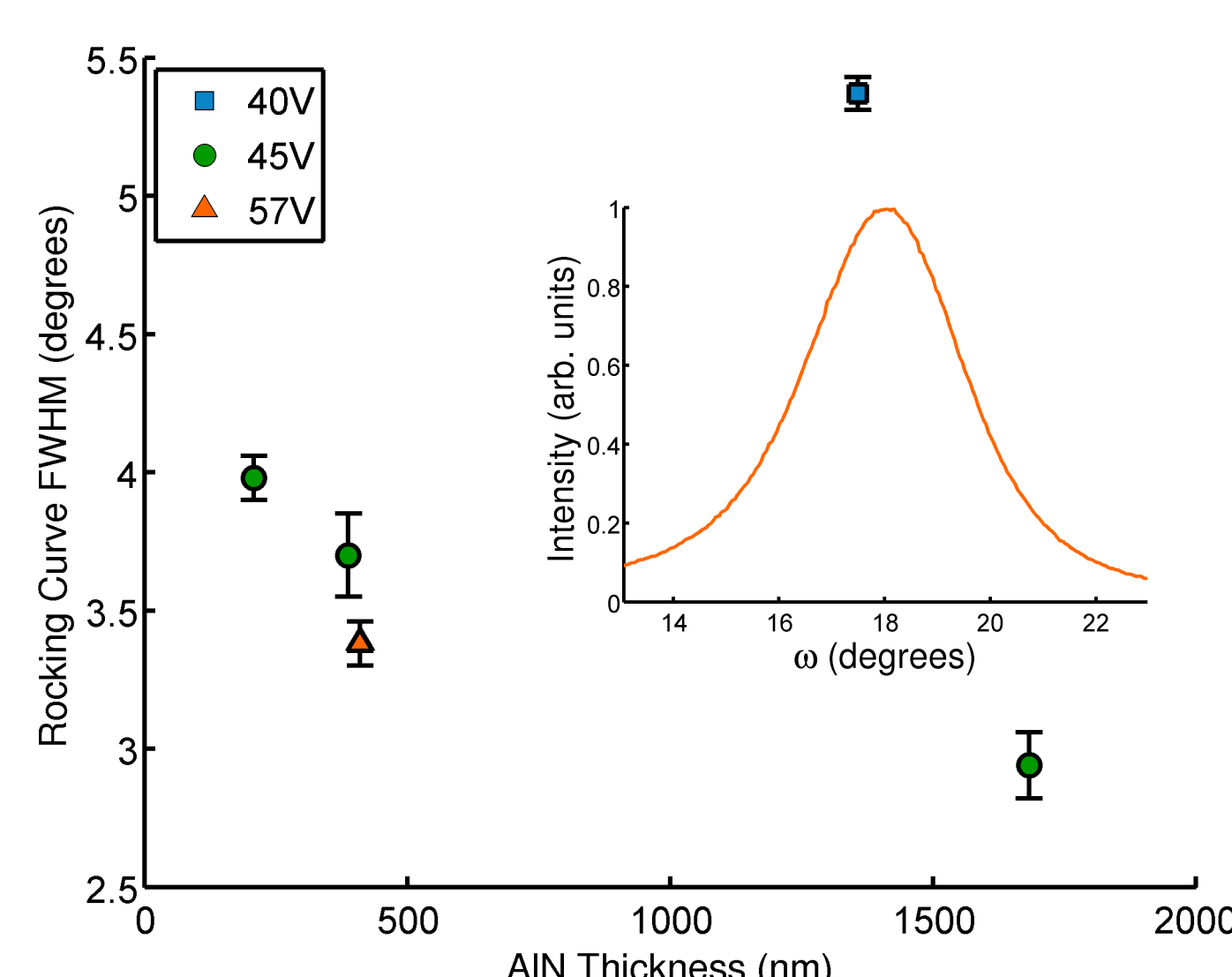
The XRD rocking curve full-width at half maximum (FWHM) varies with the AlN film thickness and bias voltage during deposition. The degree of film texture is an indirect measure of the piezoelectric response due to the possible presence of both + and - oriented AlN grains.
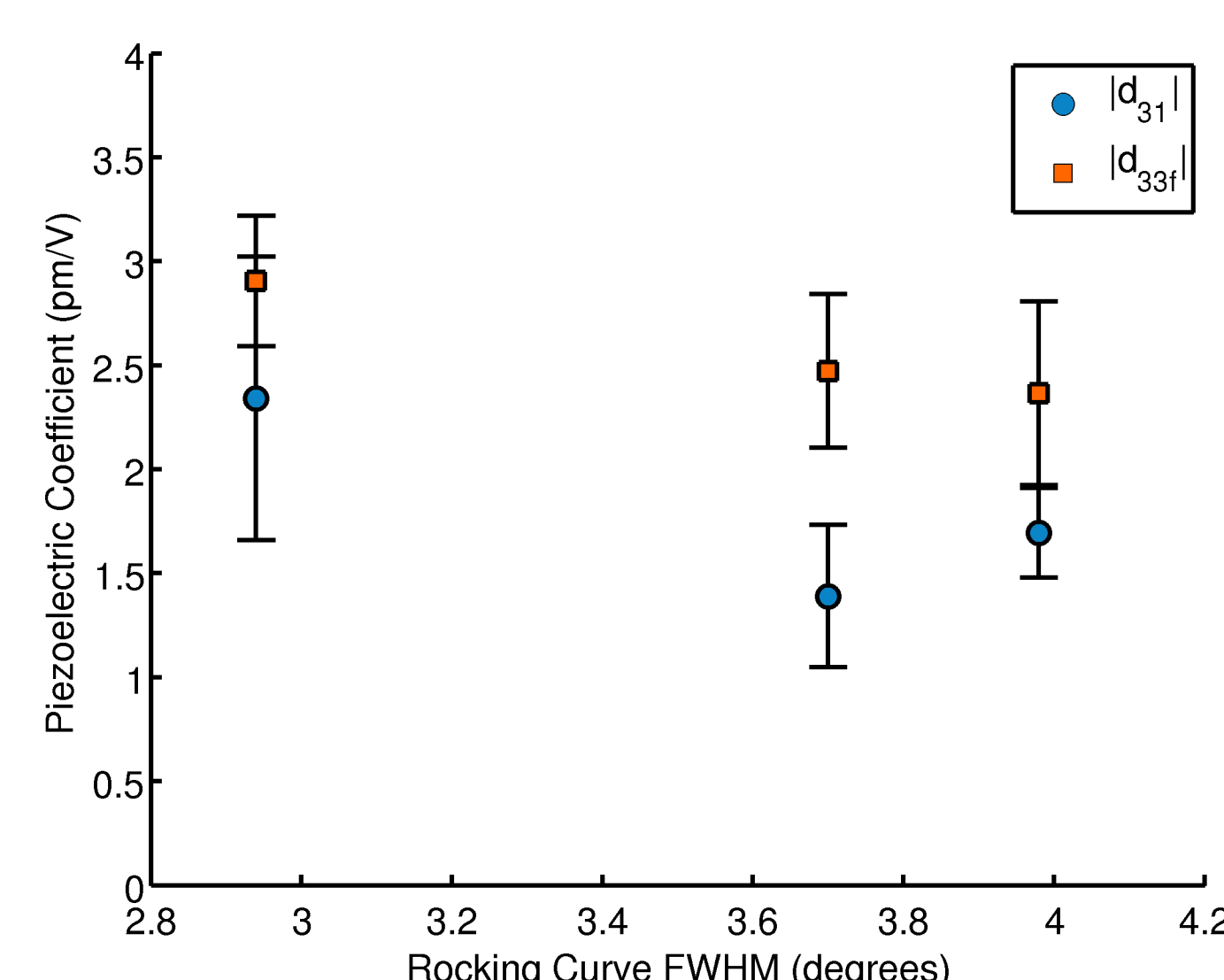
The measured values of d_{33f} (the thin film coefficient, reduced by substrate clamping) and d_{31} correspond to a d_{33} of up to 6.5 pm/V. The data compares well with results for epitaxial AlN on sapphire (d_{31} = 2.6 pm/V) and AlN on Pt (d_{33} = 6.8 pm/V).

Conclusions

We have characterized the piezoelectric properties of AlN deposited on a Ti electrode by pulsed DC reactive sputtering. The film texture of the AlN actuation layer is improved by cleaning the substrate in-situ and depositing the piezoelectric stack sequentially under vacuum to maintain a uniform growth surface.

We have also fabricated piezoelectric unimorph cantilever beams using a post-CMOS compatible fabrication process using Ti electrodes and TMAH patterning to achieve etch selectivity. The piezoelectric properties of the AlN film were characterized by laser doppler vibrometry and found to be comparable to AlN deposited on non-CMOS standard metals such as Pt or Mo.

Acknowledgements