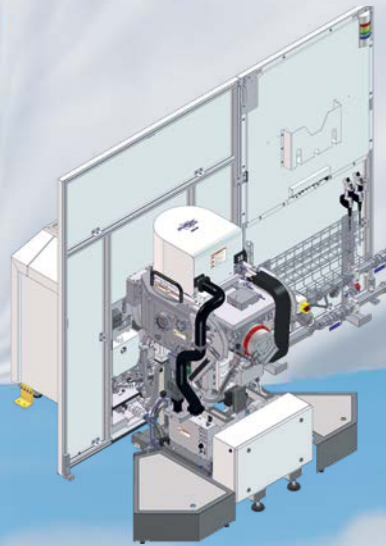
Flying the **high performance ferro- & piezoelectrics** flag in the USA

Evatec North America's Managing Director, **Helfried Weinzerl**, shines a light on some of the leading work on AlN and AlScN being done at universities in North America.

CLUSTERLINE® & MSQ 200 – the perfect tools for development

In its high-volume production configuration, CLUSTERLINE® 200 is already well established in North America and around the world when it comes to mass production of AlN or AlScN for MEMS and Wireless applications on 6-inch and 8-inch wafers. However, it's also available in configurations with process module set ups that support the R&D community. Evatec's MSQ Multi-Source with flexibility to install up to 4 ARQ 81 100mm sputter sources in one MSQ for single target or co-sputtering in DC, RF or mixed modes, is turning out to be an invaluable aid in development work. In North America, we are honored to work with a vibrant community of research groups looking to push the boundaries of ferro- and piezoelectric performance. In this edition of LAYERS, I'm excited to showcase some of the work they are doing.



University of Pennsylvania

We chose an Evatec MSQ as the cornerstone purchase in founding our research lab at the University of Pennsylvania. The decision was based on the excellent film quality for Aluminum Scandium Nitride (AlScN) reported by Evatec at the PiezoMEMS workshop and the MSQ's flexibility for rapidly exploring multiple Scandium compositions.

Our research has focused on high frequency AlScN bulk (BAW) and surface acoustic wave (SAW) resonators, filters, and delay lines. One particularly exciting development exploits the ferroelectricity of AlScN to overcome the traditional frequency scaling limits of BAW resonators, where the device layers become too thin. Using periodically poled piezoelectric films (P3F), we achieve frequency scaling while maintaining a nearly constant piezoelectric layer thickness. An example of this concept is shown in Figure 1 below, where for the same 692 nm piezo thickness, the device realized using a P3F material resonates at ~17 GHz, compared to ~4 GHz for the resonator realized in a unipolar film. This approach improves both the small and large signal performance as the operating frequency is increased.

Another major research thrust of our lab has focused on ferroelectric AlScN for non-volatile memory, where we have deposited and characterized ferroelectric films as thin as 5 nm in our MSQ. Even the initial layers of these materials are highly c-axis oriented. The measured breakdown fields exceed 10 MV/cm, demonstrating the high quality and low defect densities possible when sputtering AlScN films in the MSQ. Evatec has been amazing to work with, actively collaborating with Penn on materials research and supporting upgrades to our tool so we can explore new research directions we didn't envision when the MSQ was first purchased.

Troy Olsson is a Professor in the Department of Electrical and Systems Engineering at the University of Pennsylvania. He received his Ph.D. degree in Electrical Engineering from the University of Michigan. He was awarded an R&D100 award for work on Microresonator Filters and Frequency References, the 2017 DARPA program manager of the year, the NSF CAREER award, and the 2022 Bell Labs Prize for his work on Memory Enhanced Computing with III-Nitride Ferrodiodes.

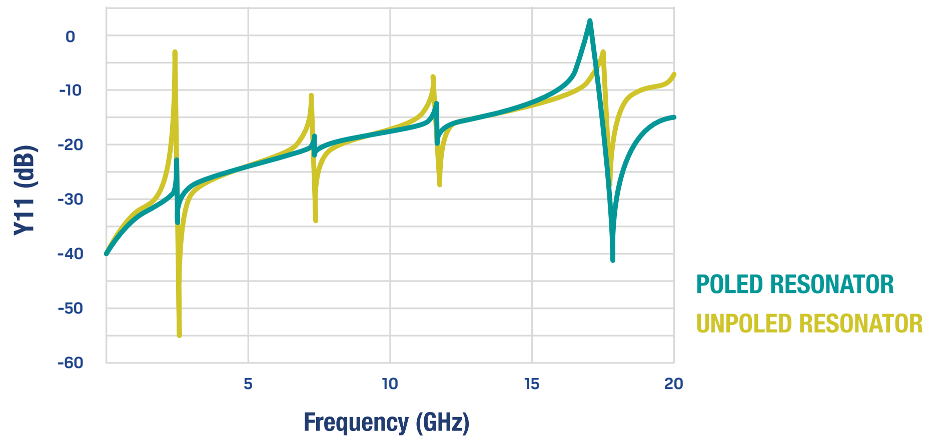


Figure 1: Measured admittance of resonators constructed from unipolar and P3F AlScN of the same thickness. The device realized in the unipolar film exhibits typical BAW operation preferentially resonating in the 1st thickness extensional mode (TE1). The device realized in the P3F film, by contrast, exhibits a strong resonance in the 4th thickness extensional mode (TE4) just above 17 GHz.

Texas A&M University

Prof. Milad Koohi earned his Ph.D. in Electrical Engineering from the University of Michigan in 2020. He led R&D at Qorvo Inc., integrating ferroelectric nitrides into acoustic wave devices for microwave and mm-wave applications. In 2025, he joined Texas A&M University. His research explores multiphysical interactions in emerging materials for advanced devices, microsystems, and integrated circuits. He has received awards including the Qorvo Best New Technology Award and IEEE MTT-S Fellowship, and authored over 40 publications and patents.

At Texas A&M University, the Koohi Research Group develops technologies for next-generation (nextG) wireless communication and sensing by advancing acoustic, electromagnetic, and multifunctional microsystems. Our research spans from materials to systems, and from KHz to THz, bridging fundamental material science with device physics and circuit engineering.

We investigate new material compositions, particularly within III-nitrides and complex oxides, to enable acoustic wave integrated circuits (AWICs), reconfigurable RF frontends, and multiphysical microsystems that address the performance and scaling demands of nextG communications and sensing technologies.

The Multi-Source Sputter system provides the foundation for this effort by enabling controlled growth of advanced nitride films and multilayer structures. Its co-sputtering capability allows us to systematically vary composition and stress, tailoring piezoelectric and acoustic properties to meet device requirements. Uniformity and reproducibility across substrates are critical as we transition from exploratory studies of material behavior to the fabrication of high-performance device prototypes.

Our ongoing projects include the development of high-frequency resonators, filters, and integrated modules that operate across sub-6 GHz, millimeter-wave, and emerging sub-THz bands. By coupling material innovation with careful device design, we aim to reduce insertion loss, improve reconfigurability, and achieve compact, energy-efficient architectures suitable for nextG communication systems. Beyond supporting individual projects, the system also strengthens collaborative research across disciplines at Texas A&M. It enables a device, material co-design framework. This integrated approach accelerates the translation of new compositions into practical RF and MEMS technologies, ensuring that materials advances directly inform system-level performance. Such co-design is central to our vision for advancing the next generation of wireless infrastructure.

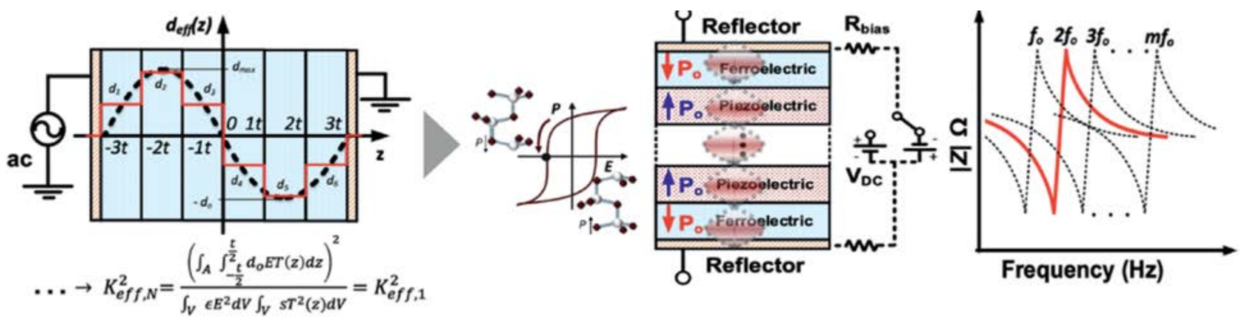


Figure 1: Inhomogeneous piezoelectric media based on multilayer ferroelectric heterostructures enable excitation of harmonic resonance modes with electromechanical coupling comparable to that of the fundamental mode [1], [2], forming the foundation of next-generation mmWave acoustics. This behavior can be realized using ferroelectric III-N materials.

References: [1] M. Z. Koohi and A. Mortazawi, "Negative Piezoelectric-Based Electric-Field-Actuated Mode-Switchable Multilayer Ferroelectric FBARs for Selective Control of Harmonic Resonances Without Degrading K2," IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 67, no. 9, pp. 1922–1930, Sept. 2020. [2] A. Mortazawi and M. Koohi, "Bulk acoustic wave resonators employing materials with piezoelectric and negative piezoelectric coefficients," U.S. Patent US12206388B2, 2025.

University of Texas

Kristen Nguyen is a PhD candidate in Prof. Xiuling Li's group at UT Austin. Her work focuses on the piezoelectric and ferroelectric tuning of strain-induced self-rolled-up membranes for high-frequency passives, with several publications on S-RuM passives and piezoelectrically-tunable capacitors and a provisional patent on S-RuM piezoelectrically-tunable passives.

In Prof. Xiuling Li's group at the University of Texas at Austin, AlN and AlScN thin films deposited with Evatec's CLUSTERLINE® 200 are used to create strain-induced self-rolled-up membrane (S-RuM) devices.

The S-RuM platform consists of a strained bilayer deposited on a sacrificial layer that, when etched, releases the strained bilayer and allows it to roll up into a tube, enabling the formation of complex 3D multi-turn architectures with only 2D processing techniques. Sputtered AlN and AlScN can achieve extremely high stresses of >1 GPa and, when used as the S-RuM strained bilayer, allow the shrinking of device footprints while avoiding the pinhole issues associated with PECVD SiNx, a commonly used alternative.[1], [2] By patterning different materials atop the AlN and/or AlScN before rolling, we've demonstrated ultra-small (~0.15 mm²) inductors with ~1 μH-mm⁻² and Q/area >100 mm⁻².[3] AlScN is also known for its good piezoelectric properties – by integrating piezoelectric AlScN, we've achieved piezoelectrically-actuated tunable S-RuM capacitors with footprints of 0.18 mm² and large capacitance tuning ratios for RFICs (see Figure 1).[4] S-RuM devices can further target a wide range of applications including MEMS, passive electronics, biofluidics, and photonics, due to their easily modifiable design with little increase in footprint or process complexity.

By depositing films in the test lab in Switzerland and modifying recipes based on our results, Evatec has enabled us to further push the S-RuM technology into the AlN/AlScN material space, with performance comparable to or better than previous SiNx-based devices. Our new CLUSTERLINE® 200 Multi-Source tool at the Microelectronics Research Center (mrc.utexas.edu) was recently installed, and we're looking forward to trying out the tool for ourselves!

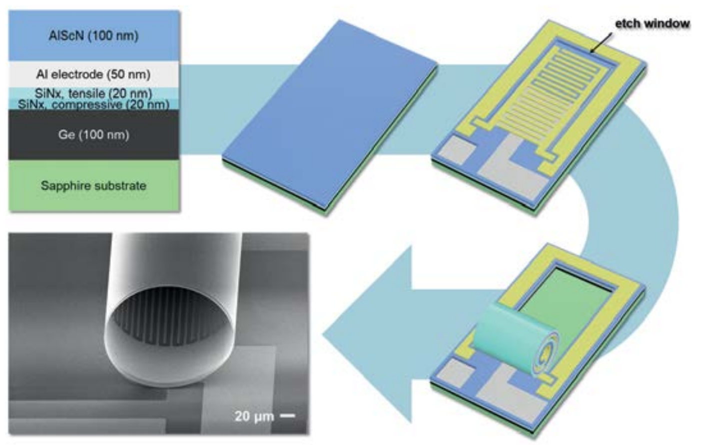


Figure 1: Process flow of self-rolled-up membrane (S-RuM) device based on AlScN thin films.

References:
[1] A. Khandelwal et al., "Self-Rolled-Up Aluminum Nitride-Based 3D Architectures Enabled by Record-High Differential Stress," ACS Appl. Mater. Interfaces, vol. 14, no. 25, pp. 29014–29024, June 2022, doi: 10.1021/acsami.2c06637. [2] Z. Yang et al., "S-RuM Technology for Extreme Miniaturization and Integration of Passive Electronics and Microfluidics," in 2024 IEEE 37th International Conference on Micro Electro Mechanical Systems (MEMS), Austin, TX, USA: IEEE, Jan. 2024, pp. 202–205. doi: 10.1109/MEMS58180.2024.10439466. [3] Z. Yang et al., "Unleashing the Performance of Self-Rolled-Up 3D Inductors via Deterministic Electroplating on Cylindrical Surfaces," Adv. Mater. Technol., vol. n/a, no. n/a, p. 2400092, doi: 10.1002/admt.202400092. [4] K. Nguyen, Z. Yang, A. Wang, S. A. Wicker, and X. Li, "Tunable Ultra-Small Monolithically-Rolled-up Capacitors by Piezoelectric Actuation," in 2024 IEEE 37th International Conference on Micro Electro Mechanical Systems (MEMS), Jan. 2024, pp. 683–686. doi: 10.1109/MEMS58180.2024.10439577.

Northeastern University

At the Institute for NanoSystems Innovation at Northeastern University, Evatec's CLUSTERLINE® 200 equipped with a Multi-Source Module (MSQ 200) has been central to our exploration of co-doped nitride piezoelectrics. The platform let us validate experimental compositions using convenient 4" targets, while iterating process windows directly on 200mm wafers. In the past four years, we used this capability to explore AlScN thin films with variable Sc composition (0-42%) and thicknesses (10nm-2µm) for a variety of applications, including PMUTs for medical imaging, RF resonators for acoustic filters and sensors, metamaterials stacks, and ferroelectric memory cells.

Beyond ternary alloys, we used the MSQ to explore quaternary compositions where two elements are introduced simultaneously within the AlN lattice to further manipulate its properties. In a recent study we installed a 4" $Al_{0.45}Sc_{0.45}B_{0.10}$ cast alloy target on the MSQ to systematically map stress, texture, and surface quality versus several process parameters, and subsequently characterized the ferroelectric and piezoelectric of these B and Sc co-doped AlN thin films.

The resulting films exhibited both strong piezoelectric and robust ferroelectric responses, with d_{33} coefficients above 25 pm/V, and clear polarization switching with asymmetric coercive fields. Further work is on the way on this front, as these results validated dual doping as a promising avenue to discover new micro-acoustics materials.

The MSQ architecture materially reduced risk by proving experimental target chemistries at small sizes before committing to larger targets, and it shortened iteration cycles by enabling rapid condition trials on 200mm production wafers. We see this workflow as an important enabler for universities pursuing leading-edge MEMS and wireless devices, as well as an attractive platform for academia-industry joint R&D efforts.

Prof. Simeoni is an Assistant Research Professor at Northeastern University, affiliated with the Institute for NanoSystems Innovation and the Department of Electrical and Computer Engineering. His research centers on piezoelectric electromechanical sensing platforms for trace-chemical monitoring, optical detection, and medical imaging. He earned his B.S. in Physics Engineering (2014) and M.S. in Nanotechnologies for ICTs (2016) from Politecnico di Torino, and his Ph.D. (2021) from Carnegie Mellon University, focusing on airborne ultrasonic communication for low-power wake-up applications.

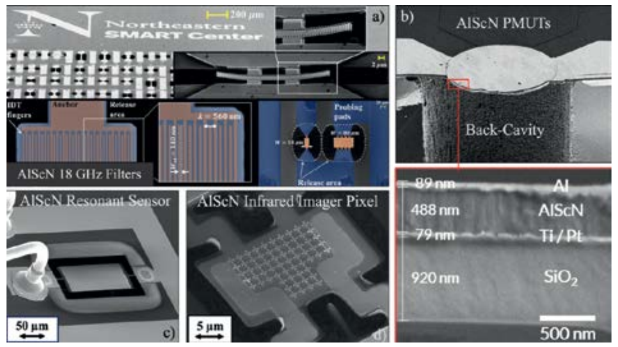


Figure 1: a) CLMR resonators for high frequency acoustic filters, b) PMUTs for intrabody ultrasonics, c) N2O resonant gas sensor, d) Infrared sensing nanoplate for imaging.

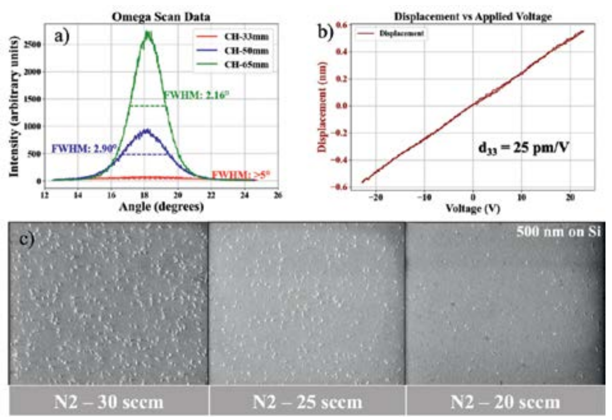


Figure 2: a) 500 nm AlScBN rocking curve vs. chuck height, b) AlScBN films DBLI d_{33} measurement, c) Surface SEM showing abnormally oriented grains vs. nitrogen flow.

University of Florida

We use the Evatec tool to sputter AlN thin films and electrodes to fabricate MEMS dynamic pressure sensors. One such device, shown below, was fabricated using sequentially sputtered AlN seed layer, Mo electrode, and AlN device layer without breaking vacuum.

This capability enabled us to achieve high-quality AlN layers with a FWHM of less than 2°, maximizing our device sensitivity and performance. For similar high-temperature applications, including hypersonics and gas turbines, we will be integrating the AlN layer within NASA Glenn's SiC JFET-R process to create a first-generation monolithically integrated pressure sensor and transistor for >500°C environments in air.

These devices will aim to measure pressure fluctuations at frequencies up to 1 MHz, enabling boundary layer characterization of hypersonic flows to improve vehicle design and direct feedback control in gas turbines to increase efficiency. Recently, we have successfully verified operation of a pressure sensor device (Figure 1a) at up to 800°C in air (Figure 1c) via electrical excitation under a digital holographic microscope (DHM), proving the feasibility of the device design at these high temperatures.

Moving forward, we will look to characterize the material properties of the device materials at high temperatures, both to improve modeling and design of the device and understand the temperature limitations and failure mechanisms of the materials for pressure sensing.

Alexander Reilly is a graduate research assistant at the Interdisciplinary Microsystems Group (IMG) at the University of Florida (UF). He graduated summa cum laude with a B.S. degree in aerospace engineering at UF in 2022 and is currently pursuing a Ph.D. degree in mechanical engineering at the same institution. His work focuses on the design, fabrication, and characterization of microelectromechanical-systems-based transducers, particularly those for high-temperature applications.

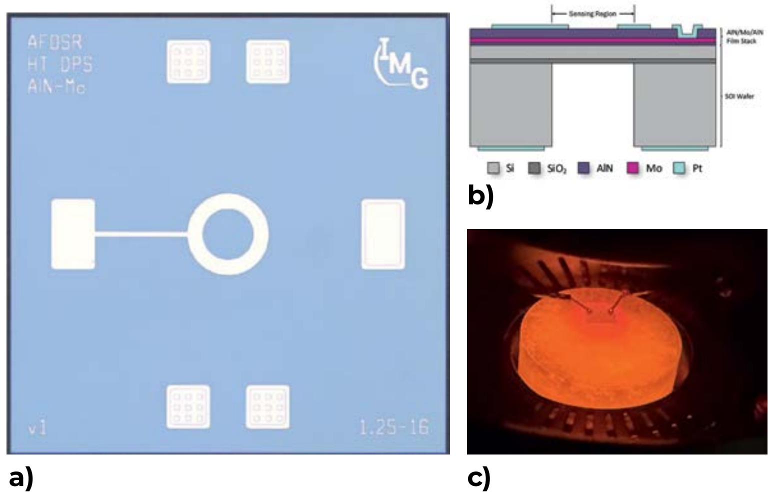


Figure 1: a) Photograph of AlN MEMS pressure sensor (2.5x2.5 mm² die size). b) Cross-sectional schematic of pressure sensor structure. c) Device testing under probe station at 800°C in air.

Want to know more?

If you would like to learn more about Evatec's cost effective CLUSTERLINE® 200 tool configurations for R&D, simply contact your Evatec sales and service organization.