

## APPLICATION BRIEF

## AlN PVD for RF & MEMS

### Introduction

AlN, a dielectric material with piezoelectric properties has become a widely used material in the manufacturing of MEMS resonator based devices, such as RF BAW filters, microphones, speakers, energy harvesters, pressure sensors and fingerprint sensors. The material is deposited using modified PVD equipment commonly used in standard IC manufacturing lines, capitalising on existing optimised device control and manufacturing costs. This is a key benefit over other piezo materials such as PZT, which is significantly more difficult to integrate, with the added risks attached to its lead content.

With the largest AlN customer install base over any competition, SPTS has been able to meet the surge in demand with the award winning Sigma® fxP PVD AlN platform. Based on over 20 years' experience and patented IP, SPTS has become the market leader for volume PVD AlN with over 60% market share.



Sigma® fxP PVD

### AlN Piezoelectric Devices

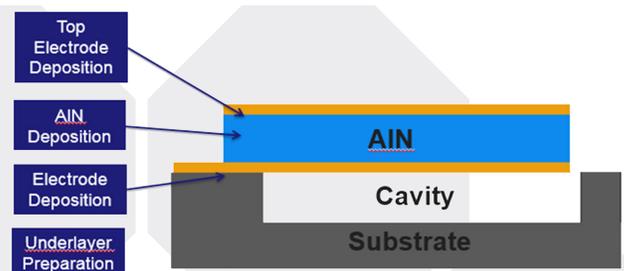
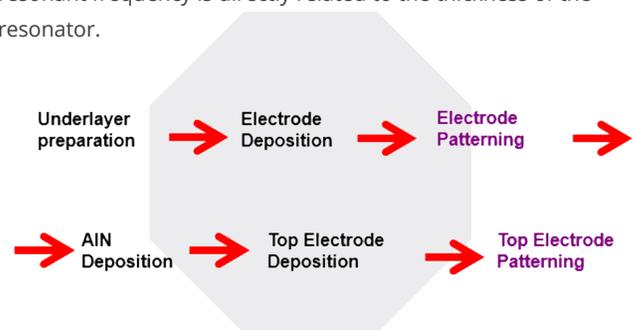
Although BAW filters historically drive the AlN market and its technical development, additional growth will be fuelled by new AlN based MEMS devices. Devices such as AlN based pMUT finger sensors and microphones, currently in production, are expected to see double digit growth in the next few years, significantly increasing the overall market size for this material. AlN based MEMS devices that show improved performance over traditional

designs, share similar fabrications steps to well-understood BAW resonator devices, making these devices easier to realise to mass markets.

To meet the all production and development AlN deposition needs, Sigma® AlN PVD is the right choice to ensure critical film control. With SPTS's extensive experience in volume production and a continuous focus on AlN development, customers benefit from

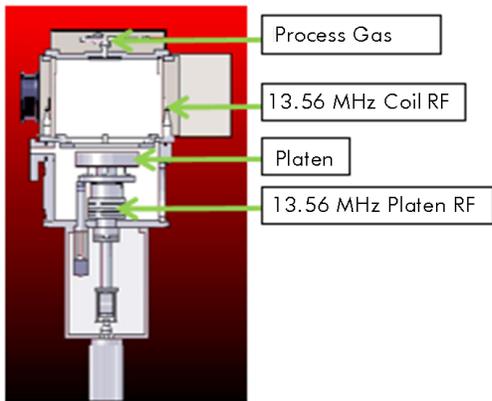
### Typical Process Flow

A typical process flow and resonator structure is shown below. It consists of depositing a resonating AlN piezoelectric layer sandwiched between two PVD deposited electrodes and suspended over some form of cavity so that it can freely resonate. The resonant frequency is directly related to the thickness of the resonator.



Schematic diagram of MEMS resonator/cantilever

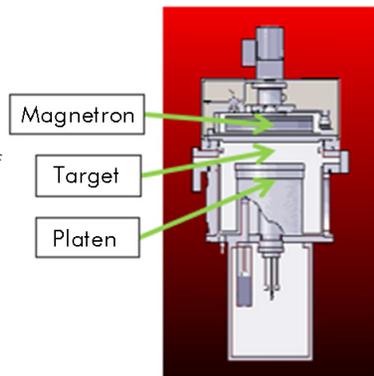
## Pre-treatment Process Module



In order to get the best AlN resonator performance, a high level of deposition process control is required in all the process steps. The surface roughness of the substrate and bottom electrode have a critical influence on the final AlN film. In order to promote excellent AlN growth, a smooth mirror-like surface can be prepared using SPTS Soft Etch (SE) module. The module is based on an ICP Ar sputter etch design, utilising two RF generators in order to provide a low damage high rate etch performance.

## PVD Deposition Modules

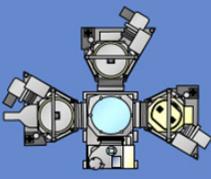
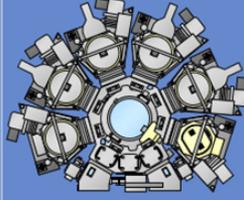
Electrodes and AlN films are deposited on the Sigma® standard PVD process chamber using dc magnetron sputtering. A simple change of target material and chamber shielding is required to swap between deposition of different materials, easing future configuration requirements and lowering overall development to production cost. For AlN deposition, a pure Al target is sputtered in an Ar/N<sub>2</sub> atmosphere. Metal electrode PVD utilizes Ar only. Thickness control is key for producing accurate stable MEMS resonator type devices. Sigma® PVD deposition modules employ a range of thickness uniformity tuning control options for this.



## Sigma® Handling Platforms

Sigma® pre-treatment and PVD deposition modules can be configured on two different ≤ 200mm wafer handling platforms, the Sigma® c2L and fxP.

The production proven Sigma® fxP with twin vacuum cassettes, and accommodating up to 6 process modules is widely used across a range of PVD applications, and is first choice for high volume AlN production needs.

	Sigma c2L	Sigma fxP
		
	R&D	Production
Loadlocks	1	1 or 2
Degas/Pre-clean	1	1
PVD Modules	Up to 2	Up to 5

For low volume manufacturing or R&D, the single cassette Sigma® c2L can accommodate up to 3 process modules, and meets the minimum typical AlN process flow configuration of a surface pre-treatment chamber, electrode chamber and AlN deposition chamber, but at lower cost than fxP, or many competitive systems.

Both platforms can be configured with the same high quality Sigma® pre-treatment and deposition process modules, have uptimes in excess of 90%, and can be configured with a range of handling options for increased handling reliability. Due to common shared components, starting pilot production on a c2L allows customers to easily upgrade as volumes increase to the Sigma® fxP by reusing existing modules, without the need to requalify processes. This means minimum initial investment in product development stages without sacrificing device performance.

## Applications Performance Requirements

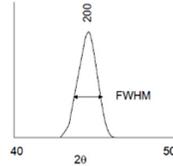
Developments in device manufacture, means SPTS continuously improves the AlN deposition to meet more exacting requirements. Requirements are focused on both the AlN layer control and more recently on improving the material properties characteristics, i.e. the piezo electric coupling coefficient Kt<sub>2</sub>. Below a table outlines the general requirements for different AlN device requirements.

	Best Quality AlN Texture	Best WIW Thickness Uniformity	Best WIW Stress	Best Coupling Coefficient
BAW Filter	✓	✓	✓	✓
MEMS Microphone	✓	-	✓	✓
MEMS pMUT finger print sensor	✓	-	✓	✓

SPTS offers a range of performance enhancement options which can be chosen in order to meet the exact requirements for each device, i.e. texture, thickness uniformity and coupling coefficient.

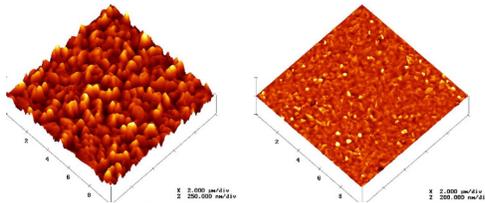
## AlN Texture Improvement

A materials crystal orientation (texture), can be measured by X-Ray diffraction analysis. Right, a typical rocking curve where texture is determined by the Full Width Half Max (FWHM) value in degrees. A lower texture value, means better orientation of the crystal growth, resulting in high Q factors for resonator type devices.



By utilising the Sigma® “Soft Etch” module and patented ‘Smoothing Etch’ for under layers prior to AlN deposition, it is possible to minimise AlN texture. In RF BAW filters, this means increased filter Q factor and improved filter pass/rejection performance.

	Smoothing Etch	AlN Texture (FWHM)
"Rough oxide underlayer	No	>2.5°
"Rough oxide underlayer	Yes	1.4



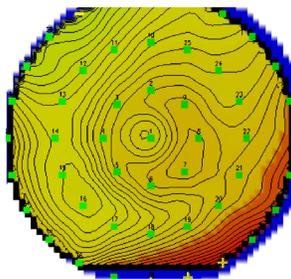
AFM data illustrating effect of a smoothing etch

## WIW & WTW Thickness Uniformity

AlN Film thickness is a critical parameter used to control the frequency range in resonator based devices. In RF BAW filters operating in the 2.5GHz range, multiple channels are packed close together, and have frequency tolerances of < 0.05% to avoid issues like cross talk and line drops in mobile communications. Uniform and repeatable thickness control is vital.

Sigma® deposition modules can be fitted with a range of performance features designed to minimise thickness variation. For WIW thickness variation, options include advanced magnetron position control, plasma focusing, and wafer rotation. Combined features result in best in class WIW uniformity performance for wafer sizes up to 200mm, with minimal edge exclusions in order to maximize device yield. WTW Repeatability is controlled by an automated magnetron adjustment feature for repeatable performance across full target campaigns.

Mean: 14025.1543 (Å)  
 STD Dev: 18.6965(Å) (0.1333%)  
 Min: 13985.6621 Å  
 Max: 14066.1279.3779 Å  
 %Range: 0.5737  
 Size: 200.0000mm



AlN 200mm wafer thickness control WIW NU <0.2% 1s (3mm EE)  
 Repeatability over 350 <0.2% 1

## Stress Control in AlN/AlScN films

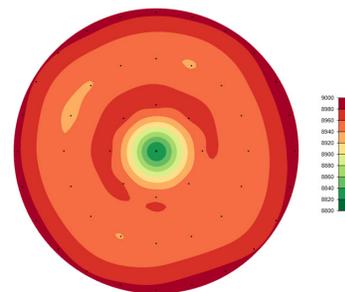
Improving the mechanical to electrical conversion properties of AlN, i.e. Kt2 coupling coefficient, can improve existing device performance and allow the introduction of thinner resonators for 5G and new MEMS devices. The main development path to enable higher Kt2, has been the addition of Sc to the AlN in the target manufacturing phase. Higher Sc content means higher Kt2, but is limited by target manufacturing, and reliable deposition techniques.

The material stress and induced bow of the AlN is very important in applications where there are cantilevered type resonators. The micro resonator deflection, and therefore performance is dependent on the deposited film stress. As there are many devices across a wafer, it's not only the mean stress of the film on the wafer, but the within wafer stress variation within a 2D map which needs to be controlled in order to guarantee stable device performance for all devices on the wafer.

Stress of the deposited film is primarily controlled by ion bombardment at the wafer surface. RF bias is the standard control with undoped AlN, to set the desired film stress level from tensile to compressive. However, with the addition of scandium, stress control using standard methods becomes extremely difficult. SPTS has developed a unique platen-based technology called Crossbow to overcome the effects of ion bombardment without affecting the thickness uniformity of the deposited films. Crossbow provides excellent WIW stress range <100MPa for both tensile and compressive films, and has been demonstrated on films with up to 20% Sc, maintaining thickness non-uniformity <0.5%  $\sigma$ .



500nm AlSc<sub>9.5at.%</sub>N films with WIW stress range <100MPa for tensile, compressive and zero-stress conditions

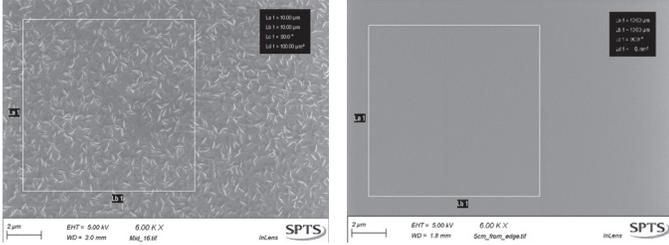


AlSc<sub>30at.%</sub>N WIW thickness NU: 0.37% 1 $\sigma$ , 3mm EE on 200mm using B-Max

(continued overleaf)

When depositing AlScN films using PVD, defects can be a significant issue, due to uncontrolled stress mismatch between Sc and AlN crystal growths.

SPTS applies patented stress control process techniques to provide defect free films. These techniques along with thickness and stress control options, provide defect-free best in class AlScN deposition.



*AlSc20at.% N "as-deposited":  
high density single crystal defects*

*AlSc20at.% N after stress control  
techniques applied:  
<10 defect per 100µm<sup>2</sup>*

## Sigma<sup>®</sup> AlN solution for RF filters and MEMS device manufacture

With our exhaustive application knowledge gained over 20 years and the largest base of customers against our peers. The SPTS Sigma<sup>®</sup> fxP and c2L provides a high productivity solution to meet your AlN production and development needs for current and future RF and MEMS device requirements.

### Key Benefits

- Market leader > 50% share
- 20 years' experience in AlN and wide install base with multiple customers
- Best in class performance – WIW & WTW thickness NU, Stress control, productive AlScN
- IC manufacturing equipment levels of uptime > 90%

**SPTS Technologies**, a KLA company, designs, manufactures, sells, and supports etch, PVD, CVD and MVD<sup>®</sup> wafer processing solutions for the MEMS, advanced packaging, LED, high speed RF, & power device markets. For more information about SPTS Technologies, email [enquiries@spts.com](mailto:enquiries@spts.com) or visit [www.spts.com](http://www.spts.com)