# Reducing Impact of Stress on Coupling Coefficient in 30% Scandium Aluminum Nitride Films

Sergey Mishin
Advanced Modular Systems, Inc.
Goleta, CA USA
smishin@amssb.com

Yury Oshmyansky
Advanced Modular Systems, Inc.
Goleta, CA USA
yoshmyansky@amssb.com

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## I. INTRODUCTION

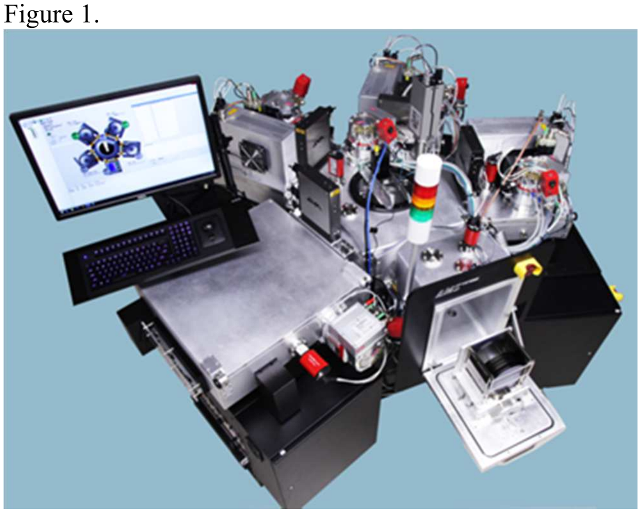
Adding Scandium (Sc) to the aluminum nitride (AlN) is widely used to significantly increase coupling coefficient in Piezo-MEMS devices [1], [2] and [3]. Stress impact on the coupling coefficient in 30% Sc films is a major issue [4], [5]. Stress variation across wafer and over the target life is a major hurdle to keeping coupling coefficient in the range acceptable for most RF filter applications. We have developed a process that uses high voltage surface treatment in conjunction with optimized AlN barrier layer to make coupling coefficient less sensitive to stress in the film.

## II. METHODS/RESULTS

In this investigation we used Advanced Modular Systems cluster tool with AlN and AlScN deposition chambers and ion beam trimming module, see Figure 1.

The deposition chambers use standard dual conical magnetron with AC deposition source and high-density plasma configuration. Frequency of AC power is 40 kHz and power may vary from 3 to 9 kW. Wafer rotation was used to compensate edge to edge non-uniformity. Additional DC power supply was using for center to edge thickness uniformity improvement. Al target bases with inserted Sc pieces were used to adjust AlScN film composition.

Figure 1.



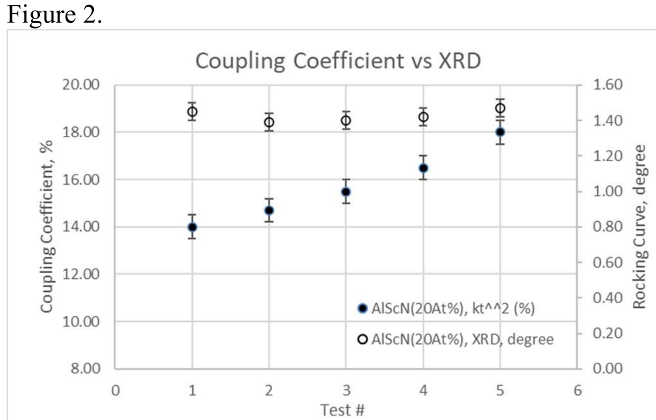
The trimming module uses DC focused ion source with up to 5kV acceleration voltage. This module was used for substrate surface clean up before deposition, as well as for improvement of thickness non-uniformity after AlScN deposition.

Effect of bottom Mo electrode pre-clean with high voltage bombardment and thickness of AlN seed layer in situ before AlSc(30%)N deposition was investigated.

Initial investigations on AlN films frequently used XRD (Rocking Curve) measurements to compare quality of the film. For AlN films there is a good correlation with films having XRD<1.5 degree on 1um thick films having good coupling coefficient.

Unfortunately, XRD does not have a good correlation to the coupling coefficient for the 30%Sc films. As can be seen on Figure 2, Rocking curve for all data points is about 1.4-degree, disregard of variation of coupling coefficient.

Figure 2.



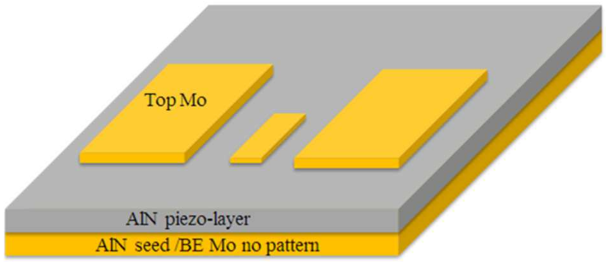

HBAR devices on the other hand have good correlation to the FBAR resonators.

A standard HBAR devices for 3,200 MHz frequency, with 1700A of electrode thickness and 6000A of AlSc(30%)N piezo thickness were manufactured.

We use two ground pads and one signal pad. The ground pads are 430um x 430um. The signal pad is 98um x 167um and the pitch for the structure is 43um. We use 350um pitch probes though. The manufactured HBAR is shown on Figure 3.

Measurements were done on Agilent Network Analyzed E5071B with Cascade RF probe station.

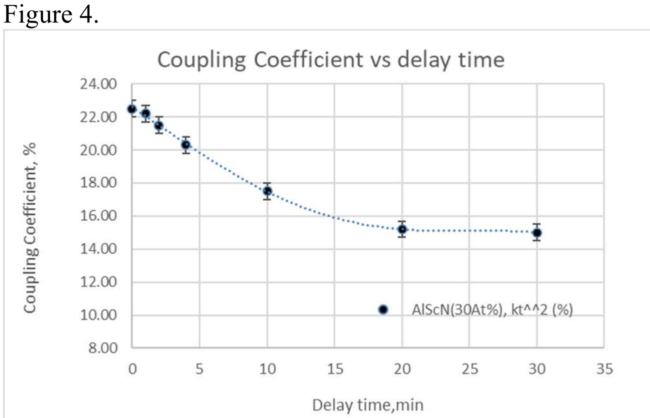
Figure 3




Treatment of Mo surface with high energy Ion beam has tremendous impact on Coupling coefficient of highly doped AlScN film. Without Ion Beam treatment, Coupling coefficient dropped down by almost 30%.

Also, it is important to have this surface treatment done right before AlN barrier deposition. Figure 4 shows correlation between coupling coefficient and the time wafer sits in the load-lock at 1E-6 Torr vacuum. During delay time between Ion beam treatment and AlN deposition, surface is covered by monolayer of oxygen and water which dramatically reduce coupling coefficient of devices.

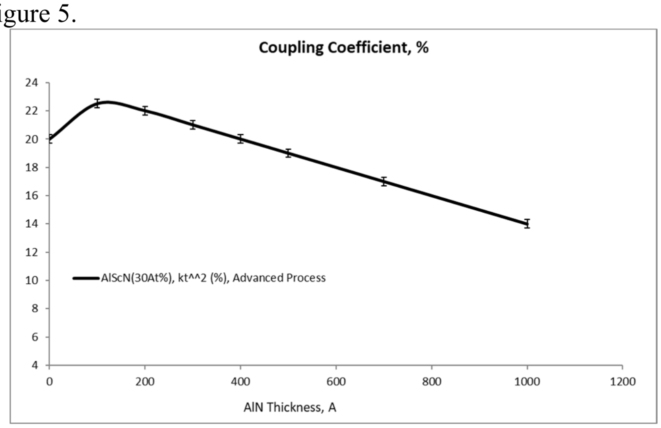
Figure 4.




As can be seen from Figure 4, the best results are obtained when wafer is immediately loaded into the AlN barrier deposition chamber. Effect of Ion Beam treatment completely disappears after about 10…15 min placing a substrate in high vacuum about 1E-6 Torr.

AlN barrier layer provides separation between electrode and the AlScN film and also is used as seed-layer for AlScN film.

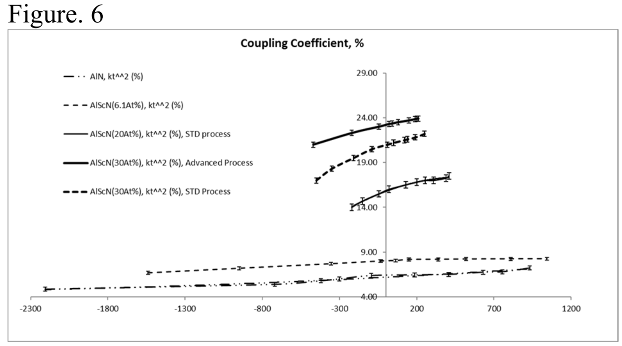
Figure 5.




As can be seen from the Figure 5, deposition that uses no barrier layer has lower coupling coefficient . Very thin barrier layer improves coupling coefficient, but as this layer gets thicker, it, most likely, develops both, crystal orientation and surface roughness, that have detrimental impact on the orientation of the 30%Sc films. Additional, thicker AlN seed-layer requires thinner AlScN film in order to keep the same frequency. This results in reduction of coupling coefficient.

Result of coupling coefficient on HBAR devices for combination of optimized AlN seed layer with Ion Mill bombardment and surface treatment vs piezo layer film stress for optimized (Advanced) and non-optimized (STD) processes is showed on Figure 6.

Figure. 6




AlN has a week correlation between stress and coupling coefficient. But as Sc is added to the film, more tensile film has much larger correlation to the stress. Ion mill bombardment of the Mo surface, improves surface roughness, making film much more compatible with AlScN deposition.

## III. Conclusions

Using high voltage bombardment of the electrode material in conjunction with appropriate barrier layer before the AlScN deposition dramatically reduces the impact of stress variation on the coupling coefficient and provides very tight coupling coefficient distribution with effective kT2 is more than 23%.

## References

[1] Paul Muralt, et.al.. "Electromechanical properties of AlScN thin films evaluated at 2.5 GJz film bulk acoustic resonators", Applied Physics Letters 99, 2011

[2] Keiichi Umeda1, et.al.. "PIEZOELECTRIC PROPERTIES OF ScAlN THIN FILMS FOR PIEZO-MEMS DEVICES", MEMS 2013, Taipei, Taiwan, January 20 – 24, 2013

[3] Qi Wang et al., "Scandium doped aluminum nitride based piezoelectric micromachined ultrasound transducers," in Proc. of Solid-State Sensors, Actuators and Microsystems Work Shop, Hilton Head, South Carolina, 2016, pp. 436–439

[4] A. Mazzalai1 , X. Yao1, "Developing production process for high performance piezoelectrics in MEMS applications" 2021 International Conference on Compound Semiconductor Manufacturing Technology

[5] Sergey Mishin, et. al., "Magnetron Deposition of AlN and ScAlN for Mass-production for BAW Devices and MEMS", 2019 IEEE Ultrasonic Symposium