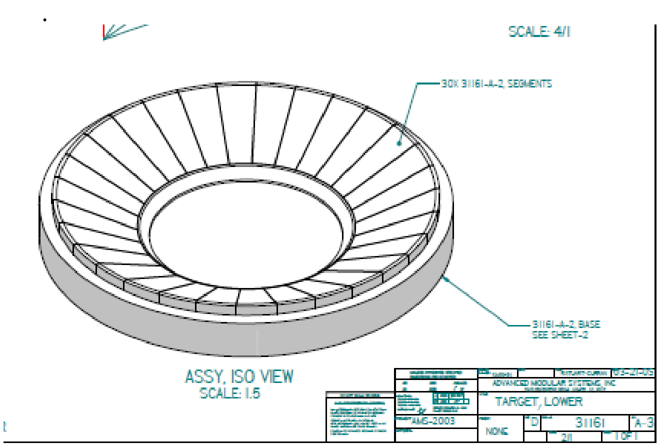
Production worthy system for piezoelectric multi-material depositions

Sergey Mishin
Michael Gutkin
Advanced Modular Systems, Inc
Goleta, CA/USA
smishin@amssb.com
mgutkin@amssb.com

Abstract— In this paper, we describe system for depositing piezoelectric films with multiple target materials using a standard production system that is used in high volume production of Aluminum Nitride films. This system uses standard dual conical magnetron with AC deposition source [1]. Targets are cut into multiple pieces/tiles as shown in Figure 1. Films containing various concentrations Scandium (Sc) and Erbium (Er) in AlSc(x)Er(y)N films have been demonstrated using different number of Sc and Er pieces compare to the number of the Al pieces. Coupling coefficient (kt2) was measured across wafer and wafer to wafer as a function Sc and Er content in the target. Previous studies demonstrate a considerable increase in kt2 as a function of Sc content of the film [2], [3], [5], [6]. Unfortunately, when higher concentration of Sc or a third material such as Er is used, composite targets are too difficult to make. Multiple target systems can be used to compensate this problem. Both stress and concentration of Sc and Er must be controlled across wafer to achieve uniform kt2 acceptable for production of Bulk Acoustic Resonator (BAW) devices [4], [7]. We were able to control kt2 across wafer and wafer-to-wafer by adjusting magnetic fields in our magnetron, rotating wafer during deposition as well as adjusting concentration of Sc and Er in our two sputtering targets.

Figure 1. Multiple material targets



Keywords-component; Aluminum Nitride; Scandium; coupling coefficient; stress

I. INTRODUCTION

Most PVD deposition processes that require multiple materials in a sputtering target use a composite target. Although it works well for most materials, some composite targets are extremely difficult to manufacture and are very expensive. Al/Sc targets are notoriously difficult to manufacture at Sc compositions above 10%. Targets with three different materials are even more difficult to make. Sputtering from multiple targets is not practical for high volume production.

In this investigation we used multiple piece targets to produce highly piezoelectric films with Al, Sc and Er materials.

II. EQUIPMENT

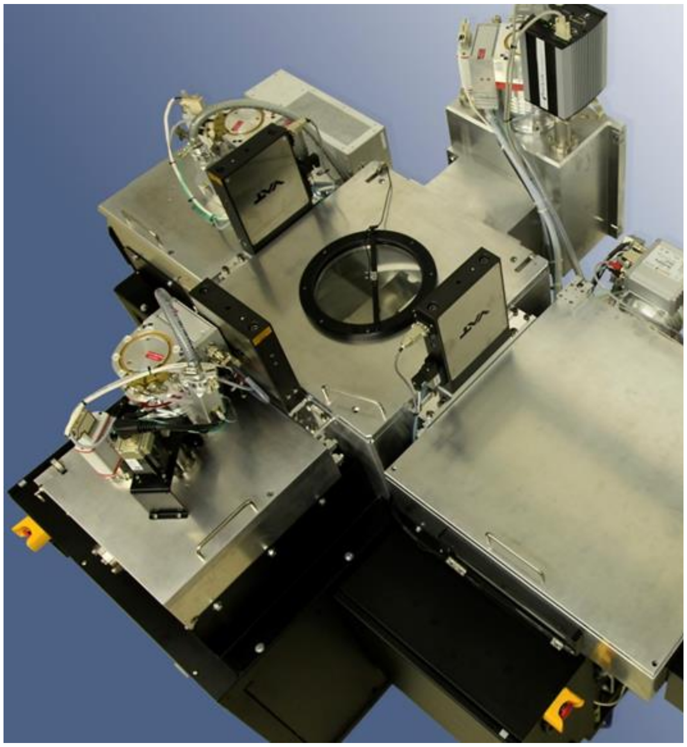
In this experiments, we used Advanced Modular Systems cluster tool with AlN and AlScErN deposition chambers and ion beam trimming module (shown in Figure 2).

Both AlN and AlScErN depositions use a dual magnetron with AC power applied between targets. Frequency of AC power is 40 kHz and power may vary from 3 to 10 kW. It is a reactive deposition process in deep poison mode. We used two targets made out of pieces/tiles of Al, Sc and Er to adjust film composition. High purity 99.9999% argon and nitrogen process gasses we used for all depositions.

The trimming module uses DC focused ion source with argon process gas to improve thickness/uniformity of either AlN or AlScN films. Film thickness trimming/tuning is processing based on ion beam scanning across a wafer with power variation based on film thickness map. Use of the trimming process opens up a much wider process window for stress control because it allows avoiding of spending too much effort on controlling thickness uniformity during deposition.

Simple resonators with three layer's Bragg reflector were manufactured during investigation for piezoelectric coupling coefficient measurements.

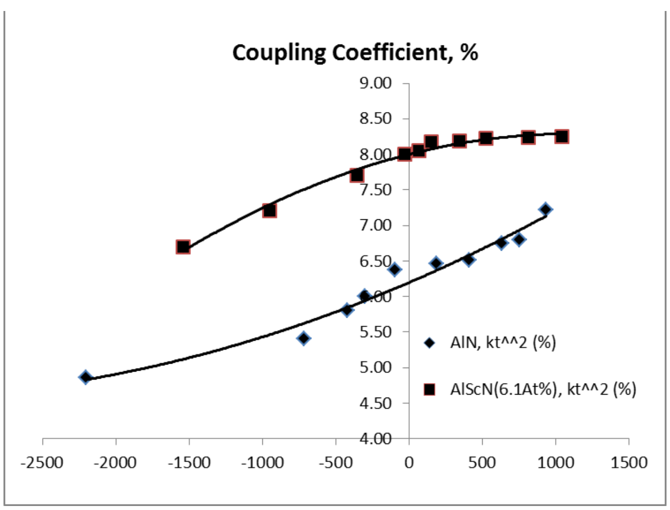
Figure 2: AMSystems cluster tool



III. Stress control

Average film stress and film stress uniformity is very important, because film strain has a great impact on piezoelectric properties, see figure 3.

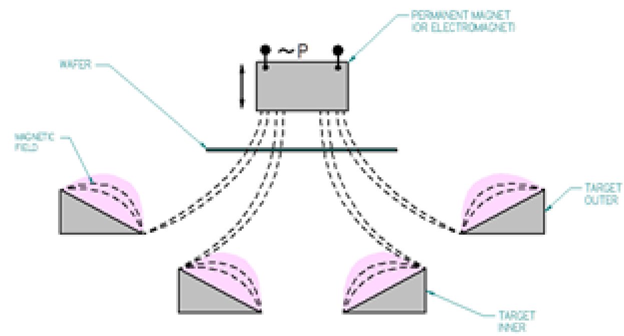
Figure 3: Effect of film stress to piezoelectric coupling coefficient



Typical stress control techniques involve either substrate bias or change in gas pressure. Unfortunately, both of these methods are capable of changing average stress on a wafer without having much impact on the local stress across wafer.

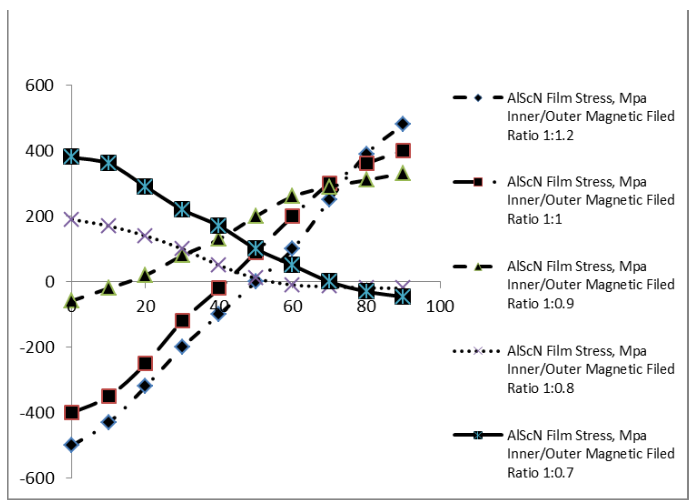
AlN Film stress depends on magnetic field on target (7). AlScN and AlScErN film stress also depends on magnetic field on target surface. We found that our standard configuration of magnetic field compensation, that we used for AlScN works for the multi-piece targets as well for both AlScN and AlScErN films.

Figure 4. Magnetron with the enhanced magnetic field



Since wafer center receive more material from the inner target and wafer edge receive more deposition from the outer target, variation of the ratio of the strength of magnetic field between inner and outer targets (magnetrons) allows controlling concentric stress uniformity.

Figure 5: Stress variation across wafer as a function of the ratio of inner to outer target magnetic fields



We found that in AMS system stress variation has an almost perfectly radial distribution that varies with the ratio of magnetic field between inner and outer magnetron. Figure 5 shows change in stress across a wafer as a function of the ratio of the inner to outer magnetron magnetic fields.

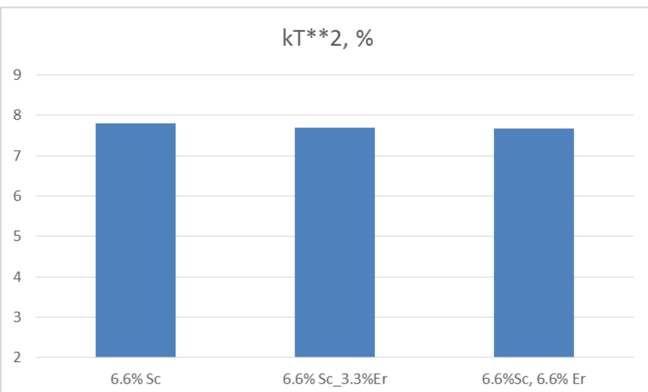
It is clear that a standard 1:1 ratio of magnetic field that produces the best results for AlN process is unacceptable for AlScN or AlScErN processes. We found that the ration of inner/outer of 1.0/0.8 is the best for stress control.

IV. COMPOSITION CONTROL

Our multi-piece targets in this investigation had 30 pieces in the inner target and 48 pieces in the outer target. Concentration of each material on the inner target can be adjusted in 3.3% increments and on the outer target 2.1%.

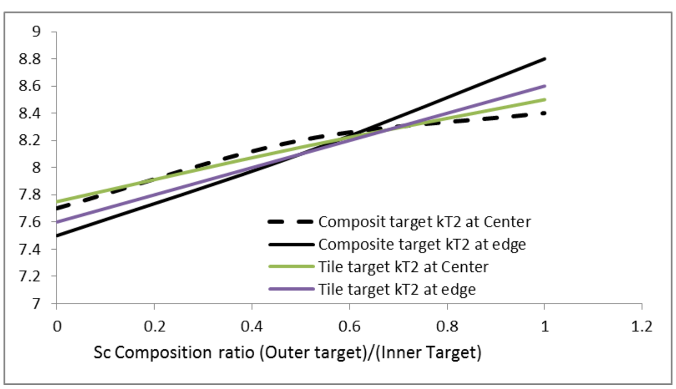
We tried Er concentrations 3.3% and 6.6% in combinations with different Sc concentrations and observed no impact on the coupling coefficient. For this reason we did not use Er in further investigations.

Figure 6. Er effect on coupling coefficient



Using wafer rotation in conjunction with multi-piece targets produced results that are very similar to the composite targets with the same concentration of Sc. Figure 7 shows a comparison of kt^2 between composite targets and multi-piece targets.

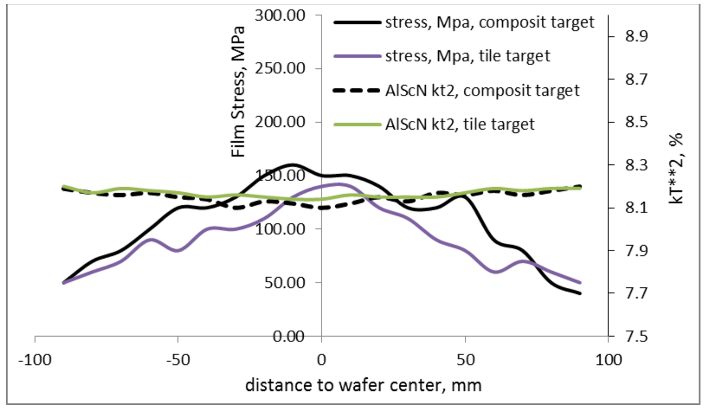
Figure 7. Coupling coefficient across wafer as a function of Sc concentration in two targets



We could not use identical concentrations for the composite targets and multi-piece targets, but in roughly the same range of Sc concentration results very similar for both configurations.

Figure 8 shows excellent control of both local stress and coupling coefficient across wafer using optimized combination of optimum magnetic field ratio and Sc concentration for both composite AlSc and multi-piece AlSc configurations.

Figure 8. Coupling coefficient and local stress on AlScN wafers



I. SUMMARY

Erbium does not have any effect on kt^2 of the AlScErN films as compared with AlScN films of the same Sc concentration. Multi-piece target produces similar results to the composite target configuration, but has much more flexibility for different concentration of Sc and allows much higher Sc concentrations that a composite targets.

REFERENCES

[1] Sergey Mishin, Rich Ruby John Larson, Yury Oshmyansky, “Sputtering Process for Bulk Acoustic Wave Filters”, Semiconductor International, 2003

[2] Milena Moeira, et.al., “Aluminum scandium nitride thin-film bulk acoustic resonators for wide band applications”, Vacuum, July 2011, Issue 1, pp. 23-26

[3] Morito Akiyama, “Influence of temperature and scandium concentration on piezoelectic response of scandium aluminum nitride alloy thin films”, Applied Physics Letters, Oct. 2009, Vol.95, Iss. 16, pp. 2107-2107-3

[4] H.P.Lobl, et.al.. "Piezoelectric materials for BAW resonator and filters", 2001 IEEE International Ultrasonics Symposium, Atlanta, GA, Oct. 7-10,pp.807-811.

[5] Pau Muralt, et.al.. “Electromechanical properties of AlScN thin films evaluated at 2.5 GJz film bulk acoustic resonators”, Applied Physics Letters 99, 2011

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

[7] Sergey Mishin, “Improving Manufacturability of Bulk Acoustic Wave and Surface Acoustic Wave Devices”, IEEE SPAWDA