Improving crystallinity of high concentration Scandium Aluminum Nitride films deposited on 200mm wafers

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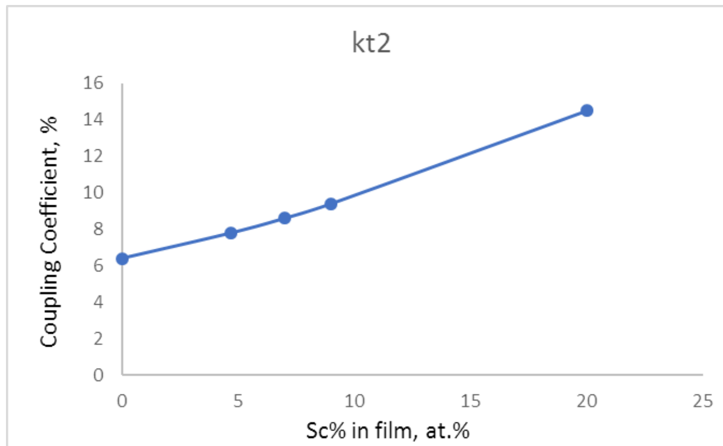
***Abstract*— There have been several investigations [1], [2], [3], [4] that demonstrated benefits of adding Scandium (Sc) to the aluminum nitride (AlN) films in order to increase coupling coefficient (kt^2) of the Bulk Acoustic Wave (BAW) devices. For concentrations below 5% atomic Sc, crystallinity of the AlScN films is very good. There is only single 002 orientation peak that can be seen. For higher concentrations deposited on wafers with less than 150mm diameter, there is no significant problem either. Unfortunately, when working with 200mm wafers and Sc concentrations higher than 5%, area outside 150mm diameter develops different crystal orientations of AlScN and abnormal peaks. This leads to degradation of Rocking curves measurement and lower coupling coefficient (kt^2) at the edge of the wafer. Since the edge of the wafer on 200mm wafers has about 40% of the dies, this leads to very poor device yields on 200mm wafers. We have developed and tested up to 20at% of Sc in AlN film process that involves depositing a thin layer of AlScN and in-situ focus Ion Beam trimming process to smooth the surface, followed by the rest of the deposition. This process has excellent XRD in both the center and the edge of the 200mm wafer with strong (002) peak.**

Keywords—Scandium; Aluminum Scandium Nitride; AlN; aluminum nitride; crystallinity

I. INTRODUCTION

In the last three decades, many applications have been developed based on MEMS structures that employ either a free-standing membrane or a cantilever structure extending over a cavity. Examples of such structures include Film Bulk Acoustic Resonator (FBAR) filters, Piezoelectric Micro-Machined Ultrasound Transducers (PMUT) and energy harvesting devices. Initially, aluminum nitride (AlN) has been most commonly used for piezoelectric because it is easy to manufacture in high volume. Recently, inorder to get higher coupling coefficient, Sc doped aluminum nitride started making its way into the high-volume manufacturing applications.

Figure 1. Kt2 vs Sc concentration in AlN-doped film.



At low Sc concentrations, it is easy to deposit high quality films. As Sc concentration is moving higher and higher in a quest to obtain the maximum possible coupling coefficient, sporadic nucleation of different crystal orientations have been observed. Figure 2, 3 and 4 shows degradation of crystallinity on the edge of 200mm wafers of AlScN film

Figure 2. ScAlN Omega 18.02 (1.803 degree)

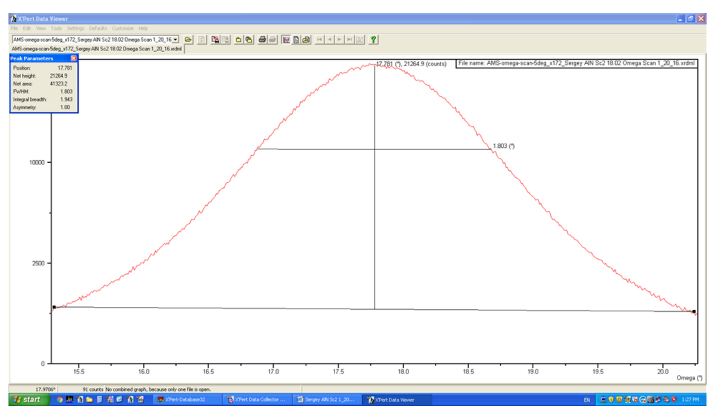


Figure 3. 2Theta-Omega Scan PEAK 1 (35.53deg)

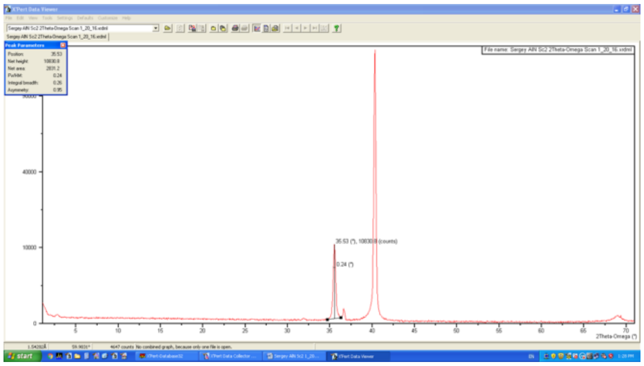
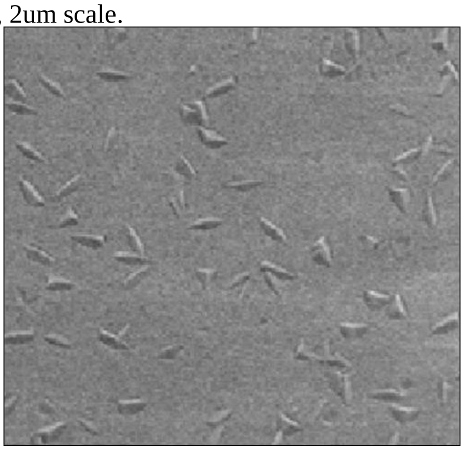


Figure 4. Sporadic nucleation on the surface of AlScN films by SEM, 2um scale.

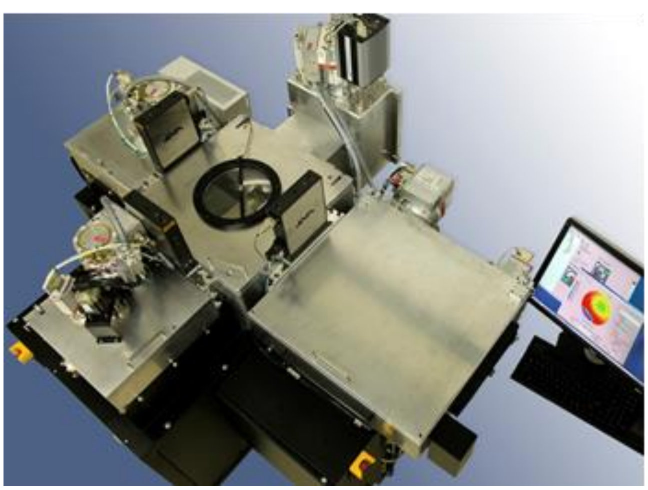


We have come up with a very simple process to eliminate this problem. Depositing a thin layer of the AlScN followed by a short ion mill treatment, prepares the surface that allows for a deposition of AlScN that has excellent XRD and no sporadic nucleation.

II. EQUIPMENT

In this experiment, we used Advanced Modular Systems cluster tool with AlN and AlScN deposition chambers and ion beam trimming module (shown in Figure 5).

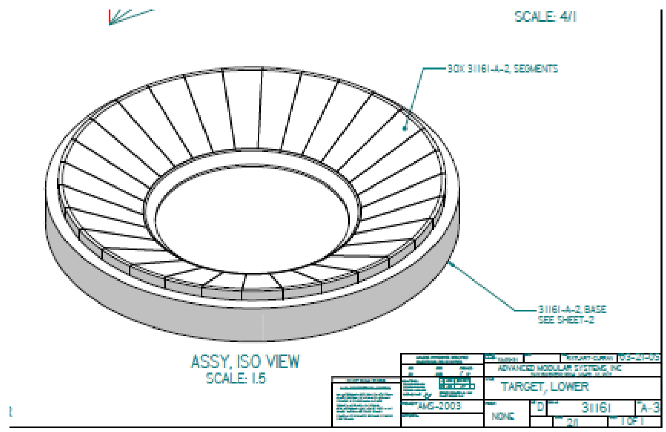
Figure 5. AMSystems cluster tool

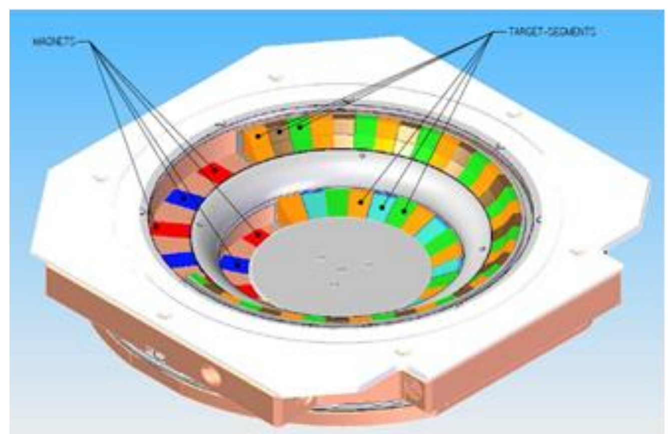


Both AlN and AlScN depositions use a dual magnetron with AC power applied between targets. Frequency of AC power is 40 kHz and power may vary from 3 to 10 kW. It is a reactive deposition process in deep poisoned mode.

We used two target rings made out of pieces/tiles of Al and Sc to adjust film composition. Preferred embodiment of such target is shown in Figure 6 below:

Figure 6. Multiple material targets





Based on simple geometry of target's surface, deposited film composition is proportional to the surface of specific pieces of target material. As sputtering area of Sc increases, composition of Sc in deposited film also becomes higher.

Substrate rotation is using to compensate variation of scattering for different materials and composition non-uniformity across the substrate.

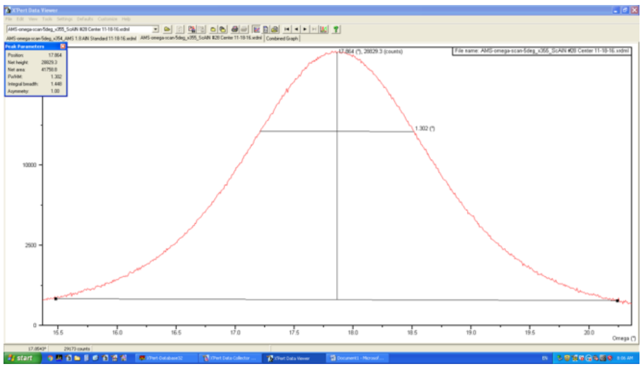
The trimming module uses DC focused ion source with argon process gas to improve thickness/uniformity of either AlN or AlScN films. It is also used to smooth the surfaces. Film thickness trimming/tuning is processing based on ion beam scanning across a wafer with power variation based on film thickness 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.

III. Surface treatment with in-situ ion mill

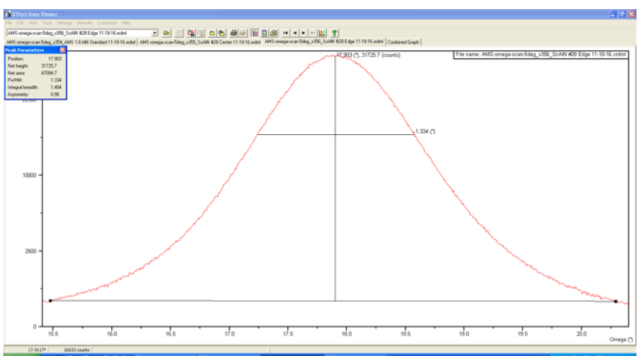
All tests were done for two different composition of doped AlN film with 9% and 20% of Sc content. We deposited films between 100nm and 150nm followed by in-situ ion milling to remove minimum of 30nm. This simple surface treatment dramatically improved the crystal orientation of the final AlScN deposition.

Figure 7 and 8 show XRD measurement of ScAlN folm on the center and edge of the 200mm wafer for 20% Sc in AlScN film.

Figure 7. 2Theta-Omega measurement of ScAlN on the center and the edge of the 200mm wafer.

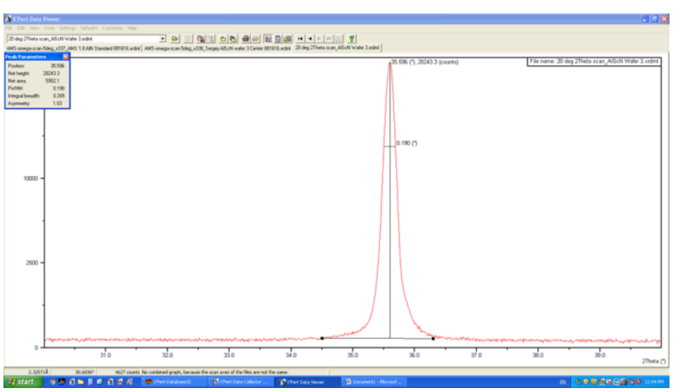


Above: ScAlN #28 Center (1.302)

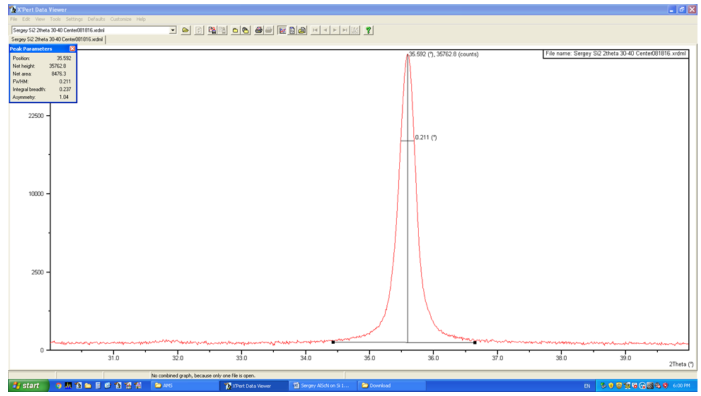


Above: ScAlN #28 Edge (1.334)

Figure 8. 2Theta measurement of the ScAlN (002)



Above: AlScN 2Theta Scan 30-40, Center



Above: AlScN 2Theta Scan 30-40, Edge

Figure 9 shows surface of both AlN (left) and AlScN (right) films by SEM clean from any sporadic nucleation. AlN film surface is shown for reference.

Figure 9. SEM surface of both AlN (left) and AlScN (right) films

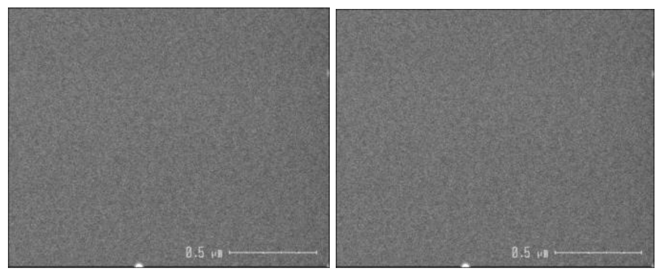
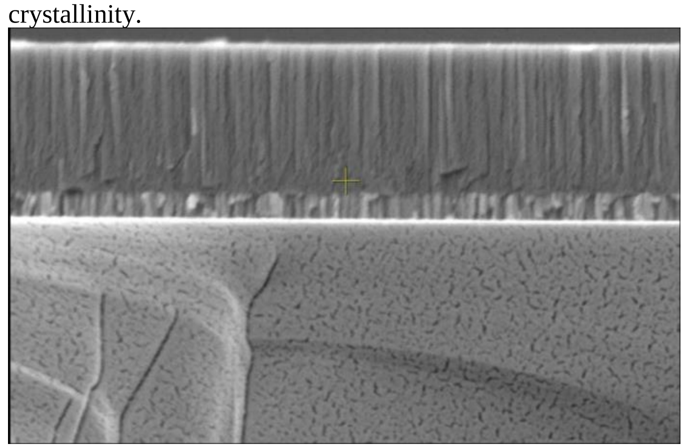


Figure 10 below shows AlScN film cross-section with good crystallinity.



IV. Summary

We have been able to demonstrate a simple and effective method of depositing 20% atomic Sc AlScN films with excellent crystal orientation and no sporadic crystal growth on 200mm wafers.

References

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