Method of controlling coupling coefficient of Aluminum Scandium Nitride deposition in high volume production.

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Abstract— In this paper, we present our studies of the influence of the stress on Aluminum Nitride containing various concentrations Scandium (Sc). Coupling coefficient (kt2) was measured across the wafer and wafer to wafer as a function of stress and Sc content of the film. Previous studies demonstrate a considerable increase in kt2 as a function of Sc content of the film [1], [2], [4], [5]. Unfortunately, when deposited on 200mm wafers we observed that coupling coefficient varies significantly more than that of a standard Aluminum Nitride (AlN). Both stress and concentration of Sc must be controlled across the wafer to achieve uniform coupling coefficient acceptable for production of Bulk Acoustic Resonator (BAW) devices [3], [6], [7]. We were able to control coupling coefficient across the wafer and wafer-to-wafer by adjusting magnetic fields in dual magnetron configuration as well as adjusting concentration of Sc in our two sputtering targets.

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

I. INTRODUCTION

Most PVD deposition processes require only average stress measurement on a wafer to provide reasonable device performance. It is not uncommon to have 300MPa to 400MPa variation of stress across wafer on AlN deposition without anyone realizing it. Actually stress has a significant impact on coupling coefficient of AlN film. Local Stress variation across a wafer produces variation of piezoelectric coupling coefficient, and, as the result, dramatically reduces device yield. Similar problem can be addressed to the stress variation of AlScN film. Figure 1 shows effect of stress on AlN and AlScN films.

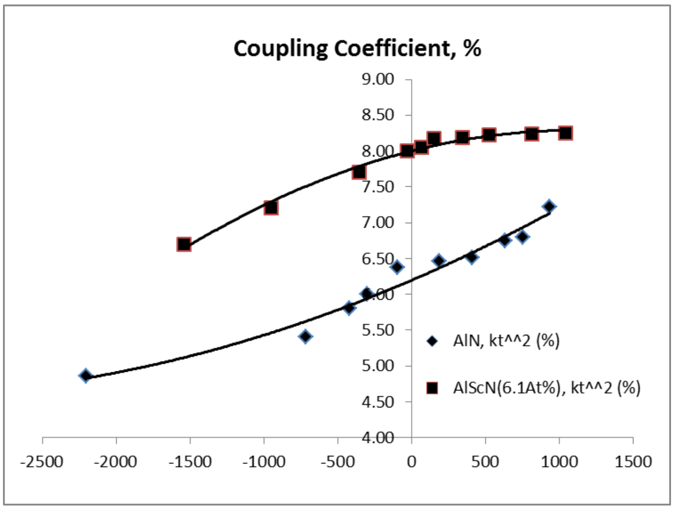


Figure 1: Variation of coupling coefficient as a function of stress for AlN and AlScN films

Tight control of coupling coefficient is essential for producing high quality devices. Using dual target magnetron configuration allows very tight control of stress and coupling coefficient across a wafer.

In this investigation we used different magnetic fields on each magnetron in conjunction with different concentrations of Sc on each target to produce the tightest control on both stress and coupling coefficient.

II. EQUIPMENT

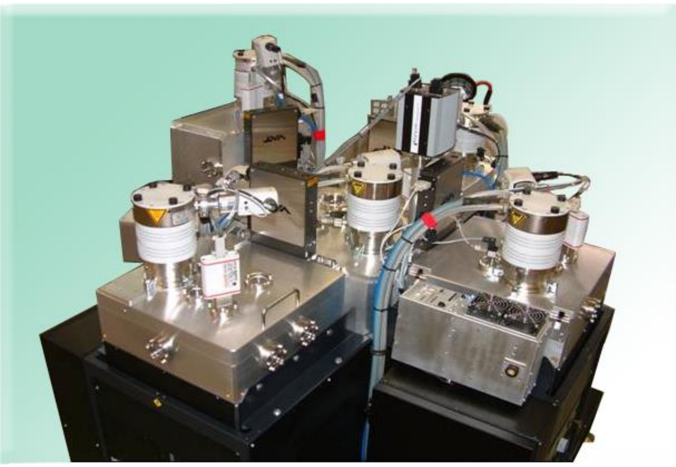
In this investigation we used Advanced Modular Systems cluster tool with AlN and AlScN deposition chambers and ion beam trimming module (shown in Figure 2).

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 poison mode using two aluminum or composite targets and, argon and nitrogen process gasses.

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 a process based on ion beam scanning across a wafer with power variation based on film thickness map. Utilization of the trimming module opens up a much wider process window for stress control because it allows to avoid 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

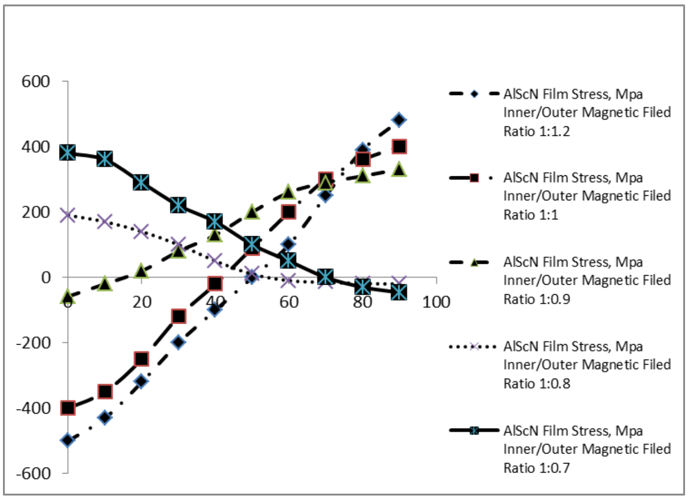


III. STRESS CONTROL

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 effect on the local stress across a wafer.

AlN Film stress depends on magnetic field on the surface of the target (7). AlScN film stress also depends on magnetic field on target surface. Since center of the wafer receives more deposited material from the inner target and wafer edge receives 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. We found that in AMS system stress variation has almost perfectly radial distribution that varies with the ratio of magnetic field between inner and outer magnetrons. Figure 3 shows change in stress across a wafer as a function of the ratio of the inner to outer magnetron magnetic fields.

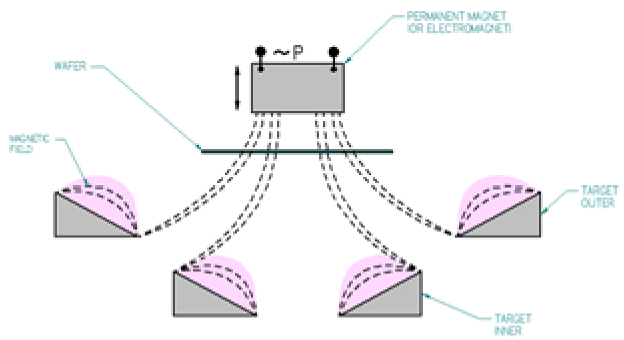
Figure 3: Stress variation across wafer as a function of the ratio of inner to outer target magnetic fields



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

Placing an additional magnetic field with an adjustable strength behind a wafer as shown in Fig.4 creates a variable unbalance effect of the either inner or outer magnetron (and, as the result, increases or reduces ion bombardment) and provides an additional fine control of the film stress uniformity across a wafer (center to edge) over the target life. This magnetic field can be varied by either an electro-magnet with adjustable electrical current or a permanent magnet with a motor that can adjust the distance between the magnet and the wafer.

Figure 4. Magnetron with the enhanced magnetic field

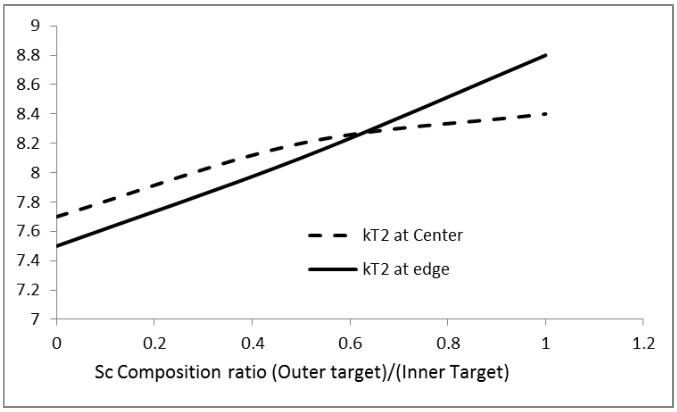


IV. COMPOSITION CONTROL

Another advantage of the dual magnetron is its capability to use targets (inner and outer) with different ratio of Sc/Al. This method provides an additional control to obtain a uniform coupling coefficient across a wafer.

We started our study by using the same composition on both targets of about 6.1 atomic % Sc with the rest being Al. Analysis showed that deposited on the wafer film contained about 4.2% Sc. In order to achieve desired improvement of coupling coefficient we changed to 8 atomic % Sc on the inner target and varied Sc concentration on the outer targets. Figure 5 shows variation of coupling coefficient across a wafer as the inner target Sc concentration is 8% and outer target Sc concentration is varied between 0 and 8%.

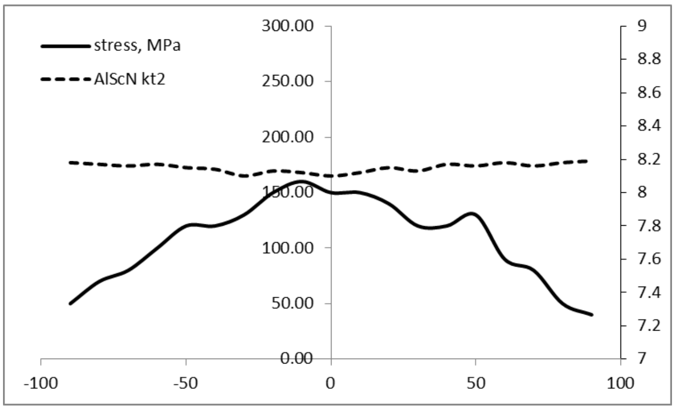
Figure 5: Coupling coefficient across wafer as a function of Sc concentration in two targets



By using the same Sc concentration of inner and outer targets we get slightly higher concentration of scandium on the edge of the wafer. The optimum concentration profile is obtained with concentration of scandium of about 8% on the inner target and 4% on the outer target. It should be noted that most cost efficient method would be to use 8% Sc for inner target and pure outer aluminum target. The Coupling coefficient on the edge is only slightly lower than that in the center, but the cost of the target set is less than half of the target set with equal concentration in the inner and outer targets.

Figure 6 shows excellent control of both local stress and coupling coefficient across a wafer using optimized combination of optimum magnetic field ratio and Sc concentration.

Figure 6: Coupling coefficient and local stress on AlScN wafers



V. SUMMARY

Using dual magnetron design is highly advantageous in controlling stress and coupling coefficient in AlScN films. By adjusting magnetic field and concentration on target, it is fairly easy to obtain highly controlled coupling coefficient and stress in a high volume production environment.

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