

# Improving Manufacturability of FBAR filters on 200mm wafers

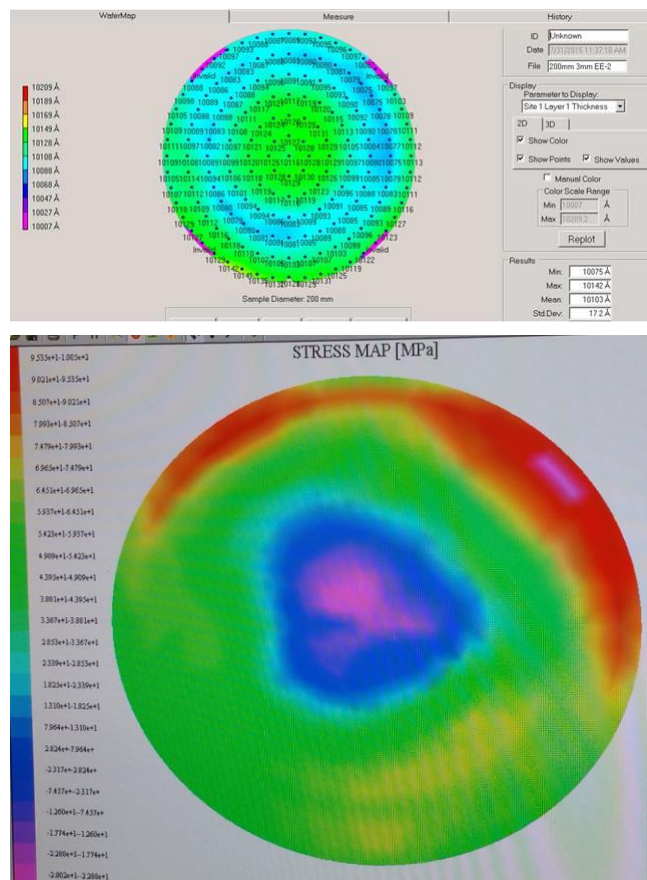
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**Abstract**— FBAR (thin film bulk acoustic resonator) filters are widely used in making filters for wireless applications [1]. Until recently, most of the FBAR filters were manufactured on 150mm wafers. In the last couple of years, manufacturing of the FBAR devices started moving onto 200mm wafers. Main reason to move from 150mm wafers to 200mm wafer is that area increases by a factor of about 1.8X. Unfortunately if the edge exclusion has to be increased in order to avoid bad stress or thickness non-uniformity near the edge of the wafer, it reduces the advantages of the increased area. For example, if the edge exclusion is increased from 3mm to 10mm, it causes 14% yield reduction. This problem has inspired the investigation in the paper.

One of the critical parameters for FBAR manufacture is AlN film stress, both, average and across a wafer. If stress varies too much, membranes can develop cracks or peel off. In BAW applications, that don't require stress control for structural reason, it is desirable to keep stress uniform across wafer in order to maintain tight distribution of coupling coefficient. Another critical parameter is film thickness. AlN (aluminum nitride) thickness control of +/-0.2% wafer-to-wafer and across wafer are important in order to obtain high yielding wafers.

In this paper we will propose a way to obtain both stress control and film thickness uniformity. Independent stress control is obtained by carefully designing sputtering magnetron with variable magnetic field. Thickness uniformity is independently controlled by ion mill trimming module. By adjusting magnetic field and the length of the plasma discharge (positive plasma column), stress uniformity across 200mm wafer was maintained at less than +/-75MPa. Thickness control on 200mm wafers with only 3mm edge exclusion was demonstrated at <0.2%.

Figure 1. AlN film thickness and stress uniformity on 200mm wafer with 3mm edge exclusion

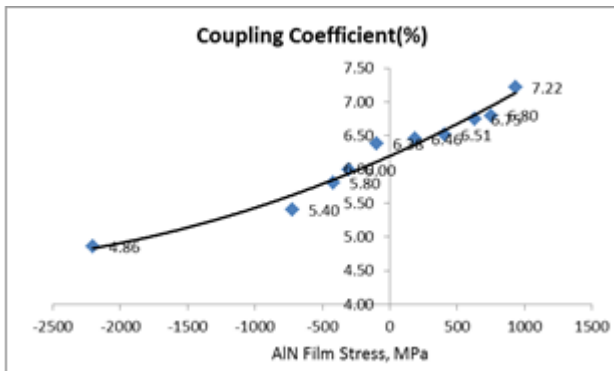


## I. INTRODUCTION

FBAR filters require very tight stress control for AlN film. AlN film stress should be within a range  $\pm 100$ MPa, not only wafer-to-wafer, but also across wafer. There are few reasons for such tight stress control.

- 1). If stress varies too much, membranes can develop cracks or peel off.
- 2). On 200mm wafer it is also critical to control stress wafer-to-wafer, because the bow of the 200mm wafer is about 40 $\mu$ m for a 10,000Å film per 100MPa stress. Since typical films, required in the FBAR filters, range from 1 $\mu$ m to 2.5 $\mu$ m, it is critical to maintain  $\pm 100$ MPa stress control to avoid having problems with the optical steppers. Most steppers have about 100...120 $\mu$ m maximum bow specification.
- 3). Another reason to keep stress uniform across wafer is to maintain tight distribution of coupling coefficient. Figure 2 show correlation between AlN film stress and device coupling coefficient.

Figure 2. Correlation between AlN film stress and device coupling coefficient



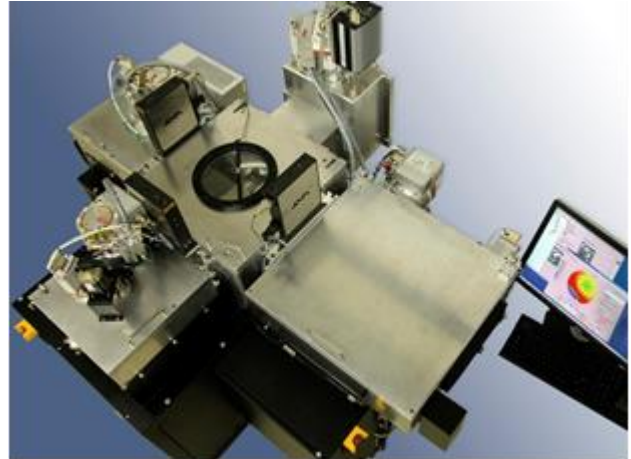
All mentioned above issues have a great impact on device yield, and as result, device cost.

Since FBAR device frequency depends on thickness of deposited layers, it is critical to have AlN (aluminum nitride) thickness control of  $\pm 0.2\%$  wafer-to-wafer and across wafer. Considering the importance of AlN film stress and film thickness uniformity, it is necessary to have independent film stress and thickness control.

## II. EQUIPMENT

In this investigation we used Advanced Modular Systems cluster tool with three modules: AlN deposition chambers, electrode deposition chamber and ion beam trimming module (shown in Figure 3).

Figure 3. AMSystems cluster tool with three modules (AlN deposition, Mo deposition and pre-clean/trimming)



AlN deposition uses a high volume production dual magnetron system with positive plasma column and 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 Al targets.

High purity research grade 99.9999% argon and nitrogen process gasses we used for all depositions.

Substrate rotation is used to reduce variation of non-uniformity of film properties across the substrate.

Electrode deposition chamber is a dual magnetron with AC power supply, electrode target (Mo, W, Pt, etc...) and argon process gas.

The trimming module uses DC focused ion source with argon process gas to improve thickness/uniformity of deposited 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 and other film properties control, because it allows avoiding of spending too much effort on controlling thickness uniformity during deposition.

Figure 4. Focus Ion Beam Profile



Unlike sputter etch module in the traditional cluster tools, AMS trimming module can be used to both, cleaning the surface before deposition, as well as improving thickness uniformity after the deposition. It is very cost effective solution, because it doesn't cost any more than RF sputter etch chamber, but does a double duty as a pre-clean chamber and trimming chamber.

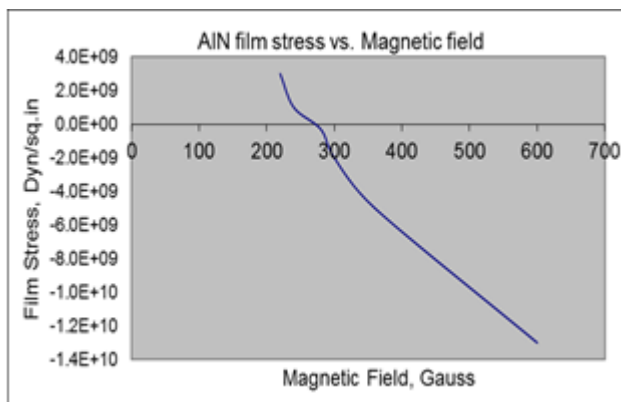
### III. SYSTEM DESIGN FOR STRESS CONTROL IN ALUMINUM NITRIDE DEPOSITION

Up till now most of the production FBAR filters have been made on 150mm wafers. Both rotary magnetron and dual conical magnetrons have been used with fair amount of success. As the industry is moving to the 200mm wafers, it becomes more challenging to keep both, thickness uniformity and stress across wafer, within the required tolerances.

Standard approach on the rotary magnetron is to increase the size of the target to get better thickness uniformity on a larger wafer. Although, it works to get better uniformity, stress variation across wafer gets significantly worse. Typical 150mm wafer has about 250MPa variation across wafer with a rotary magnetron system. For 200mm wafer, stress variation is greater than 350MPa. This is partially due to the inherent geometric limitations of the single target system, as well as the location of the racetracks on the target and the distance between racetracks and the anode. As a result, it produces high density plasma in the center of the target and low density plasma (due to elimination of positive plasma column) at the edge of the target. Since more material on the center of the wafer is deposited from the center of the target, and more material on the edge of the wafer is deposited from the target edge, it produce highly non-uniform center-to-edge AlN film properties (such as stress and coupling coefficient). It is very hard to optimize rotary magnetron system to give both, good thickness uniformity and good stress variation across wafer.

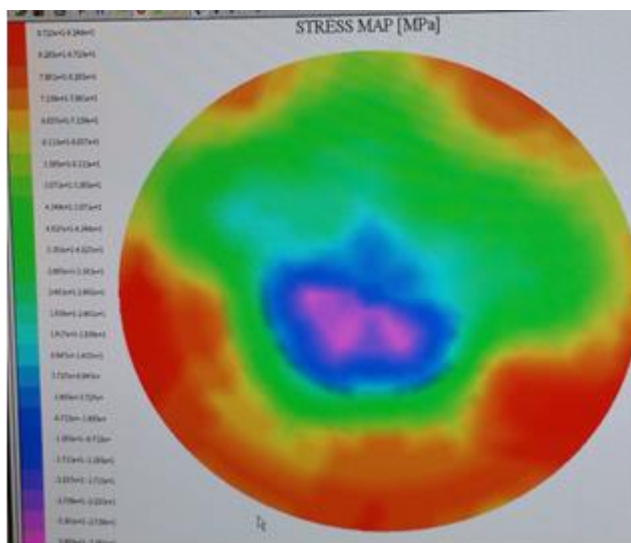
It is much easier to obtain good stress control and thickness uniformity in a system with two independent magnetrons (targets), that allow fairly easy geometric manipulation of the target surface, as well as independent magnetic field control on each target surface. Effect of the magnetic field to AlN film stress is shown in Figure 5.

Figure 5. Effect of the magnetic field to AlN film stress



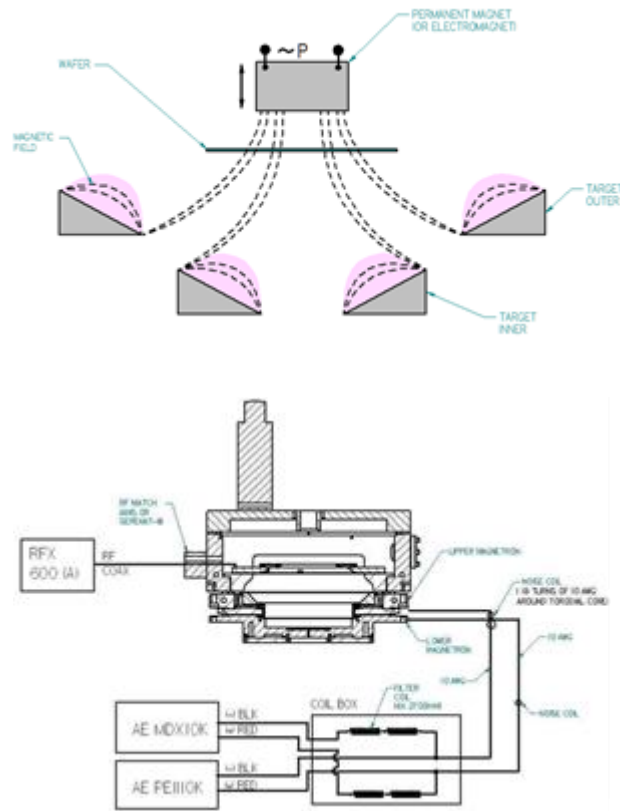
AlN, deposited from the inner target, effects on film properties, mostly on the wafer center, and AlN, deposited on the wafer edge, mostly come from the outer target. Since, it is applied AC power between two targets and shields do not participated in plasma discharge, the positive plasma columns are equals for both discharges, when material sputtered from inner target (inner target acts as cathode, and outer target acts as anode) and, when material sputtered from outer target (outer target acts as cathode, and inner target acts as anode). As result of the same length of plasma discharge, AlN film properties (stress for example) on the center fo the wafer and on the wafer edge are the same. As result, it can be reached cross wafer stress uniformity less than +/- 75 MPa for 200mm wafers.

Figure 6. AlN film cross wafer stress for 200mm



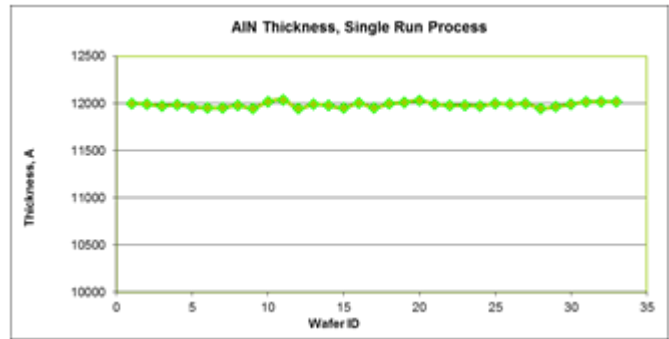
Additional DC power supply, in parallel with AC power supply, allows to shift reference point for AC power and precisely control center-to-edge thickness uniformity. Wafer rotation is also used to improve both thickness uniformity and stress variation across wafer. Figure 7 below shows a typical configuration used for the 200mm wafers.

Figure 7. Typical configuration used for the 200mm wafers.



Implementation of Laser interferometer in AIN deposition chamber allows to keep wafer-to-wafer thickness distribution less than 0.17% one sigma, see figure 8, with very accurate actual thickness to target thickness deviation.

Figure 8. Wafer-to-wafer AIN film thickness distribution

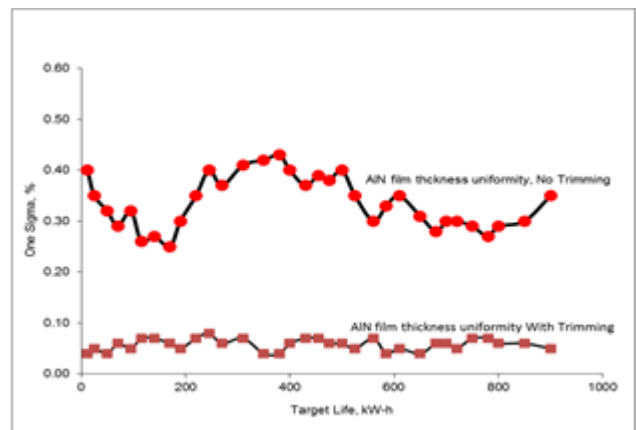


#### IV. TRIMMING FOR UNIFORMITY CONTROL

Adjusting AIN film stress across wafer does not come without problems. The biggest problem is that adjusting magnetic field, changes film thickness across wafer. Typical thickness uniformity across wafer is  $\pm 0.3\%$  if stress control across wafer is not important. Unfortunately, for the FBAR filters it is critical. When stress across wafer is controlled to  $\pm 75\text{MPa}$  with the magnetic field control, thickness uniformity across wafer can be as high as  $\pm 1\%$  over the target life. Using trimming of the film thickness with ion beam [5,6], uniformity of film can be controlled to  $\pm 0.2\%$  even with 3mm edge exclusion on the 200mm wafers.

Because trimming is done in the same cluster tool with deposition modules, it doesn't take extra time. As one wafer is being deposited, the previous wafer is being trimmed at the same time. Wafer maps are stored in the system computer and are updated throughout the life of the target based on the historical data. Figure 9 shows results with and without trimming throughout the target life.

Figure 9. AIN thickness uniformity over the target life



## V. SUMMARY

Manufacturable solution to producing highly uniform (thickness, stress and coupling coefficient) AlN films for FBAR for 200mm wafer size was demonstrated using a dual magnetron deposition system with integrated pre-clean/trimming module.

### REFERENCES

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