Improving coupling coefficient distribution on BAW filters manufactured on 200mm wafers

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***Abstract*— In the past, most BAW and FBAR filters were produced on 150mm wafers. Typical yield on 150mm wafers was >90% [1], [2]. In the last few years, most filter manufacturers started migrating to 200mm wafers in order to reduce the cost of manufacturing. Unfortunately, due to variation of coupling coefficient (kt^2) [3], [4], [5], yields on 200mm wafers were significantly lower than on 150mm wafers. Stress in the piezoelectric material is the largest variable that changes coupling coefficient [6]. Figure 1. Shows how coupling coefficient varies with stress for devices that use piezoelectric aluminum nitride (AlN) and molybdenum (Mo) electrodes. Depending on the exact processing involved in making a filter, the same AlN deposition process will produce a completely different stress/kt^2 variation across the wafer. Figure 2 illustrates a difference coupling coefficient variation across wafer, using tungsten (W) vs. Mo electrode material while leaving everything else the same. In order to be able to obtain the best coupling coefficient with different processing on 200mm wafer, it is critical to have independent control of film stress across wafer. In this paper, we will demonstrate a method of controlling coupling coefficient across wafer within less than +/- 1% (total range) of the target.**

Keywords—film stress; coupling coefficient; AlN; aluminum nitride; stress control

Figure 1. Coupling coefficient as a function of average stress in AlN films.

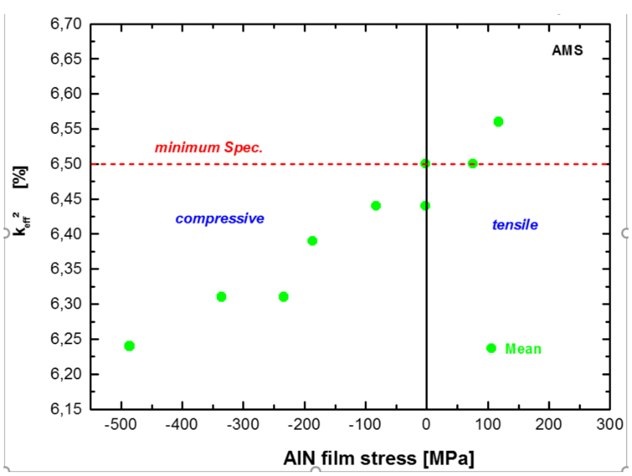
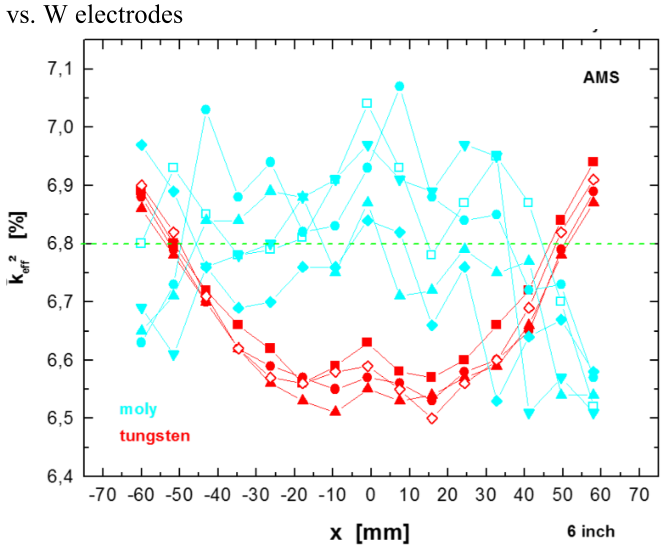


Figure 2. Coupling coefficient variation across wafer on Mo vs. W electrodes



I. INTRODUCTION

As most of the high volume manufacturers of FBAR/BAW filters are moving to 200mm wafer from 150mm wafer, new challenges emerged. One of the most critical is significantly higher variation of kt^2 across 200mm wafer. As can be seen in Figure 3, area of the 200mm wafer that can meet the kt^2 specifications is almost the same as on the 150mm wafer. In order to meet the same or even tighter specifications of the new filter products, it is important to be able to produce highly uniform kt^2 across wafer. For different processes it means ability to control stress across wafer.

Considering the importance of AlN film sterss and film thickness uniformity, it is necessary to have independent film stress and thickness control.

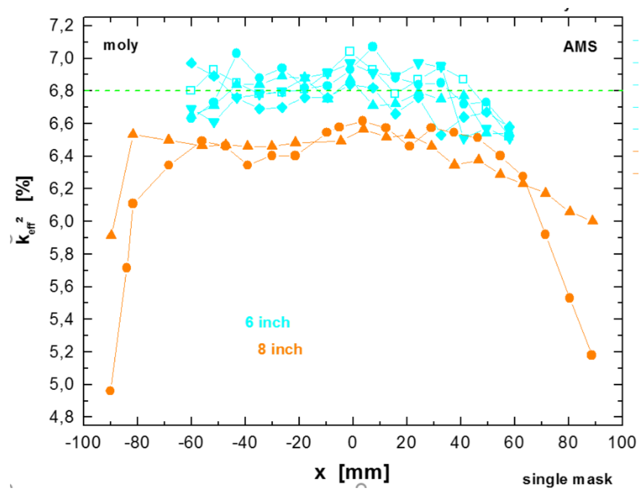


Figure 3. Typical results from 150mm wafer compared to 200mm wafer

II. EQUIPMEMT

In this investigation, we used Advanced Modular Systems cluster tool with three process modules: AlN deposition chamber, electrode deposition chamber and focus ion beam trimming module (shown in Figure 4).

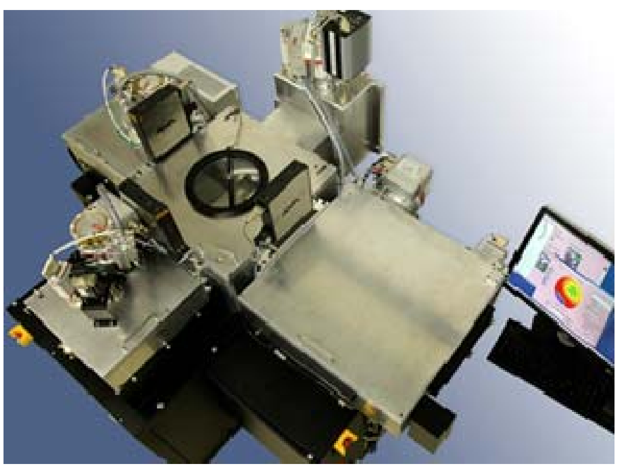


Figure 4. AMSystems cluster tool with three modules (AlN deposition, Mo deposition and pre-clean/trimming)

AlN deposition process uses a high-volume production dual magnetron system with positive plasma column and with AC power applied between targets (magnetrons). 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 pure 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 deposited film properties across the substrate. Integrated Laser interferometer is used to control average deposition thickness of the AlN films during process.

The trimming module uses DC focused ion beam 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 the deposition.

Figure 5. Focus Ion Beam Profile

Unlike back-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.

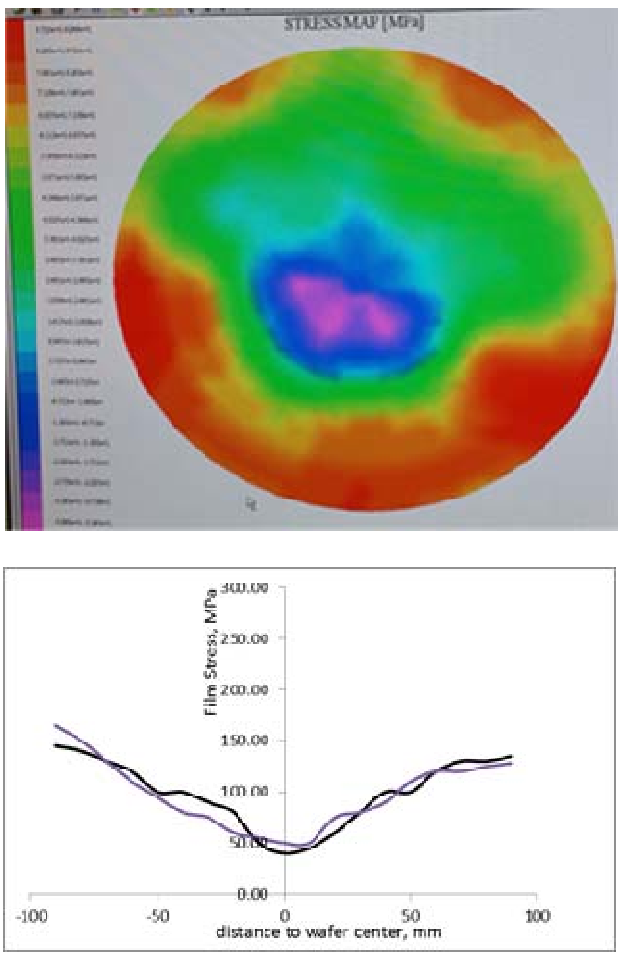
III. SYSTEM DESIGN FOR STRESS CONTROL IN ALUMINUM NITRIDE DEPOSITION

When using a standard rotary magnetron deposition system for the piezolectric AlN on 200mm wafer, stress variation across wafer is typically greater than 350MPa. In most designs, it also produces more tensile films in the center of the wafer. 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 or chamber wall. As a result, it produces high density plasma with positive column 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 produces 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 of deposited film 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.

The AlN film, deposited mostly from the inner target produces largest effects on film properties near the center of the wafer. The AlN film, deposited on the wafer edge, mostly come from the outer target. Since, the AC power is applied between two targets (shields do not participated in plasma discharge) it creates symmetrical discharge and the positive plasma columns that are equal for the discharges. During the deposition, each target acts alternatively as an anode or cathode for the half of the cycle. Due to the same length of plasma discharge and plasma density, AlN film properties (stress for example) on the center of the wafer and on the wafer edge are the same. As result, the stress uniformity across the wafer is less than +/- 75 MPa for 200mm wafers, see Figure 6.

Figure 6. Typical AMS AlN film cross wafer stress for 200mm

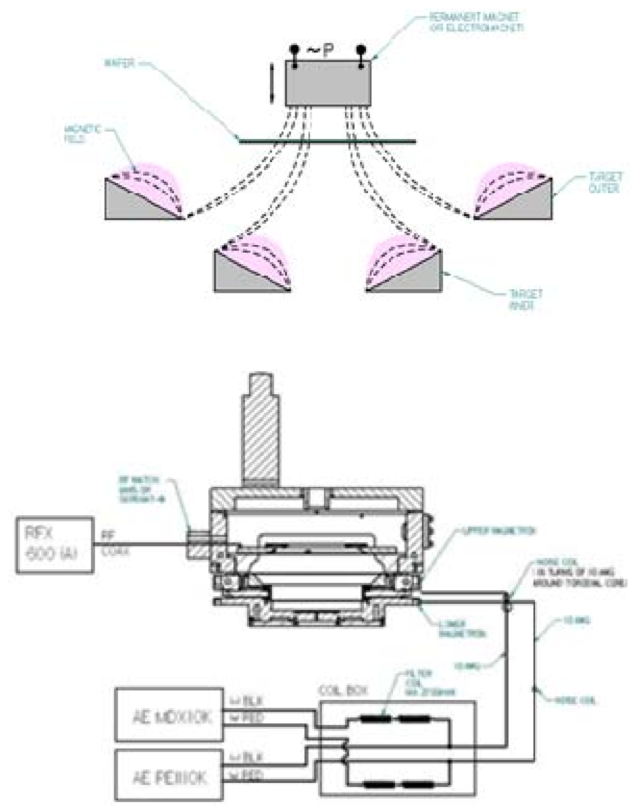


Additional DC power supply, in parallel with AC power supply, allows to shift reference point for AC power and precisely control center-to-edge thickness uniformity.

Wafer rotation is also used to improve both thickness uniformity and stress variation across wafer.

Figure 7 below shows a typical configurations (magnetic and electrical) used for the 200mm wafers.

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



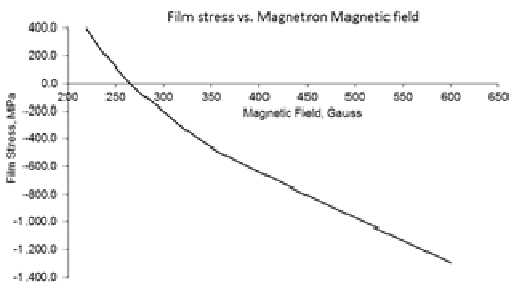
IV. CONTROLLING COUPLING COEFFICIENT FOR DIFFERENT PROCESSES

Depending on the processing used in manufacturing a particular filter technology, it is sometimes required to have a non-uniform stress distribution on a wafer. For example, when a film, that has perfectly uniform stress distribution on a prime silicon wafer, is deposited on a product wafer, stress is much more compressive in the center than on the edge of the wafer. This typically results in lower coupling coefficient in the center of the wafer. There are three potential ways of addressing this problem through AlN deposition:

1. Dis-balancing magnetons magnetic field (inner or outer) with supplemental magnetic fields located above the wafer.
2. Adjusting magnetic field on the magnetrons to purposely unbalance the stress across the wafer.
3. Increasing/decreasing the ratio of the deposition coming from outer vs. inner target.

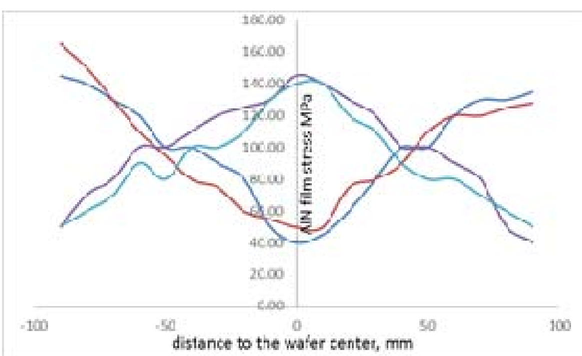
Since magnetron magnetic field has significant impact on film stress (see figure 8), it would be reasonable to spend significant amount of effort to control the magnetron magnetic field.

Figure 8. AlN film stress depeds on Magnetorn magnetic field



The easiest way to adjust the stress across wafer is to adjust magnetic field by dis-ballancing magnetic field by changing the magnetic field strength behing the wafer. This requires either a simple change of the permanent magnets or adjusting current to the electromagnet located behind the wafer. This methode allows to sputter more compressive or more tensile stress from inner target to the center of the wafer and can provide up to 300MPa stress change from the center to the edge of the wafer. It has a small impact on thickness uniformity that is easily corrected by the trimming process.

Figure 9. AlN film stress distribution across 200mm wafer



If a more significant change is required, it may be necessary to change the magnetic field ratio between inner and outer magnetrons. This requires much more extensive hardware modificaton and process re-carechterization. Figure 10 shows how adjustment of the magnetic field on two magnetrons can change stress across wafer.

If the magnetron ratio is already changed to have significantly different stress material coming from each magnetron on a different part of the wafer, changing the amount of material coming from each target will result in even bigger change in stress between the center and the edge. Typically, this kind of change will impact thickness uniformity the most and will require most trimming to compensate for thickness non-uniformity.

After making all of the above adjustments to the system, we were able to obtain excellent coupling coefficient uniformity over a ten wafer lot of BAW filter 200mm wafers.

Figure 10. Impact of the magnetron magnetic field ratio on stress across wafer.

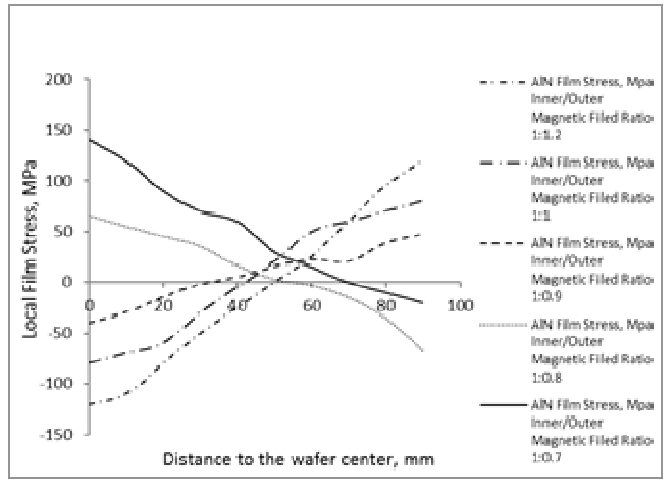
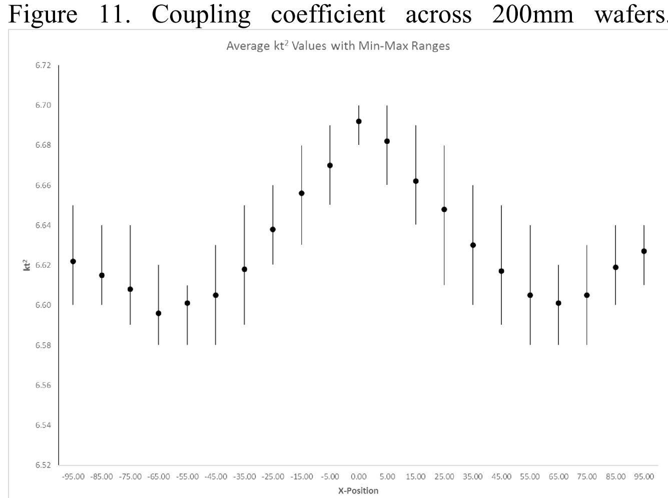


Figure 11. Coupling coefficient across 200mm wafers.



V. SUMMARY

We were able to demonstrate highly uniform coupling coefficient across 200mm BAW/FBAR wafers using AlN deposition on a dual magnetron deposition system with integrated pre-clean/trimming module. Stress and kt^2 uniformity across wafer was achieved without compromising thickness uniformity or crystal orientation of the deposited AlN film.

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