AlN Film Stress and Uniformity for BAW filters on 200mm wafers

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Abstract**—** Most standard processes only require controlling average stress on the sputter deposited films.

Recently, MEMS devices have moved into high volume applications [1], [2]. Devices such as FBAR filters, MEMS microphones, and cantilever structures have much more sensitivity to stress variation across wafer and across the thickness of the deposited film [3], [4], [5], [6].

Sputter deposited aluminum nitride (AlN) films have polycrystalline and strongly oriented grain structure, starting with extremely compressive film at the initial few thousand angstroms thickness and becoming more tensile as grains get larger. Also most deposition systems have high variation of film stress across wafer due the magnetic field strength and electrical discharge at each racetrack not being selected for the best stress control across wafer. Because most systems have been designed with film thickness uniformity and average stress on a wafer as primary goals, stress across wafer and across film thickness is sometimes highly non-uniform.

In this paper we will show how it is possible to control stress for all desired characteristics: average stress, stress uniformity across wafer and across entire film by using appropriate magnetic field design and in-situ ion beam trimming as part of the deposition process.

Average stress control cross wafer is achieved by precise adjustment of magnetic field of inner and outer target ring magnetrons, see Figure 1.

Stress variation across wafer is achieved by varying the ratio of magnetic field strength between two magnetrons as shown in the Figure 2.

Stress variation across deposited films is achieved by using multistep deposition/ion mill trimming processes, see Figure 3.

As result, film stress variation across wafer and across film is maintained at less than +/-100MPa range with thickness uniformity on 200mm wafers maintained at below 0.2% one standard deviation.

Figure 1. Average stress in AlN film vs. Magnetron magnetic field for different materials; AlN (green) and Mo (red).

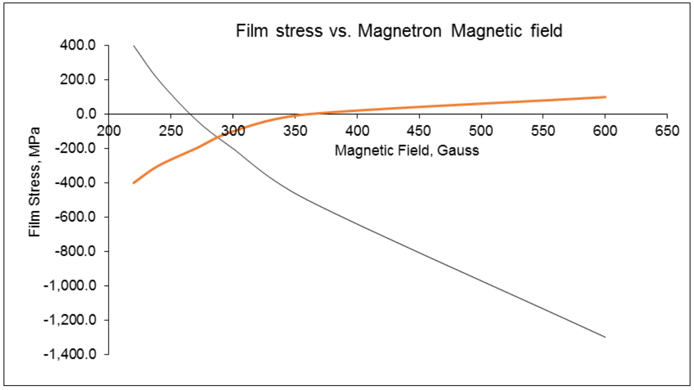


Figure 2. Stress as a function of Distance from the center of the wafer as a function of Magnetic field ratio between two magnetrons.

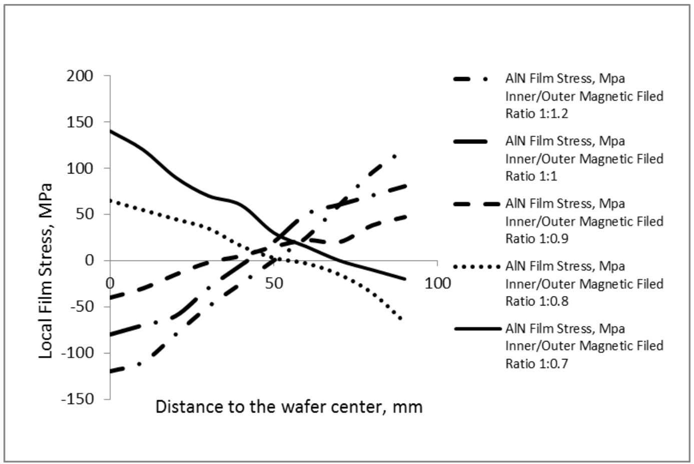
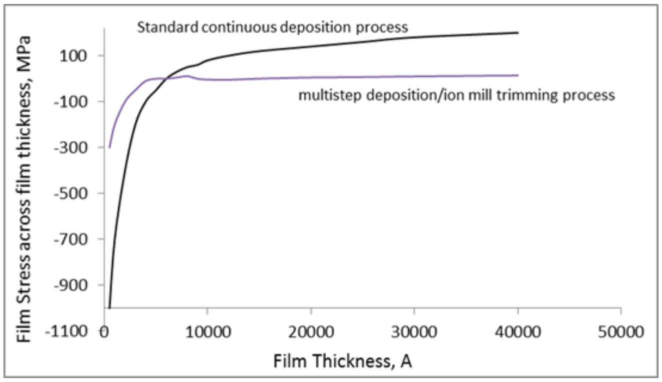


Figure 3. Stress as a function of AlN film thickness



I. INTRODUCTION

Many MEMS devices that use piezoelectric AlN films require very tight stress control. There are few reasons for such tight stress control.

1. On 200mm wafers, many processing tools (such as steppers) require <120um maximum wafer bow. This corresponds to <250 MPa stress requirement for a 1um AlN film.
2. 2. Many devices such as cantilever beam structures, for example, require stress control that is about +/-100MPa wafer-to-wafer as well as across wafer and throughout the films thickness.

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

Additional, for some devices such as FBAR, for example, for which frequency depends on thickness of deposited layers, it is critical to have AlN (aluminum nitride) thickness control of +/-0.2% wafer-to-wafer and across wafer.

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

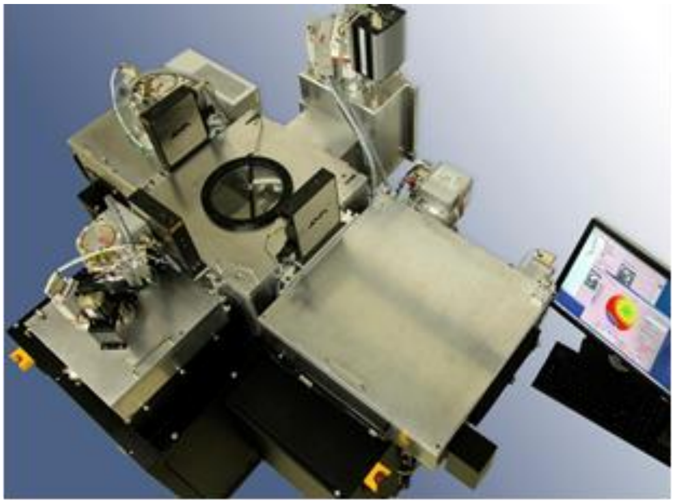
II. EQUIPMEMT

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

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.

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



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 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 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 PROCESS

When using a standard rotary magnetron deposition system for the piezolectri AlN on 200mm wafer, stress variation across wafer is typically 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 (or chamber). 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.

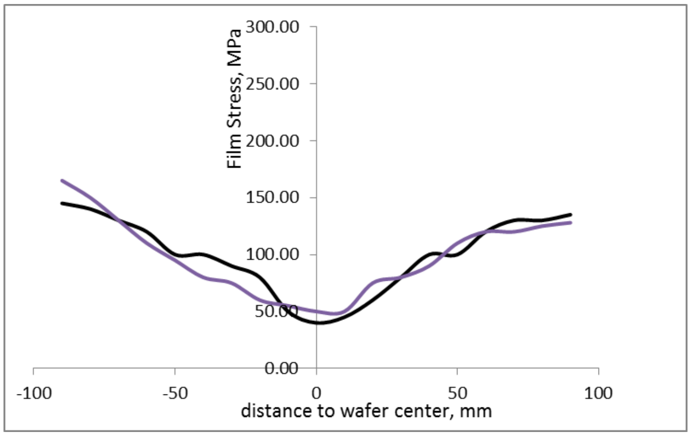
It is much easier to obtain good stress control and thickness uniformity of deposited film in a system with two independent magnetrons (targets), that allow fairly easy geometric manipulation of the target surface, as well as independent magnetic field control on each target surface. Effect of the magnetic filed to AlN film stress is shown in Figure 1.

AlN film, deposited from the inner target, effects on film properties, mostly on the wafer center, and AlN film, deposited on the wafer edge, mostly come from the outer target. Since, it is applied AC power between two targets and shields or chamber do not participated in plasma discharge, it creates symmetrical discharge and the positive plasma columns are equels 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 and plasma density, 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, see figure 6.

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 6. AlN film cross wafer stress for 200mm



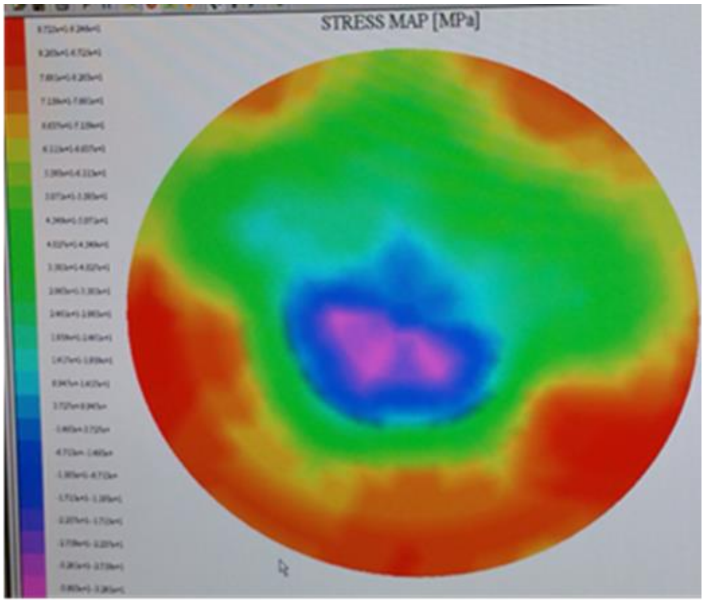
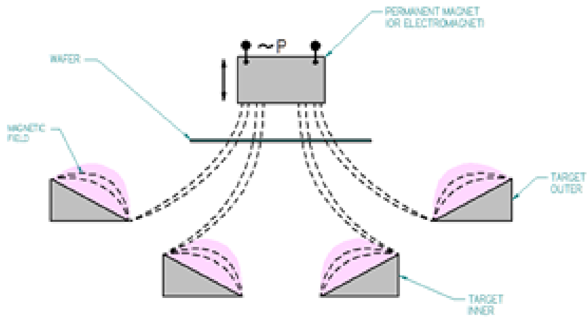
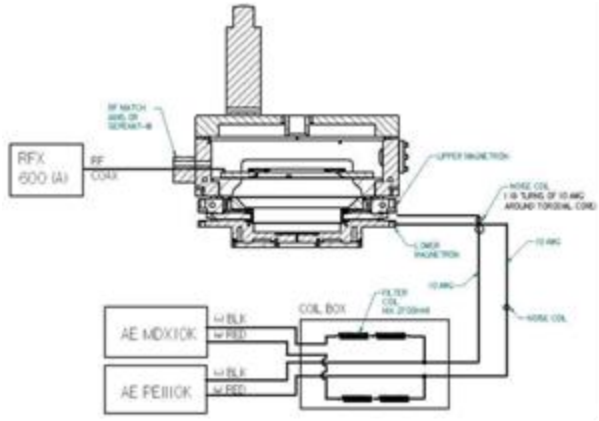


Figure 7. Typical configuration used for the 200mm wafers.

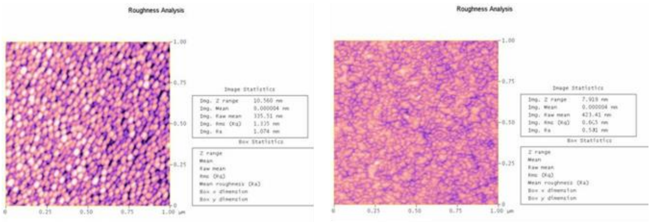




IV. TRIMMING FOR STRESS GRADIENT CONTROL

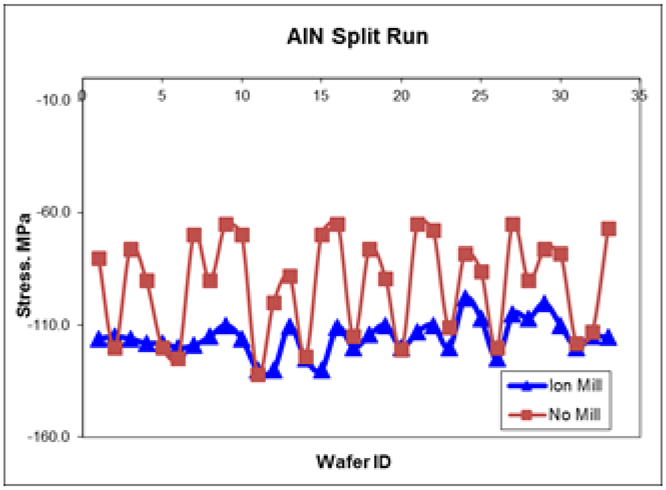
Trimming process [5], [6] can be used to smooth the surface of the AlN as well as to get thickness uniformity improved. Removing at least 200A of AlN reduces surface roughness to <0.6nm, see figure 8 below.

Figure 8. Roughness reduction after Ion Mill Trimming about 200Angstroms of AlN film



When the followingg layer of AlN is deposited on a smoothed surface it tends to be more compressive than if deposited on the un-trimmed surface.

Figure 9. Split Run for Average Stress of AlN film with/without Trimming Process



Trimming must be done without breaking vacuum. If freshly trimmed surface is exposed to the atmosphere, it can instantly oxidize and cause AlN film to grow with poor crystal orientation.

Films, that are deposited and trimmed multiple times show accellent stress uniformity throughout the film thickness. Standard depositions without trimming typically have very compressive initial films and progressively more tensile films as the films get thicker As illustrated in Figure 3.

V. SUMMARY

Manufacturable solution to producing highly uniform AlN films for FBAR for 200mm wafer size was demonstrated using a dual magnetron deposition system with integrated pre-clean/trimming module.

Average Stress control wafer-to-wafer, stress uniformity across wafer and across the entire film thickness was achieved without compromising thickness uniformity or crystal orientation of the deposited AlN film.

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