Improving Manufacturability of Bulk Acoustic Wave and Surface Acoustic Wave Devices

Sergey Mishin [1]

[1] Advanced Modular Systems, Inc. Goleta, CA 93117 USA

* Corresponding author, E-mail: smishin@amssb.com; Tel.: 805-698-6943

Bulk acoustic wave (BAW/FBAR) or surface acoustic wave (SAW) technologies are widely used in making filters for wireless applications [1]. While it is no longer a great challenge to make reactively sputtered piezoelectric aluminum nitride (AlN) films suitable for BAW applications [3] or to make a standard SAW filter, there are critical devices that require tighter control of film properties in order to achieve required device performance. Independent control of AlN thickness and stress uniformity across wafer is critical for FBAR devices that require high coupling coefficient with tight distribution. Frequency control is big issue in SAW devices. Magnetic field manipulation was used to control stress uniformity across wafer to less than +/-50MPa. Frequency control of +/-0.05% was demonstrated on temperature compensated SAW devices. A high volume production cluster tool with both deposition and trimming performed at the same time was demonstrated.

Keywords: BAW; FBAR; SAW; AlN, Trimming

1. INTRODUCTION

Many applications utilizing free-standing membrane structures (FBAR filters [2] or cantilever MEMs, for example) require +/-50MPA stress control not only wafer-to-wafer but also across wafer. If stress varies too much, membranes can develop crack or peel off. In MEMS devices stress can cause severe distortions in device performance. 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. Figure 1 shows correlation between stress and coupling coefficient.

AlN (aluminum nitride) and electrode thickness control of +/-0.1% 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.

SAW filters made today frequently use silicon nitride passivation and temperature compensating silicon dioxide films. Unfortunately, adding such films leads to degradation of frequency range control. Thickness trimming ion beam tool is an easy solution for this problem.

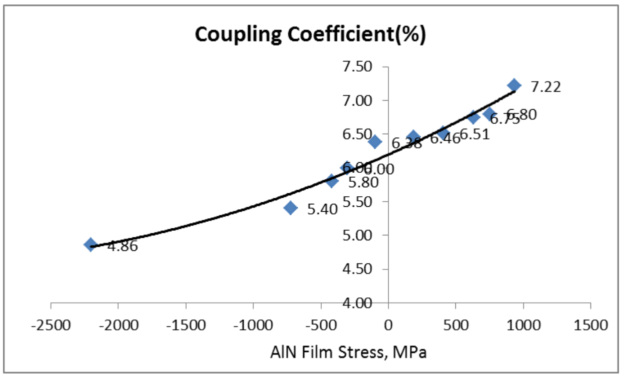

Figure 1. Coupling coefficient as a function of stress

2. EQUIPMENT

In this investigation we used Advanced Modular Systems cluster tool with three modules: AlN deposition chamber, electrode deposition chamber and ion beam trimming module (shown in Fig. 2).

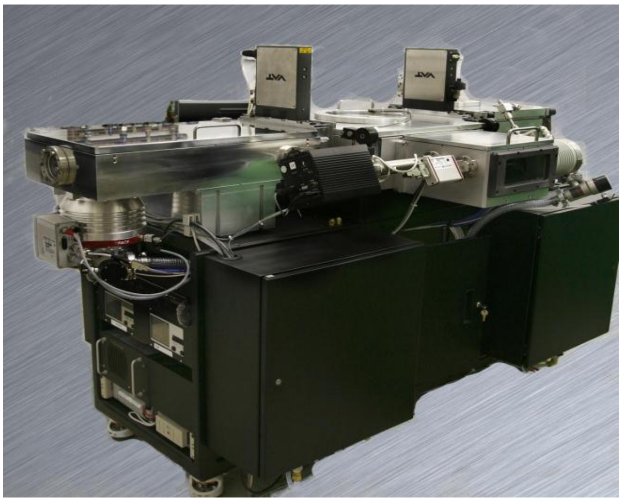

Figure 2. AMSystems cluster tool

AlN deposition module uses a high volume production dual magnetron with AC power applied between targets. It is a reactive deposition using aluminum target and, argon and nitrogen process gasses. Electrode deposition chamber is a dual magnetron with DC 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 either electrode or AlN films. Use of the trimming module opens up a much wider process window for stress control because we don't need to spend too much effort on controlling thickness uniformity during deposition.

3. SYSTEM DESIGN FOR STRESS CONTROL IN ALUMINUM NITRIDE DEPOSITION

In a typical FBAR structure electrodes are much thinner than the AlN film. For this reason, we will focus on the magnetron design for AlN films.

It is fairly easy to program deposition parameters like pressure or substrate bias [4] to control average wafer stress over the entire target life. It is much more difficult to control stress across wafer over the target life. In this investigation we used a dual conical target magnetron and adjusted the magnetic field on each target to obtain best stress uniformity over the target life. In a standard single target magnetron, it is much harder to optimize magnetic field over the erosion area without significantly impacting thickness uniformity across wafer. For this reason, dual target magnetron was selected. Unfortunately, even with two target magnetron, target erosion over the target life, causes magnetic fields on the target surface to change. This result in the variation of stress across wafer over the target life is shown in Fig. 3.

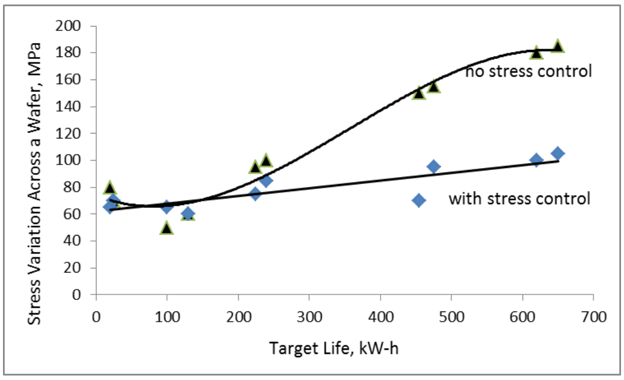

Figure 3. Stress uniformity over target life

Stress variation improves initially, but gets significantly worse at the end of the target life. Placing magnetic field with adjustable strength behind a wafer as shown in Fig.4 creates a variable unbalance of the either inner or outer magnetron (and, as result, increases or reduces ion bombardment of the deposited AlN film) and provides a control of film stress uniformity across wafer 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.

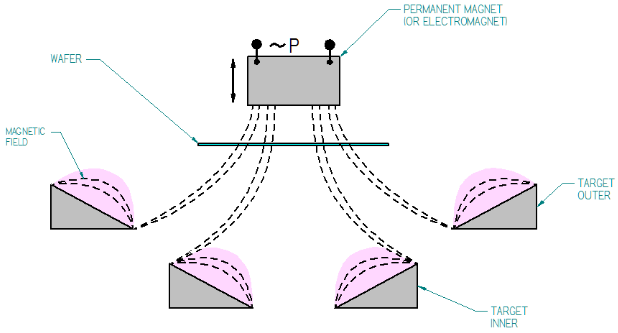

Figure 4. AlN Magnetron with the enhanced magnetic field

Either of these methods allows for an adjustment that can be programmed into the target file and provide a continuous adjustment to the magnetic field over the target life. As result, stress non-uniformity across a wafer is very low and consistent, as shown on Fig.3.

4. TRIMMING FOR UNIFORMITY CONTROL

Adjusting 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 <+/-0.3%. When stress across wafer is controlled to <+/-50MPa with the magnetic field control, thickness uniformity across wafer can be as high as +/-0.5%.

Using trimming of the film thickness with ion beam [5,6], uniformity of film can be controlled to <+/-0.1%. Because trimming is done in the cluster tool, it doesn't take much extra time. As one wafer is being deposited, another 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 5 shows results with and without trimming throughout the target life.

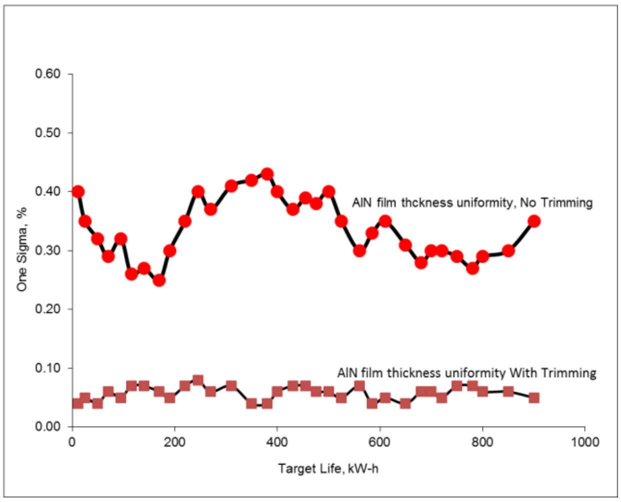

Figure 5. AlN thickness uniformity over the target life

Trimming is also important in improving yield of SAW devices. Some SAW filter require frequency control of +/-0.05% in order to achieve yield of >90%. In modern devices silicon nitride is used for passivation and silicon dioxide films are used for temperature coefficient compensation. Because 1MHz frequency shift is produced by 10A to 30A of either film, it is critical to have film uniformity as good as possible. As result of the trimming process, device yield increases dramatically, as shown on Fig. 6.

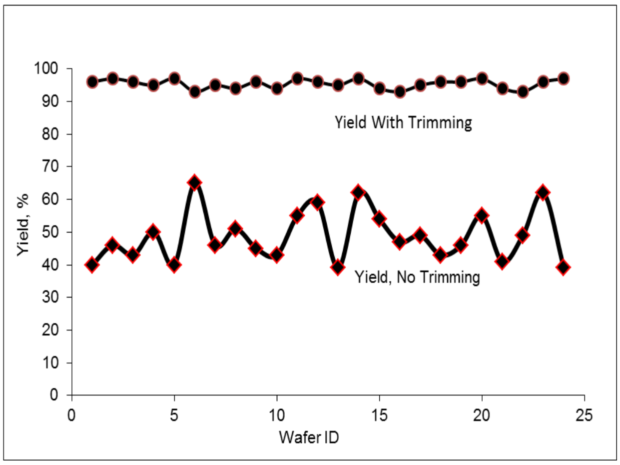

Figure 6. SAW device yield with and without Trimming Process

Trimming SAW wafer requires a special procedure. Wafers are typically lithium niobate or lithium tantalite crystal of 200um to 250um thickness. These wafers require special handling to avoid breakage. No clamping or holding clips utilizing tension are allowed. When SAW wafers get hot they build up high static voltage that if handled improperly can damage delicate electronics in a transfer mechanism or result in a wafer breakage.

Another issue with SAW wafer is that because they can't handle high temperature, silicon dioxide and silicon nitride are usually deposited in a PECVD system at low temperature. Silicon nitride films have high and somewhat variable hydrogen content. Silicon dioxide films have dangling Si-O bonds that interact with ambient moisture [7]. We have experienced 50% etch rate variation on films deposited at different times on the same PECVD system. Films deposited at the same time had less than 2% etch rate variation. Trimming one wafer from each batch [8] to obtain the etch rate for a specific batch of wafers deposited at the same time, produces excellent results. If tighter distribution is required, second trim can be performed as shown in Fig.7 below.

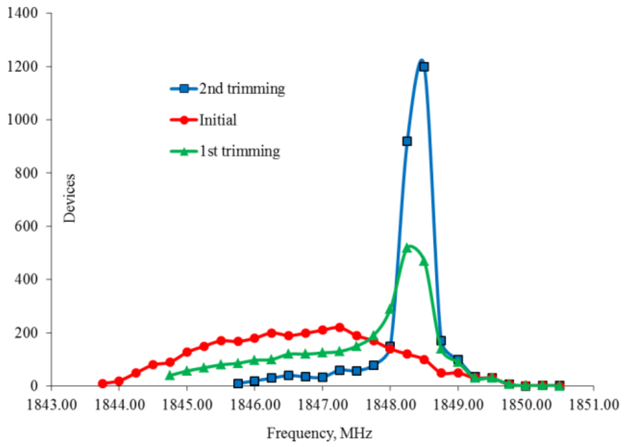

Figure 7. Two step-trimming procedure on SAW wafers

CONCLUSION

Manufacturable solution to producing highly uniform (thickness, stress and coupling coefficient) AlN films for FBAR/BAW/MEMS technologies was demonstrated.

Same trimming technology was applied to the SAW filter devices with slight hardware and process modifications and showed great improvement of device yield.

REFERENCES

[1] Mishin S, et al. "Sputtering Processes for Bulk Acoustic Wave Filters". Semiconductor International, 3/1/2003

[2] Frank Z. Bi and Bradley P. Barber "Bulk Acoustic wave RF Technology", 2008 IEEE

[3] Sergey Mishin, Brian Sylvia and Daniel R. Marx "Improving Manufacturability of AlN Deposition Used in Making Bulk Acoustic Wave Devices", 2005 IEEE ULTRASONICS SYMPOSIUM

[4] K. Hashimoto "RF BULK ACOUSTIC WAVE FILTERS FOR COMMUNICATIONS", pp.173-195

[5] Robert Aigner "Corrective Actions to Meet Extreme Tolerance Requirements for Thin Films" 2007 Octagon Communication Inc. DBA MPDigest

[6] Sergey Mishin, Yury Oshmyansky and Frank Bi "Thickness Control by Ion Beam Milling in Acoustic Resonator Devices", 2010 IEEE FREQUENCY CONTROL SYMPOSIUM

[7] M.J.Deen, et al. "Silicon Nitride and Silicon Dioxide Thin Insulating Films",Vol 97-10, pp.217-231

[8] S.Mishin, et al. "Practical issues with ion beam milling in acoustic wave resonator technologies" IC NanoTech 2010