Effect of Substrate Material and Electrode Surface Preparation on Stress and Piezoelectric Properties of Aluminum Nitride

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Abstract — Intrinsic stress and electromechanical coupling coefficient are the most important parameters of piezoelectric thin films used in membrane as well as cantilever type MEMS such as energy harvesters, transducers and others.

In this paper, practical aspects controlling stress and crystallinity in aluminum nitride (AlN) film used in manufacturing of Bulk Acoustic Wave (BAW)/ Film Bulk Acoustic Resonator (FBAR) filters [1], [2], [4] have been presented. Controlling stress by modifying deposition parameters was compared to controlling stress by surface modification. Stress was found to be an important indicator in predicting crystallinity of AlN films. Impact of the substrate material and electrode deposition on stress and crystal orientation of piezoelectric AlN was studied. In process applications where control of the surface layer thickness is critical and surface topography is variable, use of ion mill to reduce surface roughness is preferable to CMP. It was generally found that for most amorphous materials such as silicon dioxide or silicon nitride that are placed under the electrode or piezoelectric AlN, it is critical to get the best possible surface smoothness. On the other hand for the electrode material such as molybdenum, it is more important to get material with the best crystal orientation. Polishing of the well oriented electrode material did not provide further improvement. It was also observed that if AlN is deposited on a smooth or well oriented layer, orientation of the AlN is improved when the stress in the film is more tensile. On the other hand if the tensile stress is caused by residuals on the surface or surface roughness, tensile stress usually leads to poorly oriented films.

I. INTRODUCION

Early in the development of AlN films, it was observed that stress could vary for variety of reasons. Sometimes most compressive stress in the AlN film produced best crystallinity, other time tensile stress produced best results. Controlling stress was particularly important for FBAR applications where membranes are susceptible to cracking or delaminating due to high stress. Even in BAW technology, high stress can simply cause yield loss in photo-lithography due to high warpage of the wafers. Three major factors must be addressed to control stress in the AlN films:

- Substrate or pre-electrode processing
- Electrode or pre-AlN processing
- Deposition of AlN

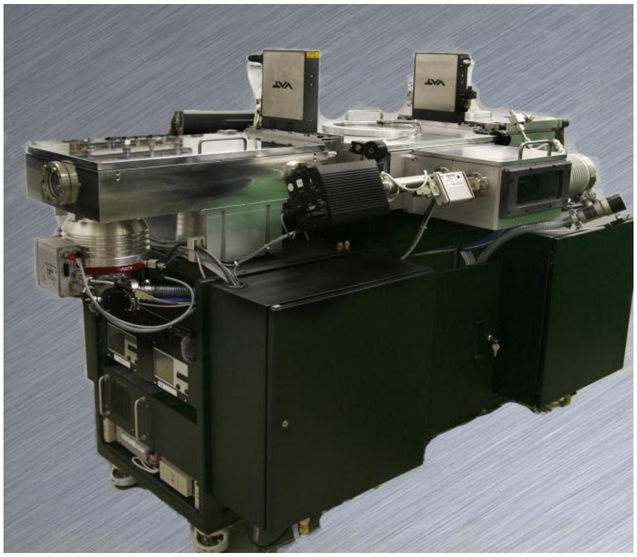
We propose some practical guidelines to successful stress control with high electromechanical constant.

II. 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 Figure 1).

AlN deposition uses a 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.

Figure 1: AMSystems cluster tool



III. SUBSTRATE OR PRE-ELECTRODE PROCESSING

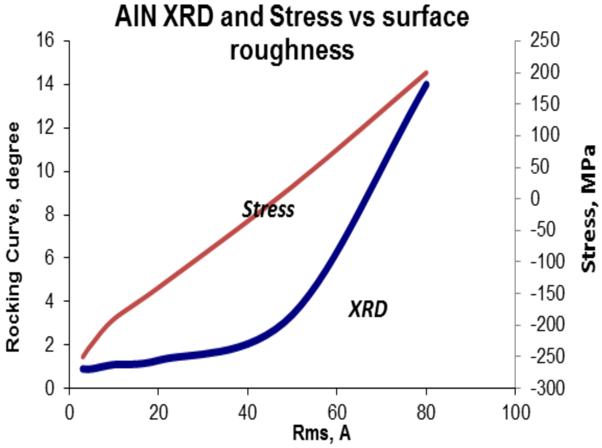
A. *Surface Cleaning*

The surface on which the electrode is deposited can irreparably damage quality of the piezoelectric aluminum nitride. It is very critical to have a smooth and uncontaminated surface before depositing the electrode material. If substrate was exposed to the photoresist, it is critical to have the surface adequately cleaned. Depending on the materials used, either wet chemical or dry strips can be effective. If wafers are not adequately cleaned, it can lead to high tensile stress in the future deposited films with very poor crystal orientation and, in worse cases, delamination.

B. *Surface smoothness*

After adequate cleaning it is important to make sure that the surface is smooth. Typically, 0.6nm surface roughness is acceptable. There are two common methods for the surface smoothing: Chemical Mechanical Polishing (CMP) and ion beam milling. CMP can be performed on most materials and with appropriate selection of polishing slurry it is capable of both planarizing and smoothing the surfaces. One limitation is that it is hard to control the amount of material removed, especially if there is diverse topography of features on a wafer. Ion milling can be precise in the amount of material removed, but is only effective on hard dielectric materials such as SiN, AlN or SiO2. It requires too much material removal on metals to be useful. Figure 2 shows impact of surface roughness on the crystallinity and stress of AlN deposited on the PECVD oxide that is polished to different level of smoothness. Ion beam trimming tool was used to improve the surface roughness.

Figure 2: AlN Rocking curves and Stress as a function of oxide surface roughness

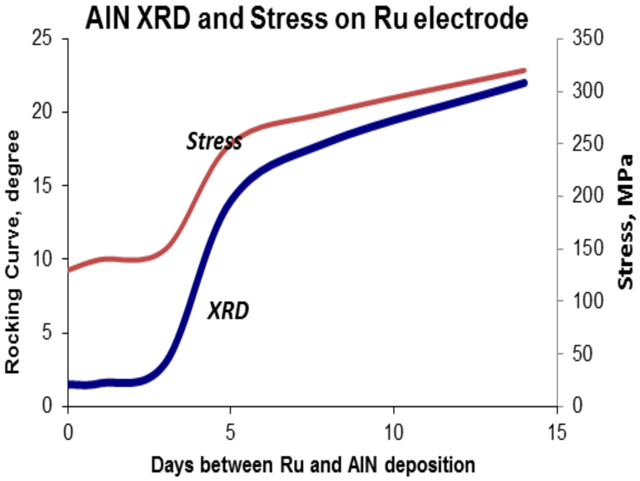


IV. ELECTRODE OR PRE-ALN PROCESSING

Before piezoelectric AlN is deposited, the electrode material is typically deposited and in most cases patterned. It is important to keep track of the stress in the electrode films because it is a good indicator of the problems with the substrate preparation. Erratic stress in the electrode usually results in problems with AlN deposition.

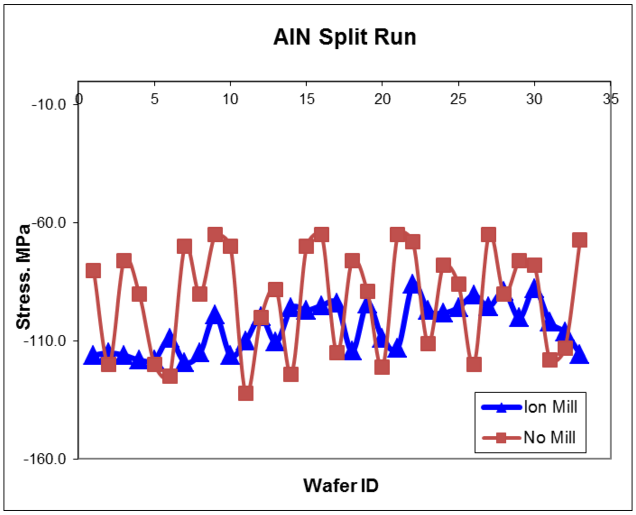
Some electrode materials such as Ru oxidize in the air if AlN is not deposited within relatively short period of time. Significant variations in both stress and rocking curves have been observed if Ru electrode is left in the ambient atmosphere for a long time. Figure 3 shows the impact on AlN parameter as Ru is left exposed for significant amount of time.

Figure 3: AlN properties on differently exposed Ru electrodes



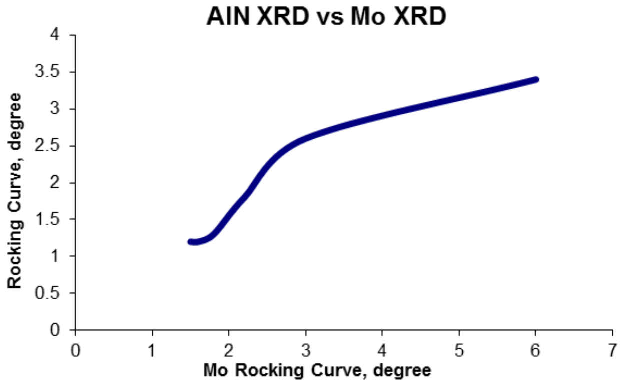
Even though electrodes such as W and Mo are not easily oxidized, it was found that removal of 10nm to 20nm of the electrode material by CMP has beneficial impact on repeatability of stress as can be seen in Figure 4. Polishing the surface of the W also produces improvement in rocking curve, but no improvement was observed for Mo.

Figure 4: Repeatability of AlN stress on polished vs. unpolished electrodes



Measuring rocking curve on Mo deposition has been useful in predicting better crystal orientation in the following AlN deposition, see Figure 5. Rocking curve measurements had no correlation to the rocking curves on AlN or stress repeatability for either W or Ru.

Figure 5: AlN rocking curve depends on Mo electrode property



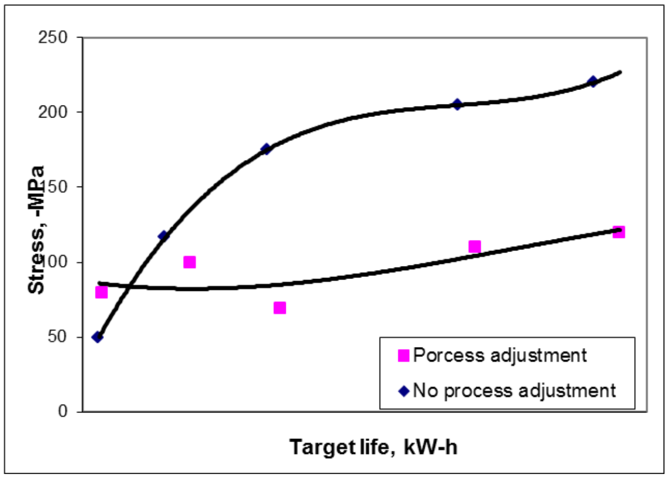
V. DEPOSITION OF AlN

Stress control in the AlN deposition is typically accomplished by controlling either deposition pressure or substrate bias. Higher deposition pressure produces more tensile stress and higher substrate bias more compressive stress [3]. It is important to establish baseline stress repeatability in the deposition module. High resistivity Si is best suitable for such application. Wafers with resistivity of >15ohm-cm are acceptable. Lower resistivity can lead to substrate interaction with the chamber components and variable stress results.

Another common cause of stress variation is a plasma-substrate coupling due to variation of plasma potential and contact through the electrode structure to the wafer holding/clamping mechanism. We have observed as much as 700MPa difference in stress due to the conductive contact to the wafer surface vs. insulated contact.

As the target material gets eroded and a thick insulating layer builds up on the shields, it is not uncommon to see stress changing from the beginning of the target life to the end of the target life. Usually such changes are repeatable from target to target and can be built into automated software adjustment on the deposition system, see Figure 6.

Figure 6: AlN film stress vs. target life



VI. CONCLUSION

In many cases it is more important to prepare the substrate and the electrode for the AlN deposition than trying to control deposition itself. Making sure that both electrode and substrate have been treated correctly will go a long way towards producing excellent AlN films.

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