Production Issues in Using Silicon Dioxide Films for Temperature Compensated Bulk and Surface Acoustic Wave Devices

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Abstract— In this paper, production oriented aspects of using Silicon Dioxide (SiO_2) films in manufacturing of Temperature Compensated Bulk Acoustic Wave (BAW)/ Film Bulk Acoustic Resonator (FBAR) [1], [2] and Surface Acoustic Wave (SAW) devices have been presented. SiO2 has been used to obtain low Temperature Coefficient (TempCo) in acoustic wave devices for more than three decades [3]. One of the big issues is that depending on the method of deposition and the amount of times SiO_2 is exposed to the ambient environment [4], it can significantly alter temperature compensating properties of the film as well as etch rate in a thickness trimming process with focused Ion Beam. Plasma Enhanced Chemical Vapor Deposition (PECVD), RF diode and RF magnetron depositions with in-situ thickness trimming and capping layers were tested on the temperature compensated FBAR and SAW structures. Repeatability of the results was tested with different amount of time before processing steps. Best results were obtained using RF diode sputtered SiO_2 with in-situ trimming process [5] and in-situ aluminum nitride (AlN) sputtered capping layer.

I. INTRODUCTION

Tight control of TempCo over the entire wafer as well as wafer to wafer is critical in manufacturing of the temperature compensated devices. This can be accomplished by:

a) Controlling the thickness of deposited SiO_2 film within 0.1% thickness uniformity,

b) Tightly controlling TempCo of the deposited SiO_2 film.

Both uniformity of the TempCo and trimming (etch) rate of SiO_2, as well as frequency shift, can be significantly impacted by a lengthy exposure to the ambient moisture. Controlling the deposition process and sealing the SiO2 film with sputtered aluminum nitride (AlN) moisture barrier film is a practical way to reduce TempCo variation.

In this investigation we used ion mill based trimming tool to control thickness and thickness uniformity of the SiO_2. It is very important to limit the time between deposition and trimming of the SiO_2 film in order to control trimming rate.

II. EQUIPMENT

In this research we used Advanced Modular System's (AMSystems) three chamber cluster tool pictured in fig. 1 for the deposition and trimming of all films except PECVD deposited SiO_2.

This system had one module with AlN deposition chamber that uses reactive deposition process with dual magnetron with AC power applied between two aluminum targets and Ar/N_2 process gasses. Second module is a trimming chamber with a focused DC ion source with argon gas used for improvement of SiO_2 thickness uniformity. Third module was configured as either RF diode or RF magnetron with a 3KW RF power supply and argon/oxygen sputtering gases. High purity SiO_2 target was used on both sources.

PECVD reactor was used with RF power at 2KW and $SiH_4/Ar/O_2$ gases at 350C.

All etch rate tests were performed on 4” Si substrates and all electrical tests were performed on SAW type of devices on 4” lithium-tantalite substrate or BAW type devices on Si substrate.

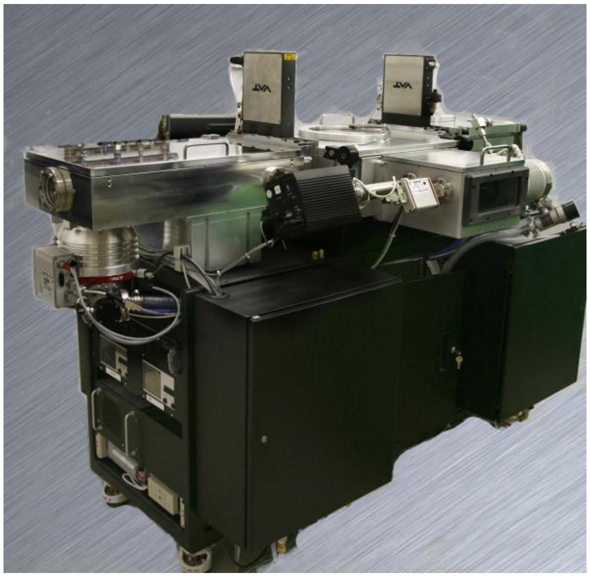

Figure 1. AMSystems cluster tool

III. TRIMMING FBAR AND SAW DEVICES

Thickness variation of SiO_2 is a large source of a frequency variation for both FBAR and SAW devices. Trimming process is used to control thickness variation of SiO_2 over a wafer and from wafer-to-wafer. Fig. 2 shows typical improvement in thickness uniformity accomplished by a two-step trimming process.

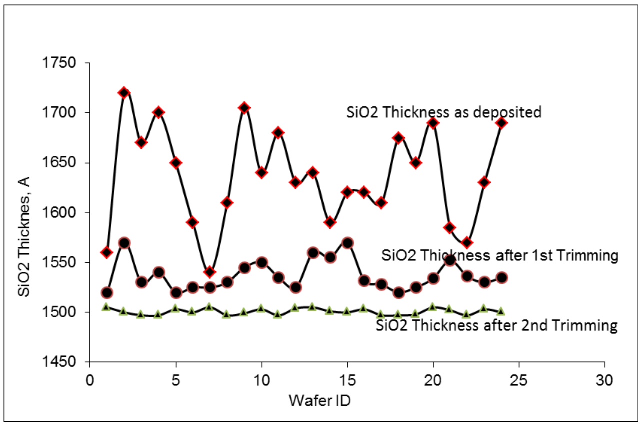

Figure 2. Wafer-to-wafer thickness repeatability for two step trimming process

If trimming rate is well known for the given film, uniformity and target thickness can be controlled very precisely.

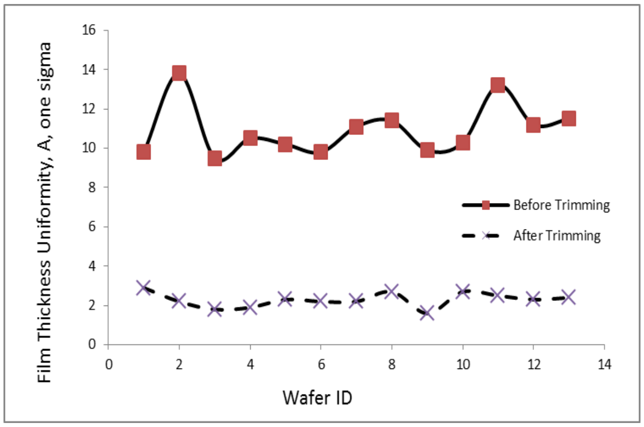

Figure 3. SiO2 Thickness uniformity after trimming process

Fig. 3 shows dramatic improvement of SiO_2 film uniformity across a wafer after trimming process. Good uniformity allows to reduce and even to eliminate noise signal during experiments.

We have found that trimming rate of SiO_2 reflects film properties and can vary depending on the time the wafer is exposed in atmosphere after the deposition and before it is trimmed. Fig. 4 shows variation in the trimming Etch rates depending on the method of deposition and time period between deposition and trimming processes.

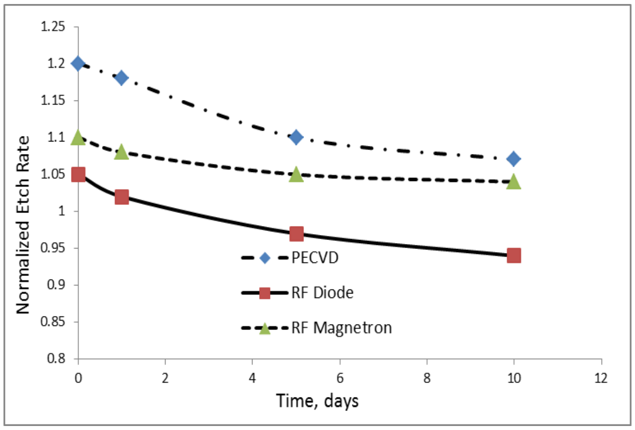

Figure 4. Trimming rates as a function of deposition conditions and time of atmosphere exposure

It can be seen that SiO_2 sputtered film is somewhat less sensitive to the exposure to the ambient moisture, but all films have somewhat variable etch rates if exposed to the ambient for a long time.

At the same time, dramatic variation of the magnetic field during magnetron sputtering of SiO_2, has little effect on the etch rate and the etch rate stability over lengthy exposure to the ambient moisture, see fig. 5.

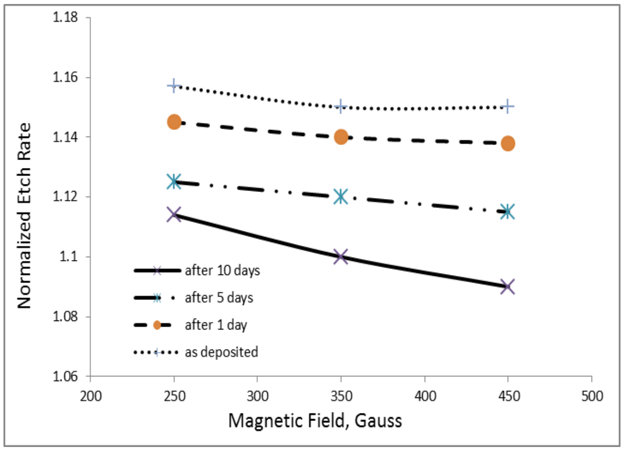

Figure 5. Etch rates as a function of magnetic field during magnetron sputtering of SiO2 and ambient exposure time

The most consistent trimming rate is obtained by trimming wafers in-situ right after the deposition without vacuum break. In this case, trimming etch rate is extremely stable from wafer-to-wafer and within wafer.

We also observed changes in frequency of SAW devices during long exposure to the ambient humidity. It is more evident after trimming process reduces variation across a wafer. Fig. 6 shows relative frequency and frequency variation across a wafer after SiO_2 deposition, after trimming process and after 15 and 30 days exposure to atmosphere with elevated humidity.

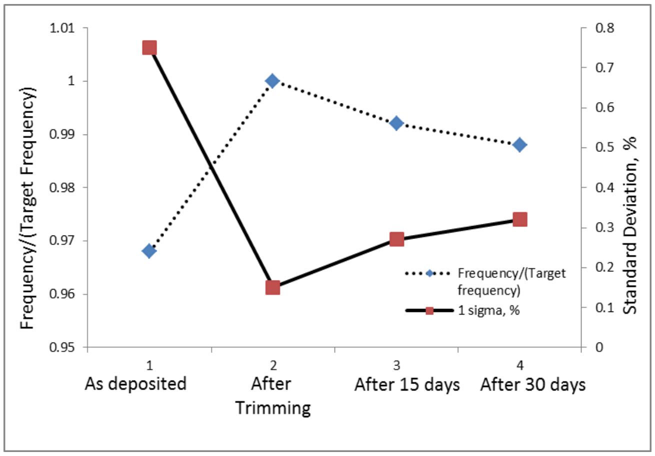

Figure 6. Average Frequency and Cross wafer Frequency variation as a function of time exposure to atmosphere

IV. METHODS FOR IMPROVING TEMPCO CONTROL

There is a large variation in contribution of SiO_2 to TempCo due to the method of deposition and the consequent treatment. Fig. 7 and 8 show the impact of the deposition method and the use of the capping layer on TempCo and its variation across a wafer.

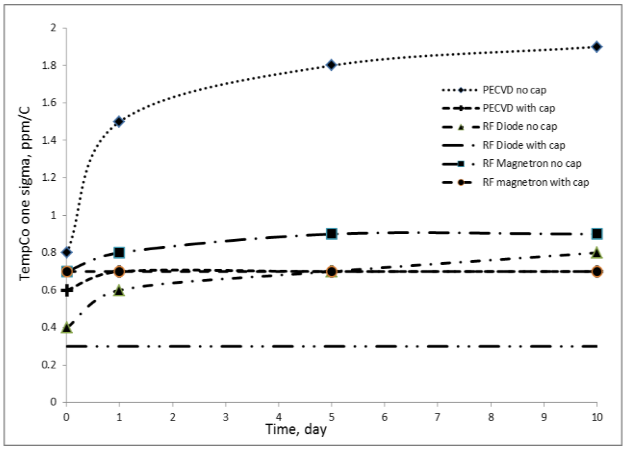

Figure 7. Cross wafer TempCo variation as a function of deposition method and capping process

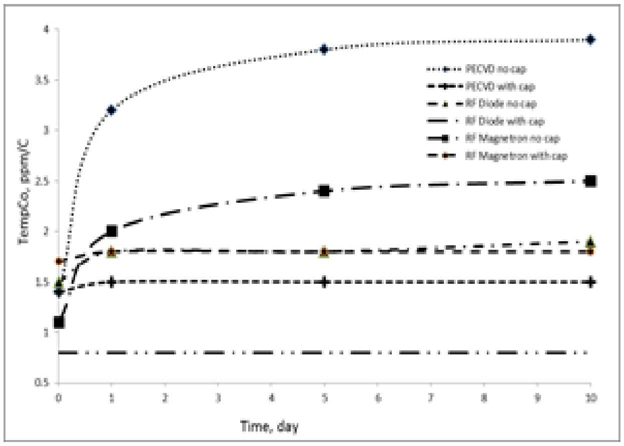

Figure 8. TempCo variation for different SiO2 preparation

There is an additional option to stabilize properties of SiO2 films. We found that annealing wafers in a steam environment at ambient (atmospheric) pressure for about thirty minutes and then baking them for about 1 hour at 250C stabilizes etch rate in the trimming module.

Treated wafers have also shown almost no change in either frequency or etch rate in trimming after a month. Fig. 9 shows the impact of exposure to high humidity at the elevated temperature and the following bake out on the TempCo of SiO_2

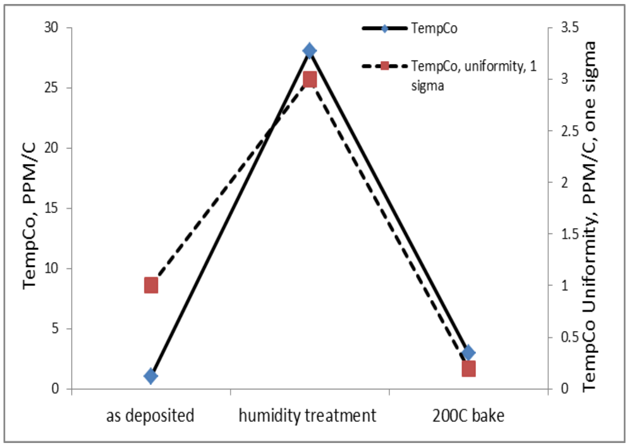

Figure 9. Average TempCo and TempCo uniformity across a wafer as a function of humidity and baking treatments after the deposition

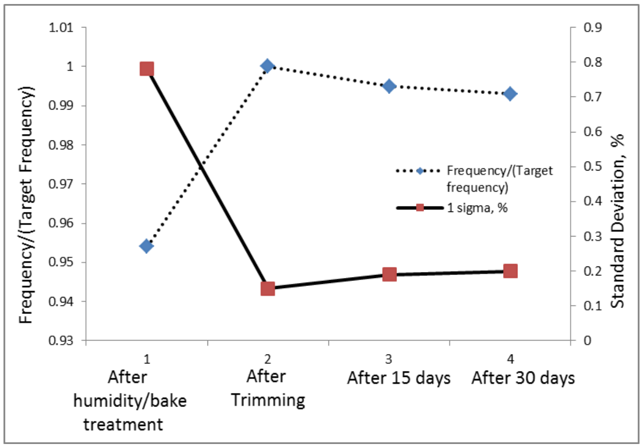

Figure 10. Frequency and frequency variation across a wafer after humidity/bake treatment over a time period

It is likely that at low temperatures, that is required for SAW processing, SiO_2 has a lot of strained Si-O bonds. These bonds are likely to interact with moisture and may form silanols (Si-OH bonds). The newly formed bonds tend to be somewhat unstable leading to variation in all parameters, such as TempCo, frequency and trimming etch rate. Forcing these bonds to react with the excess of moisture at elevated temperature will cause the maximum reaction as well as moisture absorption. The following anneal at 250C drives off the unstable or un-reacted moisture or hydrogen leaving a stable matrix of Si-O bonds. Resulting material stays stable for long periods of time and provides stable trimming rates and uniform and repeatable TemCo, as well as frequency and frequency uniformity. Fig. 10 shows frequency and frequency variation across a wafer after humidity/bake treatment over time.

V. SUMMARY

When using SiO_2 for temperature compensation, the most favorable approach is to deposit a capping layer, such as thin AlN film, to prevent interactions of Si-O bonds in the film with the ambient moisture. If such process is not practical, then using steam treatment at elevated temperature followed by a bake can stabilize strained Si-O bonds and make them less sensitive to being exposed to the ambient moisture.

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