Development of an I-Line Negative Resist Process for High Resolution Liftoff Applications

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ABSTRACT

Surface Acoustic Wave (SAW) devices require the formation of dense line and space structures referred to as inter-digital transducers (IDTs). Precise dimension control of these features is essential to the performance of the device.
Design requirements for SAW applications are becoming more aggressive such that standard process capability is restrictive. Therefore, a new process development effort was initiated to enable a simple, yet lower cost process, which can precisely and repeatedly define the IDT structures with critical dimensions anywhere from 1um to as low as 300nm. Such a process capability is beneficial not only in SAW manufacturing, but could easily be used in other wafer fabrication environments.
This paper discusses the process development effort to establish a fine line liftoff process using a negative tone resist for a SAW filter application. Discussion is focused on the process optimization sequence required to enable a robust process which can define features as small as 300nm using existing 365nm stepper technology.

Keywords: High Resolution, Liftoff, Process Development, Process Capability

INTRODUCTION

Liftoff is known as an additive process; which in many applications is a more attractive solution than to etch away the excess material. In the manufacture of SAW devices there are a variety of metal stacks which the designer may use at a variety of thicknesses. Today however, the device performance and power handling requirements are becoming increasingly challenging, particularly for handset applications. As a result the current process capability is becoming restrictive; this is the motivation for the development of a high resolution liftoff technology.

There are several liftoff resist options, bi layer resist processes for example. A material such as PMGI is coated followed by a photosensitive material. The PMGI is readily soluble in aqueous TMAH developer. The resulting undercut of the photosensitive material creates the liftoff pro file. Negative tone chemically amplified photo resist would be another.

For this investigation a PMGI process was compared to a chemically amplified negative tone resist.
The bi-layer approach did not show sufficient margin or repeatability below 500nm for the given application. Resist footing was observed or resist structures were toppled over.
Evaluation of the negative tone material showed a significantly improved stability and reproducible performance. The process also demonstrated the ability to resolve patterns as small as 250nm with the additional benefit of a more streamlined process. The negative tone resist processing will utilize existing chemistries such as developer and ERB which are currently used in the lithography area. The process itself lends to an expected 8% reduction in wafer processing cost when compared to the existing approach to IDT fabrication. This is primarily due to the simplified process sequence with a reduced number of processing steps.
Subsequent discussion of this paper will focus on the negative tone resist process.

LITHOGRAPHY PROCESS DEVELOPMENT

The resist under development is AZ5510 from AZ microelectroic materials. This resist chemistry is a negative tone resist formulation which is based on acid catalyzed thermal cross linking of the resist polymer upon exposure to i-line radiation and the subsequent post exposure bake.

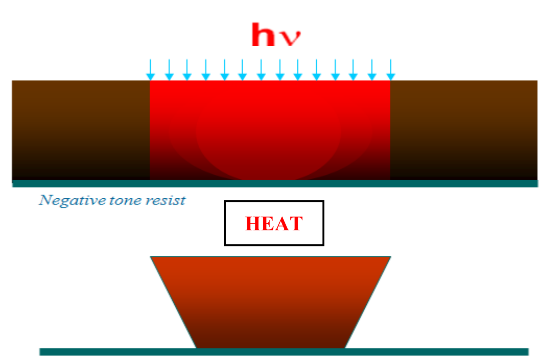


Figure 1. Negative tone resist

In general negative tone resists are a good choice for liftoff applications. These resists are designed to attain a reproducible undercut which makes the subsequent liftoff easier. The cross linking of the resin also ensures the profile can be maintained at higher temperatures commonly experienced in the lithography process.

The desired resist thickness for the application was selected based on the modeled swing curve while considering the range of metal thickness that would be utilized. Optimizing the exposure and post exposure bake processes proved to be a delicate balance. For such acid catalyzed resist chemistries the post exposure bake used to accomplish the critical chemical stage must be considered as critical as the exposure in terms of process control. [2]

A matrix of bake conditions varying both temperature and time was required for each substrate type utilizing this process. The primary substrates used for SAW fabrication are Lithium Tantalate and Lithium Niobate, both of which have very different thermal conduction properties. Once this process is tuned the properties of AZ5510 have been proven to be less sensitive to small temperature fluctuations that some other similar materials. [1]

Bottom Anti Reflective Coating

Transmittance of the various substrates utilized in SAW manufacturing is varied, and was found to influence the resolution capability below 500nm. For example, lithium tantalate wafers have the higher transmittance and standing waves were shown to be more pronounced than for the highly doped black lithium tantalate. Standing waves are an exposure variation within the resist layer which results from the coherent interference between the incident and reflected radiation. [2] These undesirable effects can negatively impact control of critical dimensions.

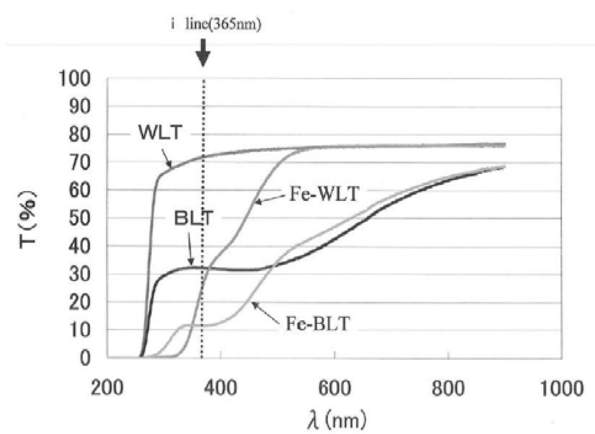


Figure 2: Transmittance varies significantly at 365nm for differing substrates used in the manufacture of SAW filters

A bottom anti reflective coating (BARC) can be applied between the resist and the substrate to suppress these reflections. As this additional layer increases the overall processing cost, and also because larger geometries did not show to be as sensitive, the BARC is only applied for devices where line size is below 700nm.

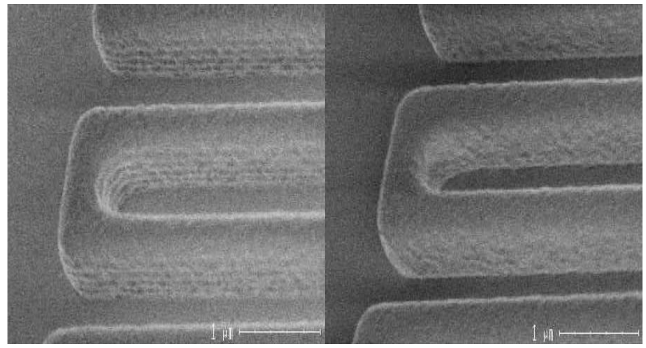


Figure 3: Standing waves which can be suppressed with a bottom anti reflective coating

Another significant influence into the repeatability and uniformity of the line size control was found to be wafer flatness. The flatness of a wafer was mapped using lithography equipment and was found to have several um of non flatness as shown in figure 4. This clearly has an impact on the ability to resolve smaller features.

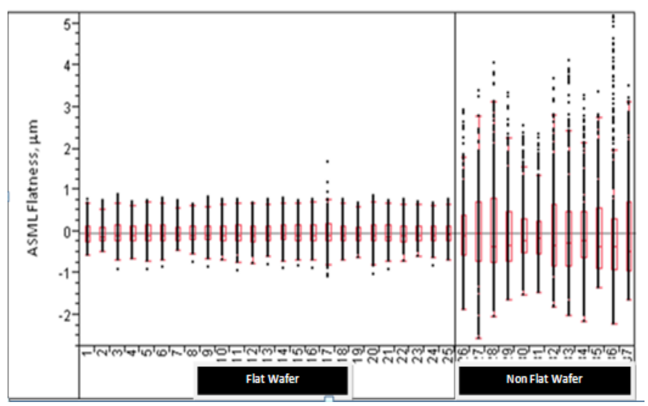


Figure 4: Mapping of wafer flatness for the incoming wafer

Wafers with a tighter flatness specification were procured and evaluated in comparison. As expected, flat wafers showed improved resolution capability and tighter line size control within a wafer, figure 5.

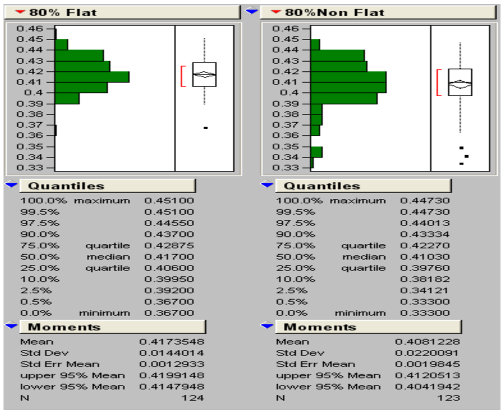


Figure 5: Comparison of line size across wafer for a flat and non flat wafer

METAL DEPOSITON AND LIFTOFF

The resist image forms a negative of the required metal pattern which will be formed on the final device. Once patterned with liftoff resist, the wafers are deposited with the required metal stack. Depending on the specific performance requirement for a particular device, the metal stack and target thickness may vary.

The resulting IDT shape is essential to the device performance for a SAW filter. If the re-entrant profile is not sufficient, or if the metal stack is too thick, it becomes more difficult for the solvent to penetrate and for liftoff to occur. In this case it was found that an aspect ratio of 3:1 for resist thickness to the required metal thickness must be maintained to ensure a clean liftoff profile

If the resist thickness is too low, metal tearing, or 'wings', were observed as illustrated in figure 6. This was found to have a detrimental effect of the quality factor of the filter.

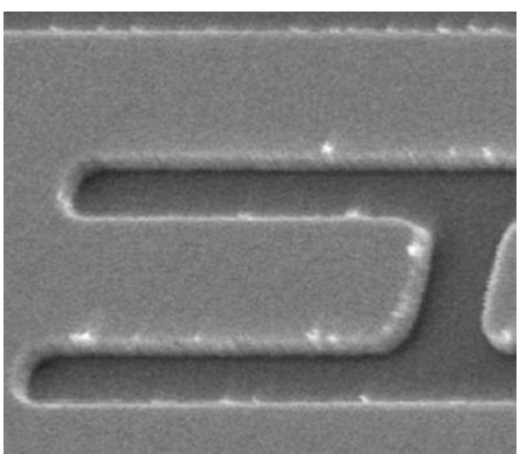
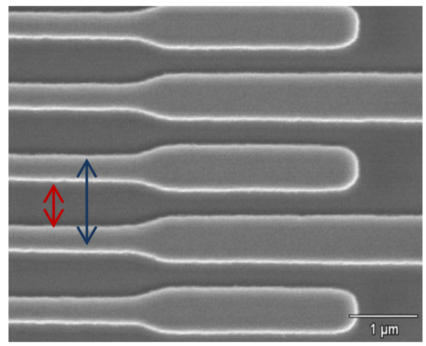


Figure 6: Metal 'wings' which are detrimental to device performance

Maintaining a robust lithography process with sufficient resist thickness ensures that a simple 30 minute liftoff process in NMP solvent will remove the resist pattern along with the unwanted metal. The liftoff quality is consistent which is reflected in the electrical performance of the filter itself.

PROCESS CAPABILITY

Volume manufacturing for SAW devices requires a tight tolerance on the critical dimension of the IDT features. When developing the process, attention to the within field and across wafer variation was monitored. Critical features would be expressed in terms of duty factor as illustrated in figure 7.



DF = (Line/Period)*100

Figure 7: IDT structure with 350nm critical dimension

To meet the performance specifications, a typical SAW filter requires that duty factor be controlled within 2-3% of target. The negative tone liftoff process once optimized demonstrated an excellent process capability across a range of line sizes, figure 8.

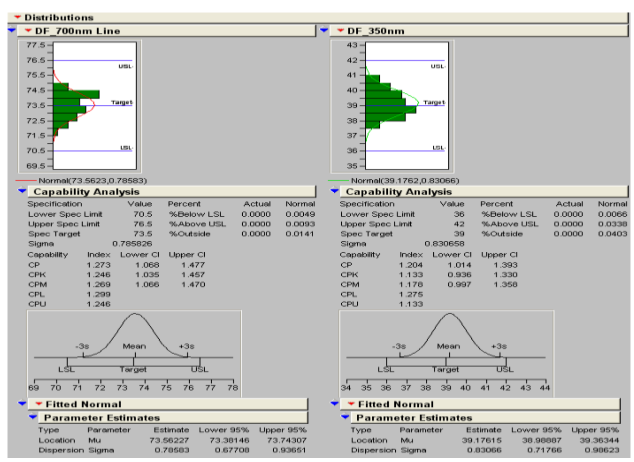


Figure8: Process capability of AZ5510 printing features of 700nm and 350nm

The liftoff process developed using AZ5510 shows sufficient process capability for line size control. As shown in figure 7 the duty factor tolerance can be accommodated even down to 350nm.

CONCLUSION

The objective of the process development was to enable a high resolution liftoff process which could reduce overall process cost while accommodating the more challenging line size and metal deposition requirements required during the fabrication of surface acoustic wave devices.

During the development phase some unique challenges were encountered, mainly due to the nature of the substrates and subsequent processing requirements. The liftoff process was developed utilizing standard equipment and chemicals available for 356nm stepper technology. The resulting process demonstrates a capability more than adequate to accommodate the aggressive requirements for line size control. In addition to which the simplified process flow offers the potential cost saving up to 8% over the existing fabrication approach.

ACKNOWLEDGEMENTS

The authors would like to thank AZ Microelectronic for their support in developing the photolithography process. Thanks also to the staff at TriQuint Florida for their continued support.

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