# Extending MTBC to High Productive Performance Levels in ICP SiN Etching for Advanced RF Applications

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## Abstract

**Frontside fabrication for advanced Radio Frequency (RF) applications involves the Inductively Coupled Plasma (ICP) etching of thin layers of Silicon Nitride (SiN) to define critical features. The ability to attain high Mean Time Between Cleans (MTBC) figures in a production environment doing this etching is key for low Cost of Ownership (CoO) and critical wafer throughput metrics within the fab. Applying advanced Optical Endpoint Spectroscopy (OES) endpoint setup and control for SiN etching, along with wafer handling and maintenance protocol changes, were key elements in doubling initial tool MTBC figures and more than tripling historical company benchmarks on this application.**

## INTRODUCTION

High performance RF applications are key enablers for critical military, commercial and scientific devices [1]. Many RF devices such as these rely on precise and repeatable processing of GaAs substrates containing various films. These films with small Critical Dimension (CD) features are normally processed using dry etching techniques in order to deliver the quality and design functionality required. One such film is the patterning of thin (<2μm) SiN using a photoresist mask. The $CF_4$-based chemistry employed in this type of SiN etch process generates byproducts that accumulate within the ICP chamber in several locations, leading to reduced MTBC (caused by low etch rates, high particle counts, missed endpoints and loss in productivity). The aim of this project was to triple the initial MTBC by proactively tackling each potential root cause of poor performance.

## BACKGROUND

The processing of GaAs wafers with a variety of films, features and steps is required to create many RF devices today. In order to deliver required features, quality and performance on these type of devices the use of dry etching techniques, specifically ICP based dry etching with plasma reactors is required. SPTS provides and serves these type of semiconductor markets as an equipment supplier with many plasma based etching and deposition systems. CF4 is one of the main etch gases for SiN etching and etch rates >200nm/min with the ability for OES endpoint control on stopping layers, such as GaAs, are routine applications. In the case of Skyworks' growing production demands, a new ICP platform was required. In mid-2016 SPTS was selected as this equipment supplier and for this application.

## EXPERIMENT

An initial MTBC figure of merit for the newly installed SPTS ICP etching system was >40% higher in RF hours than the previous Process of Record (PoR) performance on same application. The SPTS chamber's process performance for SiN etching was able to meet initial targets, although early monitoring of key metrics highlighted potential improvement areas that could extend this target even further.

First, as SiN etching takes place on the ICP module there is a normal accumulation of etch byproducts within the chamber from processing the supplied wafer. This by-product collects on all plasma wetted surfaces but to differing degrees and amounts within the chamber. The main areas for collection would be the chamber lid, ceramic vessel and areas near the wafer, such as the Electro Static Chuck (ESC) area. In order to minimize this buildup and reset the chamber for the next wafer run, a short $O_2$ waferless clean is used. During this interwafer clean, the chamber is cleaned specifically on areas on the ESC and supporting items. This is an effective clean as OES endpoint is used to control the process time, however, there is a slow buildup near the ESC area which can impact ESC to wafer clamping. This degradation in clamping performance can limit the maximum wafer usage per chamber usage cycle (i.e. Preventative Maintenance (PM) kit life) and hence limit MTBC. When a PM is performed on the chamber the chamber is vented and items cleaned to reset their usage state. In many instances, the quality of the PM done affects the ability of that module to reach its maximum MTBC figure. As there was variability in this PM quality, a complete review was completed by Skyworks engineers of the maintenance procedures, staff experience and PM practices of the actual ICP PM steps. In this review, several improvement areas were identified to be key elements to extending normal MTBC levels: completeness of the cleaned parts, inspection of the ESC clamping area post cleaning and OES endpoint window clouding. It was found to be critical to fully reset the ESC clamping area (fully cleaned), hot swap the chamber lid and all chamber consumables with a fully cleaned/ready part and adding an OES booster part to the OES window. By implementing these three key items a 65% improvement in MTBC was seen. An image of the OES booster, that reduces OES window clouding and extends the OES signal levels with RF usage, is shown in Figure 1. The normal accumulation of etch byproducts in this process degrades the optical signal of employed OES endpoint techniques. A key hardware change to the OES attachment method on the chamber enabled less byproduct to accumulate on the OES window, ensuring that the cleanliness of the optical window is maintained and thus ensuring an optimal endpoint signal is maintained. This OES “booster,” shown in Fig. 1, was specifically developed by Skyworks to aid in 1) minimizing OES signal loss 2) maintaining operational placement of the optical fiber detection path and 3) enabling quick and efficient preventative maintenance of the module.

Figure 1. Endpoint booster [2] for enhancement of the standard OES attachment on the ICP chamber.

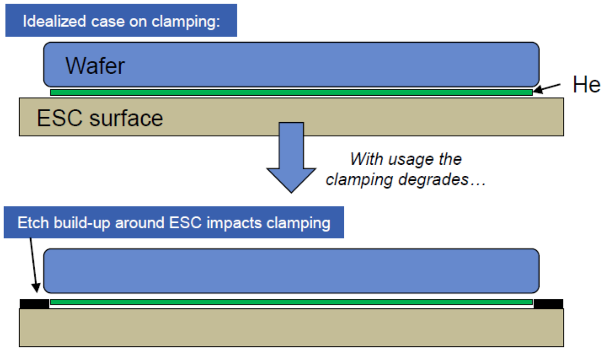

Figure 2. Wafer to ESC clamping and impact of SiN etch byproduct on clamping performance inside the ICP chamber.

Second, processed wafers require the application of backside Helium (He) gas between the wafer and ESC to ensure adequate heat transfer. Figure 2 outlines the state of ideal ESC to wafer clamping. In the ICP module, the ESC chuck applies a clamping force (by the application of a +/- 5kV clamping voltage within the ESC) to a placed wafer. Once properly clamped, a backside He pressure (ranging from 6T to 15T) is applied in order to improve the heat transfer between a wafer being processed and the thermally controlled ESC. This He “pillow” enables a much improved heat transfer in this application and aids in maintaining acceptable wafer processing temperatures. The resultant He flow (an output between how well the wafer is clamped and the state of the ESC-to-wafer surfaces) is monitored to ensure adequate clamping and wafer temperature control. An increase in overall He flow on known good and clean backside production wafers indicates poorer cooling conditions. Poor clamping (i.e. high He backside gas flows) can result from particles on the ESC, particles on the wafer, a degradation in ESC chuck lifetime or materials on wafer backsides to name a few. It was noted that post-PM kit changes showed variability in starting He flows leading to premature fault conditions and subsequently lower MTBC figures. Advanced cleaning and maintenance improvement projects developed specifically for this module were mentioned earlier and improved the ESC state. In order to further improve overall module utilization and increase MTBC levels, a detailed Design of Experiments (DOE) study was performed investigating the necessary backside He flow and He pressure settings on ICP SiN etch quality. It was found that a reduction in initial install He pressure for production recipes did not result in worsened etch performance but enabled a much more extensive usable RF time window. With DOE results and etch process results outlining the acceptable He pressure settings and further increase of 35% in MTBC was realized.

Last, in production environments with this type of application the use of endpoint techniques is a key element to providing consistent, repeatable and high yielding etch steps. Endpointing allows for the correct determination of etch time for a particular etch and reduces the variability found in thin layer etching if thickness vary slightly or etch rates change as the module is used. There are many endpoint techniques available on SPTS ICP chambers, however, the most common approach for this SiN application is OES. OES consists of using a spectragraph that is collecting spectral intensities of the plasma as a process is performed. This spectragraph has its light signal provided by an optical fiber routed between the spectragraph detector and an optical window on the ICP chamber. Usually, the optical window is observing the plasma directly above the wafer being processed. The SPTS ICP module also integrates software processing of this OES signal where specific wavelengths (between 200-800nm) are utilized. As an etch process is performed, the spectral intensities of certain wavelengths change, it is this change in spectral intensity that used to determine current processing states. In the case of SiN etching, we monitor spectral lines specific to this process (typically between 350-500nm) and watch the decay in those signals, and at endpoint (i.e. at the point where the exposed SiN layer is completely etched away at the stop layer) these signals decay in intensity. On-board module software allows for the setting of specific signal triggering features and once collected the signal triggering levels can be specified within the recipe. With correct signal triggering in place, consistent and repeatable triggering of the process time can follow on each wafer of this same type and recipe. Without OES control, the use of fixed time recipes would be required but those would lack the feedback control required in a production environment. An additional challenge to ICP etching where OES endpoint is used is that the normal accumulation of etch byproducts in this process degrades the optical signals due to coating optical elements with deposited films. This deposition, if thick enough, can reduce the OES signals to the point that OES does not work. Figure 3 outlines the direct OES signal intensity changes as a function of RF hours on the ICP chamber in this specific SiN etch application. A detailed inspection of collected OES endpoint data off entire production usage logs noted intermittent and degraded OES signals to the point of missed endpoint triggering. Comparing the OES data at key points in the PM kit life of production etches, as shown in Fig. 3, enabled a detailed update to the endpoint triggering levels in the endpoint recipe steps. These changes to the endpoint recipe provided a final 30% improvement in the MTBC with no failures to endpoint on production wafers. Currently, the MTBC figures are routinely three times the initial RF hours and across multiple ICP chambers employing this overall MTBC improvement program.

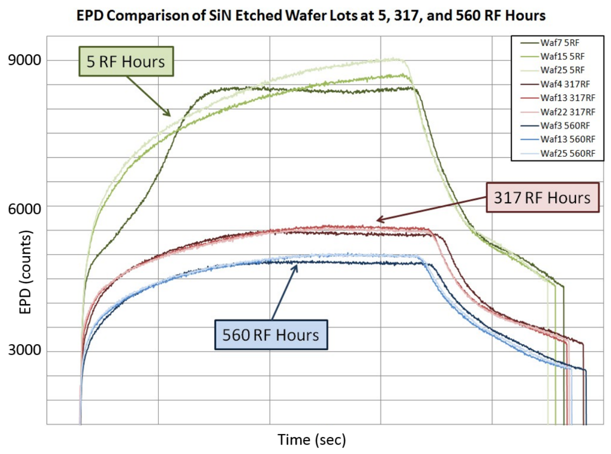

Figure 3. OES signal degradation during PM kit usage.

In summary, a detailed collaboration with SPTS and Skyworks identified several improvement areas of initial ICP chamber operations. Reviewing the key aspects of the SiN etch application and determining the limiting factors in attaining higher MTBC values was critical to implementing improvements on this project. Figure 4 outlines the three key task areas and their corresponding impact on MTBC. From this chart it is clear that the PM procedures and cleaning of the module has the largest percentage impact on MTBC levels.

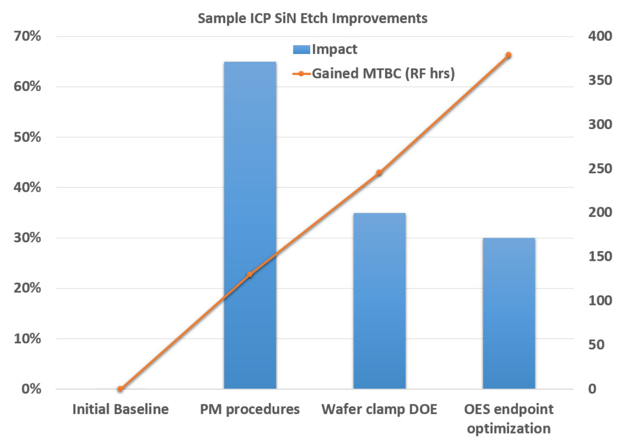

Figure 4. MTBC improvement tasks and impacts.

## CONCLUSION

Several key elements to extending the MTBC were identified in this particular SiN etch application. Identifying backside He maintenance and PM operational key points, developing a more complete understanding of backside He conditions for production performance, an endpoint booster and overall endpoint recipe triggering optimization enabled a 3x improvement in initial install MTBC values (gaining more than 350 RF hours in production quality usage on the module). Further implementation and approach changes on other applications will utilize this tiered problem solving approach.

## ACKNOWLEDGEMENTS

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## REFERENCES

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## ACRONYMS

CD: Critical Dimension
CoO: Cost of Ownership
ESC: Electrostatic Clamp
ICP: Inductively Coupled Plasma
MTBC: Mean Time Between Cleans
OES: Optical Endpoint Spectroscopy
PM: Preventive Maintenance
PoR: Process of Record
RF: Radio Frequency