Improvement of Base Ideality through Improved Surface Cleans

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Abstract

For both commercial and industrial applications, HBT intrinsic reliability requires that performance does not degrade with time. Long-term reliability has been associated with low-voltage base current [1, 2], of which one source is base ideality. This paper explores factors affecting surface cleanliness and their influence on base ideality, including base metal evaporation and post-metal liftoff cleans.

INTRODUCTION

Base ideality is routinely monitored in the process of manufacturing of HBTs. Statistical device trends are used to identify out-of-control situations that require engineering response. Such an indication occurred with base ideality (Nb) standard deviation for one of our HBTs. A team was formed to investigate 1) the cause of increased Nb variation and 2) how the variation could be returned to historical values. Base current is extremely sensitive to cleanliness of the GaAs surface between the base contact and ledge epi layer (Fig. 1). Using our lot tracking system, an overlay of good and affected (increased Nb standard deviation) lots was plotted by time and process stage. This analysis technique identified the problem stage. Subsequent lot splits between processing tools through the base metal deposition stage revealed variation between evaporators combined with post-liftoff cleans. It was also learned that the statistical variation increase manifested during periods of high-volume processing. Since attempting equipment modifications to evaporator systems can be difficult and costly, we decided to focus our efforts on improvement of our post-liftoff cleans.

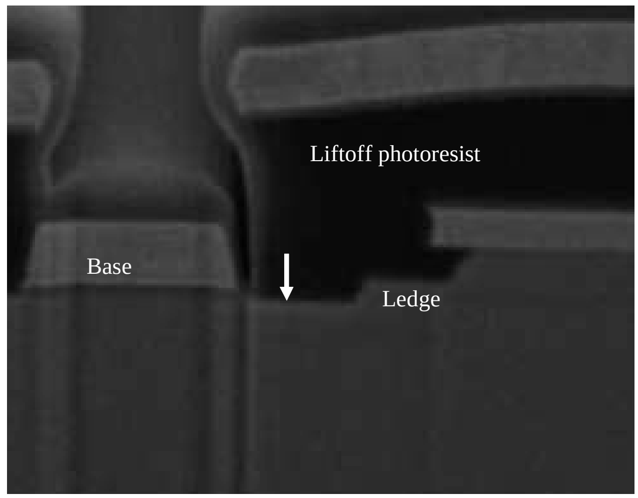

Figure 1 SEM view of HBT after base metal deposition, prior to metal liftoff. Arrow indicates GaAs surface of interest, the region between base contact and ledge epi.

EXPERIMENTAL

Prior to running wafer-processing experiments, samples from sites already tested with higher Nb (causing overall increase in wafer standard deviation) vs. a historical value were analyzed by PEELS. Results revealed detectable carbon and oxygen at the surface passivation-GaAs surface interface on samples with higher Nb, where neither element was detected on samples with historical Nb (Fig. 2). Interpreting the carbon and oxygen in the PEELS spectra as originating from residual photoresist, we were directed toward a more aggressive post-liftoff photoresist clean.

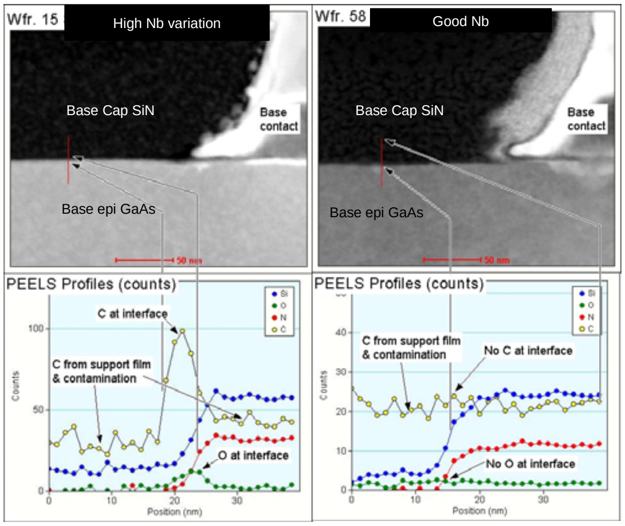

Figure 2 PEELS line scans across surface passivation-GaAs interface for a site with higher Nb (left) and a sample with historical Nb. Note carbon and oxygen are detected at the interface of the sample with higher Nb.

To evaluate our surface cleanliness theory, lot splits were performed between 1) process tools; 2) a more aggressive, NMP-based photoresist strip chemistry; and 3) oxygen plasma exposure. Also, during the course of this work, we experienced three wafers from a lot having difficulties at base metal liftoff. The caused of the problem was due to excessive heating of photoresist during base metal deposition, so we decided to test our new cleans on this severe case. The wafers had high levels of residual photoresist, visible by optical microscopy. One of the wafers was exposed to our more aggressive photoresist strip chemistry and another to the same plus oxygen plasma. We decided to first make the change to the more aggressive photoresist stripper and add the oxygen plasma later, if necessary.

RESULTS

Test results from the three wafers with extreme photoresist residue supported suppositions that our post-liftoff clean was marginal and that a more aggressive form of photoresist removal could recover wafers with even extremely high Nb values (Fig. 3).

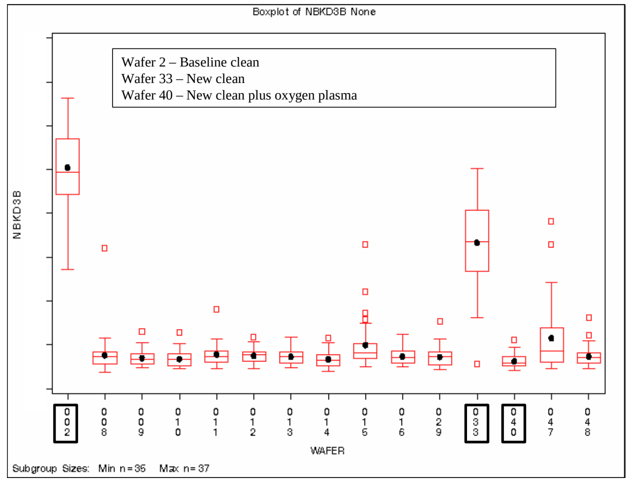

Figure 3 Nb plots of wafers with known residual photoresist from baseline cleans (wafer 2), NMP-based photoresist clean (wafer 33), and NMP-based photoresist clean plus an oxygen plasma exposure (wafer 40). Note Nb improvements with NMP-based photoresist clean and return to baseline values with the addition of oxygen plasma.

Results from lot splits clearly demonstrated that implementation of the improved photoresist stripper reduced Nb variation and that a modification to the deposition tool would not be required (Fig. 4).

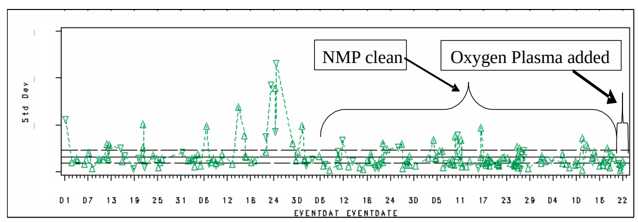

Figure 4 Device trend chart for Nb standard deviation. Note that standard deviation was improved with the NMP-based photoresist stripper and further improvement was obtained with the addition of oxygen plasma.

Additionally, the combination of a more aggressive photoresist stripper and oxygen plasma exposure has so dramatically improved Nb standard deviation (versus historical) that we can now distinguish between epi vendors and individual epi runs (Fig. 5).

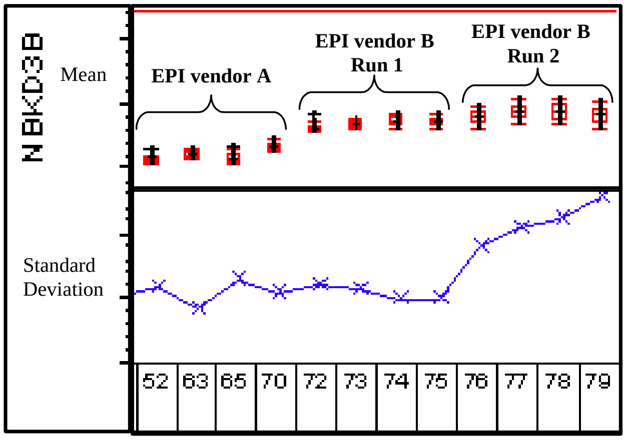

Figure 5 Plot of Nb mean and standard deviation for a group of wafers with combined NMP-based photoresist stripper and oxygen plasma. Note epi vendors can be resolved by Nb means and that individual runs between the same epi vendor are distinguishable by standard deviation.

CONCLUSIONS

This work has demonstrated use of a cross-functional team to identify the source of our increase in Nb variation using our lot tracking system. The lot tracking system identified specific process tools and factory run-rates as the source of variation. PEELS analytical method was also used to identify photoresist residue at the surface passivation-GaAs interface that helped identify the fundamental problem, thus focusing efforts on improved cleans. Results from this work have allowed us to implement process changes without having to make challenging and costly modifications to our metal deposition equipment. Finally, we have improved Nb variation, vs. historical trends, allowing the ability to resolve differences between epi vendors and individual epi runs.

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REFERENCES

[1] Long-Term Base Current Instability: A Major Concern for AlGaAs/GaAs HBT Reliability, Liou, J.J., 1998 Proceedings of the Semiconductor Conference (CAS '98), Volume 1, 6-10 Oct. 1998 Page(s):23 – 32

[2] Production InGaP HBT reliability, Cheskis, D, et al., GaAs Reliability Workshop Proceedings, 5 Nov. 2000 Page(s):167 - 179

ACRONYMS AND ABBREVIATIONS

HBT: Hetero-junction bipolar transistor

PEELS: parallel electron energy-loss spectroscopy