Improved Plasma Etch Process Control of TiWN Gate Length

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Abstract

In this fab, a plasma etch process is used to define the TiWN gate length. An isotropic etch process is used to undercut the photoresist mask to etch the TiWN metal. To improve the control of the TiWN gate etch process, a system was developed to change the etch time based on the photoresist critical dimension. By measuring the photo cd, and then feeding that data through an equipment interface to the etch tool, the etch time is adjusted to target a desired final cd. Consequently, the lot-to-lot photo cd variation has a reduced effect on the final cd.

INTRODUCTION

In GaAs devices, the gatelength is one of the most critical parameters affecting the electrical performance. Since it contributes to several electrical parameters, the non-uniformity of the gatelength within wafer, wafer-to-wafer, and lot-to-lot should be minimized. This paper discusses a method for improving the lot-to-lot gatelength uniformity with inline process control.

The TiWN gatemetal is deposited on an electrically sensitive layer. Since this layer cannot be etched or damaged, a low power plasma etch process is used. Consequently, this process etches the metal isotropically, undercutting the photoresist mask to define the final gate length, see Figure 1. In the original process, the photoresist critical dimension (cd) was measured to make sure the pattern was put down correctly and fell within statistically derived limits. If the cd measured within the limits, the lot would be plasma etched to endpoint plus an overetch determined by a set percentage of the time to endpoint. The final etched cd was then measured on the lot to ensure the electrical cd requirements would be met. With this process running in manufacturing, the yield loss was unacceptable for gate length cd's which did not meet the specification.

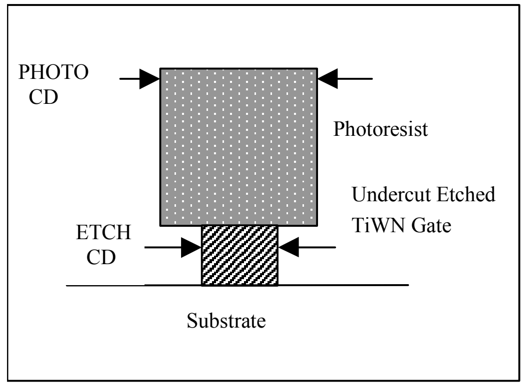


Figure 1: After etch TiWN Gate Process (not to scale)

The primary loss was based on the lot-to-lot variation where entire lots were either in the specification or out of specification limits for the etched cd. This was driven by the photo cd variation. Within a lot, the cd on every wafer was consistent, but lot-to-lot variation was significant. These lot-to-lot differences came from the different photo processing tools used (coaters, steppers, developers) as well as the day-to-day variation within those tools. One possible solution would have been to limit the processing tools to reduce variation, and another would have been to shrink the photo cd window so that lots would be reworked until the cd fell within tighter limits. These were not desirable, long term manufacturing solutions.

PHOTO PROCESS CONTROL FOR CRITICAL DIMENSIONS

Systematic variation in critical dimensions can be seen over long periods of time from lot-to-lot. These variations are induced primarily by the use of different processing tools, along with long-term machine drifts and periodic maintenance. Coaters used for spinning on the resist play a role in the final cd. Process variations include different tool sets, different coater cups and hot plates, resist batches, resist temperature, spin speed and time, baking technique, and baking temperature and time. Resist thickness is controlled daily within a 140 angstrom window using six-sigma capability.

Developers used in removing the exposed resist also play a role in the final cd. Variation is induced from the use of different tool sets and from the use of different hot plates and cool plates within the same tool set. Post exposure bake temperature and time, post bake temp and time, baking technique, and developer time also contribute to variations in the final cd. DUV (deep ultra-violet) resist curing ovens are another source of variation affecting the final cd. Light uniformity, light intensity, temperature control and the use of different tool sets bring about variation. DUV intensity and uniformity are monitored weekly on control charts using six-sigma capability. Accepting the fact that the variation is still expected among these processes, adjustments to the steppers exposure dose are a means for compensating coater, developer and DUV process variations. This is performed by measuring cd's after develop then translating the cd measurements into a recommended exposure dose for each stepper.

I-line optical steppers used in the patterning of the wafers correspondingly play a role in the final cd obtained. One of the primary variables is the difference in numerical aperatures (NA) between unmatched tool sets, which consequently affects the resolution and the depth of focus. This difference in depth of focus between the tool sets subsequently affects the final cd profile, as shown in Figures 2 and 3. Figure 1 a slope of 2.4 degrees on stepper A. Figure 2 shows a slope of 4.5 degrees using stepper B.

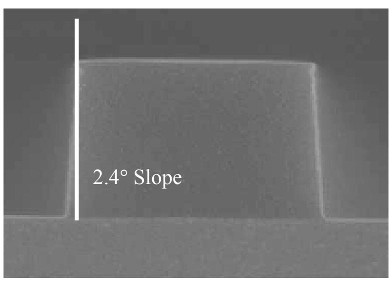


Figure 2: Stepper A

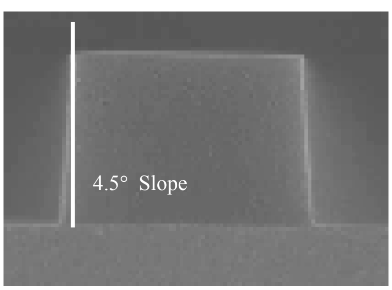


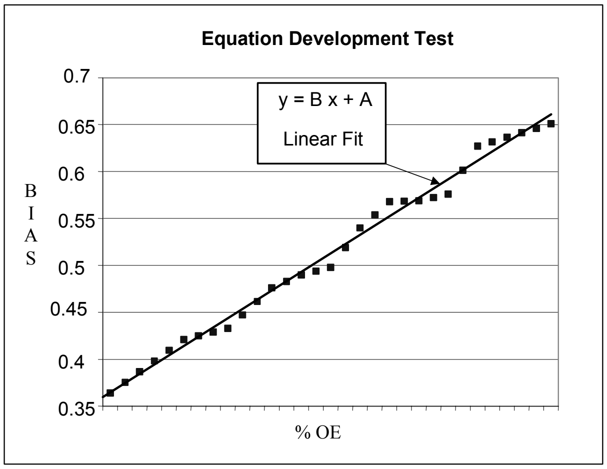
Figure 3: Stepper B

The difference of these slopes can have an overall effect of .08microns in the final cd produced. To minimize the effect of process variation between unmatched steppers, all critical masking layers are restricted to run on single tool sets.

Metrology is another factor that contributes variation to the final cd. Two types of tool sets are used in measuring the cd. One type measures using the technique of Optical scatterometry and the other type measures using Scanning Electron Microscopy (SEM). Optical scatterometry measures approximately the center of the cd by taking the steepest feature and comparing against the lowest feature. Optical scatterometry is not an accurate method for measuring cd's that have variations in the slope such as those shown in Figures 2 and 3. The SEM has been set up to measure the bottom of the CD by averaging the distance between the bottom edges. The difference in these two measuring methods causes a bimodal distribution and affects the overall equation in the feed forward process, therefore, to minimize the affect of process variation between the two measurement systems, all critical masking layers are restricted to run on single tool sets.

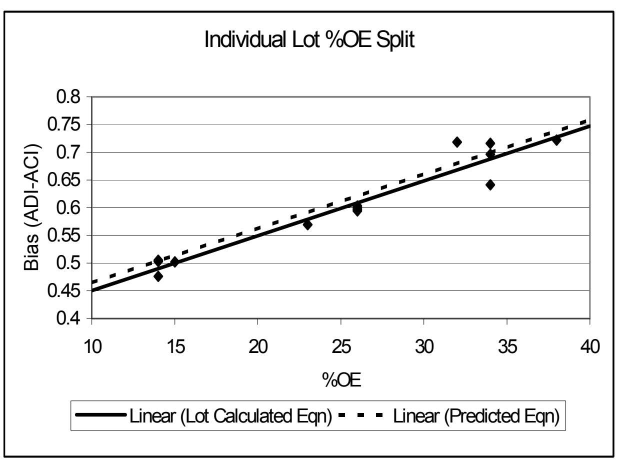
Data Analysis For An Etch Process Solution

The direction that was taken to improve the process was to work on reducing the lot-to-lot photo cd variation, but at the same time, change the plasma etch process time to compensate for the photo cd variation. The first part of the investigation was to determine if the overetch (based on percent of time to endpoint) could be adjusted to control the photo cd to etch cd bias (bias = phote cd - etch cd). Test wafers were processed through the TiWN gate metal deposition and photo patterning process. The photo cd's were measured, and then the overetch was varied from 0% to 30%. A plot of the overetch percentage verses cd bias showed a good linear fit from which an equation was derived using the spreadsheet linear regression. The equation was: OVERETCH% = (Photo CD – Etch CD – A) / B where A and B were constants based on the slope and intercept of the line. When the actual photo cd measurement and desired etch cd measurement are known, a overetch percentage can be calculated. See Graph1.

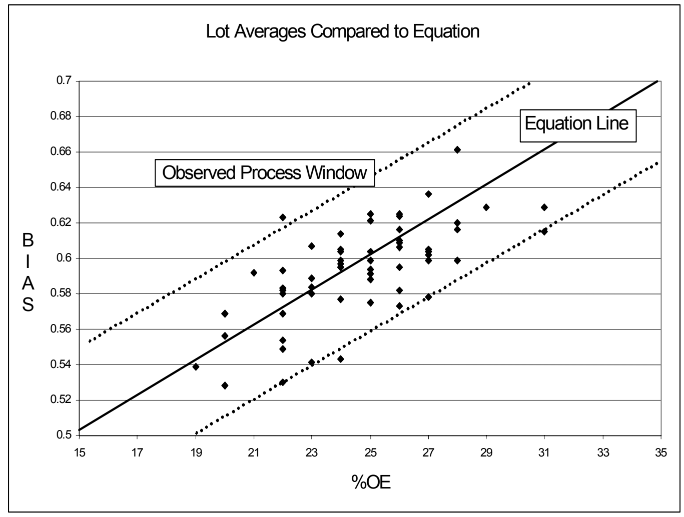


Graph 1: Linear Regression Line Fit for %OE vs. BIAS

Several other tests were run to see how consistent and accurate the equation would be at predicting the overetch to attain the desired final etch cd. Individual lots were run with varying overetch to validate the equation, and all tests gave very similar results for constants A and B. Data was also analyzed using multiple lot averages to see the how the lot-to-lot variation compared to the equation on average. See Graphs 2 and 3.

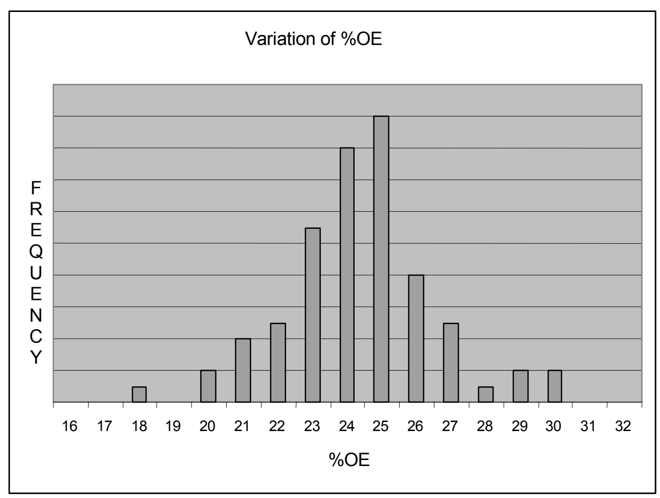


Graph 2: Single lot bias compared to calculated equation



Graph 3: Multiple Lot Averages Plotted with the Prediction Equation

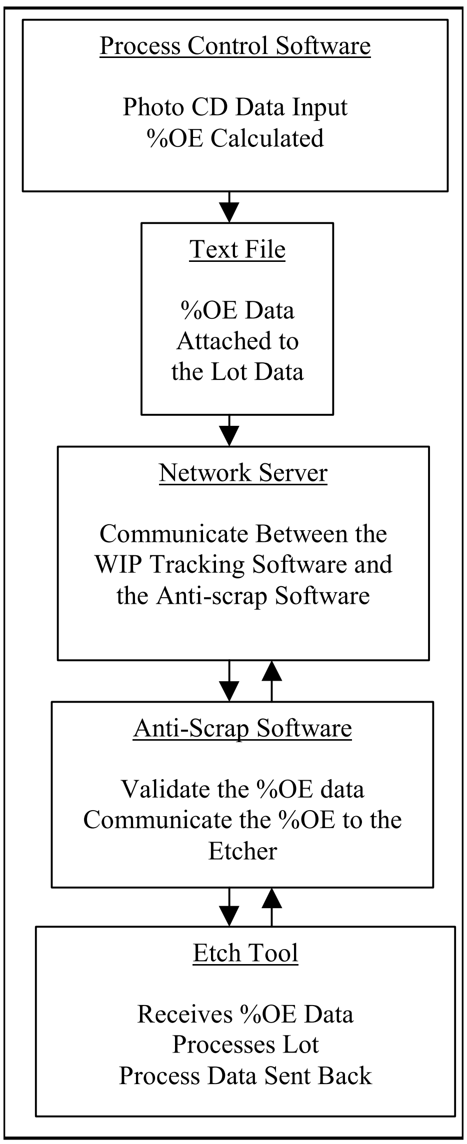
As can be seen from the data, the equation was a reasonable estimate of the correct etch time. There were lot-to-lot differences from the equation, and these differences can be attributed to normal day-to-day process variation within the metal deposition, photo patterning, and etch steps. Even with these differences, the data indicated the feed forward system would be an improvement over the existing, constant overetch process. Graph 4 below shows how much the %OE varied from lot-to-lot.



Graph 4: Histogram of the %OE on Multiple Lots

METHOD TO IMPLEMENT THE PROCESS

The second part to the improvement plan was to find a way to make the system automated so that tool operators were not responsible for changing the overetch leading to possible misprocess. The goal was to feed the OE values forward to the etch tool for each lot. The system was then name "feed forward." After consulting with the company which developed the anti-scrap software running on the etch tool and the internal network experts for our facility, a software solution to attain the desired automation was developed. The photo cd's are measured and the data for a lot is input into the process control database. The database uses the photo cd along with the desired etch cd target and known constants derived from the equation to calculate the overetch for the lot. The overetch value is then added to the lot information in the lot tracking software. When a lot is tracked into the etch tool on the anti-scrap software, the overetch data is pulled from the lot information and sent to the etch tool. The etch tool program is then changed. Each lot can then receive its own custom overetch percentage based on what the photo cd measured. The flowchart below shows the steps involved in "feed forward."



CONCLUSIONS

The feed forward system proved to be a very effective solution in delivering the desired process control while maintaining true manufacturability. This system is currently used in manufacturing, and it has improved the gate length lot to lot range by approximately 10%. This has, in turn, improved the process yield of the devices.

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ACRONYMS

CD: Critical Dimension
DUV: Deep Ultra-violet
NS: Numerical Aperature
OE: Over Etch
SEM: Scanning Electron Microscope
TiWN: Titanium Tungsten Nitride