Challenges of Transferring a TaN Reactive Sputter Deposition Process from a Batch Tool to a Single Wafer Tool during a 4" to 6" Wafer Conversion

Erika Schutte, Heather Knoedler, Ernesto Ambrocio

Skyworks Solutions, Inc. Newbury Park, CA USA Erika.Schutte@skyworksinc.com

Keywords: TaN, reactive sputter deposition, process transfer

ABSTRACT

To increase throughput and enable a wafer size conversion at Skyworks' Newbury Park GaAs fab, it was necessary to develop a TaN process on a sputter tool almost entirely unlike the original process tool. TaN is a reactively sputtered resistive film which is used to make resistors on the same die as power amplifiers. Many challenges arose while trying to match the original process. This paper will discuss the development of a manufacturable TaN process on the new platform, in spite of these challenges.

INTRODUCTION

A cluster tool for sputtering had originally been purchased to create a backup sputter process for another cluster tool. During the installation, it became clear that it would also be needed for the TaN process, since the 6" conversion would dramatically increase run time and reduce throughput on the existing batch TaN toolset. Beyond just learning to run the tool and setting up a relatively straightforward process transfer for the original process, could the cluster tool also be made to run an unrelated, more complicated reactive process?

PROCESS EVOLUTION

When comparing the platforms, many differences were evident, as shown in Table 1:

TABLE I
TOOL FEATURE COMPARISON

	Established Platform	**New Platform**
# Wafers Processed	Batch	Single (Cluster)
Shutter?	Yes	Yes
Target and Wafer Orientation	Vertical	Horizontal
Target Shape	Rectangular	Round
Magnet	Fixed	Rotating
Ar MFC Limit	200 sccm	300sccm
N2 MFC Limit	10 sccm	50 (300) sccm
Chuck Temperature	Room Temp	0-450 C
In House Experts?	Yes	No

With these differences, it was not clear how similar the process recipes or resulting films could be. The key deliverables for the Newbury Park process are sheet resistance (Rs), Rs uniformity, and temperature coefficient of resistance (TCR) at parametric test. The process also had to be compatible with both the photoresist patterning process of record, and the upcoming process used to pattern 6" wafers.

The inputs available to achieve the desired deliverables are:

1) Power
2) Ar flow rate (chamber pressure)
3) N_2 flow rate (Ar/N_2 ratio)
4) Time
5) Chuck temperature
6) Target preconditioning

Creating a sputtering tool recipe to deliver a particular Rs is relatively trivial; setting it to deliver the selected Rs with the correct TCR is challenging. "TaN" is actually a shortcut reference to the many possible Ta_xN_y compounds and phases which make it so useful – the TCR ranges through positive and negative values depending on the composition achieved through reactive sputtering. There is a story to tell with setting each one of these parameters to obtain matching deliverables with a robust process.

The "standard TaN" process recommended by the tool manufacturer was very different from the process of record. Just copying as much as possible from the existing recipe resulted in a process that would not even run on the new tool. It was clear that a completely new recipe was needed. Looking back on the effort, each value was narrowed down by various means to a trial range then tested exhaustively to refine the choices to a narrow, workable band which delivered reliable results. But, it was daunting to start with what seemed to be a blank page on an unfamiliar tool. The Newbury Park fab was fortunate that although the cluster tool was new to us, it was not new to Skyworks. Our Woburn facility had several similar tools in production and the engineer was able to share some best practices that were independent of process material. For example, they assisted with target ordering, lifetime monitoring, and cross wafer uniformity adjustments. The vendor sent a representative to offer suggestions for where to start, running the shutter pre-conditioning and how to better utilize the available options. Their suggestions helped narrow the options but did not lead directly to a final solution.

Starting with power, the challenge was to find a setting which provided the system with enough energy to strike and maintain a plasma while not overheating a photoresist covered wafer. The established process used a fairly low power (near 1KW) which the manufacturer did not recommend for our new-to-us tool. A trial confirmed that setting would not run. They suggested keeping the power below 3 KW to avoid burning the photoresist needed for liftoff, and more than our existing 1KW process to make sure the plasma was stable. Based on results from transferring the more straightforward recipes, the key was found to be matching the power density (KW/target surface area) of the existing process, which fortunately fell between those two limitations. Fine tuning required additional testing since the effective sputtered area does not cover the whole target area, but instead has varied intensity in a concentric ring pattern. The power setting required was also found to be dependent on the nitrogen level, so while picking the initial boundaries was systematic, finding the final value required running several designed experiments within those boundaries.

At the start, there were three options for setting the initial Ar flow rate: match the established flow rate, set a flow rate to match the established pressure, or use the manufacturer's suggested value. All of the alternatives produced stable plasmas and gave roughly similar millitorr process pressures. But, it was unknown initially if the key factor for nitrogen incorporation, and thus Rs and TCR, was the Ar:N_2 ratio or just the Nitrogen partial pressure (or both). Papers supplied by the vendor indicated that the ratio was critical. It was good to have a wide process space for testing the gas flows because setting the N_2 flow was not only complicated, but one of the most critical settings.

The process of record had an Ar:N_2 ratio over 20:1 but the ratio recommended for the new tool was just over 2:1. Would it even be possible to get a stable process on the tool when the recipe models started an order of magnitude apart? Additionally, the supplied mass flow controller (MFC) for the N_2 was too large to operate precisely in the region we were testing. Not being sure what operating range we would need, and being offered few setpoints (10, 50, 100, 300) we chose conservatively by replacing the 300sccm with a 50sccm controller, assuming that further alteration could be done if the process dictated it, but hoping not to need another three-week delay.

With our MFC adjusted, a baseline check of Rs vs. N_2 flow gave a clear pattern of nitrogen's effect on Rs, as shown in Figure 1. The established process used a gas flow which in the new tool was likely an unstable point between decreasing and increasing Rs.

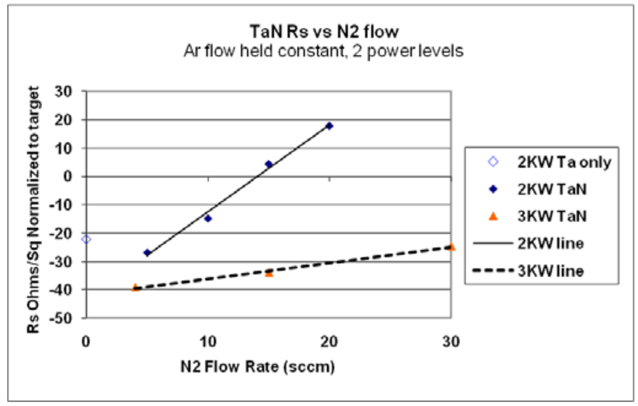

Figure 1: Graph of resultant Rs vs. N_2 flow rate for two power settings. Ar flow rate and dep time were held constant; the ratio of Ar to N_2 varied.

There was another issue with low N_2 flow. The cross wafer standard deviation increased by 70to 300 percent (depending on power and Ar flow) over the higher flow rates, with a marked change from side to side. This result ruled out directly copying the lower "matching" N_2 flow from the process of record, unless we wanted to consider reconfiguring the gas delivery hardware.

Deposition ("dep") time was also needed to develop the process. The assumption was made that a similar dep rate would yield a similar film. However, calculating a "matching" dep time was not straightforward. The established process runs all the wafers at once, rotating the wafers in front of a target, and requires dep time changes with target consumption. The new process runs the wafers individually in sequence. The starting calculation for the new dep time range was the established time divided by the number of times the wafers passed the target for the start and end of the target life. Initial tests to assess the tool were done with a generically picked 30 or 60 second dep time.

Based on the results from Figure 1, power setting options were narrowed further. Since the 3KW setting required a very short dep time to reach the target Rs, there was a concern there would not be enough process margin to easily adjust the recipe within the control limits. Therefore testing focused on the middle of the 1 to 3KW range.

Having found several setpoint combinations to get at or near our target Rs, the next step was to determine if any of the higher N_2 gas flows would deliver the required TCR with good uniformity. During development it was found that our assumption was correct that the dep time value calculated to match the established process dep *rate* was a good indicator of how well a particular recipe would create a film to match our deliverables.

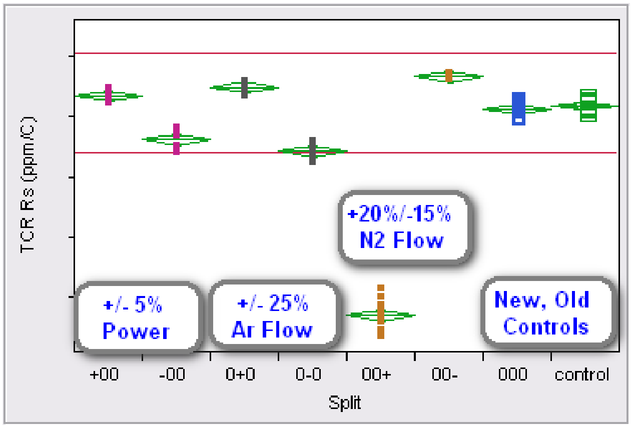

Figure 2: Graph of TCR to check range of major settings vs. TCR. Red lines define desired process region. 000=power, Ar flow, N_2 flow

Based on the preliminary data gathered, a trial process was selected. The process inputs for the cluster tool were then tested over a fairly broad range (see Figure 2) to determine the effects of each setting on TCR. In our acceptable operating range, there was still a wealth of settings. It was found N_2 flow was a much larger lever on TCR than Ar flow or power. This, and subsequent testing, showed relatively small changes in Rs and TCR with moderately large changes in Ar flow. Extra Ar in very large amounts (+100%) did affect N2 incorporation. However, the results from a consistent ratio of Ar:N_2 were not consistent over the sample set showing that the N_2 flow was the key parameter to set, not the ratio. Additionally, for TCR measurements, the process settings were additive; the result of changing two settings could be predicted by adding their individual expected changes, as long as the changes were modest.

To ensure the process space that was selected would provide a robust manufacturing process over time, additional testing was done. First, to account for the change in deposition rate that occurs as a sputtering target ages, input parameters are modified throughout the target life to create a stable process. Next, additional testing ensured the TCR was in a stable region and would not shift out of tolerance as the target aged. Starting with longer and shorter dep times, the effects were minimal. Finally, since the N_2 was the most sensitive setting, it was tested at closer intervals around the central point of the new process. While it was determined that the process chosen was far enough away to prevent the TCR from falling off the process cliff, the rate of change decreased with lower N_2 flows making a slight reduction of N_2 potentially useful. Coupled with the additive quality of the setpoints, it was clear that less N_2 made the TCR less negative and less power made the TCR more negative. To hedge against future unknown risk related to N_2 consistency, two alternate N_2/power setpoint combinations were tested and delivered viable results in the desired region. The Ar was kept at the midrange value that gave good repeatability.

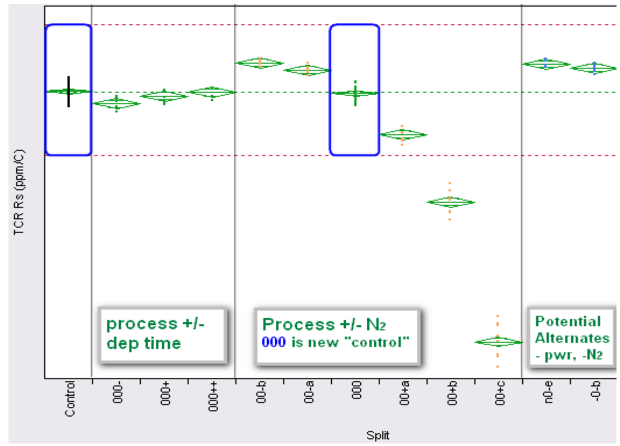

Figure 3: Graph of TCR to check effect of process variation from adjusting the controllable range of options inputs against process limits and target.

At the time the cluster tool was qualified, all existing sputter processing in our Newbury Park fab utilized time adjustments to compensate for the decrease in deposition rate with target life. Due to limitations with the new tool, a combination of power and time adjustments needed to be used to keep the Rs on target with a good Cp_K. This different approach required buy-in from management and additional data to show the TCR would not shift as the target aged. In addition, an interactive spreadsheet was created to ensure the process engineering technicians understood the correct adjustment methodology.

After selecting new process parameters, additional equipment parameters were tested. The chuck and chamber temperatures were varied within a range which accommodated the photo resist limitations. This factor was found to have minimal effect on TCR at these moderate temperatures. The temperature of the system components did, however, affect Rs, with a hotter system delivering a higher Rs. With this realization, target preconditioning steps were then optimized. With the selected shuttered burn in sequence, the key deliverables remained right on target, as desired. The final TaN process selected for production delivers a Cp_K greater than 1.66, and decreased the 6” throughput time from six hours per lot (old batch tool) to 45 minutes per lot.

Conclusions

It required some out of the box thinking to decide the best paths and the best comparisons to meet the challenge of getting matching films from unmatched toolsets. Since TaN TCR is so dependent on process variables, recipes had to be checked throughout their expected operating range to confirm there would be no unexpected shifts. It was necessary to devise methods of selection for reducing the test samples to a reasonable, measurable quantity. In the end, a process emerged which required rather different inputs than our previous batch tool to get the desired matching outputs. The 6" TaN process developed meets all production and engineering requirements.

ACKNOWLEDGEMENTS

The authors would like to thank the people that helped make this project successful. Cristian Cismaru and Mark Banbrook measured and analyzed TCR data. Brian Melvold, Julio Castillo, and Randy Abara carried out inline processing and measurement. Our equipment support techs made many adjustments. Special thanks to Mark Carruthers of Aviza/Sumitomo for help getting up and running with the shutter process.

REFERENCES

[1] Rhonda Hyndman, *TaN Deposition*, "Commercial in Confidence" paper from Aviza's Deposition Group 12April 2007.

[2] Hong Shen & Ravi Ramanathan, *Fabrication of a low resistivity tantalum nitride thin film*, Microelectronic Engineering, 18Aug. 2005

[3] Hong Shen, with Heather Knoedler et al., *Fabrication and Characterization of Thin Film Resistors for GaAs-Based Power Amplifiers*, 2003 GaAs MANTECH Technical Digest, 2003.

[4] H. B. Nie, et al., *Structural and electrical properties of tantalum nitride thin films fabricated by using reactive radio frequency magnetron sputtering*, Appl. Phys. 73, 2 (2001) 229-236.

[5] Jeffrey L. Perry, *Effects of Sputter Deposition Parameters on Stress in Tantalum Films with Applications to Chemical Mechanical Planarization of Copper*, RIT MS Thesis, 2004.

ACRONYMS

TaN: Tantalum Nitride, Ta_xN_y.

TCR: Temperature Coefficient of Resistance, the change to film resistivity with change in temperature.

MFC: Mass Flow Controller, controls flow of gas into process chamber.

Rs: Sheet Resistance, the electrical resistance in a sheet of thin film material.

Ar: Argon gas.

N_2: Nitrogen gas.