# Wafer-to-Wafer Metal Sputter Deposition Process Control by Automatic Deposition Rate Adjustment

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**Abstract**

**Automatic deposition rate adjustment is introduced for metal sputter deposition process. Characteristics of deposition rate change along with target usage for different target types were discussed. With implementation of the automatic deposition rate methodology, significant improvement of film thickness control and process capability was observed. Further application on thin film resistors shows potential improvement of electrical parameters by using automatic deposition rate adjustment approach.**

## INTRODUCTION:

For semiconductor metallization, wafer-to-wafer thickness uniformity is critical for consistent device quality and performance. Sputtering metal deposition is known to have variable deposition rate due to target erosion [1]. Different target materials have different characteristics of deposition rate change with target life. In this study, we focused on Ti/Pt/Au targets since these metal layers are commonly used as contact materials for GaAs compound semiconductor metallization schemes. Single or stacked multi-metal layer deposition is required in many processes/flows for different applications, such as base, emitter or gate processes, and have a direct effect on device performance.

In sputter metal manufacturing, the deposition rate is normally controlled by manually adjusting process time or target power. Advanced process control systems can be used to combine metrology data to monitor the deposition rate [1-2]. However, engineering evaluation of electrical data and metrology data is necessary for any recipe adjustment. The decision process causes significant tool downtime and engineering resources. Therefore, automatic deposition rate adjustment is highly desired in semiconductor manufacturing. It not only optimizes device performance by improving wafer-to-wafer metal thickness uniformity, but also minimizes tool downtime, reduces test wafer usage and increases process capability.

In this paper, the methodology of deposition rate calculations along with sputter metal target usage is introduced first. The derived algorithm is then applied to make a real time automatic deposition rate adjustment possible. Results of film thickness and process capability are discussed to show the advantages of this study.

## RESULTS AND DISCUSSION:

A direct calculation of deposition rate can be obtained by using film thickness and deposition time. Rigaku XRF was used for thickness measurements in this study. The deposition rate can be analyzed at different stages of the target life. However, since other process parameters, such as gas flow, or target power, could also affect deposition rate, we used "Tooling Factor" to include all related factors in order to accurately predict deposition rate change along with target life change. Tooling Factor (TF) was collected for several target life cycles for each type of target.

Figure 1 shows the trend of TF change within an entire target life for different target materials.  The

Ti target deposition rate was almost linear along with target usage, while Pt and Au deposition rates fit 4th order polynomial equation well. We could predict that the gradual increase of the Ti deposition process time should compensate the decrease of deposition rate. However, the deposition rates of Au and Pt decreased sharply at beginning of the target life, then remained stable or slightly increased in the middle of the target life. Subsequently, it decreased again towards the end of target life when we saw a final increase. Data from several target life cycles of the same chamber displayed the same trend.

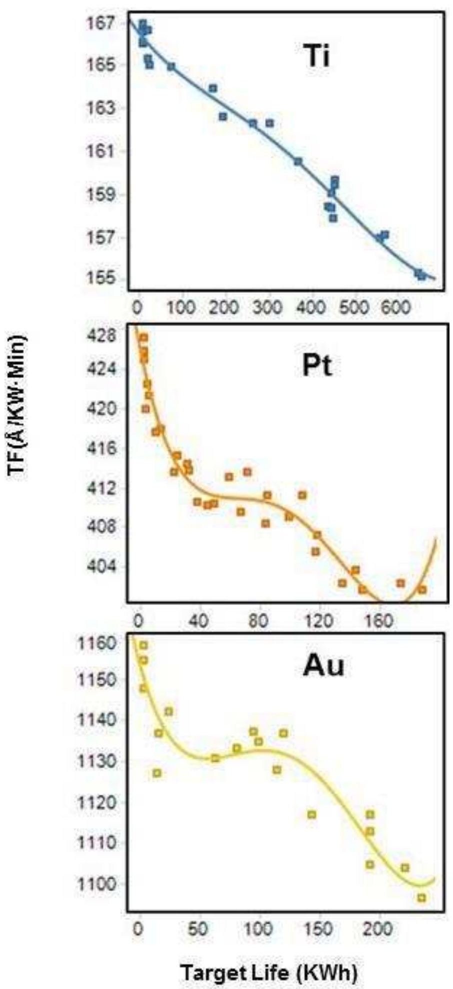


**Figure 1. Tooling factor change along with target usage for Ti/Pt/Au deposition.**

Film thickness data from different chambers with the same target materials was also analyzed. Similar trend of deposition rate change over target life was obtained. Figure 2 shows the derived deposition rate change over an entire target life for three Ti chambers. Among those three Ti chambers, the derived algorithm was very close for chamber 2 and chamber 3 with an offset. The offset was due to chamber to chamber variation. The target erosion characteristic was the same. However, chamber 1 data was more scattered and it indicated there were other factor(s) affecting deposition rate in addition to target erosion.

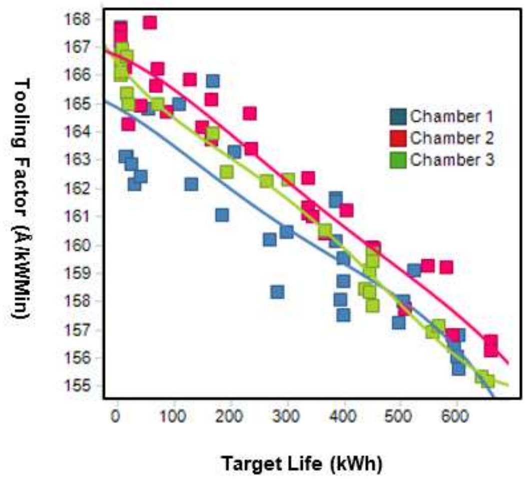


**Figure 2. Tooling factor change along with target usage for three Ti chambers.**

SPTS Sigma fxP sputtering systems were used for deposition. By using the derived algorithm and feeding back to the deposition tool, the deposition rate is controlled automatically across the whole target life. An example of Ti film thickness measurement before and after the application of automatic deposition rate adjustment is shown in Figure 3. Large film thickness variation was observed before the implementation of automatic deposition rate adjustment. Constant TF and process time adjustments based on SPC charts were required to keep the film thickness in control. However, since the implementation of automatic deposition rate adjustments, standard deviation has been reduced by half and the film thickness was well within control limits during several target life cycles. No manual

TF/process time adjustment or engineering intervention was needed.

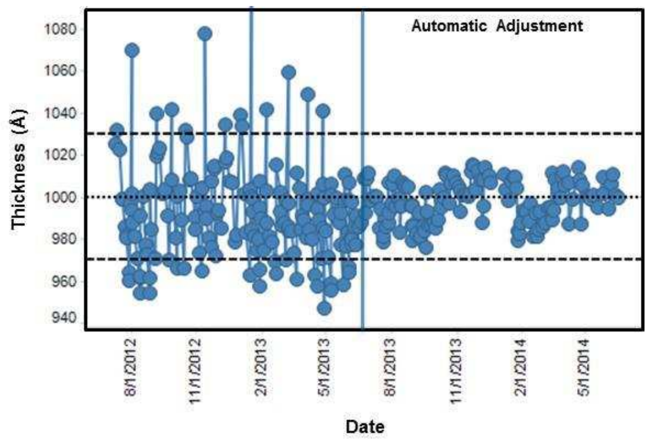


**Figure 3. Thickness of Ti film deposition before and after the application of automatic deposition rate adjustment.**

For Pt and Au film, wafer-to-wafer thickness uniformity was significantly improved by using automatic deposition rate adjustment, shown in Figure 4a and 4b. Standard deviation was tightened by 40%. Compared to Ti targets, larger target to target variation was observed. Manual deposition rate adjustment was still required at the very beginning of target change to calculate the offset due to target variation. Then the deposition rate can be controlled through automatic adjustment through the rest of target life.

The deposition rate algorithm is derived for several sputter tools and consistent results are observed. Small offset adjustments to the calculation are required due to tool to tool variation. From the results shown in Figure 5, process capability was significantly improved from less than 0.9 to greater than 1.4 for all sputter deposition tools. It indicated the consistent performance and capability of this automatic adjustment approach.

In addition to contact materials, we also studied thin film resistor deposition. The correlation between sheet resistance Rs and target life was established first. Using the automatic adjustment, the consistence of specific thin film resistance parameters can be controlled from wafer to wafer.

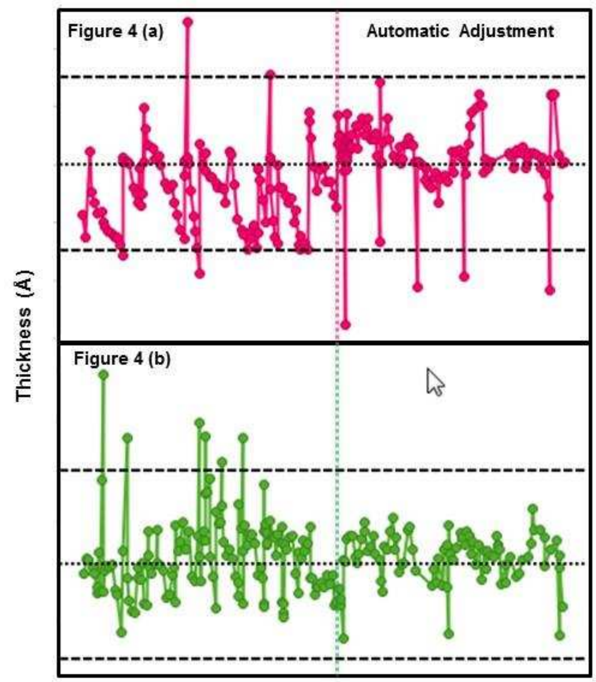


**Figure 4. Thickness of Pt and Au film deposition before and after the application of automatic deposition rate adjustment.**

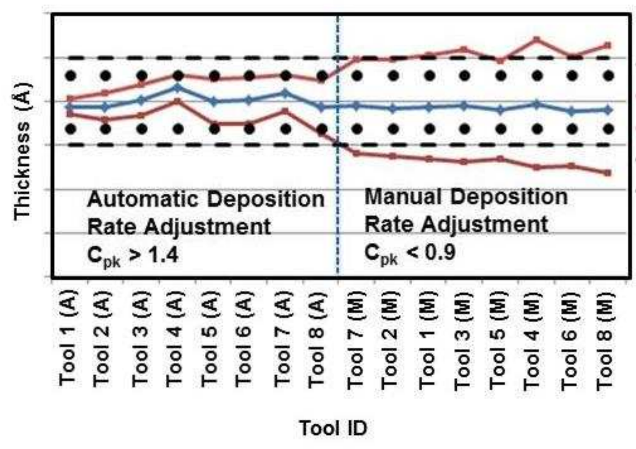


**Figure 5. Results of implementation of automatic deposition rate adjustment for all sputter tools.**

Figure 6 shows the tooling factor derived from sheet resistance measurement across an entire target life for two resistor structures. Similar trends were observed. Deposition rate changed abruptly at the beginning of the target, then remained stable till middle of the target life. Deposition rate gradually decreased for the second half of target life. The results indicated closely monitoring of deposition rate at the beginning of target life was necessary. And automatic deposition rate control using the derived algorithm can improve thin film resistor Rs consistency. Similar approach can be used to control other electrical parameters affected by film thickness.

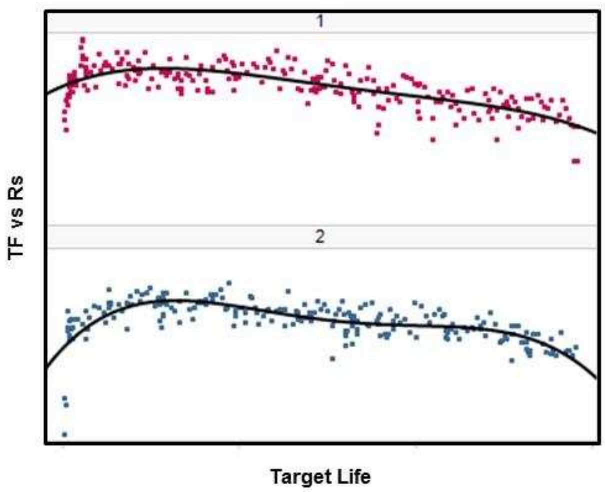


**Figure 6. Tooling factor derived from Rs for thin film resistor deposition over an entire target life.**

## CONCLUSION AND FUTURE WORK:

With the increasing demand of high performance devices, metallization film thickness accuracy of a few angstroms is required. Using the automatic approach discussed in this paper, film thickness can be well controlled automatically for different processes that require different process times. The results showed significant improvement in process capability with minimum engineering intervention. This has led to more than a 30% reduction in test wafer and tool down time. The initial development of automatic deposition adjustment on thin film resistors also showed that broader application of this approach is promising. The same methodology can be applied to other deposition systems.

## ACKNOWLEDGEMENTS

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## REFERENCES:

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## ACRONYMS

TF: Tooling Factor
XRF: X-Ray Fluorescence
Rs: Sheet Resistance