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

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INTRODUCTION:

For semiconductor devices, metal layer thickness accuracy is critical for consistent device quality and performance. Metal deposition, especially sputtering metal deposition is known to have unstable deposition rate due to target degradation [1]. Different types of target materials have different characteristics of deposition rate change. In this study, we focus 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 to device performance.

In sputter metal manufacturing, the deposition rate or process time is normally adjusted manually. 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, application of automatic deposition rate adjustment is highly desired in semiconductor manufacturing. It not only optimizes device performance by wafer to wafer deposition control, 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 is 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 use "Tooling Factor" to include all related factors in order to accurately predict deposition rate change along with target life change. Tooling Factor (TF) is collected for several target life cycles for each type of target.

The plot in Figure 1 shows the trend of TF change within an entire target life for different target types. The Ti target deposition rate shows almost linear along with target usage while Pt and Au deposition rates fit 4^{th} order polynomial equation well. We could predict that gradual increase of the Ti deposition process time should compensate the decrease of deposition rate. However, for Pt and Au deposition, the deposition rate decreases sharply at beginning of the target life. Then, it remains stable or slightly increases in the middle of the target life. Subsequently, it decreases again towards the end of target life when we see a final increase. Data from several target life cycles indicate the same trend.

SPTS Sigma fxP sputtering systems are used for the deposition. By using the derived algorithm and feeding back to the deposition tool, deposition rate is

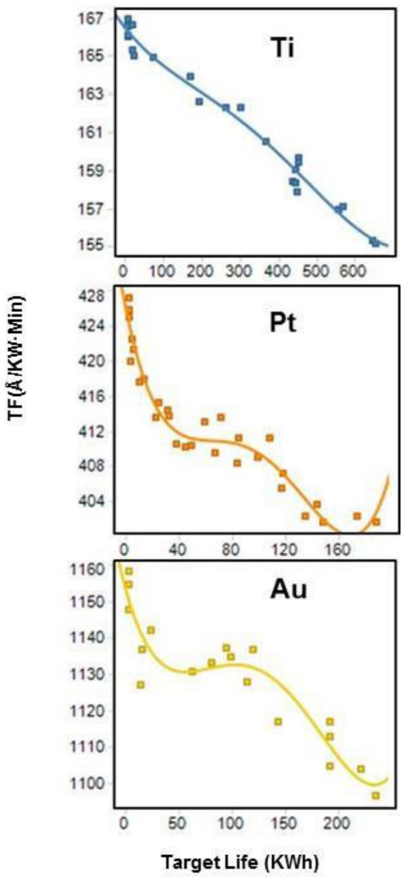

Figure 1. Tooling factor change along with target usage for Ti/Pt/Au deposition.

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 2. Large film thickness variation is observed before the implementation of automatic deposition rate adjustment. Constant TF and process time adjustments are 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 now the film thickness is well within control during several target life cycles. No manual TF/process time adjustment or engineering intervention is needed.

The deposition rate algorithm is derived for several sputter tools and the consistent results are observed. Small adjustments to the calculation are

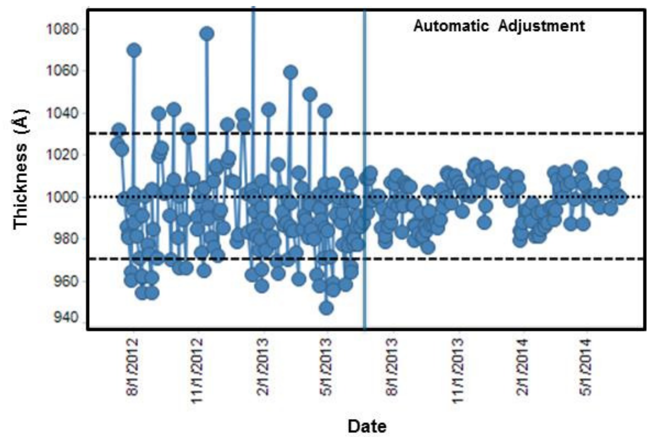

Figure 2. Thickness of Ti film deposition before and after the application of automatic deposition rate adjustment.

required due to tool to tool variation. From the results shown in Figure 3, process capability is significantly improved from less than 0.9 to greater than 1.4 for all sputter deposition tools. It indicates the consistent performance and capability of this automatic adjustment approach.

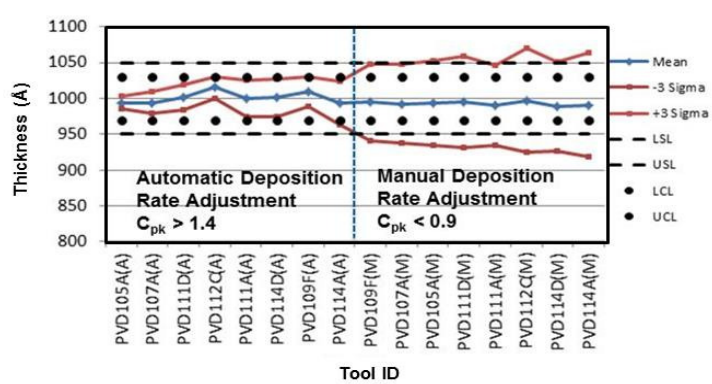

Figure 3. Results of implementation of automatic deposition rate adjustment for all sputter tools.

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

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 show 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 shows that broader application of this approach is promising. The same methodology can be applied to other deposition systems.

ACKNOWLEDGEMENTS

The authors would like to thank production technician team for their efforts of thickness measurements. Special thanks to Chris Roper, Gary Snow and Ken Khai for target life data collection.

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ACRONYMS

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