NiCr Sheet Resistance Adjustment During Wafer Fabrication Process

Lena Luu, Minkar Chen, and Alex Vigo

Global Communications Semiconductor, LLC., 23155 Kashiwa Ct, Torrance, CA 90505
e-mail: lluu@gcsincorp.com, Phone: +1 310-530-7274 ext. 169

Keywords: NiCr, Sheet Resistance, PCM, process control

Abstract

This paper presents the process control methods used at Global Communications Semiconductor (GCS) for the evaporated NiCr resistor. The NiCr source preparation and charge conditioning are critical for controlling the sheet resistance at deposition and the sheet resistance changes through the remainder of the fabrication process. Continuous monitoring of the change of the sheet resistance from deposition to final test can provide feedback to further tighten the control at film deposition.

INTRODUCTION

NiCr (nickel chromium) and TaN (tantalum nitride) are used at GCS as resistors in many products at GCS. The advantages and disadvantages of each material are discussed in the paper by Shen H, et al. [2]. This paper focuses on the use of NiCr for resistors. In resistor fabrication, the final sheet resistance must conform to each product specification; however, due to the difference in vapor pressure between nickel and chromium, it is very challenging to control the film to consistently reach the target sheet resistance after later processing steps. Depending on the product, the sheet resistance (R_{sh}) target at deposition is different. This is to account for the difference in final specification and the expected change from deposition to final test. The expected R_{sh} change is related to the difference in downstream processes.

The NiCr film deposition has controls such as source material quality, charge preparation procedure, charge conditioning, deposition thickness, and Rsh specification. In addition, the change in R_{sh} at different process steps is also monitored as another process control parameter. The NiCr R_{sh} is measured multiple times throughout the wafer fabrication process; at deposition, after M1 interconnect, and again after final front side processing. There is an expected difference and any deviation can point to a drift in deposition process. Using this feedback loop, GCS has been able to further control its NiCr resistor process.

NICR DEPOSITION

The NiCr metal goes through several layers of inspection and qualification before it is used for production. Each delivered NiCr batch is checked for purity based on the certificate of analysis from the vendor. The analysis requires compositional analysis of contaminants in addition to the 80/20 composition requirement. The material is also qualitatively checked for any physical deviation such as shape, size, shine, and roughness. Once the source material passes the incoming material check, it is ready for melt. At GCS, the NiCr is e-beam evaporated. During charge preparation, metal spitting and uniform melt are monitored as an indication of source material quality or contamination. The charge is conditioned and then a qualification deposition is performed. For every deposition, glass monitors are added for NiCr R_{sh} measurement. Each ring of the evaporator dome has one monitor. R_{sh} is measured using a 4-point probe station. The charge is considered qualified when the R_{sh} from ring to ring and from run to run is within the process specification limits. A large range between the dome rings or process runs is an indication that the NiCr source melt is not physically and compositionally uniform. The melt may have irregular thickness from center to edge or there may be localized areas with different compositions.

For product NiCr evaporation, the product wafers are not measured for R_{sh}. Instead, glass monitors are added to the same run to measure the R_{sh}. The product NiCr R_{sh} is measured after M1 processing and again after front side processing is complete. Regardless of the product type, there is a similar TLM test structure in the PCM to measure the NiCr R_{sh}. The change in Rsh from deposition to M1 test and final test is not the same for different product types due to differing downstream processing even after accounting for the difference between four-point probe measurement on the glass monitors and PCM electrical measurement on the product wafers. This change needs to be mapped in order to correctly target the Rsh at deposition.

Figure 1 is a box and whisker plot of the change in NiCr Rsh from deposition to final test for the HBT and PHEMT processes. Both have large distributions due to the inclusion of data from deposition runs where other parameters such as optimized source melt procedure and source conditioning have not been implemented. The increase in NiCr R_{sh} for the HBT process tends to be about 1 Ω/sq less than for the PHEMTs. This difference is attributed to the difference in downstream processing. Both products have one process layer before the NiCr is passivated. After passivation, the

HBTs go through 5 additional process levels before final test while the PHEMTs only go through another 4 process levels. These process levels have different high temperature bakes that can both anneal and affect oxygen content of the NiCr film. R_{sh} of thin NiCr films tend to increase with oxidation, but decrease with annealing [1].

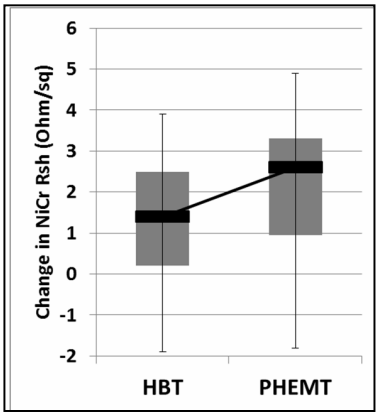

Fig. 1. Box and whisker plot for the change in NiCr R_{sh} during processing for HBT and PHEMT.

Knowing the difference in behavior for each product and adjusting for it at deposition is not enough to match the product final specification. It is also necessary to control the spread in NiCr R_{sh} change seen in Figure 1.

Process Review and Optimization

Further review of the deposition process is needed to reduce the large variation in NiCr Rsh change. Figure 2 shows the data for production runs of the same Rsh target. Each point represents the film thickness and Rsh data from one deposition run. The thickness of the deposited NiCr film varied up to 20% and showed no correlation with the resulting sheet resistance. This is indicative of differences in the film structure and/or composition. Comparing the change in NiCr R_{sh} for lots at different deposition thicknesses showed that thinner films behaved more predictably. Thicker films even have a reversal in the change in R_{sh} (See Figure 3A).

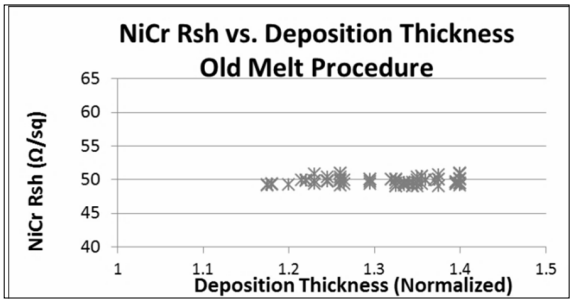

Fig. 2. NiCr R_{sh} based on deposition thickness using the old, un-optimized source melt procedure.

To reduce the variation in the NiCr sheet resistance change, the source melting procedure was optimized. The goal is to reduce the tuning of film thickness to achieve the same target R_{sh}. If the thinner film and thicker film have the same R_{sh}, the composition must vary as can be seen in the film behavior after downstream processing (Figure 3A).

The original melting procedure called for a manually controlled beam sweep in order to melt the source. Time and power level had guidelines, but choice was ultimately up to the operator or technician. To qualify the melted source for production, successive tests runs were performed with the thickness adjusted until the desired R_{sh} was reached.

The optimized melting procedure used a fixed recipe to melt and condition the source. The power used to melt the source is the maximum value from the original guideline which is also the power used during deposition. The thickness tuning to reach the target R_{sh} is also restricted to a lower range.

Results and Discussion

The optimized melting procedure produces a melt that is smoother and more uniform from center to edge. This improves the thickness uniformity of the different rings of the dome. The constant deposition parameters and restricted deposition thickness also lead to a more stable deposition composition and maintains the same source shape from run to run and source to source. The higher power used to melt the source also leads to a hotter deposition which may also produce more stable films [3].

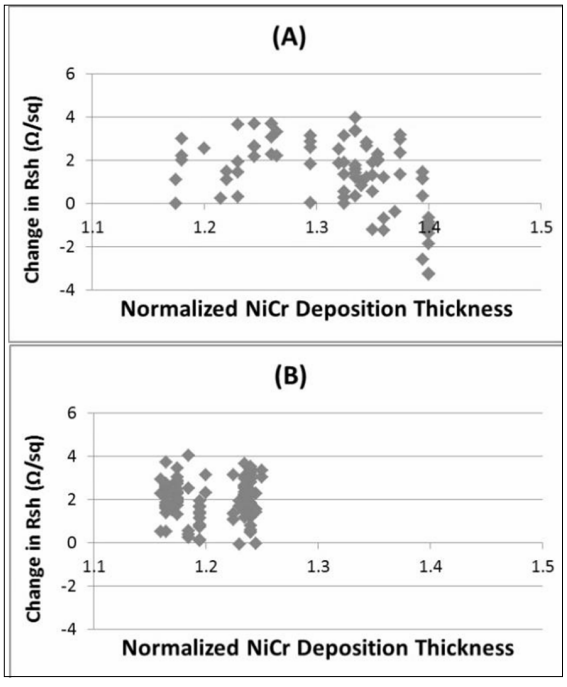

Fig. 3. Change in NiCr R_{sh} versus normalized deposition thickness: (A) Old melt procedure; (B) New optimized melt procedure.

With these changes to the source melting procedure, it is possible to achieve the same target R_{sh} with less thickness tuning required. Figure 3B shows that the behavior of the NiCr film with the new melt procedure similar to that with the old procedure for the same film thickness. This new melting procedure did not affect composition but improved the deposition stability from run to run. Figure 4 shows the data for production runs of the same R_{sh} target using the new optimized melt procedure. As expected, the NiCr R_{sh} still does not depend on the deposition thickness; however, the spread in film thickness is halved. Figure 5 shows the process improvement for the four months before and the four months after the deposition optimization. The R_{sh} change after downstream processing is about the same before and after the optimization, and the R_{sh} spread is tighter.

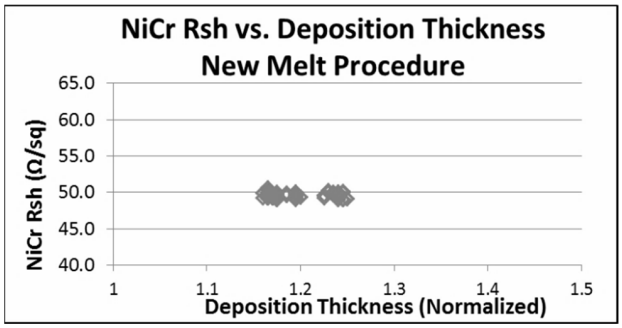

Fig. 4. NiCr Rsh based on deposition thickness using the new, optimized source melt procedure.

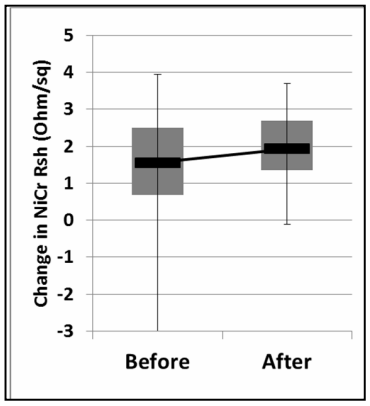

Fig. 5. Box and whisker plot for the change in NiCr R_{sh} during processing for HBTs from 4 months before and 4 months after the deposition optimization.

CONCLUSIONS

The NiCr R_{sh} change from deposition to final test can be mapped for each product and the film deposition can be optimized to produce more predictable film change in order to conform to the final R_{sh} specifications. GCS has demonstrated that monitoring and controlling the change in NiCr R_{sh} throughout the fabrication process can be used as a process control parameter and can drive process improvements and confirm the validity of those process changes. Standardization of the NiCr melting procedure led to better uniformity from run to run and from source to source. The amount of film thickness tuning needed to reach the required target R_{sh} was reduced. The optimized melting procedure also produced films that had less variation at final test.

ACKNOWLEDGEMENTS

The authors would like to thank the production team for their help in running so many tests depositions during the optimization process.

REFERENCES

[1] L. Lai, et al., "Comparison of Microstructure and Electrical Properties of NiCr Alloy Thin Film Deposited on Different Substrates." Surface & Coating Technology 235 (2013): 552-60. Elsevier. Web. 16 Sept. 2016.

[2] Shen, H, et al., "Fabrication and Characterization of Thin Film Resistors for GaAs-Based Power Amplifiers." GaAsMantech. (2003) 6.2 CSMantech. Web. 14 Sept. 2016

[3] Rolke, Joachim. "Nichrome Thin Film Technology and Its Application." Electrocomponent Science and Technology 9 (1981): 51-57

ACRONYMS

HBT: Heterojunction Bipolar Transistor
PHEMT: Pseudomorphic High Electron Mobility Transistor
R_{sh}: Sheet Resistance
M1: First interconnect Metal (Metal 1)