High Value Thin Film Resistor for GaAs IC Manufacturing

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Abstract

An optimized thin film resistor based on a sputtered WSix alloy has been developed. Sheet resistance of 1000 Ω/□ and a temperature coefficient of resistivity (TCR) of -650 ppm/°C have been measured. When subjected to reliability tests, the new resistor exhibits good sheet resistance and TCR stability. Initial results from the pilot line demonstrate that this film can be integrated into a repeatable and uniform manufacturing process.

INTRODUCTION

IC designs that include high value resistors represent a manufacturing challenge that often requires making a non-ideal compromise. The most commonly used resistor structures are created by deposited thin films or isolated semiconductor sections. Typical thin film resistor materials target a sheet resistance in the range of 25-150 Ω/□ and are based on metal alloys (e.g. NiCr, TaN) with relatively low resistivity. High value resistors that make use of these films could spend substantial die areas dedicated them. One solution to this added consumption of precious die "real estate" is to increase the sheet resistance of the film. Substrate semiconductor resistors outlined by an etch or implant process could achieve higher sheet resistance values, in the range of 500-2000 Ω/□, but they lack precision, exhibit large TCR's and are susceptible to electrostatic damage (ESD.)

Numerous high resistivity metals were described in the literature but so far none of them emerged as a clear material of choice for manufacturing. The Me-Si alloy systems and the silicide compounds associated with them were studied [1] for this application because they exhibit high electrical resistivity, good thermal stability and high crystallization temperature. SiCr thin films with near zero TCR and the sheet resistance in the range of 500-1200 Ω/□ were reported [2,3] but their manufacturing appears to be difficult. The sputtering targets are based on complex alloys and the deposition process involves reactive RF sputtering.

The use of WSix films as resistor material with 1000 Ω/□ has been reported in previous articles [4] but the large TCR values and non-uniformities associated with their production prevented them from becoming main stream technology. This paper reports on an optimized WSi film [5] that overcomes these difficulties and demonstrates that highly uniform resistor structures could be integrated within a well-controlled manufacturing process.

WSI RESISTORS OPTIMIZED FOR TCR

Standard $W_xSi_{(1-x)}$ films with x, the atomic fraction, ranging from 0.15 to 0.25, were sputtered on to 150 mm GaAs wafers with an insulating oxide layer. The thickness needed to obtain 1000 Ω/□ ranged from 150-200 A and various resistor structures were patterned by lift-off. TCR measurements were performed on van der Pauw structures that were heated up to 125°C. We found the electrical resistance properties of the standard $W_xSi_{(1-x)}$ alloys to be in close agreement with the results published earlier [4]. However, the large TCR values associated with these films proved to be a problem as the resistor application that was targeted required absolute coefficients that did not exceed 700 ppm/°C.

The optimized WSi films were fabricated under similar conditions as the standard WSi and were subjected to the same tests. Figure 1 shows the improved TCR of the optimized WSi film and it clearly demonstrates more stable sheet resistance values with increased temperature.

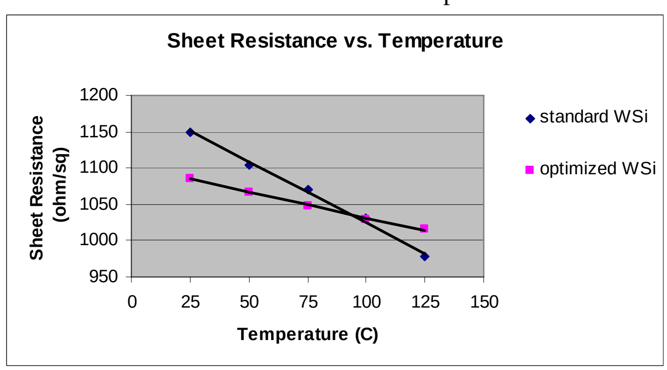

Figure 1. TCR measurements for WSi thin film resistors. Standard WSi film exhibits a -1500 ppm/°C TCR while the TCR of the optimized film was measured at -650 ppm/°C.

RELIABILITY

The optimized WSi films were subjected to a set of standard JEDEC reliability tests and Figure 2 shows a summary of the results.

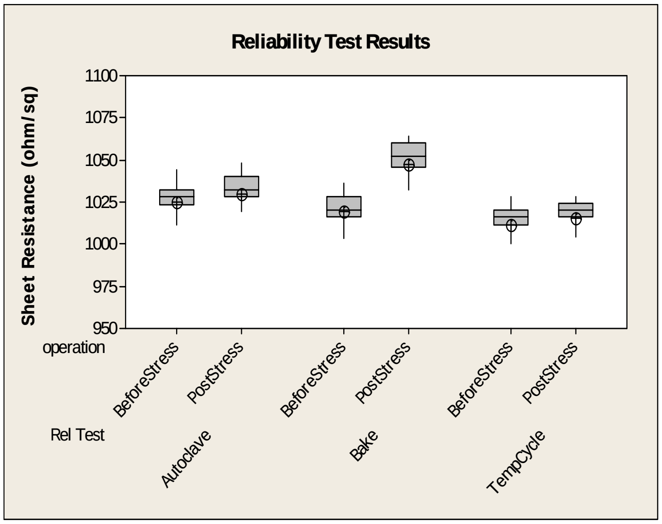

Figure 2. Reliability test results for the optimized WSi film. Each group contains approximate 150 test points. The bake test produces a 2.5% shift in sheet resistance.

The autoclave conditions were set at a temperature of 121^{o}C, 100% relative humidity, 2 atm overpressure and the stress time period lasted 96 hrs. During the temperature cycle test, the wafers were subjected to 500 heat cycles that shifted the temperature between -40^{o}C to +125^{o}C. There were no significant changes for the wafers that were stressed under auto-clave and temperature cycling. The bake stress consisted of a heat treatment at 275 ^{o}C for 7 days and it produced only a minor 2.5% shift in the sheet resistance.

PROCESS INTEGRATION

There were several challenges associated with the process integration of this resistor film. WSi is sensitive to the fluorine-based etch chemistry that is commonly employed for etching of the nitride dielectric layer and the lack of etch selectivity proved to be difficult to overcome. The resistor feature definition was complicated by unreliable lift-off and the alternative etch-back process proved to be too damaging for the underlying nitride layers. In general, thin metal layers are not difficult to lift-off but W-based alloys release large solidification energies during the vapor deposition process and the integrity of the photoresist suffers.

In spite of these hurdles, we were able to define a process window that fits well within various integration schemes and one such implementation is illustrated in Fig 3.

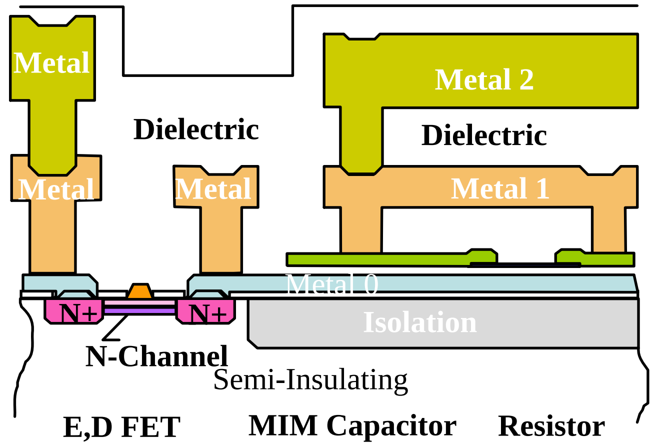

Figure 3. Process integration method for the high value resistor.

TEST RESULTS

Resistors with various layout dimensions were tested for linearity. The average resistance collected from several runs is normalized against the measured sheet resistance and the results are presented in Figure 4. Both, the 2 and 3 µm wide resistors series show good linearity and scaling.

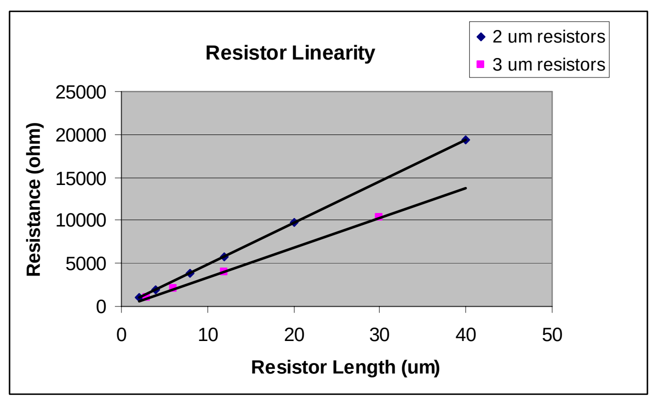

Figure 4. Resistor series with 2 and 3 µm width plotted against the layout length of the elements.

The new WSi resistor was implemented in several new test products and the initial parametric test trend shown in Figure 5 demonstrates that this process is repeatable. Also, this data reveals that within-wafer non-uniformity is less than 3%, which guarantees a high precision capability for the resistors.

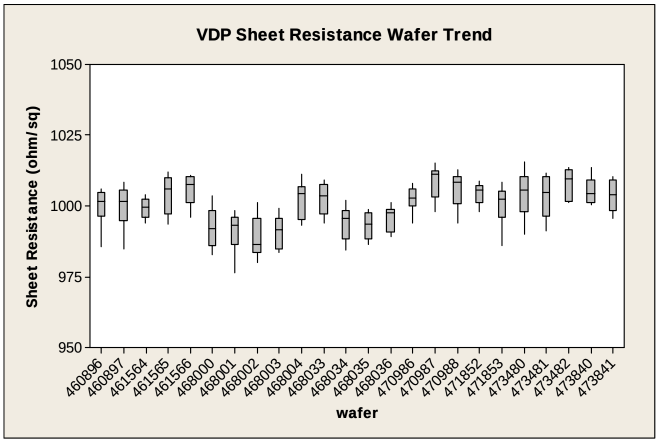

Figure 5. Pilot line sheet resistance measurement trend demonstrates capable process.

CONCLUSIONS

We demonstrated a new resistor material that was successfully integrated into a high production GaAs fabrication line. The electrical properties of the WSi film were optimized for TCR reduction. The new material proved to be stable and its high value resistivity allowed for significant reductions in the die area consumed by the resistor elements.

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REFERENCES

[1] R.K. Waits, *Silicide Resistors for Integrated Circuits*, IEEE Proceedings, v 59, No 10, October 1971

[2] F. Wu, A.W. McLaurin, K.E Henson, D.G. Managhan, S.L. Thomasson, *The effects of the process parameters on the electrical and microstructure characteristics of the CrSi thin resistor films: part I*, Thin Solid Films, 332, pp. 418-422, 1998

[3] V. Felmetsgeris, *Controlled Sputtering Enables Better SiCr Films*, Semiconductor International, Oct. 2000

[4] C.J. Blackhouse, G. Este, J.C. Sit, S.K. Dew, M.J. Bret, *WSix Thin Films for Resistors*, Thin Solid Films, 311 pp. 299-303, 1997

[5] F. Radulescu, *Thin film resistor and method of making the same*, U.S. patent pending

ACRONYMS

Rs: Sheet Resistance
Me-Si: Metal-Si alloy
TCR: Temperature Coefficient of Resistivity
JEDEC: Joint Electron Device Engineering Council
NiCr: Nickel-Chromium
TaN: Tantalum-Nitride
ppm: parts per million ($x10^{-6}$)