An E-beam Evaporation Deposition Process for TaNx Thin Film Resistors

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Abstract

This abstract outlines the process development of an electron beam evaporated TaNx thin film resistor. This method can provide advantages over the traditional sputtered TaN TFR, if the challenges of evaporating tantalum can be overcome and the process is optimized.

INTRODUCTION

Thin layers of Ta_xN_{1-x}, here denoted as TaNx, are commonly used in electronic components for thin film resistors, particularly in III-V semiconductors. These layers are generally deposited by sputter deposition, for ease of control of composition and TCR for precision resistors, where uniformity and reproducibility are important [1]. Dry etching of TaN films is difficult and involves harsh chemistry. In addition, it is difficult to get high selectivity with chlorine chemistry when the film is deposited over silicon nitride. In III-V semiconductor circuits, like on GaAs substrates, lift-off patterning process is preferred. Patterning over silicon nitride is done by dielectric assisted lift-off (DAL) process, where the nitride is etched off and the TaNx film sits on GaAs. This process has several drawbacks. Evaporation method allows the use of standard lift-off technique to define the resistor, eliminating the need for DAL. In addition, the TaN resistor can be placed on SiNx that improves the resistor to active device leakage current. Furthermore, with the ability to form the thin film resistor directly on silicon nitride, the TCR of the TaN resistor would be considerably more stable and the resistors less susceptible to leakage through the GaAs substrate. Resistors deposited and patterned by the DAL process are electrically narrower than the drawn dimension. Therefore a large bias is applied to the mask. This places a limit on resistor to resistor spacing. This paper describes an alternative method for depositing TaNx film by means of electron beam evaporation with nitrogen incorporation in the process chamber. By optimizing the input parameters, a stable TaNx film can be achieved matching the desired properties of the sputtered TaN resistor.

In the current work, standard e-beam evaporators are used for the TaNx deposition with minimal additional hardware. N_2 is plumbed into the process chamber simply by a feed-through, tubing and the gas distribution controlled via a MFC and a pressure gauge. Tantalum is a refractory metal with a very high melting point which is generally a challenge to evaporate. High power is required to evaporate tantalum metal. However, with proper melt setup and maintaining a low deposition rate, the process can be established with reasonable power control. The process is manufacturable since the film thickness desired for a typical thin film resistor with a sheet resistance of 50 ohms/sq. is only a few hundred angstroms.

A series of DOEs were completed to determine the range of N_2 gas flow on sheet resistance, particles, and film stress. N_2 is incorporated into the tantalum deposition throughout the entire process layer. Figure 1 (a) and (b) show details of the inline data stress and Rs as a function of N_2 flow with a TaNx thickness of approximately 500Å. The results of the DOE indicated that the properties of the TaNx film can be easily controlled by varying the nitrogen content of the film. Tantalum appeared to be readily reactive to the nitrogen resulting in a fairly wide range of N_2 flow with stable and repeatable film resistance and stress. The optimum deposition conditions were ultimately determined based on finding a N_2 gas flow in a range that is not sensitive to small changes and achieving low film stress. Within this range, the composition of the film can be chosen to achieve a resulting film that meets the properties needed for TFR.

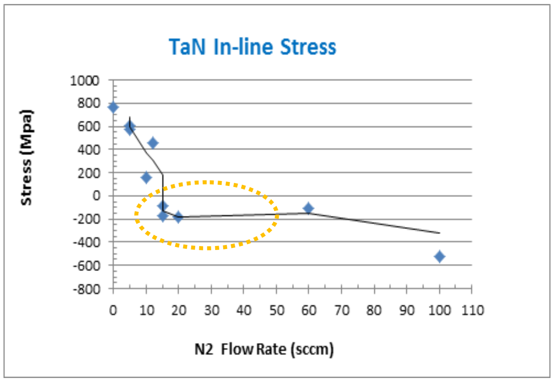

Figure 1 (a): TaNx Film Stress as a function of N2 flow.

In addition to the Rs and stress data, characterization data of the evaporated TaNx film was also collected from the

9

following: optical inspection, EDX, SIMS, FIB cross section, TCR, and overall thermal stability. Visual inspection of the evaporated TaNx film was comparable to the sputtered TaN. FIB cross sections provided validation of the target thickness (see Figure 2).

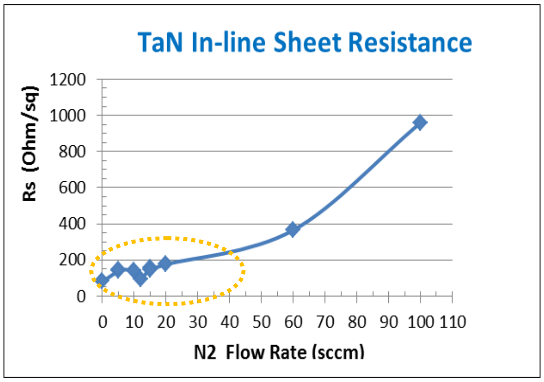

Figure 1 (b): TaNx Film Sheet Resistance as a function of N2 flow.

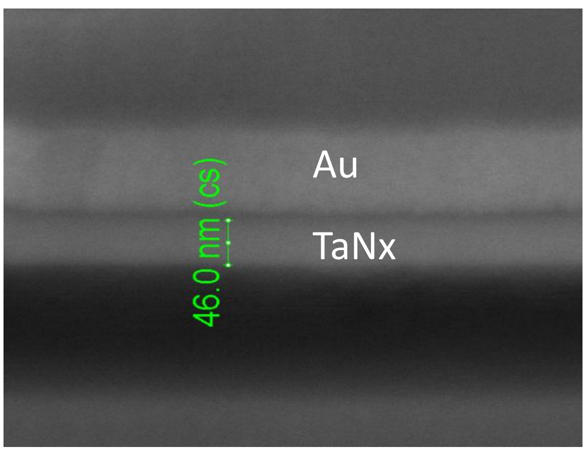

Figure 2: FIB cross section of an approximately 500angstroms evaporated TaNx film.

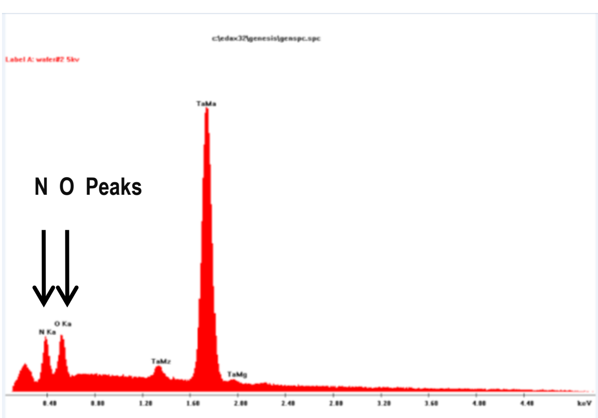

Figure 3: EDX of evaporated TaNx film showing N_2 peak as well as O_2 peak.

EDX and SIM analyses were performed to confirm the composition of the film with both tantalum and nitride peaks being identified. Fig. 3 shows the EDX of evaporated TaNx film. It was discovered that the amount of nitrogen incorporated into the film is strongly dependent on the N_2 flow and the level of background oxygen and carbon within the chamber and the source. Figure 4 (a)-(c) depict the SIMS results of several evaporated TaNx films of varying N_2 flow as compared to a traditional sputtered TaN film. In comparison, the SIMS profiles showed a stable concentration of tantalum and nitrogen with a low level of oxygen for the sputtered TaN film. This poses a challenge to achieve a similar stoichiometry as the sputtered TFR film. Work with N_2 ion source has shown better N_2 incorporation, but this technique requires additional equipment [2].

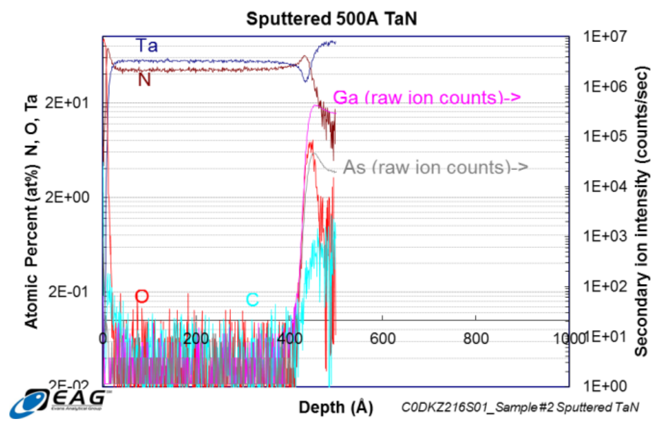

Figure 4 (a): SIMS of sputtered TaNx film showing N_2 peak and low level of O_2.

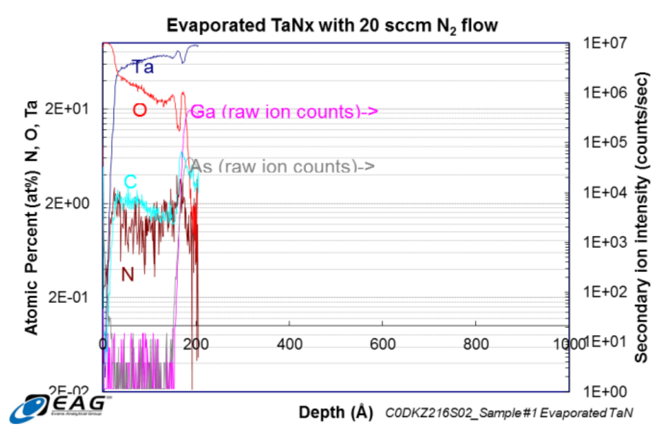

Figure 4 (b): SIMS of evaporated TaNx film with 20 sccm of N_2 flow showing N_2 peak as well as O_2 peak.

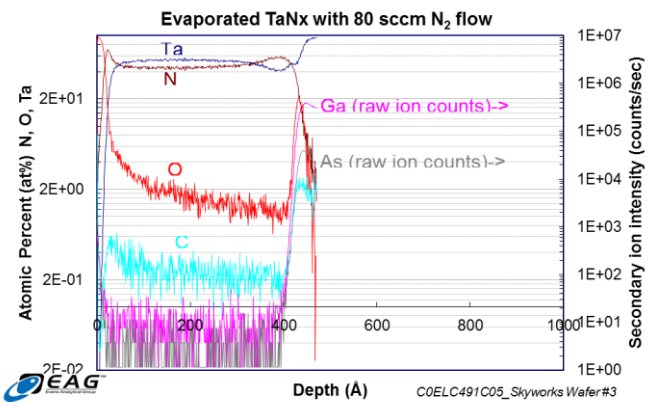

Figure 4 (c) SIMS of evaporated TaNx film with 80 sccm of N_2 flow showing N_2 peak as well as O_2 peak. Courtesy of Chris Sheppard, Skyworks, Woburn.

The TFR samples were also tested for TCR (data is listed in Table I and shown in Fig 5). TCR is more negative than the typical -100 to -130 ppm target range. Oxygen peak appears in both the EDX and SIMS spectra and may be responsible for the poorer TCR. Further optimization effort is underway to improve the composition and phase matching to the sputtered TaN and consequently reducing the TCR. Thermal cycling was also conducted to evaluate the stability of the film, with the results showing some differences between the evaporated and sputtered TFR in respect to the sheet resistance change through the interconnect process.

TABLE I TCR means of sputtered and evaporated TFR.

Wafer	Group	Mean	Std Dev
2	Sput TFR	-101	1.47
5	Evap TFR	-175	2.06
7	Evap TFR	-175	1.32

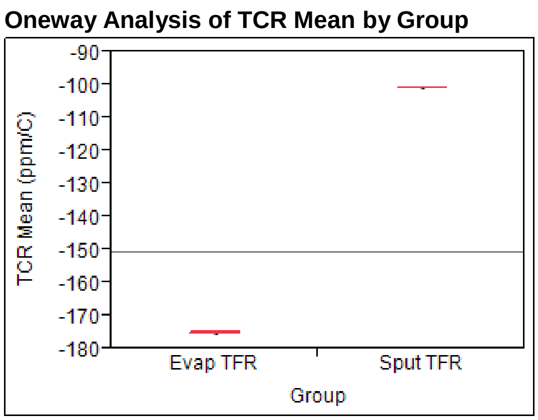

Figure5: Quantile plots of sputtered vs. evaporated TFR TCR.

The electrical effective width determined by measuring delta w (width correction factor due to process bias) using standard inverse TLM PCM, also shows the resistors are close to drawn dimensions (see Fig 6). Process manufacturability has also been verified with a number of development runs on multiple evaporators with very consistent run-to-run statistics, repeatability, and reproducibility in the subsequent resistivity, film stress, and particles.

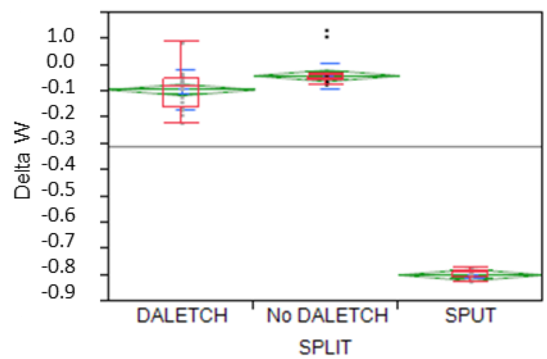

Figure 6: Width correction factor, delta w comparison of standard sputtered vs. evaporated film, ran with photo mask corrected for standard sputter DAL process with 0.8µm process bias.

CONCLUSIONS

A process for evaporation of TaNx by electron beam evaporation has been developed, in spite of numerous challenges due to the very high melting point of tantalum. There are process and performance limitations with thin film resistors that are deposited by sputtering and patterned by the dielectric assisted lift-off technique. With an evaporated TaNx film, a standard lift-off process can be applied to enable better control of structure line width. However, it is difficult to control film resistance without an in-situ film resistance monitor in the evaporator, and control TCR by maintaining low level of oxygen in the film. With additional developments, these can be addressed or minimized.

REFERENCES

[1] H.B. Nie et al., "Structural and electrical properties of tantalum nitride thin films fabricated by using reactive radio frequency magnetron sputtering", Appl. Phys. A, Materials science and Processing, vol. **73**, p. 229 (2001).

[2] Work done with Evatec.

ACRONYMS

TFR: Thin Film Resistor
DAL: Dielectric Assisted Lift Off
TCR: Thermal Coefficient of Resistance
FIB: Focused Ion Beam
DOE: Design of Experiments

9