An E-beam Evaporation Deposition Process for Tantalum Nitride Thin Film Resistors

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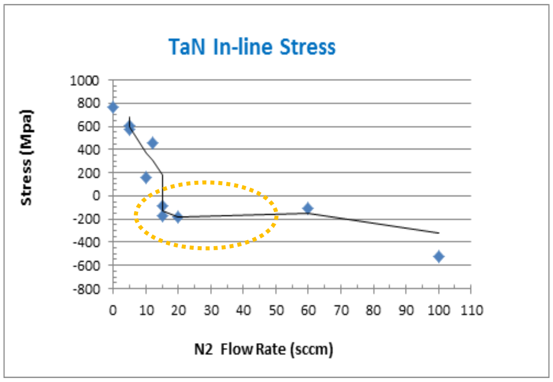
Abstract

Thin layers of Ta_xN_{1-x}, usually denoted as TaN, 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 [H.B. Nie et. al]. 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. Deposition of the TaN film by evaporation and utilizing the standard lift off process, allows for better definition of the thin film resistor and circumvents the challenges of a sputtered resistor. 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. This paper describes an alternative method for depositing Tax film by means of electron beam evaporation with nitrogen incorporation in the process chamber. By optimizing the input parameters, a stable TaN film can be achieved matching the desired properties of the sputtered TaN resistor.

Standard e-beam evaporators are used for the TaN 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), (b) show details of the inline data for particles, Rs and stress as a

function of N_2 flow with a TaN thickness of 250Å. The results of the DOE indicated that the composition of the TaN film is 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. Under these conditions, the composition of the film can be controlled easily with a resulting film that meets the properties needed for TFR.



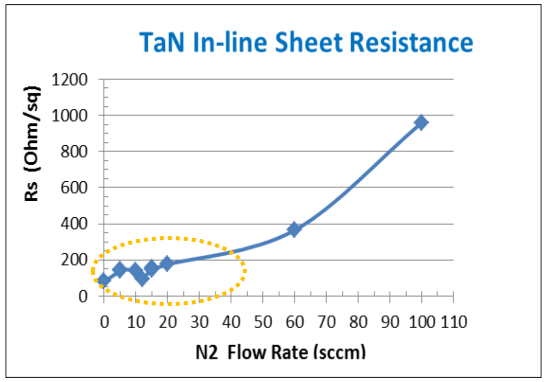


Figure 1 (a) TaN film stress (b) TaN film sheet resistance

In addition to the Rs and stress data, characterization of the evaporated TaN film was also collected from the following: optical inspection, EDX, FIB cross section, TCR, and overall thermal stability. Visual inspection of the evaporated TaN film was comparable to the sputtered TaN. EDX was performed to confirm the composition of the film with both tantalum and nitride peaks being identified. FIB cross sections provided validation of the target thickness. Samples were then tested for TCR which is more negative than the typical -100 to -130 ppm target range. 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 sheet resistance change through the interconnect process. 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. Sheet resistance of 50 ohms/sq. is achieved with a film of 550 A.

Reference

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)