Sputtered TiW/W Emitter Contact Stack Design in Terahertz Bipolar Transistors

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Abstract:

The conditions under which the emitter contact metal of a mesa-type bipolar transistor is sputter-deposited influence the contact's stress and sheet resistance, which in turn affect the transistor's structural stability and bandwidth, respectively. Through aggressive scaling of emitter dimensions, emitter-base and base-collector junction capacitances are reduced and high radio frequency (RF) bandwidth can be realized [1]; however, this scaling results in a high aspect ratio emitter contact, which requires low stress for structural stability.

The purpose of this project was to develop a recipe for use in a sputtering tool that satisfied both the low stress and low resistance requirements for the contact. It has been found that the most significant factors in determining the characteristics of interest of the resultant sputtered film are the working pressure of the deposition chamber and the working temperature of the substrate. The desired resistance has been obtained via low working pressure and elevated working temperature, while preliminary experiments indicate the desired stress can be obtained via compensation between the titanium-tungsten (TiW) alloy and tungsten (W) layers of the emitter contact. By using tensile stress in the tungsten layer and compressive stress in the TiW alloy layer, fabrication of bipolar transistors with bandwidths in excess of one terahertz was possible.

Experimental Procedure:

The sputtering system used for depositions of W and TiW onto the substrate allows control over a multitude of variables. To achieve high deposition rates, the substrate was placed as close to the sputtering gun as possible and the substrate was rotated to provide uniform film deposition. Argon was used as the sputtering process gas.

The effects of varying working pressure, working temperature, and gas flow rate were investigated to determine their effects on the resultant stress and resistance of the sputtered film. The stress was determined by using an optical measurement system to find the curvature of the wafer before and after metal deposition. Sheet resistance was measured using a four-point probe measurement system. To calibrate the deposition rate to achieve the proper film thickness, cross-sectional images of the deposited films were taken using a scanning electron microscope (SEM); very small standard deviations in four-point resistance measurements were used as an indicator of uniform film thickness.

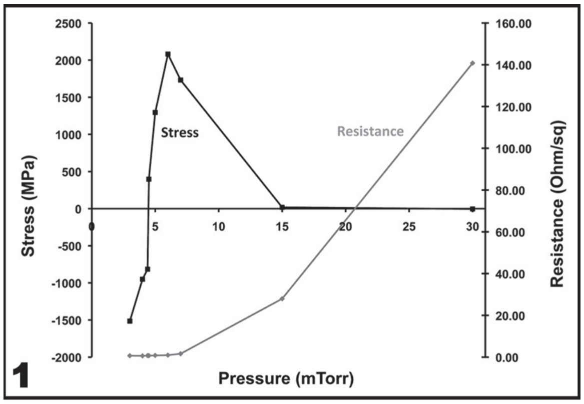
Properties of W films were characterized before those of the TiW alloy. This was because the alloy was 10% Ti, 90% W; therefore, its characteristics were highly similar to that of pure tungsten.

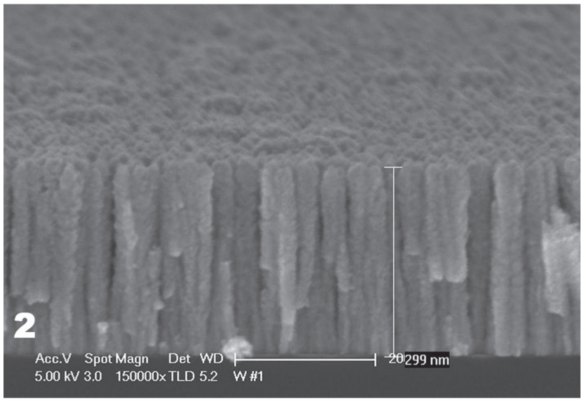
Results:

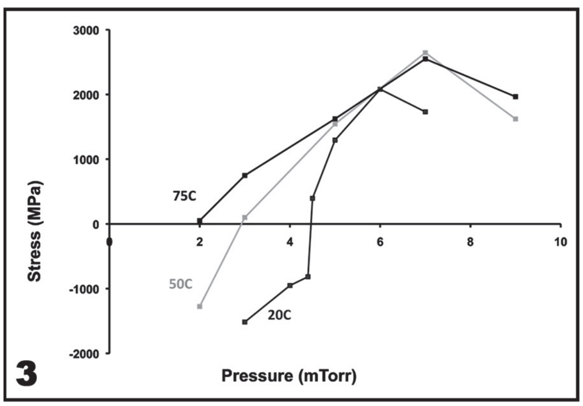
Working pressure was shown to affect the stress of the deposited tungsten film as shown in Figure 1, which followed predicted trends [2]. The resistance of the deposited film was above tolerance in the low stress region seen at higher pressures, while the zero stress transition point seen at lower pressures proved to be too unstable to yield repeatable results. Cross-sectional images taken with an SEM revealed that the low-stress, high-resistance region at higher pressures was caused by high stresses in the deposited film, breaking the film into columnar growth (see Figure 2). This columnar growth caused the film to appear low-stress while also giving it high resistance.

The working temperature was shown to affect the stress of the deposited tungsten film as shown in Figure 3. As temperature increased, the magnitude of the stress curve's slope decreased; this proved to be useful in controlling the fluctuations in stress caused by machine drift, yielding more stable points for later use.

Gas flow rate was shown to be instrumental in obtaining repeatable results, with a gas flow rate in the middle of the sputter tool's operational range proving more stable than rates situated at either extreme. This was an issue related to







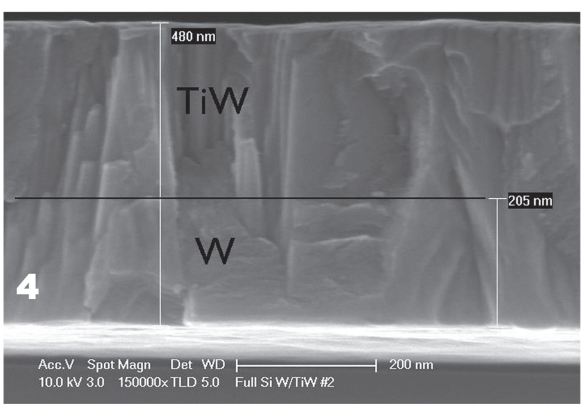


Figure 1: Tungsten stress and sheet resistance vs. pressure.

Figure 2: Columnar tungsten film growth.

Figure 3: Tungsten stress due to temperature.

Figure 4: Tungsten / titanium-tungsten film.

the mass flow controller unit; as such, the effects of gas flow rate on sputtered film stress and resistance were not fully characterized.

Therefore, the ideal sputtering deposition conditions were found to be at lower pressures, elevated temperatures, and mid-range gas flow rate. Despite the higher level of control and repeatability afforded by these conditions, the compressive-tensile stress transition point still proved difficult to obtain consistently due to the differences in the microstructure of film growth between compressive and tensile films [3]. The solution to this problem was to deposit the W film such that it was slightly tensile, then deposit the TiW alloy film such that it was slightly compressive. The equal and opposite stresses canceled each other out, resulting in a low-stress film. An example of this technique can be seen in Figure 4, which shows a tungsten and TiW alloy film with low stress, low resistivity, and desired thickness.

Future Work:

Some work must still be done to ensure repeatability and reliability of the overall emitter contact fabrication process before it can be incorporated into the transistor fabrication process. Transistors made using this metal-contact process can operate at frequencies in the terahertz range, enabling high-data-rate wireless communications and highly-efficient digital-to-analog and analog-to-digital converters.

Acknowledgements:

I would like to thank the following: Dr. Mark Rodwell, for accepting me onto his research group; Evan Lobisser, for being an all-around excellent mentor; the other members of my research group, for being patient, helpful, and friendly; the cleanroom staff, for training, assistance, and recommendations; Angela Berenstein, for her coordinating skills and unbounded cheerfulness; and the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program and the National Science Foundation for funding this entire endeavor.

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