Measurement and Management of Thin Film Stresses

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Abstract:

Metallization is a crucial step in microelectronic device fabrication. Stress in metal thin films causes yield and reliability problems. In severe cases, improperly controlled stress results in delamination of the metal film. This project systematically studied the intrinsic stresses in titanium tungsten (TiW) and gold (Au) films as a function of deposition conditions. The metal films were deposited on 2-inch <001> silicon wafers. Measuring the change in radius of curvature of the Si wafer after metal deposition derived stresses and the thickness of the metal film deposited. This information is important towards controlling the stresses in the metal film to minimize the shear force at the metal/semiconductor interface, improving device reliability.

Introduction:

Light emitting diodes (LEDs) and other microelectronic devices use is widespread. The creation of this nanotechnology involves depositing very thin layers of different materials. When depositing these layers, in-plane stresses are often generated, which can have a significant effect on the devices' performance and reliability [1]. There are two sources of stress: thermal and intrinsic. Thermal stress is generated by the difference in coefficient of thermal expansion (CTE) between different materials [2]. In single crystalline thin films, intrinsic stress is generated when the films and substrate have different lattice parameters. In amorphous or nanocrystalline films in which the film/film and film/substrate interfaces aren't coherent, the packing density of thin films determines intrinsic stress. The effect of interface bonding between films and substrates is negligible. Once the shear force resulting from the film stress exceeds the bonding strength between films or substrates, delamination occurs [3]. In order to have reliable devices, film stress must be managed.

Sputter deposition of Au at 5 mT can create a 0.30.5 µm layer over 10 minutes, while the more efficient electroplating process can add up to 2 µm of film in 20 minutes. Electroplating—which takes place in an isolated bath—only coats the conductive wafer, while sputtering coats the entire chamber. Because electroplating is done at 55°C, thermal considerations are important—which are calculated by the following equation

$$\sigma_f = (\alpha_{Tf} - \alpha_{Ts})(T_s - T_0)(Y')$$

where α is the coefficient of thermal expansion of the substrate and film, respectively, T is the temperature before and after processing, and Y' is the biaxial elastic modulus.

$$\sigma = \frac{E * t_s^2}{(1-\nu) * t_f} * \left(\frac{1}{R} - \frac{1}{R_o}\right)$$

Figure 1: Stoney equation, used to calculate stress.

Experimental Procedure:

In this work, we systematically studied the thin film stresses in sputtered TiW and Au as a function of sputtering pressure, and electroplated Au as a function of electroplating current. The Stoney equation (Figure 1) is used to calculate the stress, where *E* is Young's Modulus, v is Poisson's ratio [4], and t_s and t_f are the thicknesses of the substrate and thin film, respectively. R_0 and *R* are the radius of curvatures (RoC) of the substrate before and after deposition, respectively. Since both sputtered and electroplated film are amorphous or nanocrystalline, the intrinsic stresses aren't dependent on the underlying substrate.

We used double-side polished <001> silicon substrates for this study since its material properties are well understood. The results are applicable to other substrates, such as gallium nitride.

The radius of curvature of the wafer was measured using a Tencor Flexus laser scanning instrument. The sputter deposition was performed using a custom built AJA ATC 2200-V DC magnetron sputtering system. The Au electroplating was performed using a Technic SEMCON 1000 plating system. Film thickness was measured by lithographically patterning the blanket-deposited film and etching trenches through the film to the substrate. A step profilometer was used to measure the step height of the trench, obtaining film thickness.

Results and Discussion:

For TiW deposition, sputter pressures ranged from 2 mT Ar to 5 mT Ar. The depositions at each pressure were performed at 300W DC power for 10 mins. Stresses in the TiW film as a function of sputtering, calculated using the Stoney equation, are shown in Figure 2. The stress changed from compressive to tensile as the pressure increased. At higher pressures, there were more gas phase collisions before the deposition, reducing the kinetic energy of the atoms colliding with the substrate.

While TiW has good adhesion to many substrates, it's not stable and oxidizes easily. TiW/Au systems are often used in industry where the Au serves as a passivation layer. The Au sputter pressure is fixed at 5 mT. Figure 3 shows the overall stress in the TiW/Au calculated from the difference in RoC between a fresh Si wafer and a Si wafer with TiW/Au.

Electroplating was also investigated due to its industrial applications. Figure 4 shows stress of electroplating on a wafer as a function of current density, both with and without adjustments due to CTE. Because the stress is so low, it's determined that it's due only to the thermal expansion between electroplating and measurement times.

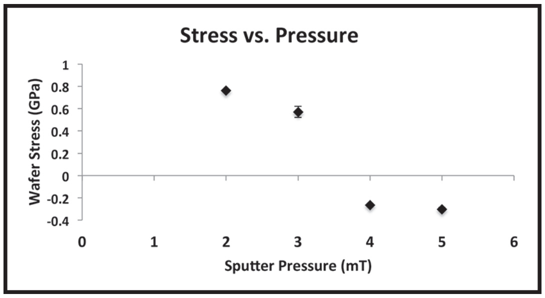

Figure 2: TiW stress due to pressure changes.

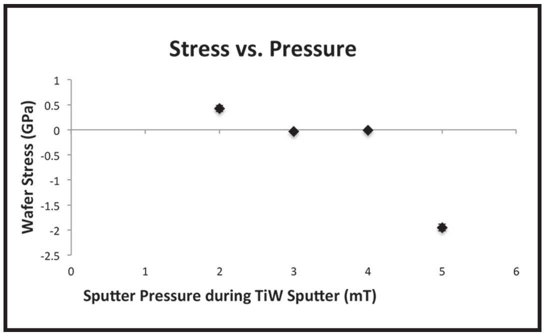

Figure 3: Stress change of sputtered Au as a function of different TiW pressures.

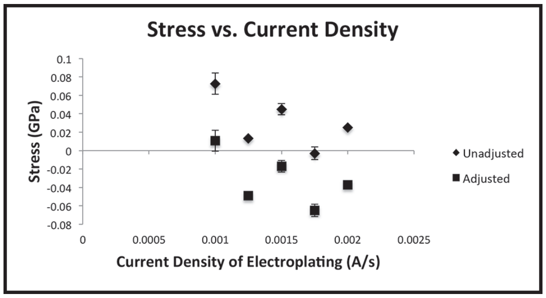

Figure 4: Stress vs. electroplating current density without adjustment for CTE and with adjustment for CTE.

Conclusions:

Electroplating stress is due to CTE mismatch and is lower than the stress due to sputtering. Though the stress due to electroplating is low, shear force is high due to the thickness of the film. Sputter deposition conditions had a large effect on the stress. While this information is vital to minimize the stress at metal/semiconductor interfaces and increase reliability, future research should investigate more sputter deposition pressures and temperatures.

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