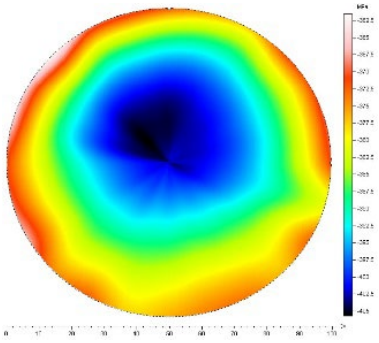
KLA INSTRUMENTS

3D Stress Measurements using KLA Instruments™ Stylus-Based Profilers

HRP®-Series and Tencor® P-Series Profilers



Introduction

As devices continue to shrink in size, bowing of the substrate can present problems with tolerances that are critical to proper device functionality. In semiconductors, film stress is a direct cause of film delamination and has negative influences on device performance and reliability. Stress is also a critical parameter that should be monitored for the photovoltaic and hard disk drive industries.

Monitoring stress due to film deposition is of utmost importance during device manufacturing. At the film level, two main failure mechanisms occur due to film stress. The first is film adhesion, which causes the creation of crystalline defects and surface deformations that limit the growth of thicker films. Second, large stresses in strongly adhered films can cause film peeling[1], rendering the film useless. At the device level, stress formation rarely ever causes instant yield loss; instead, it reduces the product lifetime. This lifetime loss is a major problem costing logic, memory, and solar cell manufacturers millions of dollars annually in product service and warranties.

By combining well established theories and models of stress calculation with the accuracy of the Tencor® P-17/170 and HRP® stylus-based profilers, 3D Stress can be used to provide accurate thin film stress measurements independent of the substrate or film material and surface characteristics. This key advantage is significant when compared to optical-based stress measurement systems, whose capabilities are limited to specific material types.

Background

The first KLA stress measurement tool calculated film stress based on one center point and one side point. As processes evolved and became more complex, Flexus developed a scanning tool that measured points across the entire substrate. Current device evolution dictates that film layers will get thinner. As this happens, a single 2D cross-section does not yield information representative of the entire surface, and 3D metrology is needed. The 3D Stress option available on the newest generation KLA Instruments stylus profilers allow for high resolution analysis of film stress over the entire substrate. Stress is an indirect measurement; it occurs as a result of thermal expansion differences between the film and substrate[2]. These differences cause the substrate to bow, thus changing its original shape. The substrate's Radius of Curvature can be obtained by measuring the bow and deflection of the substrate. By comparing the change in the Radius of Curvature before and after film deposition, it is possible to calculate the stress using the cantilever beam technique developed by G. Gerald Stoney for the measurement of thin film stress:

$$\sigma = \frac{1}{6R}\frac{E}{(1-\upsilon)}\frac{t_s^2}{t_f} = \frac{1}{6}\frac{E}{(1-\upsilon)}\frac{t_s^2}{t_f}\left[\frac{1}{Rf} - \frac{1}{Rs}\right]$$

where

$E/(1-\upsilon)$ = wafer elastic constant

t_s = wafer thickness

t_f = film thickness

R = radius of curvature (RoC)

R_s = radius of curvature of the substrate

R_f = radius of curvature of substrate with film

E = Young's modulus for the substrate

υ = Poisson's ratio

Stoney developed this technique in 1909, and the equation has proven a reliable measure of stress for most film applications.

3D Stress Measurement Technique

All stress measurements should be performed using either a 3-point chuck, shown in Figure 1, or a universal chuck with stress pins, to remove the influence of the stage itself. Prior to the first scan, the profiler performs an automated stage level to remove any unnecessary leveling error. The system then takes a series of radial scans across the substrate diameter, rotating by a user-defined increment between each scan. The total number of scans taken is equal to 180/N, where N is the Radial Interval, in degrees. The length of the diameter scans is

automatically computed as 80% of the substrate diameter as specified in the Stress Recipe.

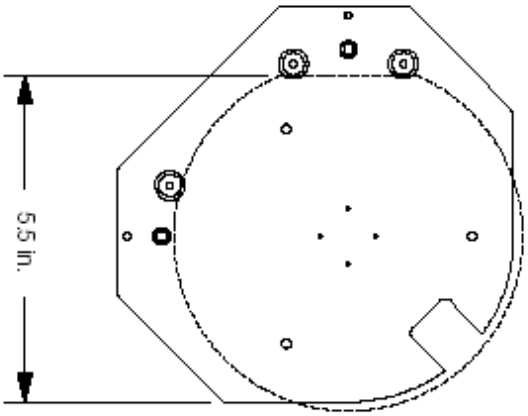


Figure 1. 6-inch (150mm) flat or square substrate locator for stress measurements.

Additionally, the Radial Interval is variable, so that the user can optimize lateral resolution and throughput. To address fast-paced technology development, the Stress Recipe offers the user the ability to add new Wafer Elastic Constants into the Substrate Database, which is shown in Figure 2.

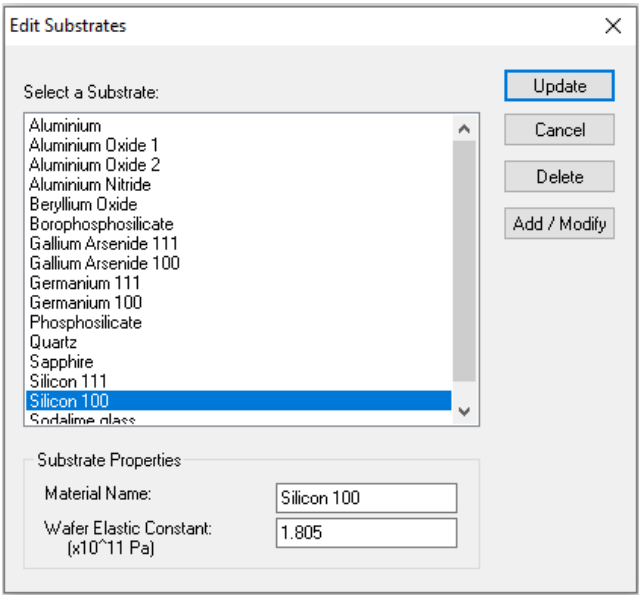


Figure 2. Substrate Database, allowing the user to enter new substrates and their properties.

Once the pre-deposition and post-deposition scans have been obtained, the pre-deposition data is subtracted from the post-deposition data and a difference curve is obtained. This curve is then fit using a fifth order polynomial, leveled using the center one-third of the curve, and the resulting Radius of Curvature is determined. Using the Radius of Curvature value, the Stress is then computed.

3D Stress Data Analysis

From the user's viewpoint, stress is calculated in an intuitive and straightforward method: simply select the two data sets for comparison and enter the film thickness.

The data analysis portion is performed by Apex Advanced Analysis Software. Within the Apex report, the user can examine the Average, Center, and Maximum stresses and radii. For increased flexibility, localized stresses can also be examined through user-defined cursors. Data rendering includes the Stress Map, Difference Map, and Curvature Map, with the Stress Map shown in Figure 3.

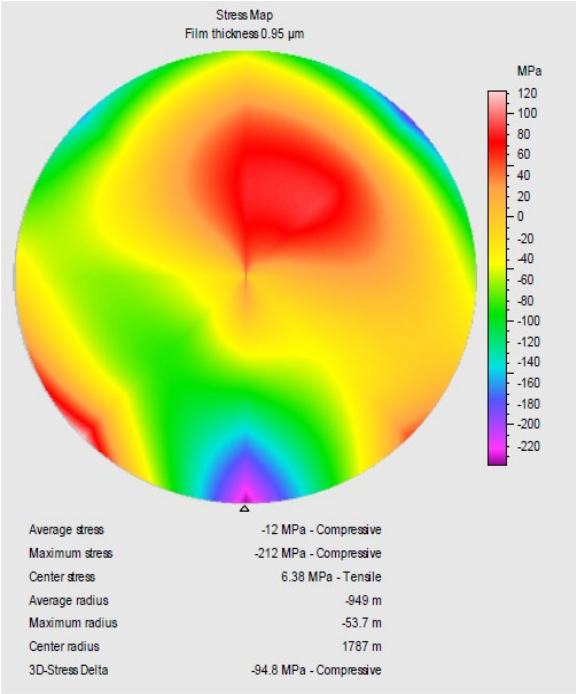


Figure 3. The Stress Map as rendered by Apex, based on a 1µm thick Silicon film on a Germanium substrate.

Stress Measurement Resolution

Stress resolution is dependent on three parameters: the vertical range of the profiler, the elastic properties of the substrate, and the thickness of the substrate and film. For the P-17/170, the vertical range depends on the head used, with a range of 6.5-1048µm. The HRP, on the other hand, can vary between 3.25µm and 131µm in vertical travel.

The minimum resolution is based on the optical flatness used (λ/3), which translates to a minimum bow of 500Å. The elastic properties of the substrate differ depending on the substrate used. Typically, these vary between 1 - 5x10^{11}Pa (100 - 500GPa). Finally, film and substrate thickness are important for determining stress resolution. Typical values for substrate thickness are on the order of hundreds of microns, while film thickness may vary between 50Å and 2µm. Using these parameters, we can now determine the stress resolution, as shown in Table 1.

Table 1. Stress resolution for a range of substrates, assuming substrate thickness to be 500µm and over a 100mm section.

	Aluminum σ_{min}-σ_{max} **(MPa)**	**Si (100)** σ_{min}-σ_{max} **(MPa)**	**SiC** σ_{min}-σ_{max} **(MPa)**
Tencor P-17/170	17 – 1763	30 – 3090	79 – 8160
HRP-260	17 - 225	30 – 394	79 – 1041

Conclusions

The Tencor P-17/170 and HRP-Series have the capability to analyze 3D stress through a fully automated method. The system incorporates a fifth order polynomial fit to accurately calculate radius, and advanced algorithms to calculate stress. The flexibility of the stress recipes makes the profilers ideal for an R&D environment, and the automation makes the 3D stress measurement production-worthy. Since the profilers are stylus-based metrology systems, the measurements are not influenced by material transparency. With its intuitive operation and its flexible analysis routines, the KLA Instruments profilometers offer users the ability to analyze global or localized stresses, which cannot be done using simple 2D Stress routines.

References

1. Stephen A. Campbell, The Science and Engineering of Microelectronic Fabrication, Oxford University Press, New York, 1996.
2. S. Wolf and R.N. Tauber, Silicon Processing for the VLSI Era, Volume 1, 1986.

KLA SERVICES
From tool installation and system optimization to productivity enhancements and global supply chain management, KLA Services is a trusted partner to customers around the world -- delivering an unrivaled experience focused on maximizing tool performance and availability.

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