Application Note #9

FILM STRESS MEASUREMENT USING THE OPTICAL CANTILEVER BEAM TECHNIQUE

INTRODUCTION

Film stress measurements using the optical cantilever beam technique require accurate measurements of the substrate shape, before and after film deposition, since stress is proportional to the substrate curvature change. [Toho's Applications Note #7 describes in detail the equation (first developed by Stoney1) used for calculating the film stress based on the curvature change.] The optical cantilever beam technique utilizes a laser beam which is scanned across the substrate (typically a silicon wafer). The slope (angle) of the substrate surface, q, is measured by monitoring the beam reflection angle along the scan direction, x. The curvature, 1/R, is simply the derivative of the angle with distance,

$$(1) \quad 1/R = \partial\theta/\partial x$$

The substrate deflection, y, is obtained by integrating the slope with distance,

$$(2) \quad y = \int_0^X \theta \, dx$$

This application note discusses improvements in the measurement of the substrate slope.

EFFECT OF SUBSTRATE TILT ON THE MEASUREMENTS

Figure 1a shows a perfectly flat horizontal substrate measured using the cantilever beam technique. As illustrated, the reflected laser beam from such a substrate (solid lines in Fig. 1a) will impinge on the detector at exactly the same point all along the scan. In other words, the substrate angles corresponding to points A1 and A2 on the detector are identical and the angle vs. distance graph (shown in Fig. 1b) will be a horizontal line. According to equation (1), the substrate curvature is zero since it is proportional to the slope of the line. A zero curvature means, of course, a flat sample.

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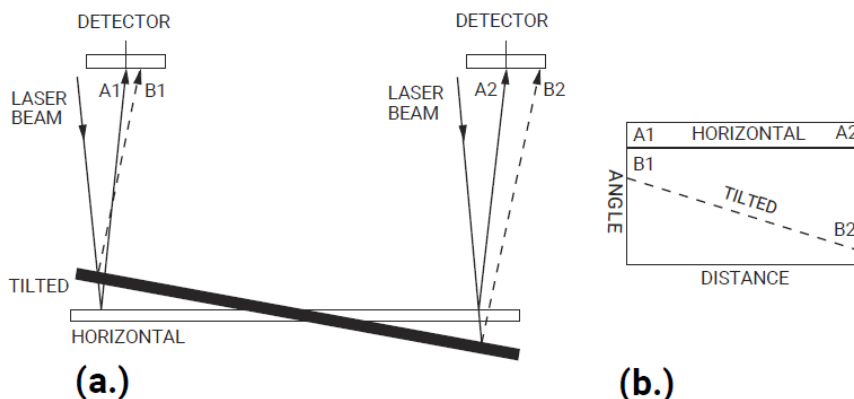

Figure 1. Optical cantilever beam technique measurements of a tilted sample. Note that a clockwise tilt results in an apparent negative radius of curvature measurement of a perfectly flat sample.

Now let us consider a tilted sample. For example, a sample with non parallel faces or a sample resting on a heater whose planarity can change during the heating cycle. Figure 1a shows such a tilted sample; still perfectly flat, but tilted clockwise, which we will define as a negative tilt. When scanned with the same laser beam, the reflected beams will impinge at points B1 and B2 on the detector since the substrate will now intercept the incoming laser beam at different locations. The difference between points B1 and B2 will depend on the difference of the substrate surface height. Figure 1b shows that the angle vs. distance plot is no longer horizontal. The line now has a negative slope, and if no allowance is made for the tilt, the apparent curvature calculated from the slope is negative. So although the substrate is flat, a curvature is measured.

A NEW MEASUREMENT ALGORITHM

A relatively flat substrate (radius of curvature of 1750 m) was measured as a function of tilt using the regular algorithm. The radius of curvature is plotted against tilt, as shown by the squares in Figure 2. It is readily seen that the measured curvature changes considerably with the tilt (a change of approximately 0.215 1/m/per radian of tilt). The effect of tilt on the measured radius of curvature was calculated and is represented by the solid line in Figure 2. As can be seen, the curvature measurements agree very well with the prediction.

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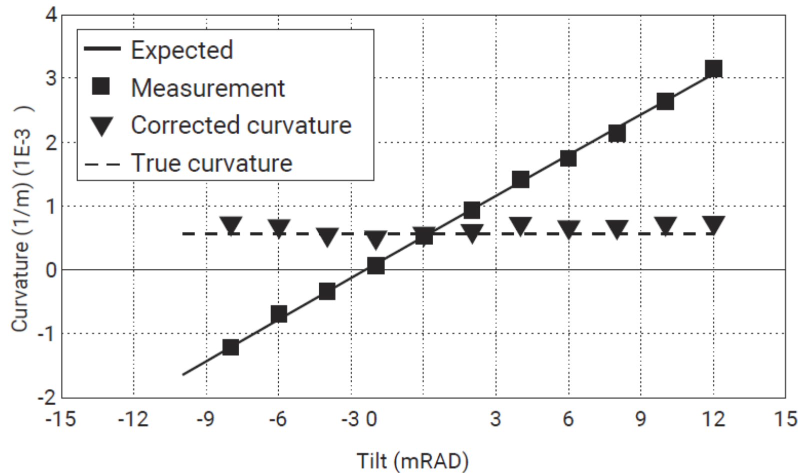

Figure 2. Apparent and corrected curvatures of a flat sample as a function of sample tilt. The square points are the measured curvatures without correction, the triangles represent the corrected curvatures with the improved algorithm.

An improved algorithm has been developed for calculating the reflection angle and thereby correcting the curvature. This algorithm takes into account the fact that the apparent reflection angle is a function of the substrate surface height over the horizontal plane. Using this algorithm, the curvatures were recalculated and the corrected curvatures (triangles) are plotted in Figure 2 for comparison. All the curvatures straddle the true curvature—1/1750 m (dashed line)—with very little scatter. The relation between curvature and stress, σ , for a 730 µm thick 100 wafer (typical 200 mm wafer) with a 10000Å film, is σ = 16000/R, where the stress is in MPa and R in meters. A 0.01 radian substrate tilt corresponds to an error of 0.00215 1/m, which amounts to an error of about 34 MPa in stress. This error is essentially eliminated by the use of the improved algorithm.

EFFECT OF SUBSTRATE CURVATURE ON THE LOCAL CURVATURE MEASUREMENTS

The effect of surface height on the measured angle is apparent on curved samples even if they rest horizontally. Consider a curved sample such as that depicted in Figure 3a. If this sample has a constant positive radius of curvature, the surface angle vs. distance plot should be a straight line crossing the zero at point A, as shown by the solid line in Figure 3b. Since the substrate is curved, the reflected beam will actually impinge on the detector at point B to the right of the detector zero, corresponding a small apparent negative deviation in the surface angle. The apparent angle vs. distance plot (dashed line on Fig. 3b) will therefore be curved. While the average curvature (the aver-age slope

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of the lines) will be about the same for the measured and expect-ed lines, the local curvature will be different. The slope of the measured line changes from shallow to steep as we proceed with the scan, showing a non-uniform curvature with an increasing stress as we proceed from left to right.

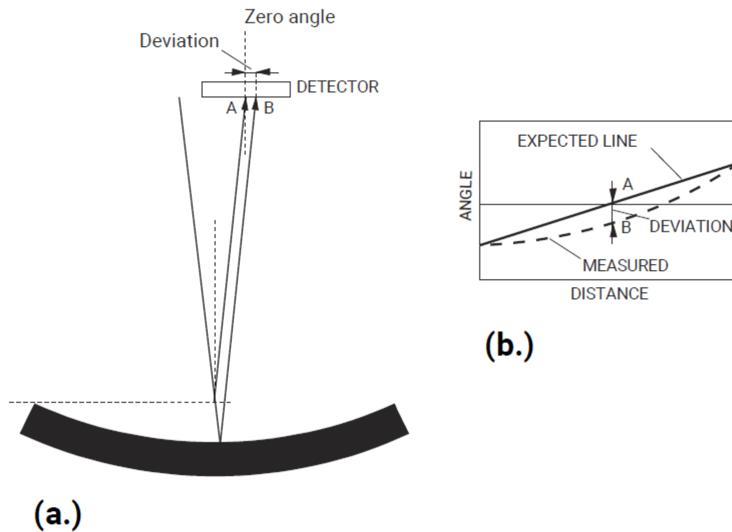

Figure 3. Apparent non-uniform curvature measurements. The horizontal portion of a curved sample reflects the beam slightly to the left creating a non linear angle vs. distance line. The slope of this line represents the sample curvature which in this case will be construed to be non-uniform.

This change in local stress can be seen in Figure 4. The local apparent curvature of a 200 mm diameter wafer with a uniform curvature of 20 m was calculated, and the curvature was translated into stress (for a 10000Å film on 730 μm 100 Si) and plotted as squares. The expected stress corresponding to the uniform curvature was 802 MPa, but the non-uniformity for the measured, non-corrected stress ranged between 788 MPa on the left to 815 MPa on the right— a 27 MPa increase. This corresponds to a change of about ±13.5/802 = ±1.6%. When the improved algorithm was applied, the local curvature was recalculated and the corresponding stress, plotted as triangles in Figure 4, showed a virtual uniform stress as expected.

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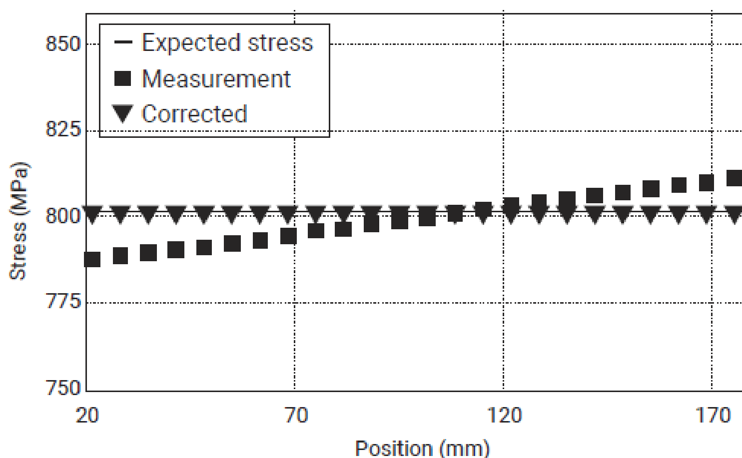

Figure 4. Local stress of a 200 mm wafer with a 20 m radius of curvature. The noncorrected measured stress is non-uniform. The corrected stress (squares) is uniform.

CONCLUSION

An improved algorithm was developed to correct for apparent reflection angle changes due to substrate height differences. The algorithm corrects errors in the measured angles due to both sample tilt and curvature.

REFERENCES

1. G.G. Stoney, Proc. Roy. Soc., A82, 172 (1909)

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