9 THEORY OF OPERATION

This chapter describes the theory of operation of the Tencor FLX-2320, and the equations used to calculate the diffusion, expansion, and elastic coefficients.

The FLX-2320 measures the changes in the radius of curvature of a substrate caused by deposition of a stressed thin film. The stress in the thin film is calculated from the radius of curvature of the substrate using the following equation:

$$\sigma = \frac{Eh^2}{(1-v)\,6Rt}$$

where

$\frac{E}{(1-v)}$ is the biaxial elastic modulus of the substrate (1.805E11 Pa for 100 silicon wafers)

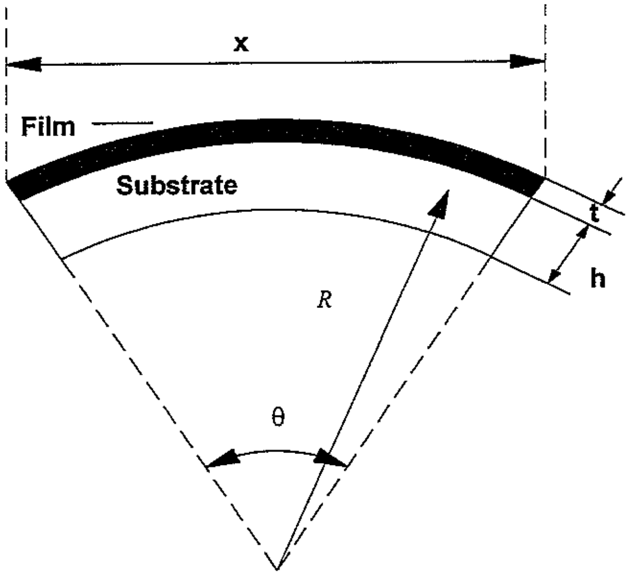
h is the substrate thickness (m)

t is the film thickness (m)

R is the substrate radius of curvature (m)

σ is the average film stress (Pa)

The following picture is a schematic drawing of substrate deformed to radius R by the deposition of a film. In this case, the film is under compression deforming the substrate.



To illustrate the stress calculation, suppose that a 100 mm silicon wafer, 525 μm thick, is deformed to a radius of 30 m by the deposition of a surface film of thickness 7500Å. Since the biaxial elastic modulus of 100 silicon is 1.802×10^{11} Pa, the stress calculated according to Equation 1 is

$$\sigma = \frac{1.805 \times 10^{11} \times (525 \times 10^{-6})^2}{(6 \times 30 \times 7500 \times 10^{-10})} = 3.69 \times 10^{8} Pa = 369 MPa$$

The average radius R_1 of the bare substrate is obtained by measuring θ as a function of x and performing a linear regression. $\frac{1}{R_1}$ equals half the slope obtained from the linear regression. After the film is deposited, the substrate deforms to a new radius R_2. Since the stress is proportional to $\frac{1}{R}$, it follows that

$$\frac{1}{R} = \frac{1}{R_2} - \frac{1}{R_1}$$

or

$$R = \frac{1}{\left(\frac{1}{R_2} - \frac{1}{R_1}\right)} = \frac{(R_1 R_2)}{(R_1 - R_2)}$$

The thin film stress is now determined by using the effective radius *R* in the equation described above. To calculate the stress, the substrate radius must be measured before and after film deposition.

Single wavelength machines can run into destructive interference from transparent films such as silicon nitride. The Dual Wavelength system solves this problem by choosing automatically between two lasers and using the stronger reflection for measurement.

DIFFUSION COEFFICIENT CALCULATION

The diffusion coefficient is calculated by the least square fitting to the diffusion equation into a finite film:

$$\sigma = \sigma_0 - \Delta\sigma\left[1 - \left(\frac{8}{\pi^2}\right)\sum_{1}^{\infty}\left(\frac{1}{(2n-1)}\right)^2 \exp-\left(\frac{(1-2n)^2}{4L^2}\pi^2 Dt\right)\right]$$

where
σ is the stress at time t
σ_0 is the initial stress
$\Delta\sigma$ is the total stress change after completion
n is a running index from 1 to infinity
L is the film thickness
D is the diffusion coefficient
t is the time

For details on using this option, see Section 6.3, "Displaying Graphs."

ELASTIC AND EXPANSION COEFFICIENT CALCULATION

The stress change with temperature in the elastic range is governed by the following equation:

$$\frac{d\sigma}{dT} = \left(\frac{E}{1-\nu}\right)_f(\alpha_s - \alpha_f)$$

where
$\frac{d\sigma}{dT}$ is the derivative of stress versus temperature
$\left(\frac{E}{1-\nu}\right)_f$ is the biaxial modulus of the film
α_s is the substrate thermal expansion coefficient
α_f is the film thermal expansion coefficient

The above equation has two unknowns—α_f and $\left(\frac{E}{1-\nu}\right)_f$. To solve these, two temperature cycles are done with two different substrates and the software solves two equations. For details on using this option, see Section 7.3, "Elastic and Expansion Coefficient Calculation."