Thick film stress measurement

Application Note

INTRODUCTION

It is quite common to measure thin film stress by the cantilever beam technique. In most cases the film thickness is less than 1/100 of the substrate thickness. However, in some cases it is desirable to measure the stress in much thicker films. Stress measurement calculations for thin films can be modified for use in thick film applications resulting in correction factors based on the film/substrate thickness ratio.

BACKGROUND

For films that are much thinner than the substrate, the film stress is calculated by observing the radius of curvature of the substrate created by the film:

$$(1)\ \sigma_{tf} = E_s h^2/6Rt$$

where,

σ_{tf} = *Film Stress. (Pa)*
E_s = *E/(1 - υ) - Substrate biaxial elastic modulus (E is the substrate Young's modulus, υ is Poisson's ratio). (Pa)*
h = *Substrate thickness. (m)*
R = *Substrate radius of curvature. (m)*
t = *Film thickness. (m)*

ADJUSTMENTS FOR THICK FILMS

One example of a thick film stress measurement is the stress in a silicon die attached to a package or a lead frame. The "film" is the silicon die itself and the "substrate" is the package or the lead frame. The film/substrate ratio in this case can be as high as 1/2. The stress distribution in the thick film and the substrate is schematically shown in Figure 1. A film in compression is shown on a substrate ($\sigma < 0$) with an average compression in the film of σ_0. The stress in the substrate ranges from a maximum tension of σ_m adjacent to the film, to a maximum compression on the backside.

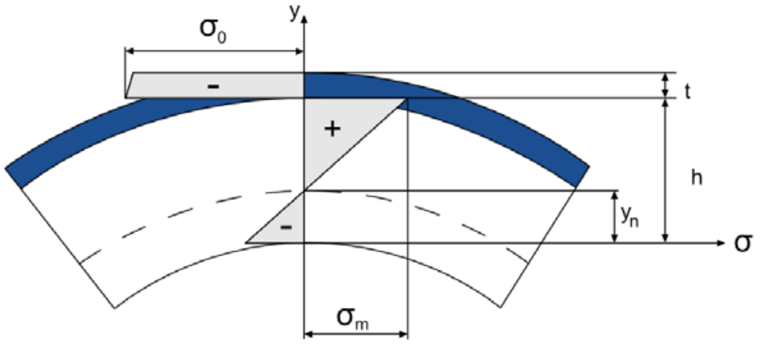

Figure 1. Stress distribution in a thick film and substrate.

The equation for the exact solution for thick film stress is,

(2) $\sigma_0 = \sigma_{tf}\ (1+(E_f/E_s)(t/h)^3)\ /\ (1+t/h)$

where, E_f is equal to the film's biaxial modulus. The maximum substrate stress is calculated by,

(3) $\sigma_0 = \sigma_{tf}$
$\sigma_m = -4\sigma_{tf}\ t/h$

Finally, the zero-stress axis of the substrate is given by,

(4) $\sigma_0 = \sigma_{tf}$
$y_n = h/3$

When measuring thin films, where the thickness of the film is substantially less than the thickness of the substrate, Equation (2) reduces to $\sigma_0 = \sigma_{tf}$, in other words identical to Equation (1), as would be expected. In addition, Equation (3) would show a maximum stress in the substrate of $\sigma_m = -3\sigma_{tf}\ t/h$ and the zero-stress axis position would be at $y_n = h/3$ (not at h/2).

Figure 2 graphs the film stress correction factor ($\sigma_0\ /\ \sigma_{tf}$) as a function of t/h for different film/substrate moduli ratios ($E_f\ /E_s$). Films as thick as 3% of the substrate require very little stress correction. For example, a film 15µm thick on a 525µm silicon substrate will require a correction of,

(5) $\sigma_0/\ \sigma_{tf} = (1 + (15\ /\ 525\ )^3)\ /\ (1 + (15\ /\ 525)) = 0.972$

This amounts to a relatively low stress correction of about 2.8%.

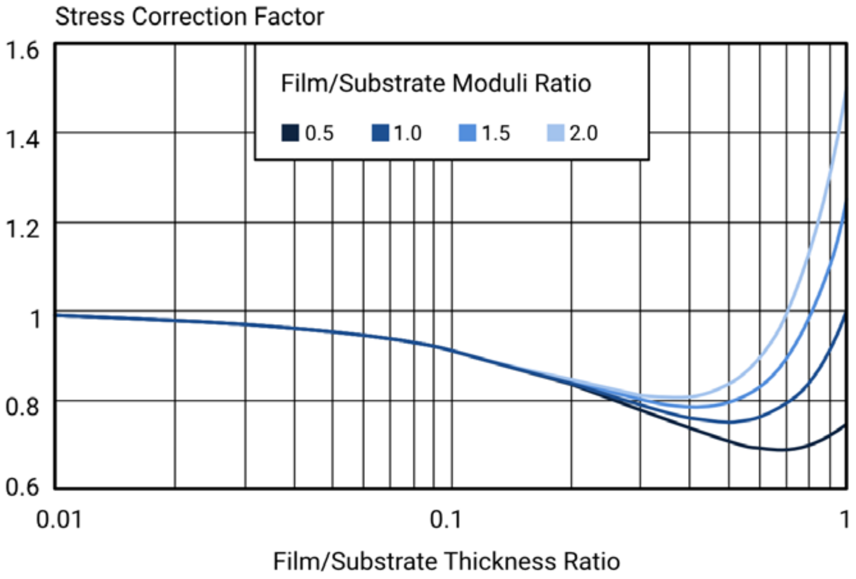

Figure 2. Thick film stress correction factors for different film/substrate thickness ratios.

EXAMPLES

To illustrate the effect of substrate thickness, the stress in a silicon die attached to a copper lead frame was analyzed. The silicon was measured with a Toho FLX Series thin film stress measurement system which uses an optical lever cantilever beam technique. The die attach material thickness and stress were ignored in the analysis and it was assumed that the silicon die behaved as an infinite film.

The silicon die with a thickness of 525µm was attached to a copper lead frame 1000µm thick. The biaxial moduli were $E_f = 1.805 \times 10^{11}$ Pa for the silicon and $E_s = 1.149 \times 10^{11}$ Pa for the lead frame. The correction factor in this case was 0.805. The average silicon stress as a function of temperature was plotted in Figure 3 before and after correction. As shown, the correction for this example lowers the calculated “thin film” stress by about 20%.

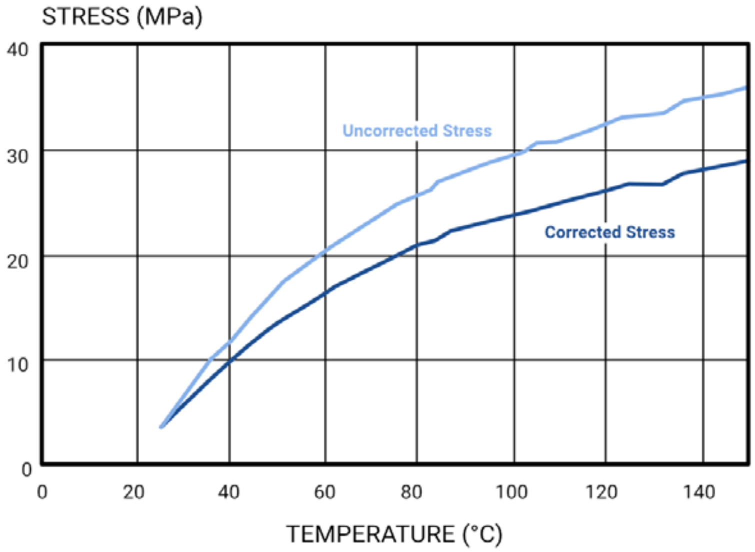

Figure 3. Average stress as a function of temperature for the silicon die on a copper lead frame shows 20% lower corrected stress.

REFERENCES

1. D.S. Gardner and P.A. Flinn, *IEEE Trans. Electron Dev.* 35, 2160 (1988).