# Using optical level technique to measure thin film stress

Wen-Shyrang Liu

## Abstract

Thin film stress can result in shrinkage, broken and other problems during VLSI processing. As a result of such mechanisms, the stress value of each thin film becomes one of important parameters in IC manufacturing. Silicon oxide, silicon nitride and aluminum films were measured by optical level techniques. Thermally grown oxide is found to have compressive stress and it does not have hysteresis behavior. By contrast, a chemical vapor deposited oxide film can have a variable stress amount which depending on film density and moisture content. In addition, the stress in silicon nitride increases with temperature and forms a hysteresis behavior. This hysteresis is caused by the content of hydrogen in films. For aluminum film, its stress depend on thickness, grain sizes and impurity content.

**Keywords:** film stress, optical level technique, chemical vapor deposition.

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# 以雷射光水平技術量測薄膜的應力

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## 摘 要

在大型積體電路製程中，若薄膜的製程技術不當，常會發生薄膜收縮，龜裂等問題，以致造成產品良率下降。因此如何量測薄膜的應力成爲積體電路製程中另一項重要的課題。本文中利用雷射光水平技術量測二氧化矽（SiO2），氮化矽（Si3N4）和金屬鋁（Al）等的薄膜。

**關鍵詞：**薄膜應力、雷射光水平技術、化學氣相沉積。

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# 1. Introduction

To maintain control of the high quality product in semiconductor industry, thin films are usually monitored off-line by different tools to measure physical, electrical and mechanical properties (1). Though the thickness and resistance of film are directly related to the device performance, the amount of stress in a thin film is more important to yield and reliability. In addition, as the IC manufacturing processes grow more and more complicated, the dimensions of devices get smaller and, there is an increasing need for stress data (2). For example, the voids in aluminum are related directly to the stress in the aluminum, it also have relationships direct or indirect to the amount of stress in the inter-metal dielectric (IMD) films stack that cover the aluminum film.

Fundamentally, there are two basic stress measurement techniques. One is measured by substrate deformation; the other is by the film itself. For the film deformation, the most noted one is probably a resistance technique. For the substrate deformation, one of the simplest methods is to measure the radius of the curvature of the sample, then to calculate the stress in films (3).

Normally, stress measurement can be done only at room temperature or in thermal cycling test. In this study, the latter one will be the main object. Because thermal cycling stress testing allows for a more fundamental examination of the mechanical behavior of thin films, such as whether the films have cracking, voiding, lifting, and etc. On the other hand, the stress data obtained during thermal cycling can also be used to determine thermal expansion coefficient, modulus of elasticity, and some activation energies. For example, the thermal expansion coefficient of film and substrate will be different, so changing the sample temperature will impose a thermal component of strain that can lead to high film stresses.

In this study, each sample is placed in a small electrical resistance heating furnace which is controlled by a Eurotherm controller and covered tightly with a quartz transparent plate. The laser scanning system can operate easily during thermal cycling in an inert gas environment to measure the curvature of the sample, and the stress at that temperature can be calculated and displayed on the screen immediately.

# 2. Experiment

The FLX-2320 stress measurement with heater, produced by the KLA/Tensor company, is used to determine the film stress. The advantages of this optical level technique are that it is non-contact measurement and very easy to operate. The processes used to obtain film data were discussed in this section.

Figure 1 is FLX-2320 stress equipment. When a laser is directed at the surface with a known spatial angle, the reflected beam strikes a position sensitive photodiode. By mounting the whole optical assembly on a translation stage, the angle measurement can be easily repeated during a lateral span. The laser beam is scanned across the whole wafer and the reflection angle is measured continuously. That gives the shape of the wafer, as well as the average radius of the wafer.

Like the most equipment companies, it uses the Stoney equation to calculate film stress. Fortunately, both the conditions of film and substrate in the semiconductor industry are satisfied with the three conditions of using Stoney equation, such as the characteristic length dimension of the sample should be more than 100 times the thickness of the film. The following is the Stoney equation:

$$\sigma_{film} = ( E_s / 6(1-V_s ))*( t_s^2 / R* t_f)$$

where $\sigma_{film}$ is the film stress, $E_s / 6(1-V_s )$ the bi-axial elastic modulus of the substrate, $t_s$ and $t_f$ the thickness of the substrate and the film, respectively, and R the net change in radius of curvature due to the film. Thicker film and thinner substrate result in smaller errors. There is a very important point about using the optical level technique to measure stress is that the substrate must be pre-scanned before the film deposited on it.

## 3. Results and discussions

A key to the discussing of stresses in films is to know the roots of each components of stress first. Generally, the total stress in as system is the sum of the intrinsic stress, the thermal stress, and the external stress, but the last component is usually negligible in the thin film system. The manufacturing parameters determined the amounts of intrinsic stresses in films. For example, a CVD deposited film can have a variable components depending upon the film density, moisture content, or residual reactant like hydrogen. The thermal stress results when the film and substrate have the different values of the coefficient of thermal expansion (CTE).

### (1) Silicon oxides ($SiO_2$)

Figure 2 and Figure 3 illustrate clearly the difference of the thermally grown oxide and the CVD deposited oxide. In all figures, the triangles are always heating, and the ovals are always cooling. When the stress of the thermally grown $SiO_2$ film is measured at room temperature, it is found to be compressive. In addition, it does not have hysteresis behavior. By contrast, a chemical vapor deposited oxide film can have a variable stress amount which depending on film density and moisture content.

Figure 3 is the SAUSG deposited on silicon. When the sample was heated, the stress of the oxide increased. The reason of the stress going up is that the substrate expands more than the oxide film, plus the fact that the film is dries. During the heating cycling the sample releases some of the humidity and tries to shrink. Owing to the fact that the oxide film cannot shrink at that condition, so it creates tensile stress in it. During cooling, the stress decreases fairly linearly with temperature. The final stress is considerably more tensile that at the start of the temperature cycle and it produces a hysteresis in the stress versus temperature curve. That stress decrease is due to water absorption in the film. That is the reason why the thermally grown oxide has nearly no hysteresis, but the CVD oxide has a hysteresis. If the film is kept room temperature for a long time, the stress measured at the end of the cooling cycle will be coincident with the beginning point of the heating cycle. During thermal cycle, the stress-temperature variation shows a hysteresis behavior, it depends on the manufacturing conditions.

## (2) Silicon nitride (Si3N4)

Silicon nitride, another important material in the silicon devices, is not one material, but a whole family of materials. It generally includes SIN, SION, and UVSIN. Stress is one of the most important properties of silicon nitride, since high stress can cause cracking or voiding in Al films.

Figure 4 displays the typical stress-temperature behavior of PE-Sin. Silicon nitride stresses have been found to range between $-10^{10}$ and $+10^{10}$ dynes/cm$^2$ depending on the deposition method and the deposition conditions. As shown in the Figure 4, when it is heated, the silicon nitride stress will go up. In addition, the stress in silicon nitride increases with temperature and forms a hysteresis behavior. This hysteresis is caused by the content of hydrogen in films. It is generally accepted that highly compressive silicon nitride films are commensurate with aluminum voiding. Hence in films manufacturing, it is important to create silicon nitride with low stress and not so high compressive stress.

## (3) Aluminum ( Al )

Pure aluminum and its alloys have been used long time as the contact and interconnect metal. Although it could not satisfy with all VLSI metallization requirements today, the reduction of native silicon dioxide by Al is still very important and attractive.

The stress-temperature behavior of aluminum was shown in Figure 5. The stress in as-deposited aluminum film is tensile, about 1.5 x $10^{+9}$ dynes/cm2. The main features are described as the following: ( I ) During the heating cycle, when the measuring temperature is increased, stress becomes more and more compressive, the variation is almost linear, it is in the elastic region. This change is normally reversible if the heating temperature is stopped and when the temperature is allowed to cook back to room temperature. When the temperature is beyond $200^0$C, the stress reaches a maximum compressive stress and rides along the maximum. If the film stays at this stage for long time, the film might begin to yield or form hillock. Someone also reported that re-crystallization was happened. ( II ) During the cooling cycle, the compressive stress is firstly elastically, then the stress becomes tensile and increases to the maximum tensile stress that the film can sustain.

The maximum stress after the whole thermal cycling depends strongly on the film microstructure, composition and thickness. Thinner films, smaller grain sizes and higher impurity content will increases the film yield stress. In al cases the stronger and slower relaxing film will hold higher stress, so that the room temperature stress tends to be higher.

## 4. Summary

The optical level technique and a brief discussion of stress for three individual films are included in this study. As in many of the CVD deposited oxides such as TEOS and phosphorus glass. If they take up water, they swell and go more into compression. If they dry out, they go more into tension. Hydrogen effects have been seen in silicon nitride. The aluminum thermal expansion is about 4 times that of the silicon and will try to expand, but the silicon can’t expand that much, the only thing it can do is go into compression; the film does not have anywhere to go.

Although to study the single film is not enough for understanding the actual film stack used in the VLSI, the same technique is effectively used to measure film stack. The total films stress is the sum of thermal and intrinsic components.

The thermal stress is determined by the substrate and film properties, but the intrinsic stress depends on the deposition condition and the surface on which it is deposited.

## Reference

[1] Schroder, Dieter K. (1998). Semiconductor Material and Device Characterization, (2nd edition), John Wiley & Sons, Inc.

[2] Xiao, Hong. (2001). Introduction to Semiconductor Manufacturing Technology, Pearson Education International

[3] Wilson, S. R. & Tracy, Clarence J., (1993). Handbook of Multilevel Metallization for Integrated Circuit. Noyes Publication.

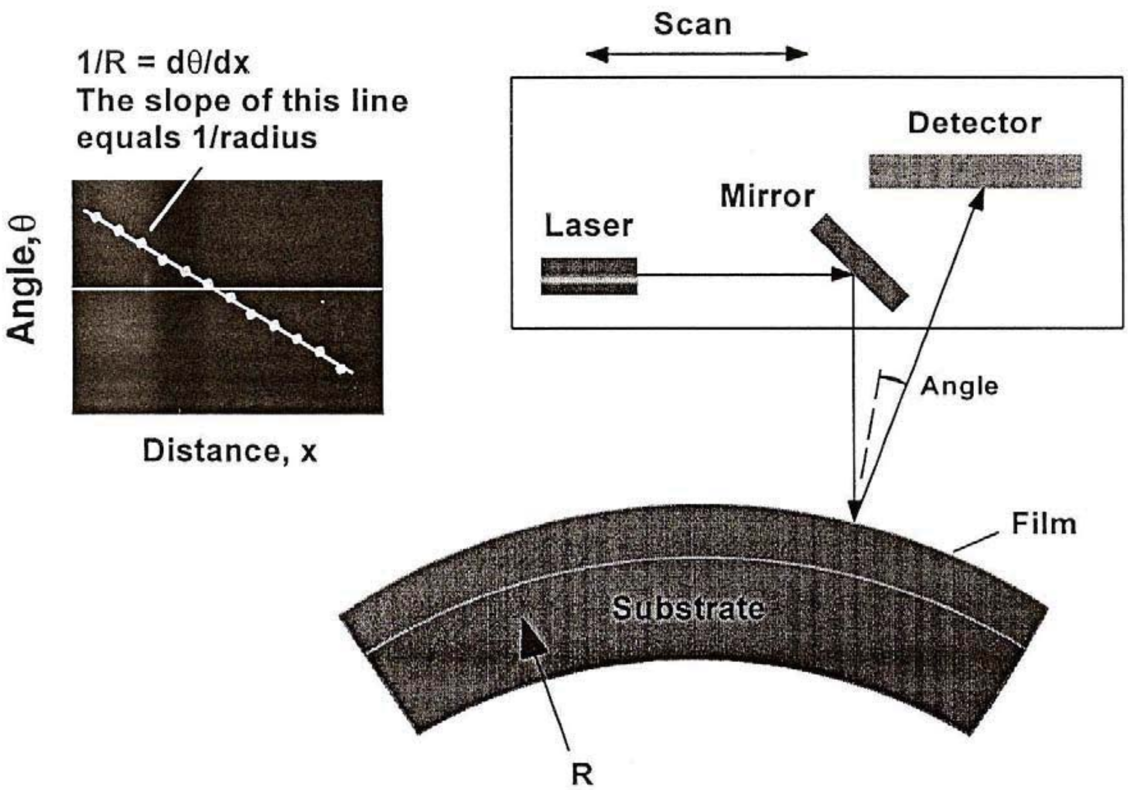


Figure 1 FLX-2320 Stress equipment

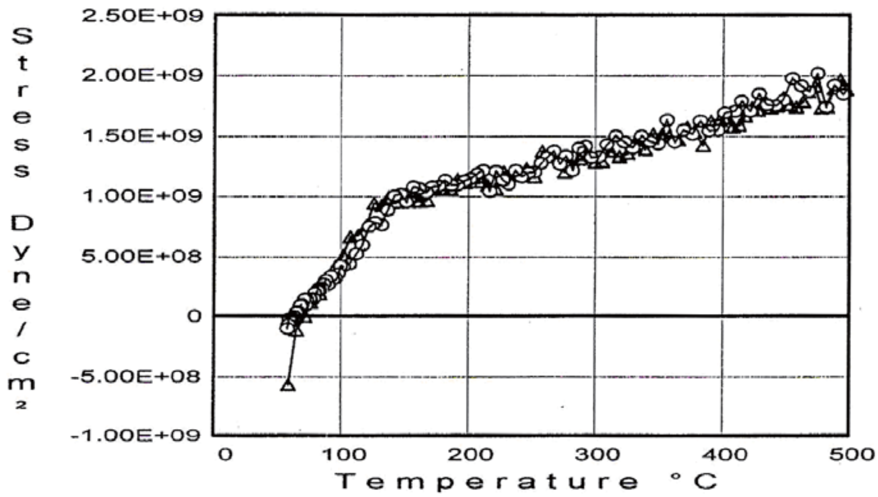


Figure 2 The stress-temperature behavior of thermally grown oxide

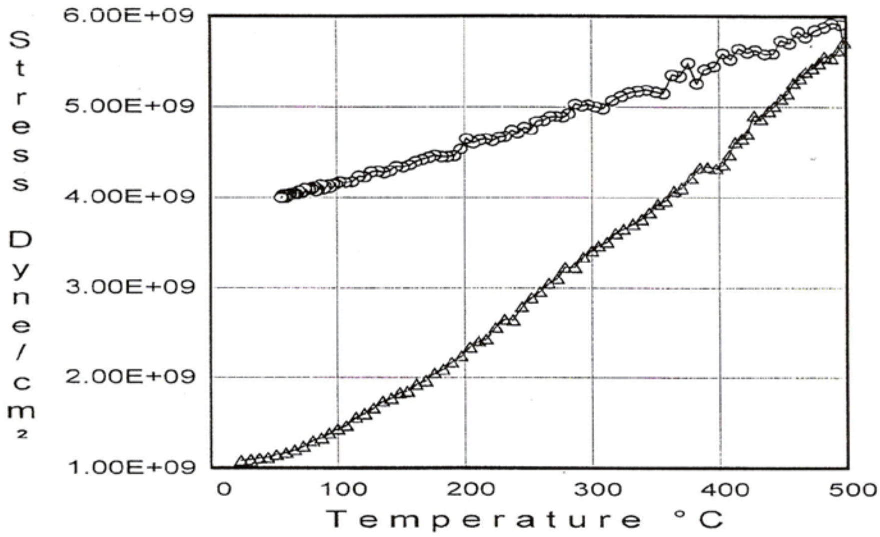


Figure 3 The stress-temperature behavior of CVD deposited oxide

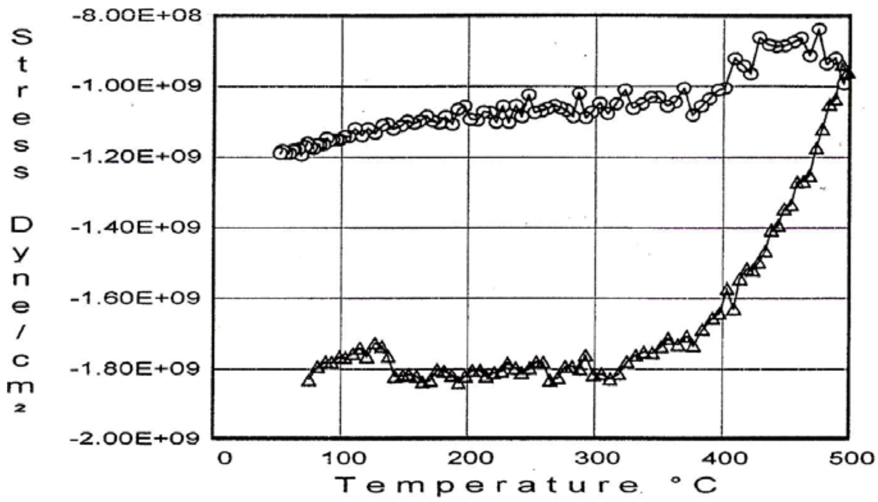


Figure 4 The stress-temperature behavior of PE-Silicon nitride

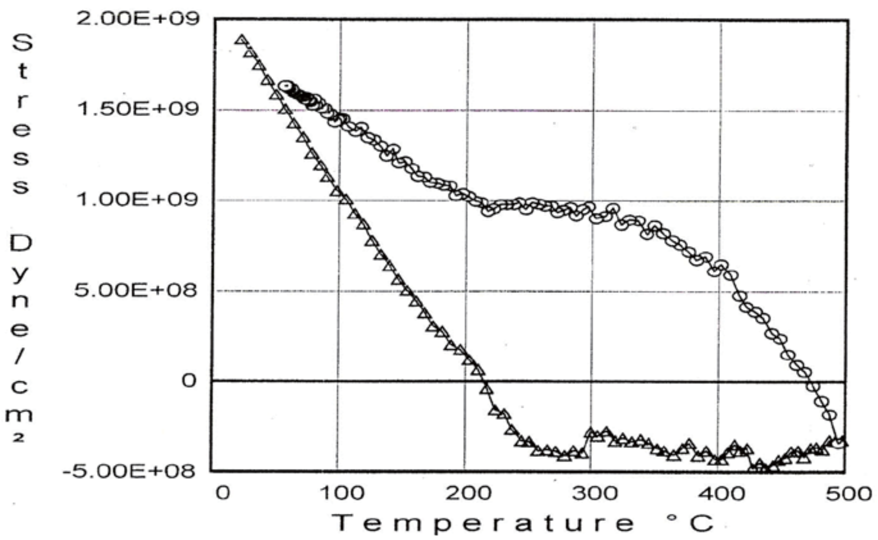


Figure 5 The stress-temperature behavior of Aluminum