Coherence Correlation Interferometry (CCI)

Precise measurement of photoresist film thickness

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> *“Accurate measurement of photoresist film thickness and its uniformity is critical to the performance of photoresist devices. Coherence Correlation Interferometry (CCI) provides exceptional accuracy over a wide range of film thicknesses.”*
>
> **Dr Yang Yu, Applications Scientist, Taylor Hobson Ltd.**

Introduction

Photoresist is a well known light sensitive masking material used to form a patterned coating on a surface. It is routinely used for photolithography and photoengraving. There are many applications in numerous technologies, including semiconductor and printed circuit board manufacture as well as in MEMS, solar PV, holography and biomedical engineering.

Correct exposure of the photoresist film is the key in controlling production costs: an incorrect exposure dose will result in an increase in the number of failed pattern parts. The exposure time can be obtained by measuring the photoresist film thickness, as a relationship exists between the developed resist film thickness and the exposure dose.

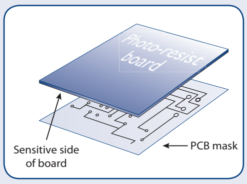
It is almost impossible to make a precise predetermination of the proper exposure because it can be very difficult to produce photoresist films with uniform thickness and constant refractive index. An ideal photoresist film should have not only the desired thickness, but also good uniformity over the surface.

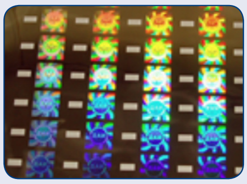
An accurate measurement of the thickness and distribution of the photoresist coating is essential in order to control the exposure of the photoresist films. Such measurements can be done on the wafer, either during or after the photoresist formation process.

A number of metrology tools have been employed to measure film thickness. These include conventional methods such as spectrophotometry, reflectometry, ellipsometry and physical step measurement. Scanning White Light Interferometry (SWLI) is becoming a popular technique because of its high lateral resolution and speed; however, traditional interferometry is limited because it can only measure film thicknesses larger than ~1.5 µm with any accuracy. It is now possible to measure thicknesses down to 50 nm or less using the CCI HD with patented Film Thickness software. Other methods have also been used to investigate film thickness, such as wavelength interferometry, prism couplers and thermal wave detection with a laser beam.

Applications

Photoresist is widely used in numerous technologies including semiconductors, printed circuit boards, MEMS, holography, solar PV and biomedical engineering.





Coherence Correlation Interferometry (CCI)

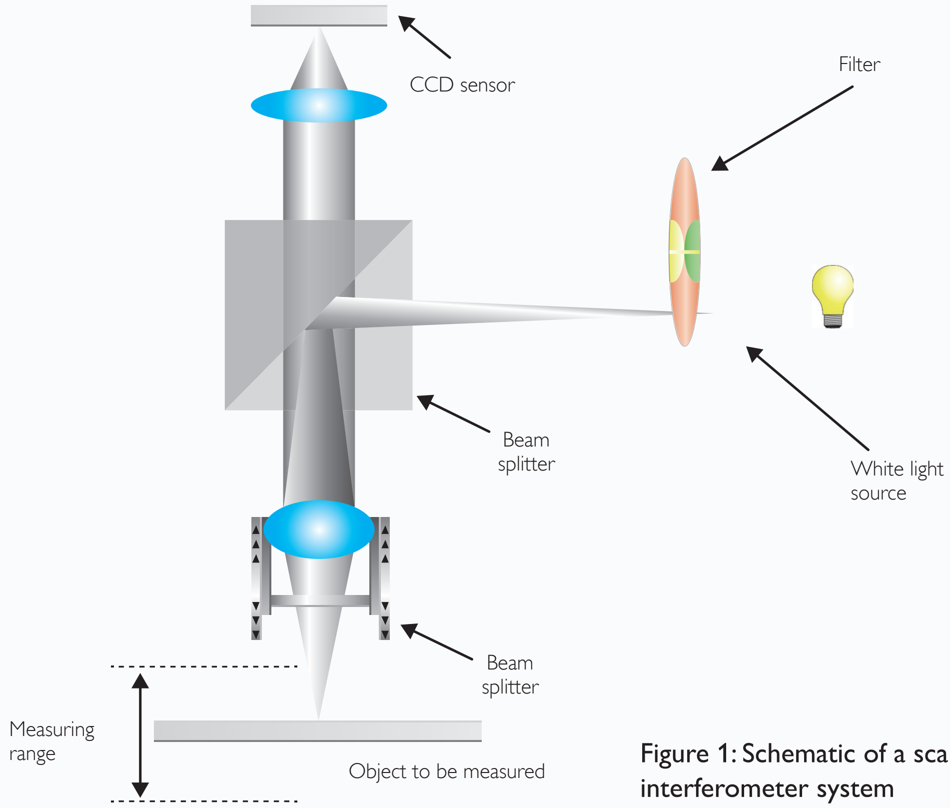


Figure 1: Schematic of a scanning interferometer system

> *The wide variety of industrial applications mean that Coherence Correlation Interferometry is increasingly important*
>
> **Dr Mike Conroy, Business Development Manager, Taylor Hobson Ltd.**

A schematic of a scanning interferometer system is shown in Figure 1. Light from the light source is directed towards the objective lens by the upper beam splitter and the light is then split into two separate beams by the lower beam splitter.

One beam is directed towards the sample and the other is directed towards an internal reference mirror. The two beams recombine and are sent to the detector. As the interferometric objective is scanned in the z direction, interference occurs when the path lengths of the two beams are the same. The detector measures the intensity, taking a series of snapshots as the sample is measured.

This creates an intensity map of the light being reflected from the surface, which is then used to create a 3D image of the surface being measured. Different techniques are used to control the movement of the interferometer and also to calculate the surface parameters. The accuracy and repeatability of the scanning white-light measurement are dependent on the control of the scanning mechanism and the calculation of the surface properties from the interference data.

Coherence Correlation Interferometry[1] is becoming increasingly important for measurements in many applications, providing:

- Fully automatic non-destructive measurements
- Accurate and quantitative characterization of surfaces
- Sub-angstrom resolution regardless of the scanning range used
- Fast and convenient sample loading and set-up
- Capability of measuring a wide range of materials
- Highly repeatable measurements
- Roughness and step-height analysis in one measurement
- Film thickness and interfacial surface measurement capability

> *With up to 4 million camera pixels with sub-nanometre vertical resolution and less than 1 µm lateral resolution it is now possible to measure thicknesses down to 50 nm or less using the CCI HD with patented film thickness software*[3,4]
>
> **Dr Yang Yu, Applications Scientist, Taylor Hobson Ltd.**

Measurement of Film Thickness

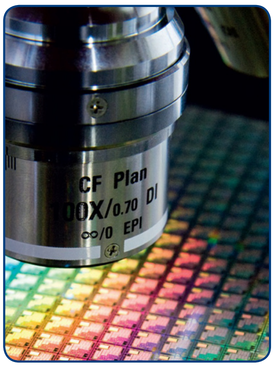
An important extension of interferometry is the ability to measure film thickness. When the interference signals appear at the surfaces of films a special algorithm is used so that the film thickness can be extracted from the interferogram. In some cases the surface information can also be obtained.

The advanced CCI HD has 4 million camera pixels and each individual pixel will act like its own 1 µm optical probe enabling high speed measurement of multiple film thicknesses with an independent thickness measurement at each point (Figures 2 and 3).

The combination of Film Thickness software and Coherence Correlation Interferometry (CCI) gives unrivalled thin film measurement capability.[1,2]

Figure 2: The CCI HD

Figure 3: CCI HD close-up



CCI technology provides two different film thickness measurement solutions:

- Thick Film (> 1.5 microns)
- Film Thickness Analysis (down to 50 nm or less)

Traditional Thick Film Measurement

When the thickness of a film is larger than ~1.5 µm (depending on refractive index), SWLI interaction with the layer results in the formation of two fringes, each arising from a surface interface (Figure 4)

The thickness of the film can be determined by locating the positions of the two maxima and applying the refractive index. In addition, the surface information of the two interfaces (air/film and film/substrate) can be obtained from the individual fringes (Figure 5).

Figure 4: Single pixel measurement from a 7 µm thick film

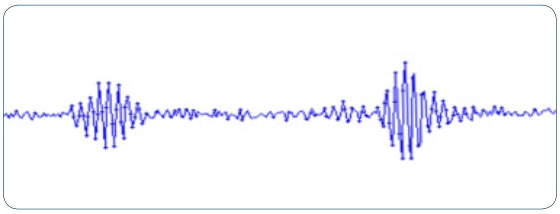
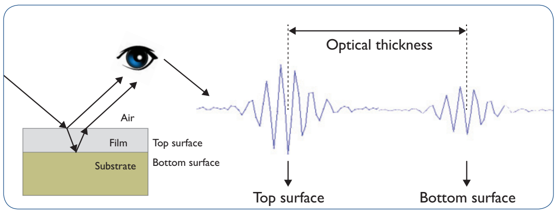


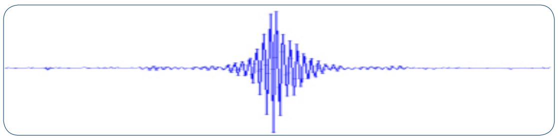
Figure 5: Determination of film thickness



Thick Film limitations

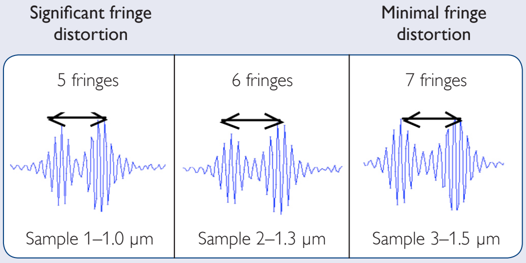
As the thickness of the film decreases, the two fringes become closer and overlap until they appear as a single interference fringe bunch. (Figure 6).

Figure 6: Single pixel measurement from a 270 nm film



For thicknesses of films less than 1.5 µm (depending on refractive index), thickness cannot be extracted using the thick film technique due to the distortion of the fringes (Figure 7). An alternative method has to be employed.

Figure 7: Single pixel fringe for each sample



Sample 1–1.0 µm
Sample 2–1.3 µm
Sample 3–1.5 µm

Fringe distortion increases significantly for film thicknesses below ~1.5 um. This has the effect of displacing the peaks, making it impossible to establish the true thickness of the film using traditional Thick Film Analysis

Film Thickness Analysis – the solution

A new solution to this problem (HCF)[2] has been developed to extract the film information. Through the application of the HCF function, coherence correlation interferometry (CCI) has become the ideal method to obtain film thickness information. HCF can be used for thickness measurement with better than 1% accuracy within the range of ~ 5 µm to ~ 300 nm. Films thicknesses down to 50 nm have been measured; however, care needs to be taken with these very thin films as the accuracy depends on the optical properties of the material.

Photoresist Measurement Results

Film Thickness Technique vs. Traditional Film Thickness

A series of experiments were carried out using photoresist standards to compare the new Film Thickness technique with the traditional Thick Film method (Table 1).

Table 1: Comparison of interferometry thickness measurement techniques[5]

Sample materials	Photoresist on silicon		
Thick film analysis (µm)	1.173 ±0.025	1.307 ±0.024	1.485 ±0.029
Film thickness analysis (HCF) (µm)	1.066 ±0.002	1.264 ±0.003	1.477 ±0.005
Difference (µm)	0.107	0.043	0.008

As the thickness of the film decreases below 1.5 microns, the difference in the measured thickness between the two techniques increases. The results in Table 1 confirm that the traditional Thick Film method is unsuitable for film thickness measurements below ~1.5 um.

Film Thickness Technique vs. Spectrophotometry and Ellipsometry

A further series of studies were done using photoresist standards to compare the Film thickness analysis (HCF) technique with Spectrophotometry and Ellipsometry. (Table 2).

Table 2: Comparison of Film thickness measurement techniques6

Sample materials	Photoresist on silicon		
Spectrophotometry (µm)	1.085	1.272	1.477
Ellipsometry (µm)	1.088	1.279	1.481
Film thickness analysis (HCF) (µm)	1.083	1.274	1.479

The results in Table 2 clearly show very good correlation between Film Thickness Analysis on the CCI HD and the other conventional methods.

Conclusions

Scanning white light interferometry (SWLI) is an established technique for the measurement of film thicknesses above ~1.5 µm (thick film analysis).

The new Film Thickness Analysis technique, together with Coherence Correlation Interferometry is the ideal metrology tool to provide fast and accurate photoresist film thickness and uniformity measurements for film thicknesses down to 50 nm or less. These measurements allow us to control the exposure of photoresist films, ensuring accurate pattern transfers and high quality device production.

References

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3 Mike Conroy, "Measurement of thin films and interfacial surface roughness using SWLI", Proc. SPIE 6884, 688408 (2008)
4 Daniel Mansfield, "Extraction of film interface surfaces from scanning white light interferometry", Proc. SPIE 7101, 71010U (2008)
5 The standard deviation (σ) for both thick film and film thickness analysis was calculated by means of 20 measurements
6 The authors acknowledge CREST of Loughborough University for their ellipsometry measurement results.

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