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Characterisation of Thin Films Using a Coherence Scanning Interferometry

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Abstract

Accurate measurement of film thickness and its uniformity are very important to the performance of many coated surfaces and for many applications are critical. Effective inspection of the film thickness and uniformity is the key to high performance. Conventionally, film thickness is measured using a spectrophotometer/reflectometer, ellipsometer or a physical step measurement; however, these techniques all have limitations. Coherence Scanning Interferometry (CSI) is an established method to measure surface topography as this technique offers many advantages such as speed, ease of use and accuracy. The measurement of "thick" films (exceeding ~1.5 μm) which gives rise to clearly separate fringe bunches is a well-established CSI capability. However, a methodology known as the 'helical complex field' (HCF) [1] [2] function allows film thickness to be measured down to ~25 nm. This new method, combined with Coherence Correlation Interferometry (CCI) [3] offers film thickness measurements with sub-nanometre vertical resolution and ~1 μm lateral resolution. It is ideally suited for detailed analysis of coated optical surfaces. In this paper, the fundamentals of the techniques are described and some case studies are presented.

Keywords

Film Thickness, CCI, Thick Film, HCF

1. Introduction

Thin films are widely used in many high-technology industries, such as solar PV, semiconductors, MEMs, displays, parylene coatings, hard coatings and photoresists. Effective measurement of thin film thickness is always a demand by both research and industry.

Various metrology tools have been employed to measure film thickness. These include conventional methods such as spectrophotometry, ellipsometry and physical step measurement in addition to the established method of Coherence Scanning Interfererometry. Other methods have also been used to investigate coating thickness, such as wavelength interferometry, prism couplers and thermal wave detection with a laser beam.

The non-contact Coherence Correlation Interferometry (CCI) instrument is an advanced coherence scanning interferometer which provides fast and accurate high-resolution 3D surface measurements and film thickness measurements.

In this paper, some case studies are presented using the CCI on a range of different types of thin film applica-

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tions: photoresist coatings, anti-reflection coatings and DLC coatings. Some of the results are also compared with conventional techniques.

1.1. Photoresists [4]

Photoresists have 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 generally not realistic to make a precise predetermination of the proper exposure because it can be very difficult to produce 'ideal' photoresist films that exhibit both a uniform correct thickness and constant refractive index. To meet these requirements and then to control the exposure of the photoresist films, it is necessary to accurately measure the thickness and distribution of the photoresist coating, typically on a wafer, during or after the photoresist formation process.

1.2. Anti-Reflection Coatings Used in Photovoltaics Devices [5] [6]

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. High efficiency together with low manufacturing and lifetime costs in PV solar cells are the biggest concerns for most solar designers and manufacturers. In order to maximise efficiency, solar panels need to absorb as high a percentage of incident light as possible.

Standard solar panels normally reflect more than a third of the light energy to which they are exposed. This means that over 30% of the light—and potential electricity—is lost.

In order to increase solar panel efficiency, anti-reflection coatings are applied to the surface of the panels so as to cancel out this reflection. This technique brings great benefits to the solar industry through its ease of application and low cost.

AR coatings play an important role in solar PV cells. In silicon photovoltaics, for example, anti-reflection coatings are used to improve the light trapping capability and efficiency. Silicon nitride thin film coatings represent the most common passivation technique used for silicon photovoltaics. The thickness of a silicon nitride layer is critical for its anti-reflective properties, since a quarter wavelength is optimal.

Obtaining accurate measurements of both the thickness and roughness of AR coatings on solar PV cells is critical to their efficiency and reliability as well as in maintaining low production costs. Most AR coating materials used in solar cells are fragile and a non-contact, non-destructive metrology solution is often essential.

1.3. Diamond Like Carbon (DLC) Coating [7] [8]

Diamond-like carbon (DLC) coatings are used to modify the surfaces of materials and improve primarily the tribological properties. DLC coatings are used in a wide range of applications because they have many advantages because of their low cost, relative ease of application and their ability to provide some of the properties of diamond to surfaces of almost any material, particularly Germanium and Silicon.

The DLC layer requires a specific thickness to achieve the desired surface properties. For example, DLC coatings are often optimised for a specific wavelength region by adjusting the layer thickness during the coating process to deliver good BBAR (Broadband Anti-reflective) performance. Precise control of the DLC film thickness is important for optimising the coatings for both R&D and industrial purposes.

2. Measurement Techniques

2.1. CCI (Coherence Correlation Interferometry)

The CCI instrument is a coherence scanning interferometer that uses special coherence correlation algorithms patented by Taylor Hobson [3]. The CCI HD, equipped with a high resolution digital cameral array, is a non-contact metrology tool providing rapid, non-destructive and accurate three dimensional measurements. It has constant 0.01 nm vertical resolution for all the objective lenses which range from 2.5 × $(6.6\ \text{mm})^2$ to 110 × $(0.16\ \text{mm})^2$. The CCI is suitable for the measurement of many different types of surface from very rough to very smooth. Given its low level light sensitivity together with its ability to provide both thickness and roughness in a single measurement, the CCI is proving itself a very versatile instrument.

2.2. Traditional Thick Film Technique

When the thickness of the film is larger than ~1.5 µm (the actual thickness will depend on refractive index and NA of the objective lens), the CSI interaction with the measured layer results in the formation of two fringes, each corresponding to a surface interface. This is shown in **Figure 1**. The CCI algorithm can therefore be used to determine the thickness, by locating the positions of the two envelope maxima, assuming the refractive index is known. In addition, the surface structure of both the top surface (air/film) and the bottom surface (film/substrate) can also be obtained [1]-[4].

2.3. Film Thickness Technique (HCF) [1] [2]

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 coalescence and distortion of the fringes (**Figure 2**). An alternative method has to be employed.

For thicknesses of films less than ~1.5 µm the two CSI-formed fringes overlap and appear as a single interference fringe bunch as shown in **Figure 2**. Such film thicknesses cannot be accurately calculated using the traditional thick film technique. An alternative method has to be employed. The patented ‘helical complex field’ (HCF) function has therefore been developed to extract the film information. In order to obtain accurate film thickness, it is necessary to have prior knowledge of the dispersive film index. The HCF approach can be used for the measurement of film thickness within the range of ~25 nm to ~10 µm.

3. Case Studies

3.1. Testing of the HCF Approach

This work was carried out using the measurements of SiO_2 films on Si substrates. 5 samples ranging in thickness from ~50 nm to ~2000 nm were tested using CCI HD (HCF). The results are shown in **Table 1**.

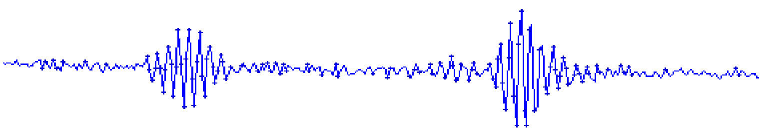

Figure 1. Single pixel measurement from a 7 µm thick film.

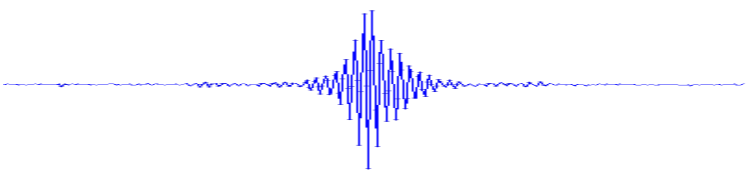

Figure 2. A single pixel fringe envelope from an actual interferometry measurement of Ta_2O_5 thin film (270 nm) coated on BK7 glass sample.

Table 1. Correlation of HCF technique with other common techniques.

Sample	VLSI sample set			Other samples	
Film/substrate	SiO_2/Si	SiO_2/Si	SiO_2/Si	SiO_2/Si	SiO_2/Si
Film thickness (nm) (ellipsometry) (NIST) spectrophotometry	47.0	191.3	1049.1	294.8	2077.7
Film thickness (HCF) (nm)	47.0	191.2	1055.7	297.4	2080.4
% Difference	0.01	0.03	0.63	0.89	0.13

3.2. Comparison Test between the HCF Approach and Physical Step Measurement

In this work, a PTB standard which contains a 100 µm strip with SiO_2 coating on Si substrate has been measured by using CCI HD and Nanostep. The test results are given in **Table 2**.

3.3. Comparison Measurements of Photoresist Films on Si Substrates

Three different film thickness samples with photoresist S1813 on Si substrates were used to carry out the tests. The HCF test results were compared to the results from traditional methods: spectrophotometry and ellipsometry. Furthermore, the results from the HCF technique were compared to those from the thick film technique. The results are given in **Table 3** and **Table 4**.

3.4. Comparison Test Measurements of Anti-Reflection Coating Used in Photovoltaic Devices

A series of AR thin films of different thicknesses in the range 75 nm to 900 nm for Niobia and 75 nm to 300 nm for Silicon Nitride were prepared using sputtering. The silicon nitride films were deposited onto polished silicon. The Niobia films were deposited onto glass. The ellipsometry data was obtained by taking the average from five different mapped points on the surface. A similar approach was taken using the CCI HD. The accuracy of the film thickness measurement was tested by correlating the results obtained from the same samples using ellipsometry (Horiba, Jobin Yvon, UVISEL).

Niobia has excellent chemical stability and corrosion resistance. Niobium oxide coating can exhibit different electrical or optical properties depending on deposition techniques and fabrications in order to optimize material characteristics for a given applications [6].

Anti-reflection coatings play an important role in improving light trapping and efficiency. Silicon nitride thin film coatings represent the most common passivation technique used for silicon photovoltaics and can be characterized easily using the CCI technique [5].

Silicon Nitride Coating

Five different values of Silicon Nitride coating thickness samples ranging from ~70 nm to ~280 nm were meaured.

Table 2. Comparison between film thickness analysis (HCF) and physical step measurement technique.

	Nanostep (nm)	CCI HD (nm)	Difference (nm)	Accuracy
	290.6	292.7	2.1	0.7%
Repeatability (σ)		0.6		

Table 3. Comparison between HCF technique and Spectrophotometry/Ellipsometry techniques.

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

Note: The authors would like to thank CREST of Loughborough University for the ellipsometry measurement results.

Table 4. Comparison between HCF technique and traditional thick film analysis

Sample materials	**Photoresist on Silicon**		
Film thickness analysis (HCF) (µm)	1.083	1.274	1.479
Thick film analysis (µm)	1.173	1.307	1.485

3.5. Measurements of Diamond Like Carbon (DLC) Coating on Silicon Substrate Using CCI HD

Two DLC coating samples with different thicknesses were tested using the HCF technique. In addition, the coating thickness results were compared with those determined using the traditional ellipsometry technique.

4. Discussions

The results from **Table 1** show good correlation between the CCI/HCF approach and ellipsometry/spectro- photometry for thicknesses of SiO_2 films on Si substrate ranging from ~50 nm to ~2 µm. It can be seen from **Table 2** that good agreement was also obtained between the HCF technique and physical step measurement. **Table 3** gives the test results from photoresist films on Si by using the HCF approach and conventional methods (spectrophotometry and ellipsometry). Good correlation is obviously indicated between the HCF and other conventional techniques. It can be clearly seen from **Table 4** that film thickness analysis (HCF) is more accurate and reliable than thick film analysis. Combining **Figure 3** and the corresponding difference between the two methods in **Table 4** shows that the error declines with an increasing film thickness, thus showing that the error in thick film analysis is due to the distortion of interference fringes.

Figure 4 and **Figure 5** show good correlation results on both Niobia and Silicon Nitride between the HCF technique and the more traditional ellipsometry approach.

Table 5 also gives good correlation results between Film Thickness Analysis (HCF) technique on CCI HD and the traditional ellipsometry technique on DLC coating measurements (**Figure 6**).

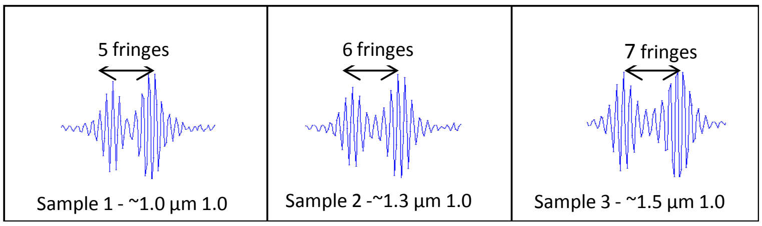

Figure 3. Single pixel fringe for each sample.

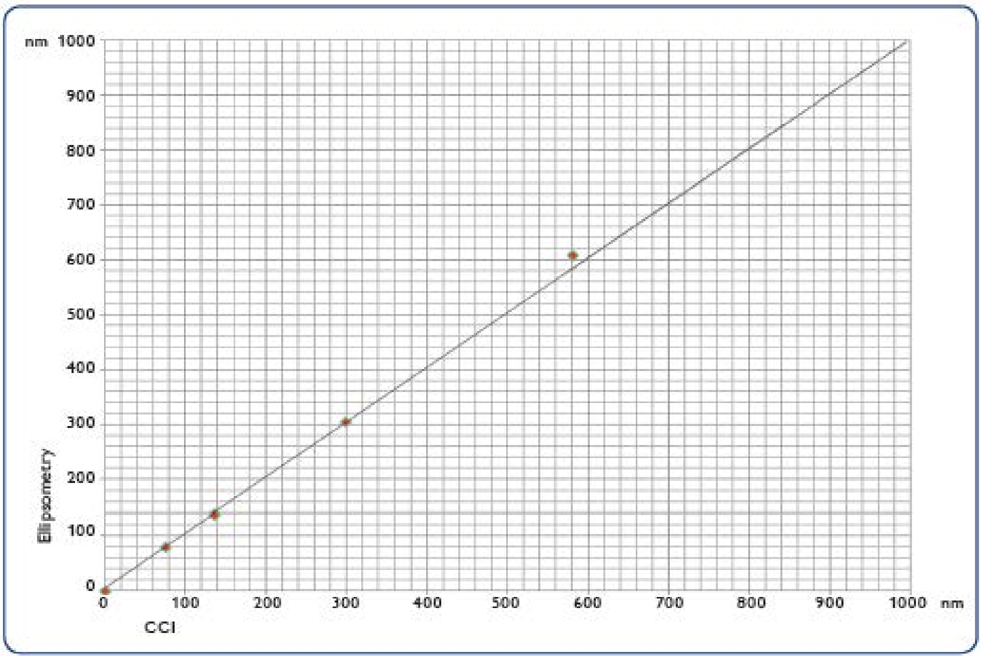

Figure 4. Thickness correlation between CCI and ellipsometry–using several Niobia thin films sputtered on glass.

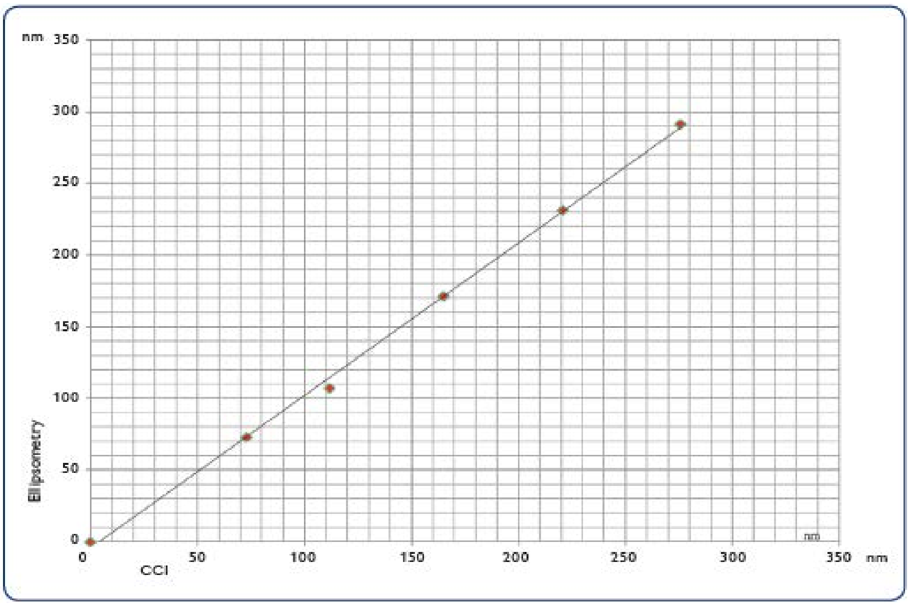

Figure 5. Thickness correlation between CCI and ellipsometry using a Silicon Nitride layer on polished silicon.

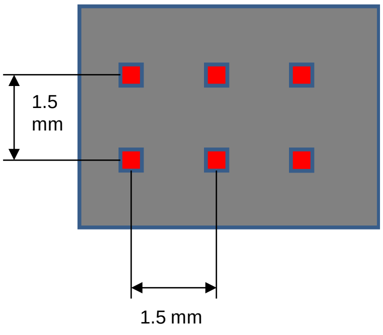

Figure 6. Auto-pattern measurements were made on a sample with DLC coating on Silicon substrate.

Table 5. Comparison between film thickness (HCF) technique and traditional ellipsometry method

Region	1	2	3	4	5	6
Film thickness (HCF) (nm)	575.2	576.6	570.1	576.6	575.2	568.9
Ellipsometry (nm)			~570			
Film thickness (HCF) (nm)	302.8	304.8	302.5	301.7	300.8	301.6
Ellipsometry (nm)			~300			

The CCI is able to measure a wide range of film thicknesses down to about ~25 nm, with a lateral resolution of ~1 micron over a large area. The technology is also able to measure surface properties such as roughness, even for these low reflectivity surfaces.

Compared to spectrophotometry and ellipsometry techniques, the CCI HD with higher lateral resolution can provide fast, accurate measurements without sample preparation and requiring minimum operator skills, for ~25 nm to 10 µm thicknesses and over a measurement area ranging from a few µm^2 to ~mm^2, while spectrophotometry can only give a single average film thickness over an area of a few mm^2. In addition, CCI HD can provide auto-pattern measurement to show the variation of film thickness through a large area of ~ 100 mm^2, to study the uniformity of the films.

5. Conclusion

The development of the Helical Complex Field (HCF) function together with Coherence Correlation Interferometry provides the ideal metrology tool to perform fast and accurate film thickness and uniformity measurements for a wide range of film thicknesses (down to 50 nm or less) in large number of film applications.

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