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**Review of x-ray and optical
thin film measurement
methods and transfer
artefacts**

**Andrew Yacoot, Richard
Leach**

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Review of x-ray and optical thin film measurement methods and transfer artefacts

Andrew Yacoot and Richard Leach
Engineering & Process Control Division

ABSTRACT

This report presents the results of a review of methods for the thickness measurement of thin transparent films in the range from 1 nm to 5 μm . X-ray and optical methods for film thickness measurement are compared and other parameters that can also be measured are highlighted, such as optical constants, crystallographic orientation and surface texture. The work being carried out in other national measurement institutes is discussed and commercially available thickness transfer artefacts listed.

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National Physical Laboratory
Hampton Road, Teddington, Middlesex TW11 0LW

Approved on behalf of the Managing Director, NPL
by Susan Evans, Engineering & Process Control Division

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1. INTRODUCTION

As part of the 2005 – 2008 National Measurement System Engineering Measurement Programme a project is being undertaken to establish a traceable measurement service for thin films in the range from 1 nm to 5 μm . This report forms the first deliverable of the project – a review of measurements methods for transparent thin film and associated transfer artefacts. The report will be used to provide input into the decision whether to use and modify existing instrumentation at NPL to set up a measurement service, or whether to invest in new capital equipment.

Thin films are used in a wide range of industries and applications. Examples include ophthalmics, displays, paints, protective layers, anti-reflection coatings, detectors, solar cells, mobile telephone filters, engineering coatings in the automobile and aerospace sectors and many more. The economic benefits of improved surface coatings will be highly significant. To take one example, a recent survey undertaken by the UK government predicted that the value of products in the UK affected to some degree by surface engineering will be over €200 billion *per annum* by the year 2005, conservatively implying a sum of €2000 billion *per annum* on a European scale (Mathews *et. al.* 2005). Clearly, not all such products will require accurate or traceable measurement of film thickness, but a significant proportion will. The successful companies will be those that demonstrate product reliability by implementing a rigorous quality system, which, in turn, depends upon highly reliable and traceable metrology.

NPL already has an existing measurement service for opaque thin films using surface acoustic waves (see Jennett *et. al.* 2004) so the emphasis in this report is transparent thin films. NPL has also recently procured a spectroscopic ellipsometer and has a vertical scanning white light interferometer that is being modified for thin film measurement. Clearly it would be better to use these instruments to set up a measurement service, as the need for capital investment would be minimised, but it was thought important to review other techniques to help to place the capabilities of the optical instruments in context.

For each of the thickness measurement techniques a brief introduction to the method is given followed by an overview of its capabilities and some examples of applications. Note that only x-ray and optical methods have been reviewed in this report. There are many other methods for film thickness measurement but such methods are typically used to measure thicker films than those considered here and their route to traceability is not well defined.

Work undertaken at other national measurement institutes is also summarised, in particular work at the Physikalisch-Technische Bundesanstalt (PTB), the National Institute for Standards and Technology (NIST) and the National Metrology Institute of Japan (NMIJ).

2. X-RAY TECHNIQUES

There are several x-ray techniques available for the analysis of thin films that provide a variety of information about the films at the macroscopic level; thickness, shape, surface roughness, orientation, distortion, homogeneity, interfaces, and density and chemical composition. At the microscopic level information about the, shape, composition, orientation, distortion interfaces and homogeneity can also be determined. The techniques have been reviewed several times over the last few years (Fewster 1993, 1994, 1996). More recently Birkholz (2005) provides a good overview of the capabilities of various x-ray techniques for studying thin films and Bowen and Tanner (2006) discuss thin film metrology for the semiconductor industry using x-ray methods. Consequently the salient points for each technique are presented regarding measurement of thin film thickness and structure. Essentially the methods employed rely on either diffraction or scattering of x-rays. The wavelengths of x-rays used in x-ray techniques are known to 1 part in 10^6 and are traceable to NIST.

2.1 GRAZING INCIDENCE X-RAY REFLECTIVITY (GIXR), X-RAY REFLECTIVITY AND X-RAY REFLECTOMETRY (XRR)

GIXR and XRR are suitable for examining amorphous, polycrystalline and molecular structures. The techniques can reveal information about film thickness, chemical composition, density and surface roughness and are applicable for measuring films with thickness in the range 1 nm up to 1 μm . They can be used to provide measurements of film thickness, density and interface width between successive layers.

GIXR and XRR rely on the fact that the critical angle for reflection of x-rays from a sample is usually of the order of minutes of arc and since the refractive index of x-rays in air is less than unity, x-rays are totally *externally* reflected from denser surfaces, rather than internally reflected as is the case for visible light.

An x-ray beam is collimated using multiple reflexions from a monochromator and incident on a sample at grazing incidence angle, θ . The sample is mounted on a diffractometer. A detector is placed the other side of the sample at an angle of 2θ with respect to the sample. This is a $\theta/2\theta$ configuration and as the sample is rotated to change the angle on incidence of the incoming x-rays, the angle of the detector with respect to the sample changes by twice the change in the angle of incidence. Measurement of the intensity of the scattered beam from a substrate, for example silicon or quartz glass (SiO_2), as a function of angle shows a rapid drop in intensity once the angle of incidence is greater than the critical angle. If an appropriately thin film has been deposited on the substrate, then the so-called Kiessig fringes will be observed (Kiessig 1931) that result from the incident x-ray beam being reflected from the substrate and thin film. The spacing between successive fringes is related to the wavelength of the x-rays used (normally copper $\text{K}\alpha$ with a wavelength of 0.154 nm) and the thickness of the thin film. As a rule of thumb, when using copper $\text{K}\alpha$ radiation, the technique is not suitable for thin films with a thickness in excess of 100 nm. NIST, however, have used GIXR to study films in the range 1 nm to 1 μm . The techniques are also sensitive to surface roughness of the substrate and the thin film (in the theoretical range from a few tens of picometres to a few nanometres) and to the density of the film. However, it

should be noted that diffusion of layers at an interface has a similar effect on the specular reflectivity as the surface roughness. Consequently, if it is necessary to separate out the effect of these two terms, a diffuse scattering technique should be used. Not taking into account the chemical mixing, can lead to an erroneously higher measure of surface roughness as compared to that obtained using other techniques such as atomic force microscopy. Keissig fringes can be easily simulated; once the fringes have been obtained, it is usual to compare the measured data with experimental simulations in order to obtain a measurement of the film thickness. The root mean square surface roughness of the surfaces can also be included in the model. In comparison with other techniques, the calculated value of film thickness is independent of the refractive index of the film and its absorption coefficient, thereby enabling accurate results to be obtained. The technique can be extended to include the analysis of multilayers and superlattices. NIST, PTB (Busch and Stümpel 2003) and NMJ use this method for characterising thin films and their interfaces. Some of the work by PTB is carried out at the Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung (BESSY) synchrotron radiation facility in Berlin.

For the studies of silicon dioxide on silicon, neutron reflectometry is a better choice than x-ray reflectometry since the contrast in the scattering length densities for the two materials is higher (65% compared to 7.6%). NIST performed a comparison of measurements of 10 nm and 2 nm silicon dioxide films using x-ray reflectivity, neutron reflectivity and ellipsometry (Dura *et al.* 1998). Good agreement was found between the three methods; measurements of the 10 nm film using the three methods had a relative standard deviation of 1.25%. This suggested that neutron reflectometry and ellipsometry are capable of measuring layers as thin as 2 nm. However, for such thin films, surface contamination is an issue.

Commercial equipment is available for XRR metrology of thin films, see for example, Bede X-ray Metrology (website: www.bede.co.uk).

2.2 X-RAY DIFFRACTION TECHNIQUES

Broadly, x-ray diffraction techniques fall into two classes, those using reflectometry and those using high angle diffraction. Reflectometry is concerned with diffraction close to the incident beam direction and high angle diffraction is concerned with diffraction close to hkl reflexions. The reflectometry techniques are suitable for amorphous structures and those without regular lattice periodicity. The high angle techniques are suitable for examining films with a regular crystalline structure and epitaxial layers that produces hkl reflections. Interference between x-rays diffracted from different boundaries within a thin film and substrate give rise to fringing around the diffraction peak. This is particularly evident in multilayer structures and is of interest to the electronics and semiconductor industry. Over the years there has been much work done in this area.

2.3 GRAZING INCIDENCE X-RAY DIFFRACTION (GIXRD)

The experimental configuration for GIXRD is similar to that for GIXRR, but with some important differences. The angle of incidence of the x-rays is again very small but is *kept constant*. However, the x-ray detector is, as with GIXRR, rotated with respect to the sample in order to detect beams diffracted close to the incident beam direction. The technique is suitable for examining either crystalline or amorphous structures, but the sample must be flat. Knowledge of the x-ray absorption coefficient of the material is required.

Fewster (1996) discusses work done to measure film thickness using this technique together with simple models. However, he points out that for a rigorous understanding of the process, one should use models based on the dynamical theory of x-ray diffraction since for very thin and very thick thin films, the simple models become unreliable.

2.4 LARGE ANGLE DIFFRACTION

The interference between x-rays diffracted from different boundaries within a thin film and substrate give rise to fringing around the diffraction peak from an *hkl* reflexion (see section 2.2). Various simple models have been developed to analyse the fringe patterns obtained, however, complex diffraction effects (Fewster 1993) can give rise to uncertainties in values obtained for film thickness.

When examining multilayer structures, the fringing around a diffraction peak is more complex since the multilayer can give rise to extra periodicity within the structure. For periods of around 10 nm, the periodicity of the fringing can be determined to within 1 nm. Generally the technique can be used to measure film thickness in the range from a few nanometres up to a few micrometres (Bowen & Tanner 2006). However, diffraction effects can again give rise to errors in the angular spacing. In order to fully interpret the data a mathematical model is needed. There are three approaches used to produce mathematical models, dynamical theory, kinematical theory and optical theories. Dynamical theory is applicable to x-ray diffraction from semiconductors and other near perfect crystal structures, kinematical theory is appropriate for polycrystalline diffraction and the optical theories are appropriate for reflectometry studies of amorphous materials.

Dynamical modelling is a powerful tool whose superiority over simple qualitative approaches has been demonstrated by Fewster (1993). Commercial software is available for modelling various thin films and multilayers, which together with appropriate x-ray equipment can quickly yield measurements of thin film thickness.

For both the diffraction and reflection techniques there are commercial software packages available for modelling experimental data.

2.5 X-RAY FLUORESCENCE (XRF)

X-ray fluorescence is an established technique for determining the composition of, and, measuring the thickness of, single and multilayer films (Jenkins *et. al.* 1995). The range of thickness that can be measured is typically in the range 1 nm to 10 μm (Bowen, Tanner 2006). It also has the limitation that the atomic number of the elements of the film must be greater than eleven. Essentially the sample is irradiated with x-rays that cause the film to emit its own characteristic radiation. There are two methods for measuring the radiation: energy dispersive and wavelength dispersive. By measuring the intensity of the characteristic radiation emitted by the sample, one can determine the film's composition. A calibration standard is required to enable an intensity against thickness curve to be plotted which together with software can be used to fit the data to a model and obtain the film thickness, sometimes with sub-nanometre resolution. Van der Haar *et. al.* (2004) describe the technique for a micro-spot XRF set up working in the energy dispersive mode that is used for metal film thickness measurement. Gao *et. al.* (2004) describe a similar system working in the wavelength dispersive mode. Both systems use polycapillary focusing optics to ensure a small beam size ($\sim 25 \mu\text{m}$). XRF has been successfully combined with XRR for in process measurement and control (Wyon *et. al.* 2004). Commercial set-ups for XRR are available from the usual manufacturers of x-ray equipment, for example PANalytical (website: www.panalytical.com).

2.6 X-RAY PHOTOELECTRON SPECTROSCOPY

The technique of x-ray photoelectron spectroscopy is based on the photoelectric effect. X-rays are incident on the surface, which results in the ejection of photoelectrons from the surface. Measurement of the energy of these electrons gives information about chemical composition and thickness. X-ray photoelectron spectroscopy is used to measure the thickness of very thin films up to a few nanometres thick and has been used to measure the thickness of silicon dioxide films in the range 1.5 nm to 8 nm on silicon with an uncertainty below 1% (Seah 2006).

3. OPTICAL TECHNIQUES

3.1 ELLIPSOMETRY

Ellipsometry is a powerful technique that can extract information about, not only the thickness of a film, but also refractive index, surface roughness, interfacial mixing, uniformity, anisotropy, composition and crystallinity. The technique of ellipsometry involves measuring the change in polarisation of a light beam when it is reflected from a surface. Once data has been collected, it is compared with a model of the thin film structure and the model adjusted until the best fit to the experimental data is found. In order to measure film thickness, prior knowledge is needed of various optical constants of the films such as refractive index and extinction coefficients. There are several commercially available software packages for processing ellipsometer data. Various types of ellipsometer are available, the most appropriate for metrological applications such as thin film measurement being the spectroscopic ellipsometer.

Ellipsometry is suitable for measuring transparent films and this can include metal films less than 100 nm thick. Above a thickness of 100 nm metal films become opaque and ellipsometry is no longer a suitable technique. Very thin films are defined as having thickness of 10 nm or less and determination of the optical constants of such films can be difficult with ellipsometry, therefore, typical values available from the literature for calculating film thickness are used. Thick films, from the point of view of ellipsometry are defined as those having thickness greater than 5 μm .

For a more detailed description of the theory and techniques of ellipsometry see Azzam and Bashara (1987) and more recently Tompkins and Irene (2005). An internet search will show that there are many manufacturers of commercial ellipsometers. For details of a range of commercially available ellipsometers see for example, J. A. Woollam Co. (website: www.jawoollam.com).

3.2 SPECTROPHOTOMETRY

Spectrophotometry is best suited to measuring the thickness of single layer transparent films, however, in some cases the thickness of transparent multilayer films can also be determined. Measurement of the spectral reflectance/transmittance enables both the dispersive refractive index and the thickness to be obtained through mathematical optimisation. Routines have been written to extract optical parameters, namely the complex refractive index and film thickness, from spectrophotometer transmission and reflection coefficients (Dobrowolski *et. al.* 1983, Kihara and Yokomori 1992, Chambouleyron *et. al.* 1997) and more recently by Nevas *et. al.* (2003). Traceable calibration is achieved *via* a set of standard films, available from NPL (website: www.npl.co.uk/optical_radiation/). Commercial spectrophotometers are available from firms such as Perkin Elmer. NPL has a National Reference Spectrophotometer for calibrating primary spectrophotometer standards that are used to calibrate a commercial spectrophotometer used for routine calibration measurements of reflectance and transmittance.

3.3 BEAM PROFILE REFLECTOMETRYTM

Beam profile reflectometry (BPR) is a method, similar to that of ellipsometry, which uses a focussed spot from a coherent, linearly polarised optical source and a high numerical aperture objective (Fantoni *et. al.* 1994, Rosencwaig *et. al.* 1992). This technique overcomes one potential problem with ellipsometry in that the measurement is usually made over several millimetres of sample. The beam is incident on the film and each ray undergoes interference in the film dependent on its angle of incidence. The back-reflected beam then forms an interference pattern that is characteristic of the film. Two detectors record two independent interference profiles of intensity versus angle (*p*- and *s*-polarised profiles), a third detects the total reflected power and a fourth is an autofocus detector. With this information it is possible to measure film thickness from 3 nm up to 10 μm . More importantly, the method allows the measurement of optical constants and transmission coefficient simultaneously. BPR is extensively used in the semiconductor industry.

3.4 WHITE LIGHT INTERFEROMETRIC METHODS

The versatility and accuracy of optical interferometric systems for measuring film thickness has long been recognised. In principle, the classical interferometer can be used to measure optical thickness, but this usually requires the use of monochromatic light and the individual fringes cannot easily be identified. To overcome this fringe ambiguity problem, white light fringes can be used thus eliminating the ambiguity in the fringe order determination. In early white light interferometers (see for example Flournoy *et. al.* 1972) the white light coherence peak is first found on one side of the film and then the reference mirror is moved so that the coherence peak is obtained on the other side of the film. The displacement between the two coherence peaks (measured as the displacement of the reference mirror) gives the optical thickness of the film. Knowledge of the optical constants of the film allows the conversion of the optical thickness to a physical thickness. This method (and the methods described below) is, however, limited by the need for a prior determination of the optical constants of the film and substrate, phase shift effects, dispersion effects due to the finite numerical aperture and other optics in the system.

The most common form of white light interferometer for measuring surface topography is the vertical scanning white light interferometer. A recent advance has been the use of such interferometers to measure film thickness. A vertical scanning white light interferometer uses a broadband light source and involves the measurement of the degree of fringe modulation contrast as a function of path difference. Because of the large spectral bandwidth of the source, the temporal coherence length of the source is short, so high contrast fringes will only be obtained when the two paths in the interferometer are closely matched in length. By looking at the sample position for which the fringe contrast is a maximum while the optical path difference is varied, the height variations across the surface can be determined. With reference to figure 1, a piezoelectric actuator is used to vary the optical path difference. Some systems measure the displacement of the actuator with a further, length measuring interferometer (de Groot *et. al.* 2002). There are a number of vertical scanning white light interferometers available that differ mainly in the manner in which they determine the position of the coherence maxima (see for example Caber 1993, Chim 1990, de Groot and Deck 1995).

and Leach and Bennett 2004). Other spectral-based methods for measuring film thickness other than white light interferometry include spectrally resolved phase-shifting interferometry (Debnath *et. al.* 2006) and sinusoidal wavelength-scanning interferometry – usually employing an acousto-optic tuneable filter (Akiyama *et. al.* 2005).

It is generally considered that vertical scanning white light interferometers cannot match the resolution in thickness measurement of that of, for example, ellipsometers. However, one advantage in vertical scanning white light interferometers is that it is possible to construct a three-dimensional surface map of the film layer (see for example Kim and Kim 1999).

For thin films (with thicknesses ~ 20 nm to ~ 2 μ m, depending on the material or films refractive index), the vertical scanning white light interferometer interaction leads to the formation of single interference maxima. In this context, it is appropriate to describe the thin film structure in terms of optical admittances; this regime is addressed through the introduction of a new function, the ‘helical conjugate field’ (HCF) function (Mansfield 2006a, Mansfield 2006b). This function may be considered as providing a ‘signature’ of the multi-layer measured so that through mathematical optimisation, the thin film multi-layer may be determined on a local scale. Through the development of the HCF function, the local topography capability of vertical scanning white light interferometers may be extended to include the determination of layer thicknesses and dispersive indexes. An additional benefit is that, through the knowledge of the thin film structure, the phase-change on reflection may be compensated so that ‘true’ physical thickness may be obtained.

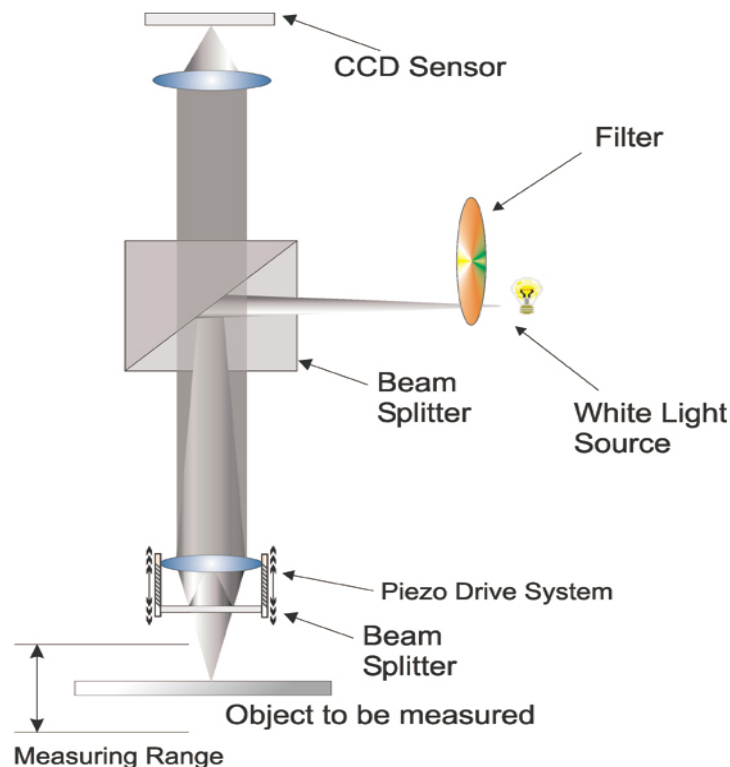


Figure 1 Schematic of a vertical scanning white light interferometer

It may be shown that through performing vertical scanning white light interferometry measurements on a thin film coated substrate (single or multilayer) together with a 'reference' substrate, such as BK7 optical glass, it is possible to construct the HCF function. This is a complex function that exists over the Fourier bandwidth of the instrument (typically 480 nm to 720 nm). The HCF function consists of the product of the conjugate of the electrical field reflectance from the surface (integrated over the numerical aperture of the objective lens) and an exponential with a phase that is proportional to wave-number (inverse wavelength). The exponential term arises from the height difference between the measured coated and 'reference' substrate. In a Cartesian space $\{x, y, z\}$ where x and y correspond to the real and imaginary components of the electrical field reflectance and z corresponds to the wave-number, the HCF function corresponds to a helix (generated by the exponential term) modified in terms of both amplitude and phase by the conjugate of the electrical field reflectance. This distorted helix then enables the thin film structure (single or multi-layered) to be extracted through a modified thin film optimisation approach.

It is useful to summarise the limits of the HCF approach. Firstly as the thickness of a thin film decreases, the distortion of the helix reduces and so the 'signature' of the thin film structure becomes progressively featureless over the HCF bandwidth; the limit (for a thin film of refractive index around 2.2 on a BK7 substrate) is around 20 nm. At the 'thick thin film' end, the single interference maximum gradually divides into two interference maxima. The multiple cavity reflections (that for thin films give rise to the standing wave electrical field pattern within the film structure) become progressively integrated out; for a single layer, the HCF function becomes progressively dominated by the sinusoidal term corresponding to the electrical fields reflected off the front and rear film surfaces. Depending on the refractive index, this limit corresponds to a film thickness of around 2 μm .

4. TRANSFER ARTEFACTS

There has been extensive work at the NMI level in the last few years on development of traceable techniques and transfer artefacts for thin film measurement. PTB have developed thin film transfer artefacts that were suitable for measurements using GXIR and ellipsometry (Thomson-Schmidt *et. al.* 2004). The artefacts also had a series of physical steps so that the film thickness could be measured by scanning force microscopy. The Type X artefacts consists of either a platinum layer or a carbon-nickel-carbon system on a polished fused silica substrate with respective nominal thickness of 10 nm and 50 nm. The Type E artefacts, designed for calibrating ellipsometers are silicon substrates having an oxide layer with a nominal thickness of 1000 nm, 380 nm, 160 nm, 70 nm or 6 nm. The artefacts were calibrated using GIXR.

NIST also developed a range of thin film reference materials that are characterised using GIXR. The artefacts have an interface roughness of 0.1 nm and thickness in the range from 2 nm to 1 μ m. NIST also has developed simulation software for the analysis of GIXR data.

NIST were also involved in a separate collaborative project with VLSI Standards Incorporated (Belzer *et. al.* 1998) to produce thin film artefacts. The artefacts were calibrated using a specially developed single wavelength ellipsometer (Chandler-Horowitz 1984). Two companies, Process Specialties Inc. (PSI) and VLSI Standards Inc., now supply the artefacts. All these artefacts are traceable to NIST and details are given below.

The dielectric and metal PSI artefacts are listed in table 1 and table 2 respectively, the dielectric artefacts of VLSI Standards are listed in table 3 and the PTB artefacts are listed in table 4.

Table 1 The dielectric PSI artefacts

Substrate diameter/mm	Film	Thickness/nm	Film uniformity/nm
150, 200, 300	Silicon dioxide	3, 10, 25, 50, 100, 200, 390, 670, 1050	0.1, 0.15, 0.15, 0.2, 0.2, 0.3, 0.3, 0.4, 0.5
150, 200, 300	Silicon nitride	10, 40, 95, 200	0.15, 0.2, 0.3, 0.3

Table 2 The metal PSI artefacts

Substrate diameter/mm	Material	Left hand film thickness/nm	Right hand film thickness/nm
150, 200, 300	Aluminium	100	380
150, 200, 300	Aluminium	470	1000
150, 200, 300	Copper	100	450
	Copper	470	1000
150, 200, 300	Titanium	10	90
150, 200, 300	Tantalum	10	45

Table 3 The VLSI artefacts

Substrate diameter/mm	Film	Thickness/nm	Film uniformity/nm
100, 200, 300	Silicon dioxide	3, 10, 25, 50, 100, 200, 390, 670, 1050	0.1, 0.15, 0.15, 0.2, 0.2, 0.3, 0.3, 0.4, 0.5
100, 200, 300	Silicon nitride	10, 40, 95, 200	0.15, 0.2, 0.3, 0.3

Table 4 The PTB artefacts

Substrate size/mm	Film	Thickness/nm	Film uniformity/nm
20 x 30	Silicon dioxide	6, 70, 160, 380, 1000	Not known
60 x 20	Platinum	10	Not known
60 x 20	Carbon-Nickel-Carbon*	2-3, 50, 2-3	Not known

*The carbon film is a protective layer

5. SUMMARY AND FUTURE WORK

It is difficult to compare the overall measurement range and uncertainty of each instrument described in this report since they are material dependant and each technique has its advantages and disadvantages or limitations. Probably the most versatile and widely used technique is spectroscopic ellipsometry. Its performance, and that of the x-ray techniques, is superior to that of white light interferometry. However, NPL has an existing vertical scanning white light interferometer and has access to future commercial software packages that allow multilayer and interfacial roughness measurement with a lateral resolution limited by the focussed spot size (Mansfield 2006a, 2006b). NPL also has a spectroscopic ellipsometer that will further compliment the white light interferometric method. The development of x-ray or optical methods, other than ellipsometry and white light interferometry, would involve a large capital investment and, in terms of thickness measurement, would not significantly enhance a measurement service based upon the existing instrumentation at NPL.

Several of the methods described in this report require measurement data to be fitted to a model in order to obtain film thickness, interfacial roughness and film texture. Clearly these models need to be validated. To confirm the validity of the ellipsometry measurements, the PTB artefacts have a physical step so that the film thickness can be measured using atomic force microscopy or stylus instruments. It is recommended that any future artefacts developed as part of the NMS project should also have a physical step.

It is not recommended that NPL produce certified standard artefacts of silicon dioxide or silicon nitride on silicon since these are already available and their traceability from another NMI would be recognised under the mutual recognition agreement. The smallest wafer on which they are available is 100 mm diameter and this may be too large for some instruments. If some of the peripheral structures were unnecessary, there is the possibility of cutting the wafer to size.

It is recommended that NPL produce at least one multilayer sample that can be used internally for checking the capability of the white light interferometry technique.

The next phase of this project will be to develop a measurement service for thin film measurement at NPL. This will involve the development and procurement of a range of transfer artefacts. All developed artefacts will have a step height to allow measurement of thickness using scanning probe microscopy and other surface texture measuring instrumentation. NPL will collaborate with Taylor Hobson Ltd to compare the method developed by Mansfield (2006a, 2006b) to the ellipsometer and to surface texture measuring instrumentation. The methods developed, together with the surface acoustic wave methods for measuring opaque thin films at NPL (Jennett *et. al.* 2004), will form a measurement service for industry and academia that covers all types of thin film in the thickness range from 1 nm to 5 μm .

6. ACKNOWLEDGEMENTS

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