Application note A131: Anti-Reflection (AR) coatings on solar cells

Coherence Correlation Interferometry (CCI)

Advanced metrology for anti-reflection coatings used in photovoltaics devices

Yang Yu, PhD

> *"The speed and extraordinary sensitivity makes the CCI SunStar an ideal tool for R&D and quality assurance."*
>
> **Prof. Michael Walls, Professor of Photovoltaics at CREST, UK**

Introduction

With the increasing demand for energy and global environmental concerns, solar energy has been considered as the most abundant, inexhaustible and clean of all the renewable energy resources to date.

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. High efficiency and low cost 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 away 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 thrown away and 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.

Anti-reflection coatings on solar cells are similar to those used on other optical equipment such as camera lenses. They consist of a thin layer of dielectric material, with a specially chosen thickness of an odd number of quarter wavelengths. This means that the wave reflected from the anti-reflection coating top surface is out of phase with the wave reflected from the semiconductor surfaces. As the phase difference between the reflected waves is 180 degrees, they destructively interfere with one another to cancel out the reflections, thereby greatly increasing the efficiency of the solar panel.

Figure 1: Close-up of a photo-voltaic solar cell

Measuring Anti-Reflection (AR) coatings

> *“Accurate measurement of both the thickness and roughness of AR coatings on solar PV cells is crucial for their efficiency and reliability and in the control of production costs. Coherence Correlation Interferometry (CCI) provides exceptional measurement accuracy for a wide range of AR coatings.”*
>
> **Dr Yang Yu, Applications Scientist, Taylor Hobson**

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[2].

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.

Solar cell metrology

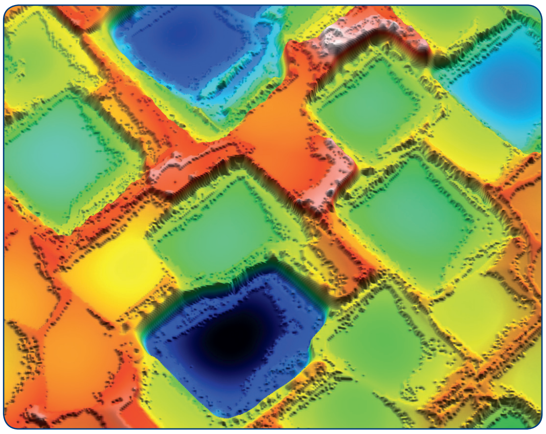
A number of metrology tools have been employed to measure film thickness. These include conventional methods such as spectrophotometry, ellipsometry and physical step measurement. Other methods have also been used to investigate film thickness, such as wavelength interferometry, prism couplers and thermal wave detection with a laser beam.[1]

Different types of metrology tools have also been employed to measure surface roughness such as stylus profilometry and Coherence Scanning Interferometry (CSI).

Coherence Scanning Interferometry (CSI) is becoming a popular technique because of its high lateral resolution and speed; however, one of the limitations of traditional interferometry is the thickness of the coating that can be measured. Typically, this needs to be larger than 1–1.5 µm to obtain accurate data. It is now possible to measure thicknesses down to 50 nm or less using Coherence Correlation Interferometry (CCI)[1] together with HCF (Helical Complex Field[3]) techniques.

Measurement of AR coatings using CCI

Coherence Correlation Interferometry (CCI) is a patented CSI technique suitable for the measurement of many different types of surface from very rough to very smooth. As it is very sensitive to low light levels, it is ideal for the study of solar panel efficiency and can provide both thickness and roughness results in a single measurement.



Coherence Correlation Interferometry (CCI)

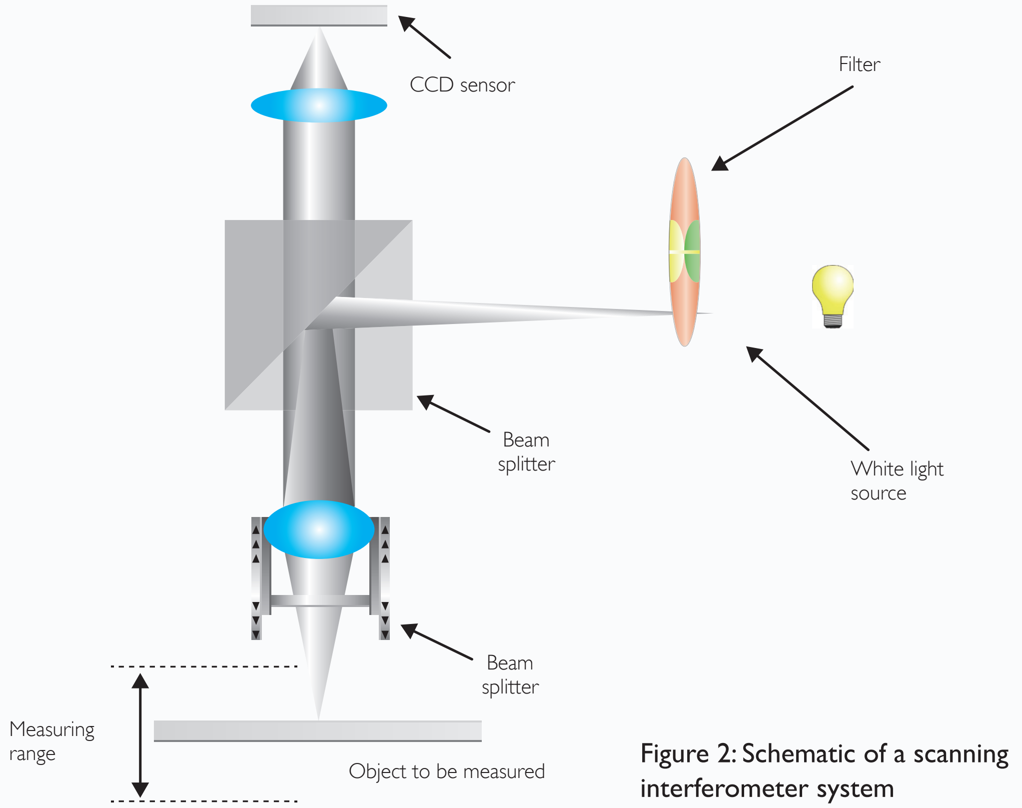


Figure 2: Schematic of a scanning interferometer system

> *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 2. 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

Measurement of film thickness

> *"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 SunStar with patented film thickness software[5]"*
>
> **Dr Daniel Mansfield, Research Manager and Company Physicist, Taylor Hobson Ltd.**

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.

CCI technology provides two different film thickness measurement solutions:

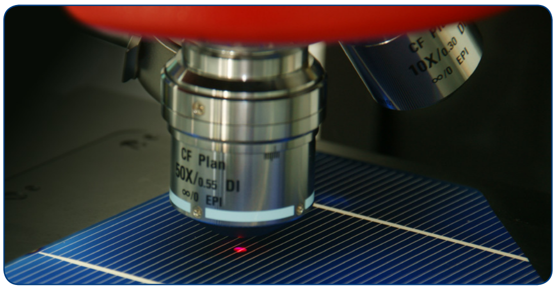
- Thick film (> 1.5 microns)
- Film thickness analysis (down to 50 nm or less)

The advanced CCI SunStar 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 3 and 4).

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

Figure 3: The CCI SunStar

Figure 4: CCI SunStar close-up



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 5).

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 6).

Figure 5: Single pixel measurement from a 7 µm thick film

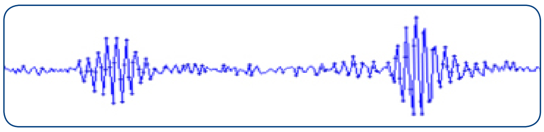
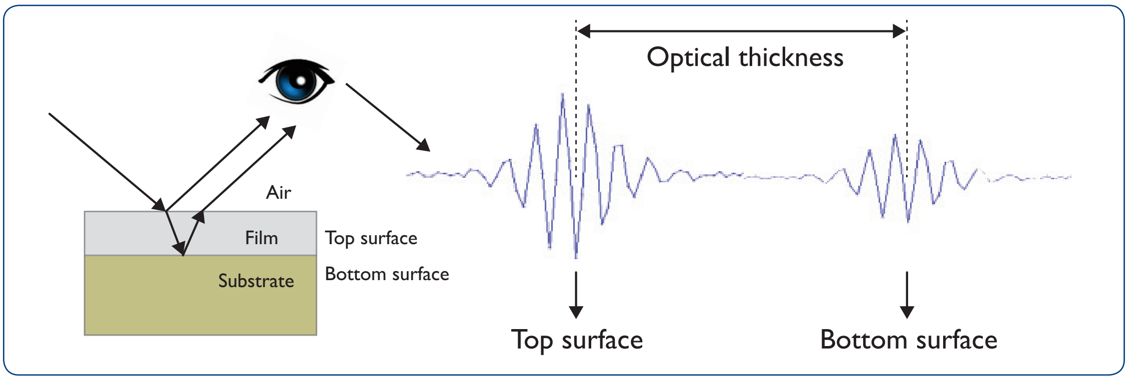


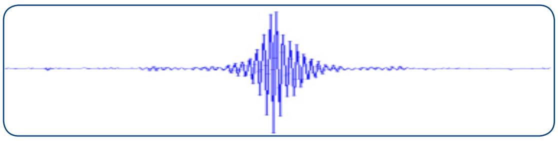
Figure 6: Determination of film thickness



Thick film limitations

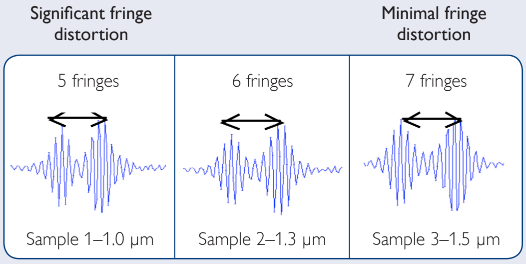
As the thickness of the film decreases, the two fringes become closer and overlap until they appear as a single interference fringe bunch. (Figure 7).

Figure 7: 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 8). An alternative method has to be employed.

Figure 8: Single pixel fringe for each sample



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)[3] 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. Film 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.

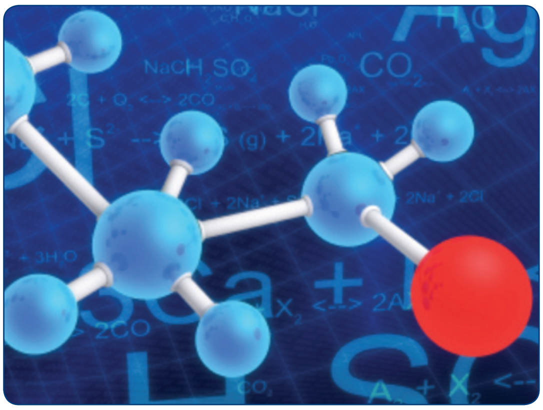
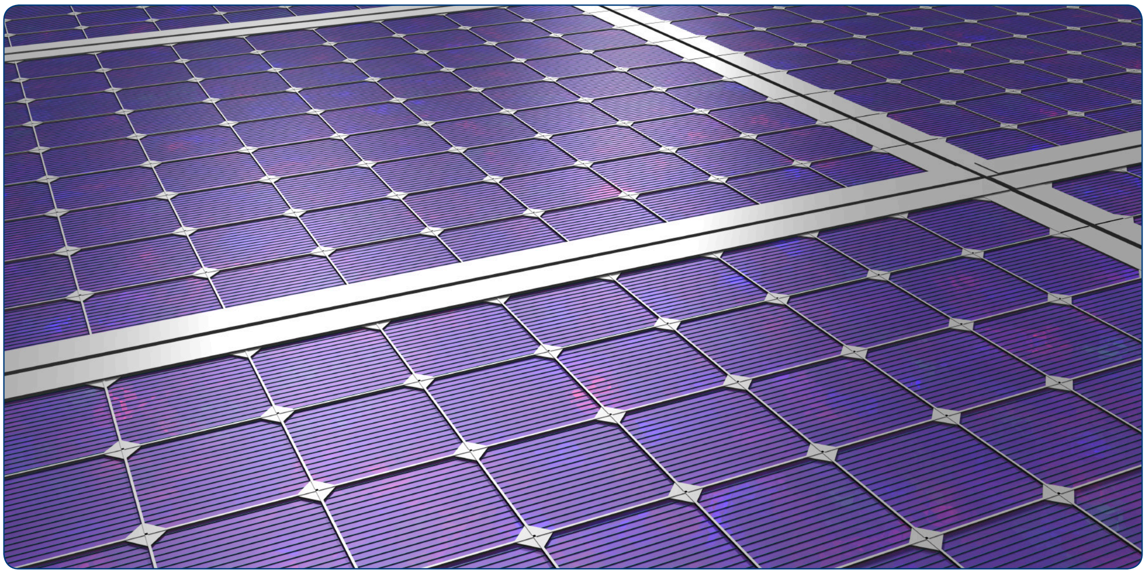


Figure 9: Solar panels



AR coating measurement results

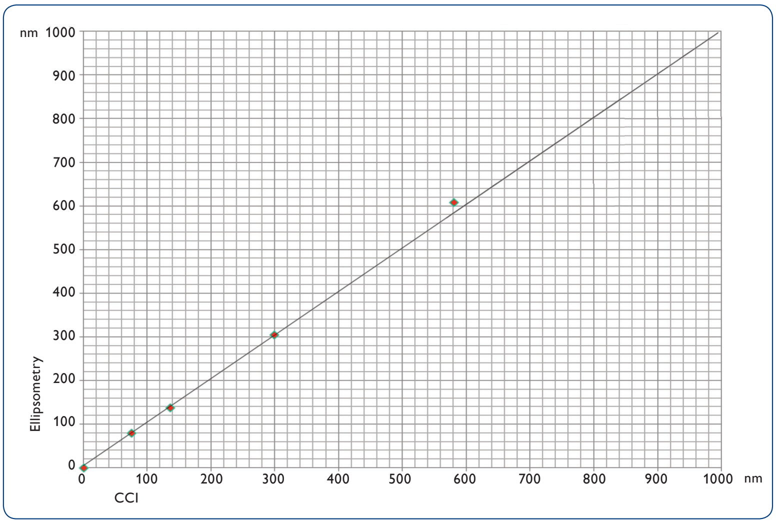
The accuracy of the film thickness measurement was tested by correlating the results obtained from the same samples using ellipsometry (Horiba, Jobin Yvon, UVISEL).

A series of AR thin films of different thickness in the range 75nm to 300nm for Silicon Nitride and 75 nm to 900 nm for Niobia 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 SunStar.

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[4].

Test 1: Niobia AR coatings

This data shows the power of the CCI approach allowing both thin film thickness and accurate surface roughness measurements to be obtained from a single measurement.



Graph 1: Thickness correlation between CCI and ellipsometry – using several Niobia thin films sputtered on glass.

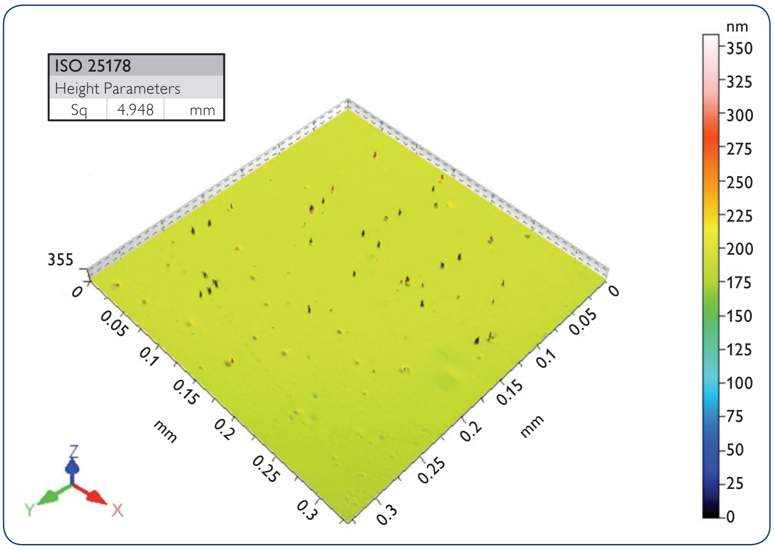
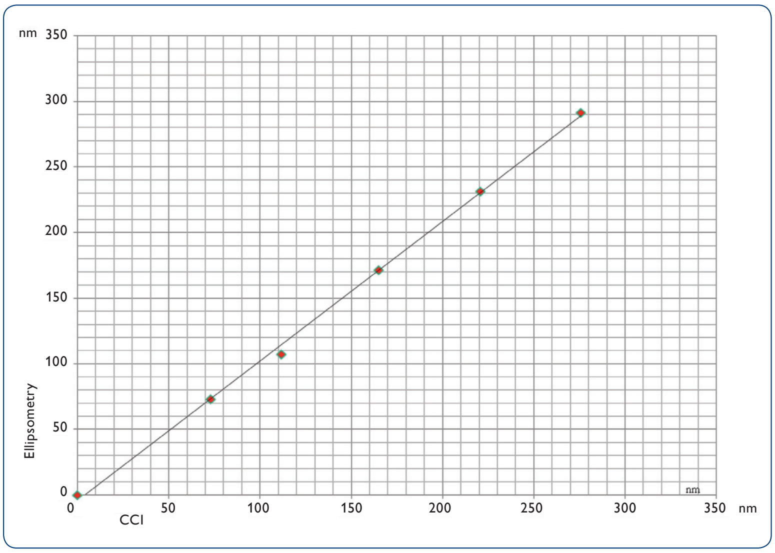


Figure 10: Three dimensional CCI image of 876.5nm thick sputter deposited Niobia layer, with RMS roughness parameter Sq =4.948nm.

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[2].

Test 2: Silicon Nitride AR coatings



Graph 2: Thickness correlation between CCI and ellipsometry – using a Silicon Nitride layer on polished silicon

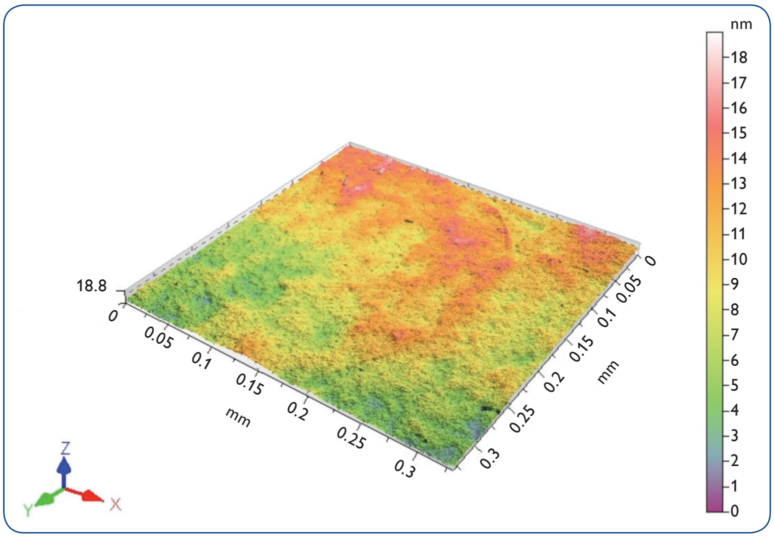


Figure 11: Three dimensional CCI image of 164.9 nm thick sputter deposited Silicon Nitride anti-reflective coating on polished silicon.

Results

Measurements on both Niobia and Silicon Nitride show excellent correlation between the CCI and the more traditional ellipsometry approach. The CCI is able to look at a wide range of film thicknesses down to about 50 nm, with a lateral resolution of 1 micron over a large area. The technology is also able to look at surface properties such as roughness, even for these low reflectivity surfaces.

Conclusions

The CCI technique provides a rapid and accurate three dimensional surface analysis which has the advantage that it is non-contacting and thereby non-destructive.

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

The new film thickness technique, together with Coherence Correlation Interferometry is the ideal metrology tool to provide fast and accurate AR thin film thickness and uniformity measurements for film thicknesses down to 50 nm or less. These accurate measurements can help to control the AR coating quality in order to eliminate the reflections and hence to largely increase the efficiency of the solar panel.

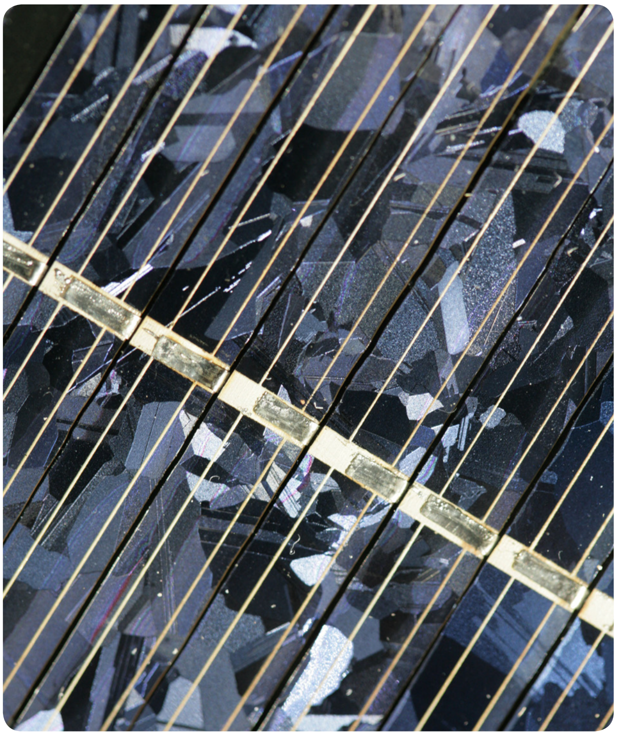


Figure 12: An example of solar cell technology

Acknowledgments

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