APPLICATIONS NOTE

Silicon Based Solar Cell Applications Using KLA-Tencor Profilers

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Introduction

As solar cell production evolves, significant hurdles will need to be overcome to meet both cost and efficiency requirements. Stylus based profilers are ideally suited to address critical metrology requirements in the Photovoltaic industry.

The solar cell industry is growing at roughly 37% per year. The current investment of roughly $2B per year is expected to increase by an order of magnitude by the end of 2008, as this is truly the only “Green” energy available. Today, roughly 90% of the Solar Cell industry is dedicated to silicon based substrates, which accounts for nearly half of the overall silicon demand.[1] With the projected growth of the Photovoltaic industry and the associated cost sensitivity, maximizing yield is of the highest importance.

Process

Wafer based solar cell production contains few process steps. The process flow begins with a mono or polycrystalline silicon ingot that is sawed, split and cleaned directly from the manufacturer. Next the substrate is roughened using a wet etch process and is followed by deposition of an Anti-reflective (AR) material. Next a front side contact grid is formed via a screen printing process, which is typically either silver or aluminum. The final step is to deposit the backside contact which is typically aluminum or boron.

Within this process, metrology should be performed after each step, to maximize efficiency and increase yield. KLA-Tencor offers two stylus based profilers, the P-16+ 3D surface profiler and the ASIQ 2D surface profiler. Both systems meet the metrology needs of the solar industry.

Applications

After the initial cleaning of the silicon wafers, a bare substrate bow measurement should be performed. This measurement can catch end yield loss and device malfunction at its beginning. Once a large number of bare substrates have been measured and completed the process cycle, bow tolerances can be determined that lead to a functional end product. Bow can be measured in either 2D or 3D,

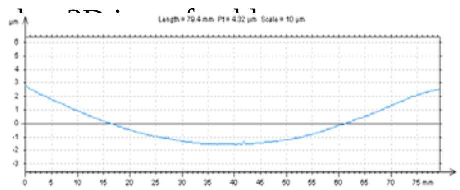

Figure 1: 2D bow measurement of a bare silicon wafer.

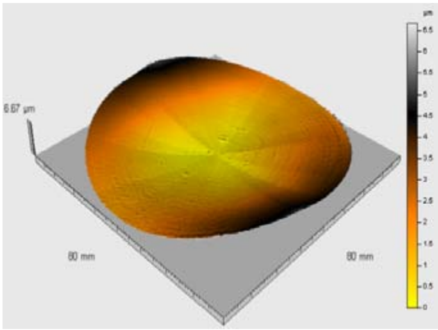

Figure 2: 3D bow measurement of a bare silicon wafer.

After the wet etch process is completed, cells should be selected for roughness measurements. This is a very critical measurement in the process, as this directly affects the light "trapping" abilities of the device. The P-16+ can determine the 3D amplitude parameters Sa and Sq using the newest ISO 25178 definitions. Additionally, 2D roughness parameters Ra and Rq can be calculated via ISO defined filtering algorithms including the Gaussian, Robust Gaussian, and the Double Gaussian filters. Both the P-16+ and ASIQ systems use ISO compliant filtering and parameter definitions to ensure global compatibility.

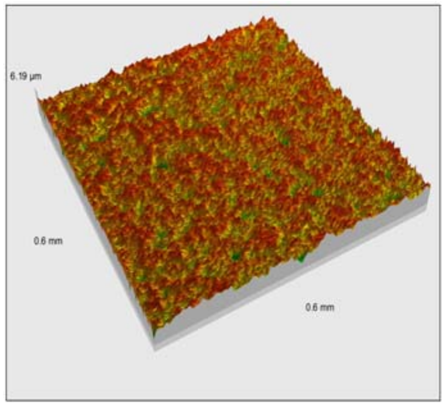

Figure 3: 3D plot of a Solar Cell after the roughening process.

After the silicon nitride AR coating deposition, the layer thickness can be accurately measured using the P-16+'s UltraLite® capacitive sensor or the transducer-based sensor on the ASIQ. This thickness value is another very important parameter in the process as it directly impacts efficiency in the same way the roughening process does: to improve the light trapping ability of the device by reducing the surface reflectivity.

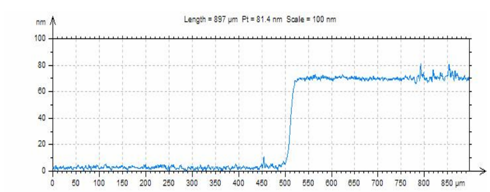

Figure 4: ARC thickness measurement obtained using the ASIQ.

Another measurement that is made after the ARC deposition, and may be directly responsible for the number one PV yield loss: cracking, is film stress. Stress is an indirect measurement that occurs as a result of a lattice mismatch between the film and substrate.[2] Since stress is typically not homogeneous across a wafer, full wafer 3D stress measurements are highly recommended. The stress measurement process is completed in two separate steps. The first step is to measure the bare wafer bow, already achieved in the first step in the metrology process above. Next, after the silicon nitride coating is deposited, the bow is measured again. By comparing the "pre" AR coating deposition bow with the "post" AR coating deposition bow, the difference in the radius of curvature between the two is calculated via a fifth order polynomial fit. The stress is subsequently calculated using Stoney's equation, which is given below.

$$\sigma = \frac{1}{6R}\frac{\mathrm{E}}{(1-\upsilon)}\frac{t_s^2}{t_f}$$

$$= \frac{1}{6}\frac{\mathrm{E}}{(1-\upsilon)}\frac{t_s^2}{t_f}\left[\frac{1}{R_F}-\frac{1}{R_s}\right]$$

where

$$\frac{\mathrm{E}}{(1-\upsilon)} = \text{wafer elastic constant}$$

and $\sigma = \text{stress}$

$\mathrm{t_s}$ = wafer thickness

$\mathrm{t_f}$ = film thickness

R = Radius of Curvature (RoC)

$\mathrm{R_s}$ = RoC of Substrate

$\mathrm{R_f}$ = RoC of Substrate with Film

E = Young's Modulus of substrate)

υ = Poisson's Ratio

Even though the typical ARC film thickness is small, its contribution to wafer deformation can be significant.

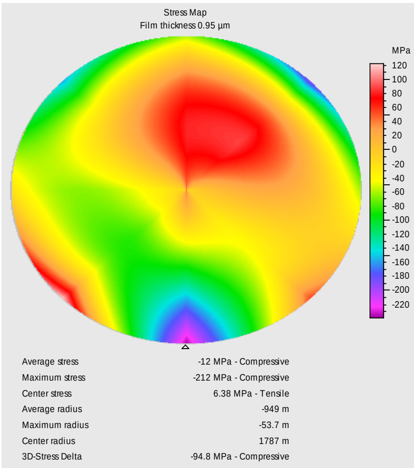

Figure 5: Typical 3D stress measurement after film deposition.

The next metrology recommendation that is easily fulfilled by both the P-16+ and the ASIQ is the Bus Bar thickness and width measurement. The Bus Bar is produced via a screen printing process and is often not tightly controlled, which may lead to short circuits, undesirable levels of resistance, or loss of valuable light collecting surface area. Due to this variability, it is recommended that a 3D area is profiled or that multiple 2D measurements are performed, and an acceptable tolerance is determined.

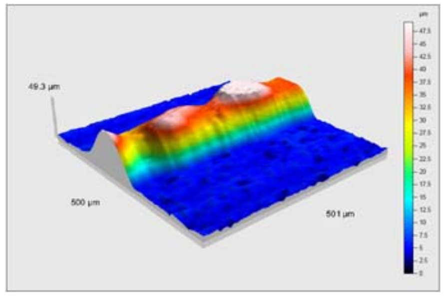

Figure 6: 3D plot of an electrical contact line.

The P-16+ employs advanced recognition algorithms to automatically detect and measure Bus Bar height and widths. This algorithm removes the need for operator interpretation of the data.

The last process step in which metrology is recommended is backside metal contact thickness. Unmonitored backside metal thickness can also lead to short circuits and high levels of resistance.

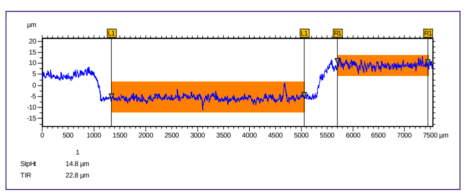

Figure 7: Profile of backside metal contact.

Below is a table that summarizes the measurement capabilities of stylus and optical based profilers.

	P-16+	ASIQ	Optical Profilometry
Wafer Bow	✓	✗	✗
Roughness	✓	✓	✓
ARC Thickness	✓	✓	✓
3D Stress	✓	✗	✗
Line Thickness	✓	✓	✓

Table 1: Chart describing capabilities for recommended wafer based metrology applications of the P-16+, ASIQ, and Optical profiler.

Conclusions

KLA-Tencor profilers meet the step by step metrology requirements of the Photovoltaic industry. Five major process steps have been identified where stylus based metrology is highly recommended to maximize yield and efficiency. These steps include bare wafer bow measurements, surface texture roughness measurements, ARC thickness measurements, full wafer stress measurements, and finally contact line thickness measurements. Stylus-based profilometry has proven to serve as a versatile technology that offers a range of scan length capability to cover a breadth of applications. Both offerings from KLA-Tencor are well suited in photovoltaic R&D environments and have a well established track record of production worthiness.

References

1. "*Photovoltaic Activities*", Gaetan Rull and Jean-Chrisophe Eloy. Yole Developpment, 2006.

2. *"Material Science of Thin Films"*, Chapter 12, p 711-712, Milton Ohring, 2nd Ed., 2002.