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OPTICAL THICKNESS MONITORING FOR THE A-SI PRODUCTION LINE

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ABSTRACT: To produce efficient a-Si:H solar modules it is essential to control the deposition processes and thus the thickness of each sub-layer. An optical thickness monitoring system was developed to measure the growth of these thin films. Thereby the change of the spectra of the reflected white light between 350nm and 1000nm is analyzed. By means of this nondestructive monitoring method the production processes itself is not influenced. The thickness of the thin films is calculated by the matrix method according to the well established theory of the optical behavior of stacked planar multilayer. The optical properties of the deposited layer materials are the fundament input of the calculation. Amorphous silicon layers with a thickness in the range between 30 – 1000 nm have been analyzed successfully.
Keywords: Thin Film, Deposition, Software

1 INTRODUCTION

Unaxis solar has the unique potential to combine the company's Know How in large scale production of TFT display on silicon deposition technology with excellent research results at the University of Neuchcatel on small scale a-Si:H cells. In the last two year promising steps were made to develop large scale production systems for mass production of thin film a-Si modules [1]. The optimization of the uniform layer deposition processes is still a key issue.

To reach the maximum efficiency of the a-Si solar cell pin structure, each layer has to be processed with an optimum thickness. Layer thickness values below this optimum will result in a lower short-circuit current of the module, while too thick layers will reduce the number of produced modules per period at the same deposition rate.

Therefore a reliable layer thickness monitoring system is also essential during the development stage of the production system, as well as the control of the deposition processes in the final production line. Here an optical thickness monitoring system will be described.

2 BASICS OF OPTICAL MODELLING

The optical properties of a layer are given by the refraction index of the material in the complex form

$$N_r = n_r - ik_r \qquad (1)$$

with n and k changing with the wavelength λ. The optical properties of a stack of planar layers (Fig. 1) will be defined by the refraction indices of the used materials and their specific thicknesses.

In a composition of different refractive thin films, each transition will reflect or absorb light as shown in Fig. 1.

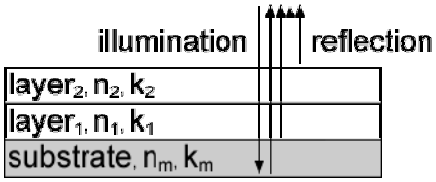

Figure 1: Optical reflection of stack of layers on glass

The incoming beam will be absorbed in the layers and reflected at the different interfaces. The intensity of the reflected beam on the top layer is a superposition of all the sub-reflections of the layers below. If the incident light beam is monochrome, the resulted reflected intensity will oscillate with growing layer thickness, caused by interfering effects. With broadband illumination these interference effects will occur in the spectrum of the reflected beam, depending on the refractive indices and thickness of the layers.

The matrix method is used to calculate the reflected spectrum according to the established formulation of H.A. Macleod [2]. The phase shift of the light traversing a distance d normal to the boundary is given by:

$$\delta_r = 2\pi N_r d_r \cos\theta_r / \lambda \qquad (2)$$

with N_r the refraction index, d_r the thickness of the layer, for the perpendicular irradiation condition. The effective refractive η_r becomes equal to N_r due to θ_r=0°.

$$\eta_r = N_r \qquad (3)$$

For each layer, a characteristic matrix describes the light intensity at the interfaces. The product of all the different layers will lead to overall reflection intensity of the layer stack in equation 5.

$$\left[\frac{B}{C}\right] = \left(\prod_{r=1}^{q}\begin{bmatrix}\cos\delta_r & (i\sin\delta_r)/\eta_r \\ i\eta_r\sin\delta_r & \cos\delta_r\end{bmatrix}\right)\begin{bmatrix}1 \\ \eta_m\end{bmatrix} \qquad (4)$$

with η_m effective refraction index of substrate

$$R = \left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)\left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)^* \qquad (5)$$

with η_0 effective refraction index of air.

The above set of equations have to be solved individually for each wavelength. The input of the refraction index of each layer material is fundamental for all calculations. Several optical material properties (n, k) reported in literature were tested to reproduce the accurate layer thickness. The best results were performed with the n, k values of a-Si:H measured by the ellipsometric method [3].

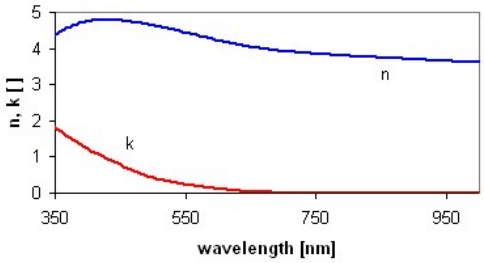

Figure 2: Optical refraction values of a-Si, measured by ellipsometry used for the thickness calculations

3 EXPERIMENTAL SETUP

The experimental setup consists of a lamp coupled by an optical fiber with the layer stack on the glass substrate and a second fiber feeding the reflected spectra into the spectrometer.

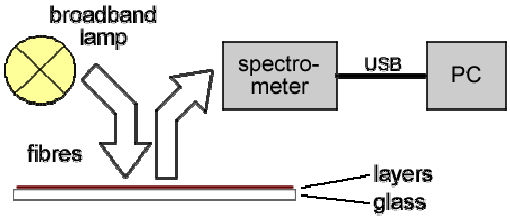

Figure 3: Components of the monitoring hardware setup

The broadband light source was designed as a combination of a halogen lamp and LEDs, driven by constant current sources. Six optical sub fibers used to illuminate the sample device and one sub fiber serves as the reading channel for the reflected light with a core diameter of 200 µm. To operate the monitoring system together with a DUT in the reactor under vacuum conditions a special optical vacuum feed trough is needed. The spectrometer has a grating for 350-1000nm, and 2048 pixels. The control of the spectrometer by the PC is done via USB-port.

To calibrate the optical setup a black and white calibration of the optical setup is required. The white calibration is performed by an aluminum mirror with known reflection spectrum.

The software allows defining the film/layer stack with the known refractive indices of the layer materials. It is possible to simulate the reflected spectrum with varying the layer thickness and compare the calculated with the measured spectrum. Both spectra shown in Fig. 4 as a print screen of the programs graphical user interface (GUI) of a 690nm thick a-Si layer on a 1mm glass substrate. The analyses of a sample with a much thinner a-Si layer on glass are given in Fig. 5 where only one minimum in the reflected spectra is observed.

In the automatic thickness tracking mode, the layer thickness of one film is changed automatically to get the best fit between measured and calculated spectra. Thus it is possible to measure spectra's and automatically fit the thickness of the layers. The present system is capable to simultaneously measure and record the growth rate of the a-Si deposition in the reactor at a maximum sampling rate of 5 S/s .

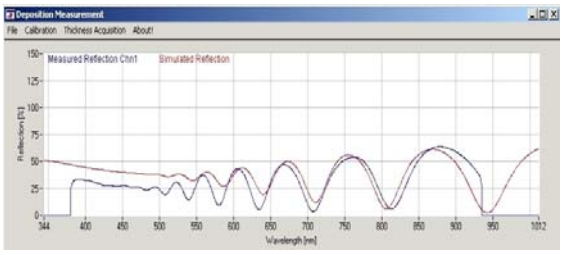

Figure 4: GUI for comparing measured and calculated spectrum (a-Si 690nm on glass, in air)

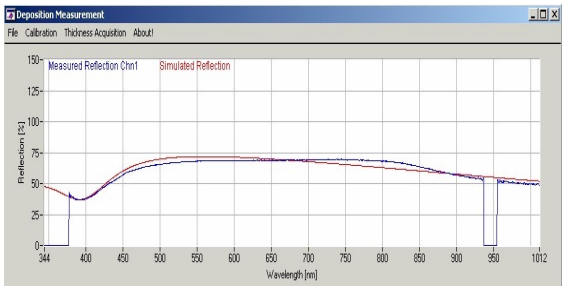

Figure 5: GUI for comparing measured and calculated spectrum with a thin sample (a-Si 36nm on glass, in air)

4 EXPERIMENTAL RESULTS

The above described experiment setup together with the developed analytical software was compared to other thickness measurement techniques. In table I film thickness results by the here presented setup are compared with the conventional sylus profiler method and with an other optical evaluation method proposed by Swanepoel [4]:

Table I: Comparison with other thickness measurement instruments (under ambient atmosphare).

Instrument	thickness [nm] of sample: 1	2
Present setup (Fig. 3)	84	296
Profiler	82	300
Swanepoel method [4]	79	270

A Tencor alpha step 200 profiler is used to measure the step height from the glass substrate to the top of the a-Si:H layer. The method proposed by Swanepoel requires a number of interference minima and maxima of the transmission spectra [4]. This technique can not be applied to a-Si:H layers smaller than 50nm, because not enough interference minima and maxima can be counted.

The uncertainty of the presented measurement technique is in the range of approx. 10% of the layer thickness. It also has to be taking into account, that the layers are not perfectly planar. Therefore the reflection properties are not in accordance to the principle of the matrix theory due to the more complex scattering of light

at the interfaces [5]. The most important factor as source of uncertainty is the reliability of the used optical material properties. Additionally these optical material properties also might vary under different deposition conditions.

It is recommended to use structures with thin glass and thin TCO to increase accuracy.

5 CONCLUSION

The presented technique is based on a nondestructive method, which does not require several minima and maxima in the optical spectra. Thus it is appropriate to measure a-Si:H based thin-films with a thickness as thin as 30 nm up to more than 1000 nm. The stylus profiler measurements become more inaccurate and Swanepoels method is impossible on thin layers. But the here presented setup approves valuable process control. Therefore the measurement system is adequate to be integrated in an in-situ thickness monitoring system to control the deposition processes of a-Si:H layers during solar module production.

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