Flames: in-line roll-to-roll application

LayTec's in-line monitoring system is capable of measuring properties of deposited layers throughout the solar cell manufacturing roll-to-roll processes: layer thickness of each layer, color values, effective absorption and roughness. The contactless optical monitor system Flames IR helps keep the processes tightly within the specification limits by direct feedback to the growth control system and statistical process control.

Flames IR is based on specular spectroscopic reflectance measurements (500 - 1600 nm) and is applicable basically to all major PV thin-film structures: CIGS- and CdTe-based thin-film solar cells, a-Si / µc-Si tandem cells and anti-reflective coatings on mc-Si and c-Si solar wafers. Since light reflected from the surface and all interfaces within a layer stack interferes, the spectrum of the reflected light shows an interference pattern bearing information on the refractive index n, the index of absorption k and the thickness d of all layers so far deposited in the PV thin-film process. A special data exchange hub between several metrology stations in roll-to-roll production processes allows taking reflectance spectra after each deposition step. The Flames IR system is adaptable to virtually any roll-to-roll process equipment.

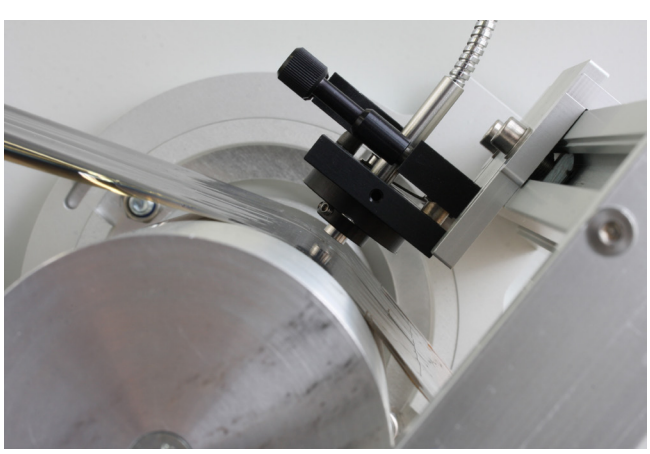

Fig. 1: Optical head of the Flames IR installed in a roll-to-roll system for investigation of CIGS-based structure on foil.

The small optical heads can be installed in-line as shown in Fig. 1 and Fig. 2. The Flames IR control computer communicates with the production line control software to assure that measurements after each deposition step relate to the same position.

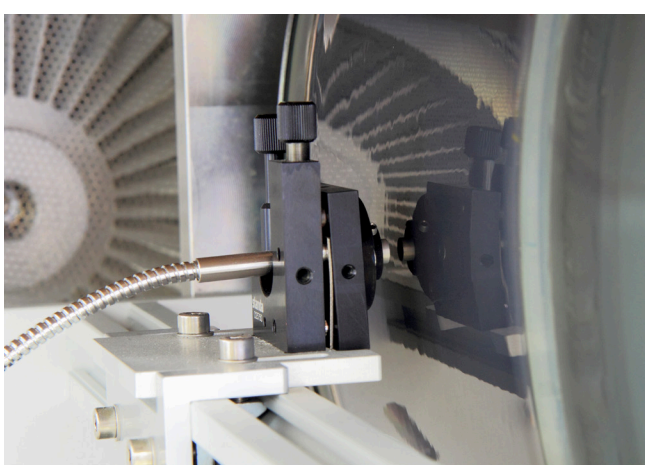

Fig. 2: Optical head of the Flames IR installed in a roll-to-roll TCO coater system.

To overcome the scattering of rough materials, we have developed focusing optical heads with large aperture for detecting specular reflection; the heads additionally suppress artefacts caused by substrate bow.

Fig. 3 shows real-time thickness measurements during a roll-to-roll process. The optical heads are measuring before and after the deposition of the CdS buffer (wet chemical process) on a flexible substrate. In the next step, after deposition of the i-ZnO layer and the Al:ZnO layer, film thickness measurements are performed in a similar way. Fig. 3a shows typical thickness measurements of the CIGS absorber layer (Fig. 3a lower curve) taken by the first sensor head and CdS buffer layer (Fig. 3a upper curve) taken by the second head. It can be seen that the thickness of the CIGS absorber layer is varying between 1900 and 2000 nm showing small fluctuations in process conditions. The thickness of the CdS buffer layer is decreasing by approximately 15 nm within 50 nm as indicated by the red line.

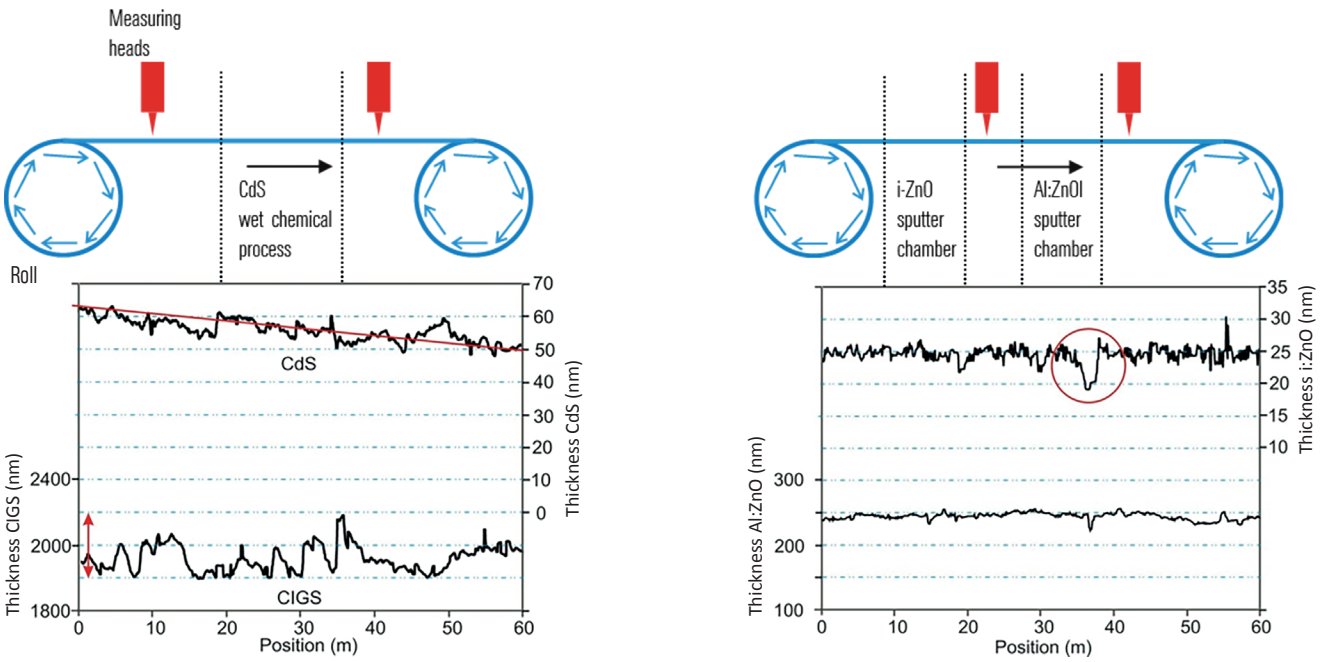

Fig. 3: In-line position resolved thickness measurements

a): Thickness of CIGS absorber (accuracy ± 1 %) and CdS buffer (accuracy ± 2%) over position.

b): Thickness of the i-ZnO and the Al:ZnO (accuracy ± 2%) over position.

This is likely caused by source depletion. The layer thicknesses of i-ZnO and Al:ZnO are shown in Fig. 3b. The Al:ZnO shows mainly statistical deviations from the target thickness of 25 nm, whereas for the i-ZnO an additional drop in layer thickness at a band position of about 38 m was observed (red circle). The reason is unknown. For the fast measurement and analysis, all results are facilitating real-time data acquisition. This allows for a dense sequence of measurement points in transport direction. The multi-head concept of the Flames IR allows for additional heads across the band along an axis perpendicular to the transport direction. As a result, a 2D uniformity map of the process can be obtained.

Flames IR offers real-time access to roll-to-roll process variations and critical process deviations can be identified instantaneously. Derivations may be caused by spitting, depletion of material sources, drift in temperature and others.

By finding correlations between deposition parameters and film thickness drift effects the manufacturing process can be minimized or compensated via feed-back control. Customers are using Flames IR for statistical process control and feedback of process parameter like chemical bath concentration for CdS deposition. Flames IR helps increase the mean efficiency of the produced modules. The production yield is increased as tight process control decreases the number of out-of-spec modules.

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