



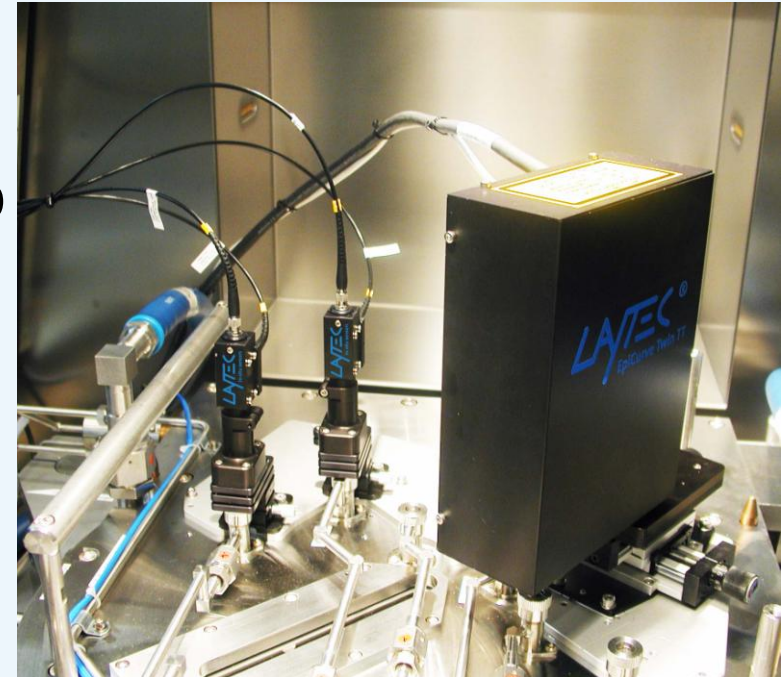
In-line Film Monitoring of Layer Thickness and Composition of CIGS and CdTe Thin Film Layers

Steffen Uredat, senior manager product development

- **Who is LayTec?**
- **Thin film production requirements**
- **In-line reflectance measurements**
- **In-line photoluminescence measurements**
- **Summary**

LayTec – optical in-line metrology for thin-films

- focus on in-situ & in-line metrology with optical methods
- market leader in in-situ metrology for LED and LASER production
- >90 employees
- world-wide distribution & service network
- belongs to the 50 fastest growing German technology companies in 2009 & 2010



New:

in-line series of products for thin-film PV applications

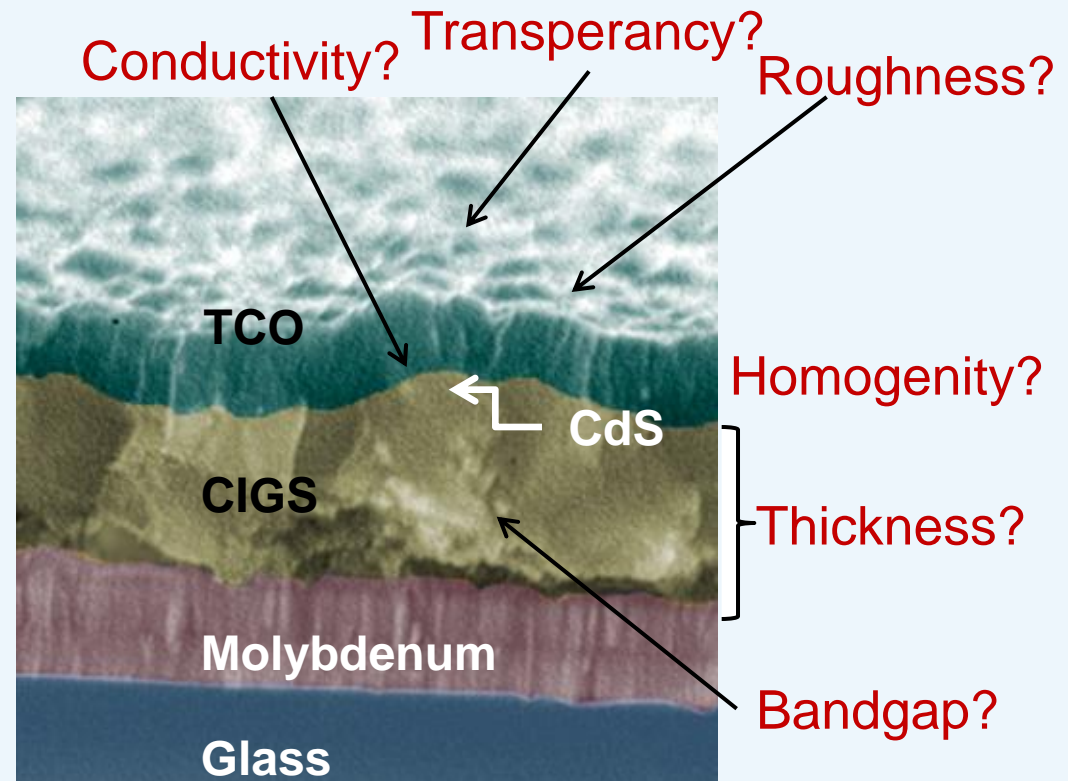
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Motivation (Layer parameter to be measured in-line)

Thin film solar cells are complex multi layer systems.

In-situ and in-line control of critical parameters is needed for:

- 100% control
- increased efficiency
- higher production yield
- process optimization



Improving production yield

- reduce out-of-spec modules
- separate plates right after failed deposition step
- fast detection of deviations
- narrow statistical distribution in efficiency
- re-establishment of conditions after maintenance



Source: Centrotherm

➤ **In-line metrology improves yield to reduce cost!**

Increasing yield

- Basis = 30 MWp / year
- i.e. yield improvement 85 % to 86 % gives additional 352,000 Watt / year

Increasing efficiency

- Basis = 30 MWp / year; 11.0 % module eff.
- i.e. eff. improvement 11.0 % to 11.1 % gives additional 272,000 Watt / year

➤ **In-line monitoring pays off in less than 6 months!**



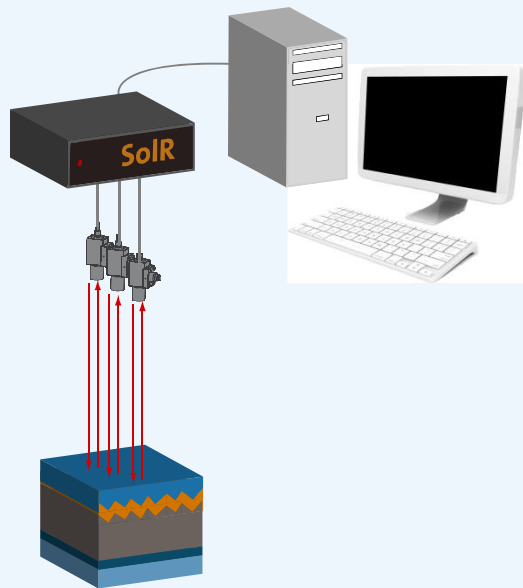
Implementing in-line control

- 100 % control of each plate
- high lateral resolution for homogeneity characterization
- on-time measurement results
- instructive visualization of measurement results
- feedback loop to system controls

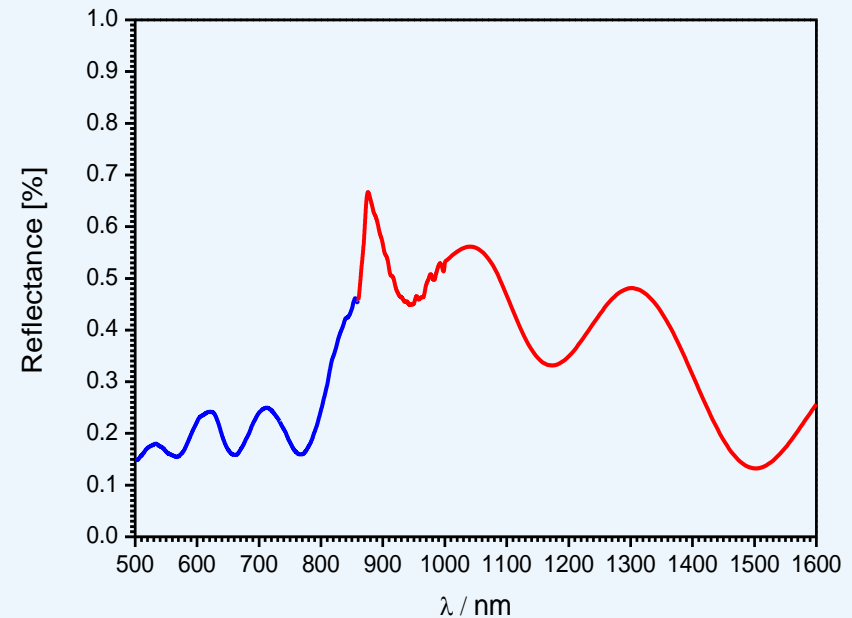
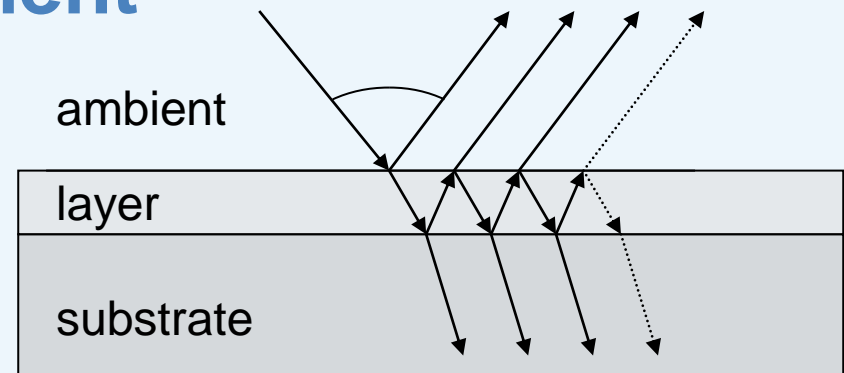


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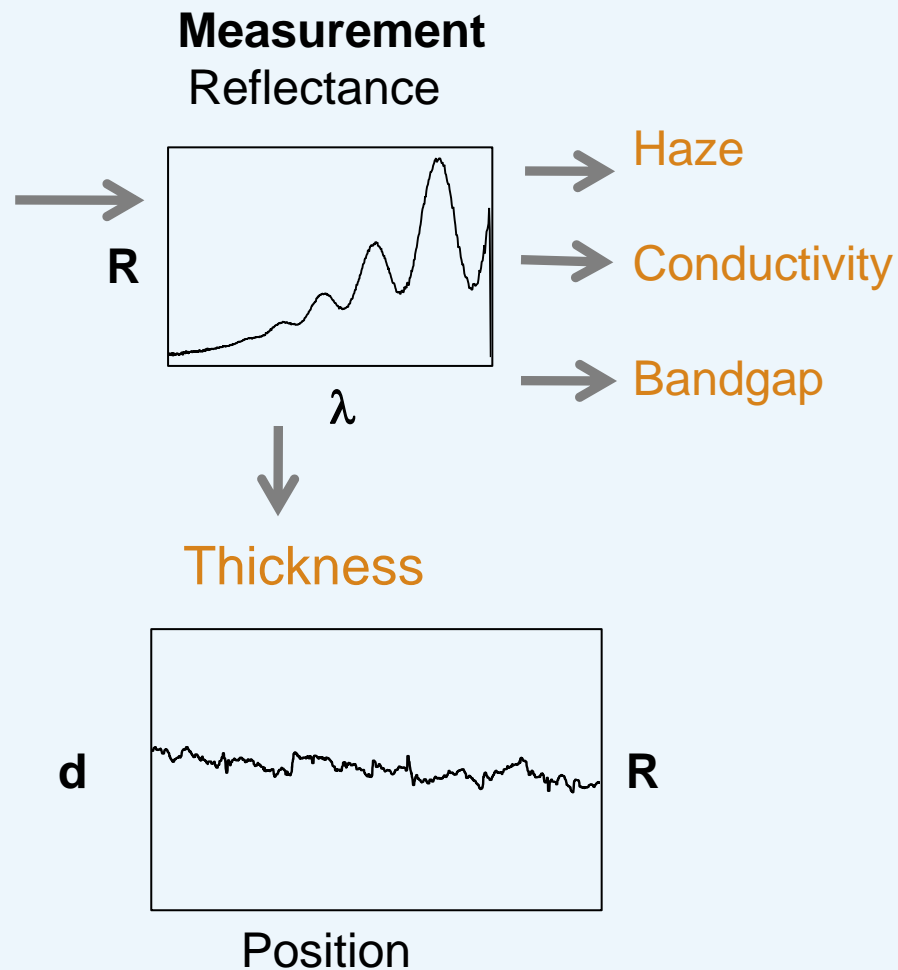
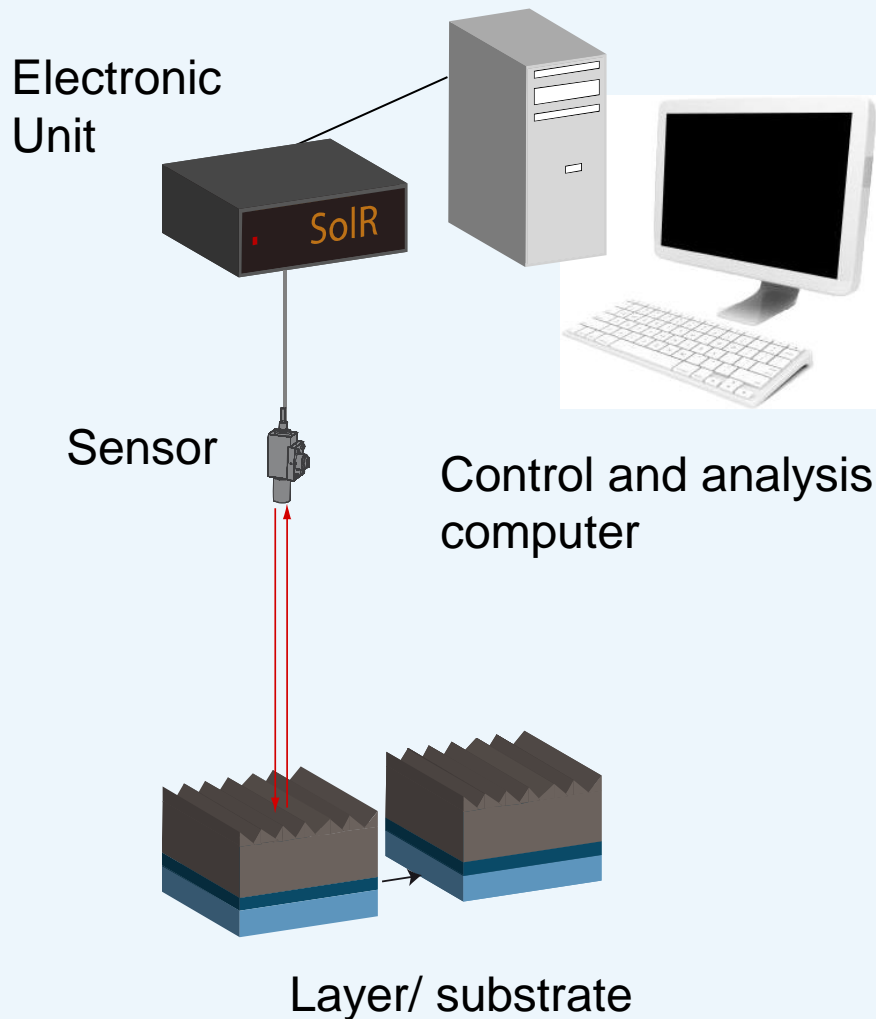
Reflectance measurement



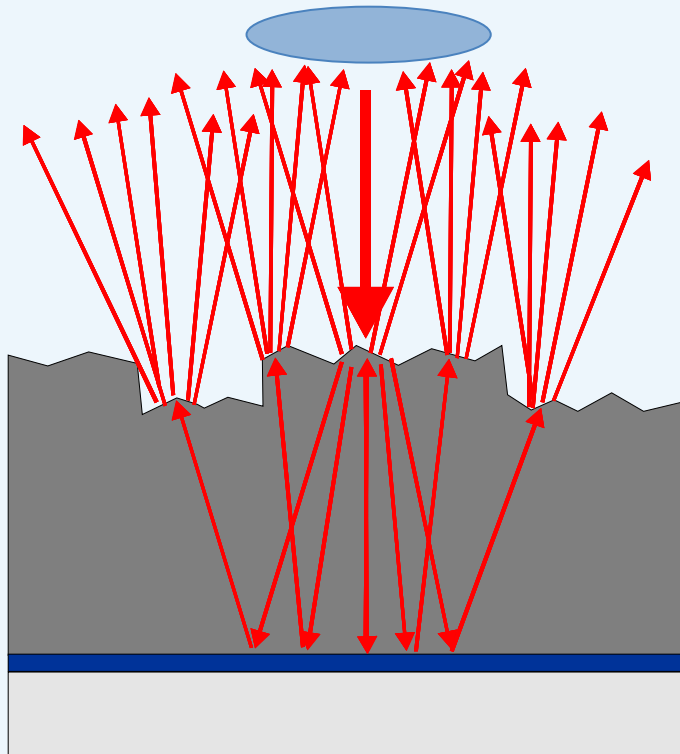
- measurement by vis-IR white light reflectance
- Fabry-Perot-Oscillations in reflectance spectra



SolR Set-up

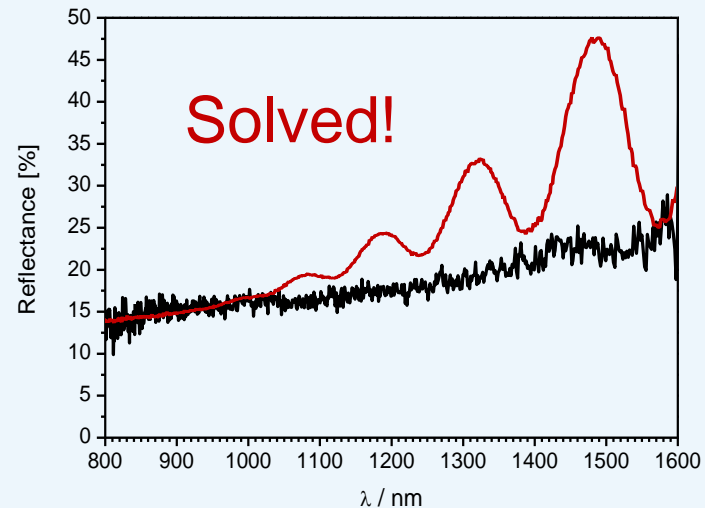


Optimized optics for rough materials



Effects of roughness:

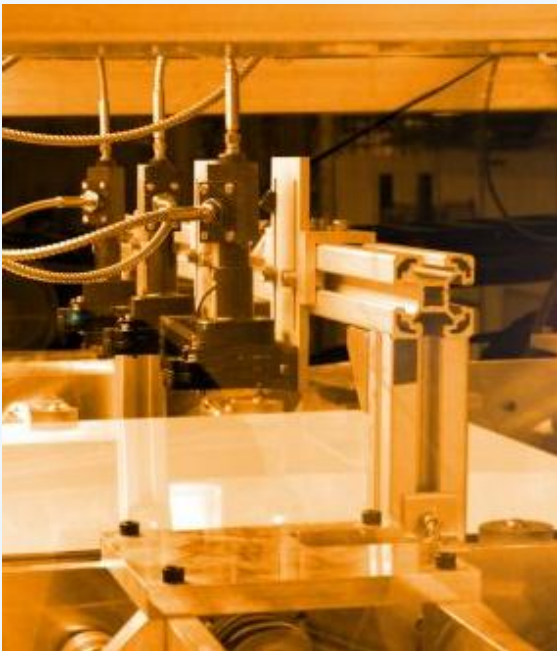
- reduced reflectance
- stray light losses
- suppressed interferences



- **Optimized sensor optics and analysis allows in-situ layer thickness measurements on rough and textured materials!**

In-line integration: specialized optical heads

Focusing optics
for absorbing
surfaces



Fiber probe in air

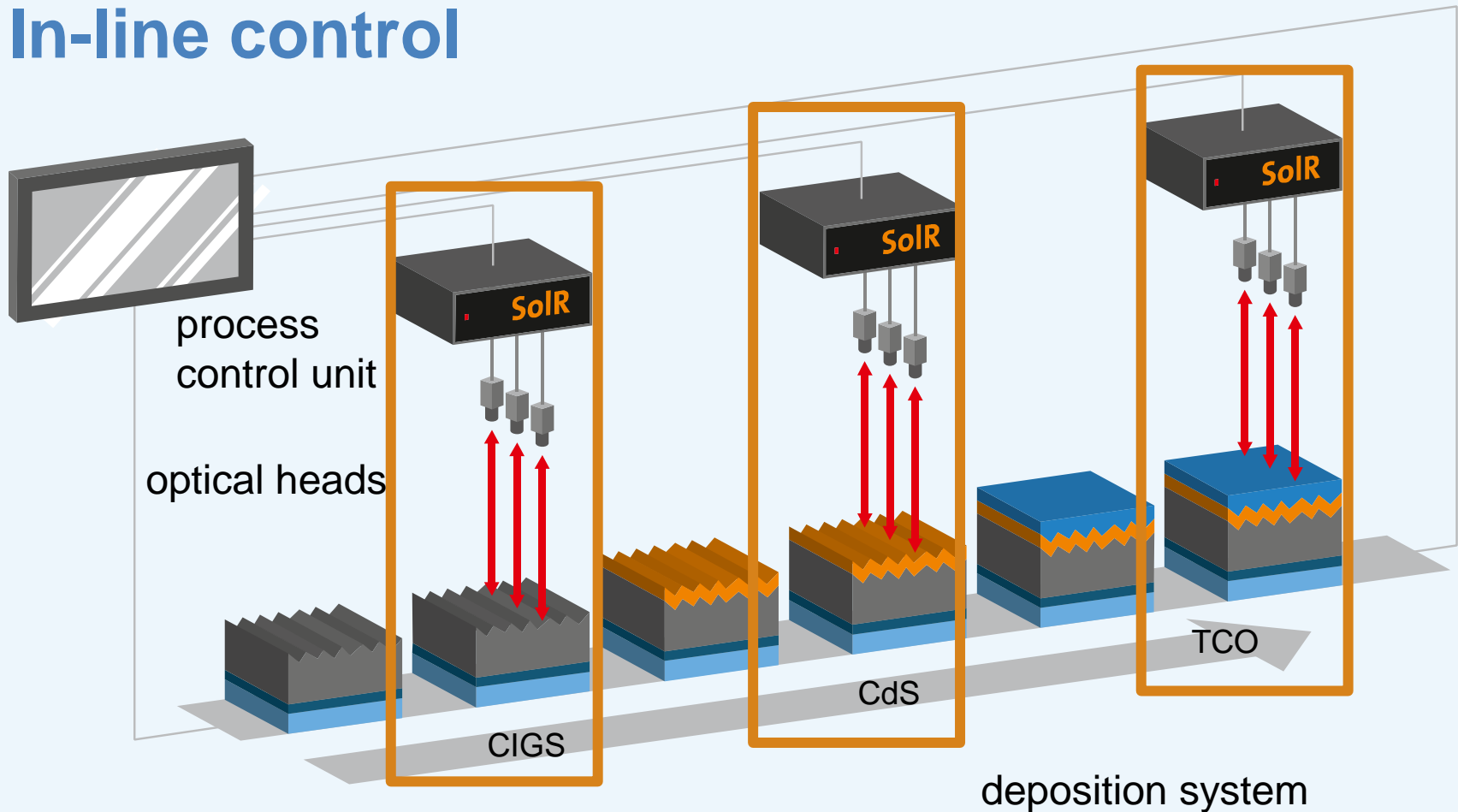


Fiber probe in vacuum



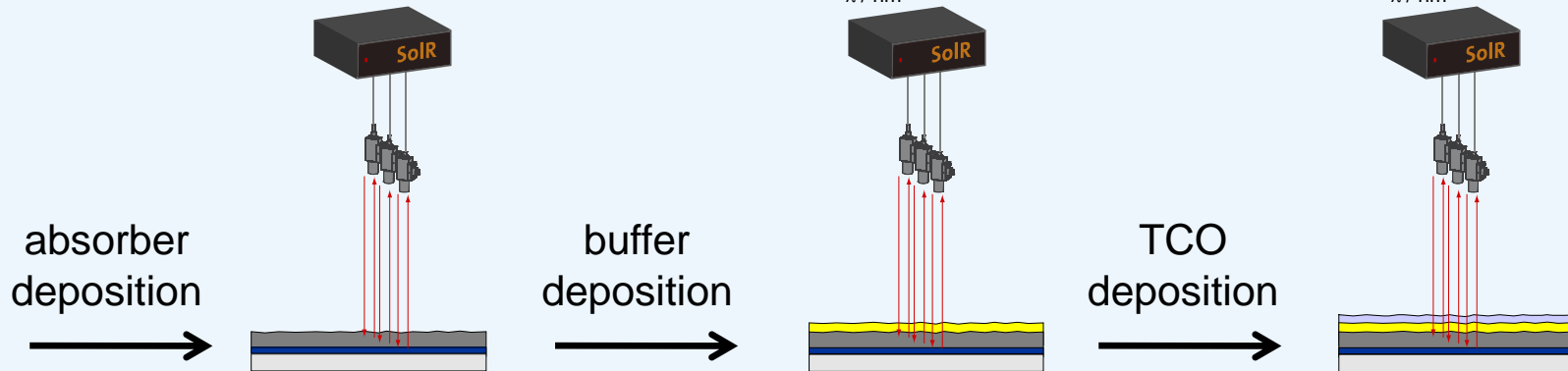
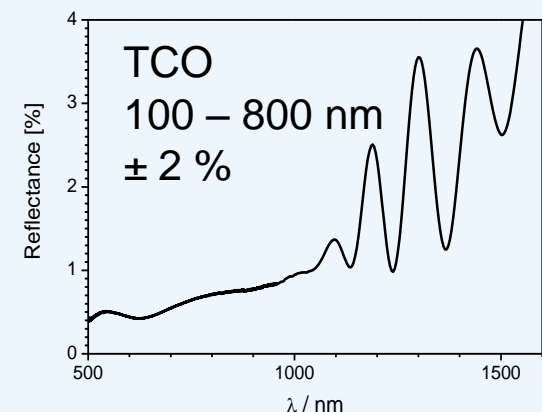
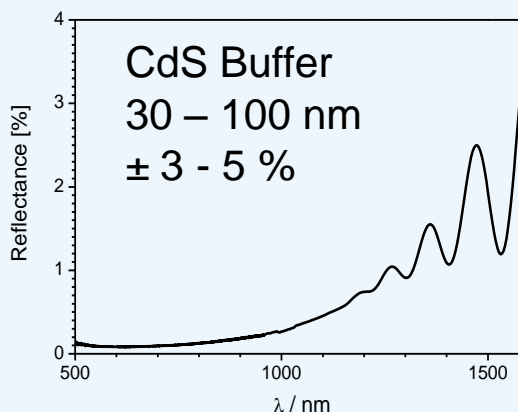
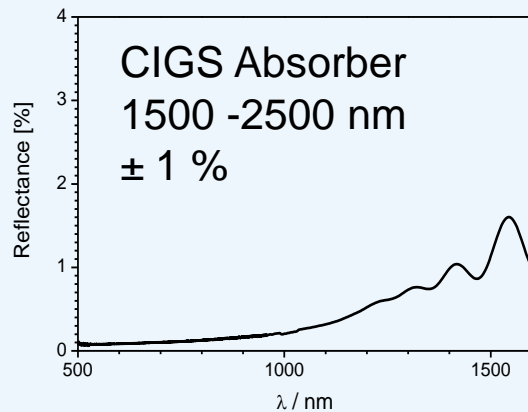
➤ **SoIR is designed for optimal in-line integration**

In-line control



- **SoIR provides in-line access to key parameters of each layer and establishes complete control!**

In-line control



Reflectance measurement after each deposition step –

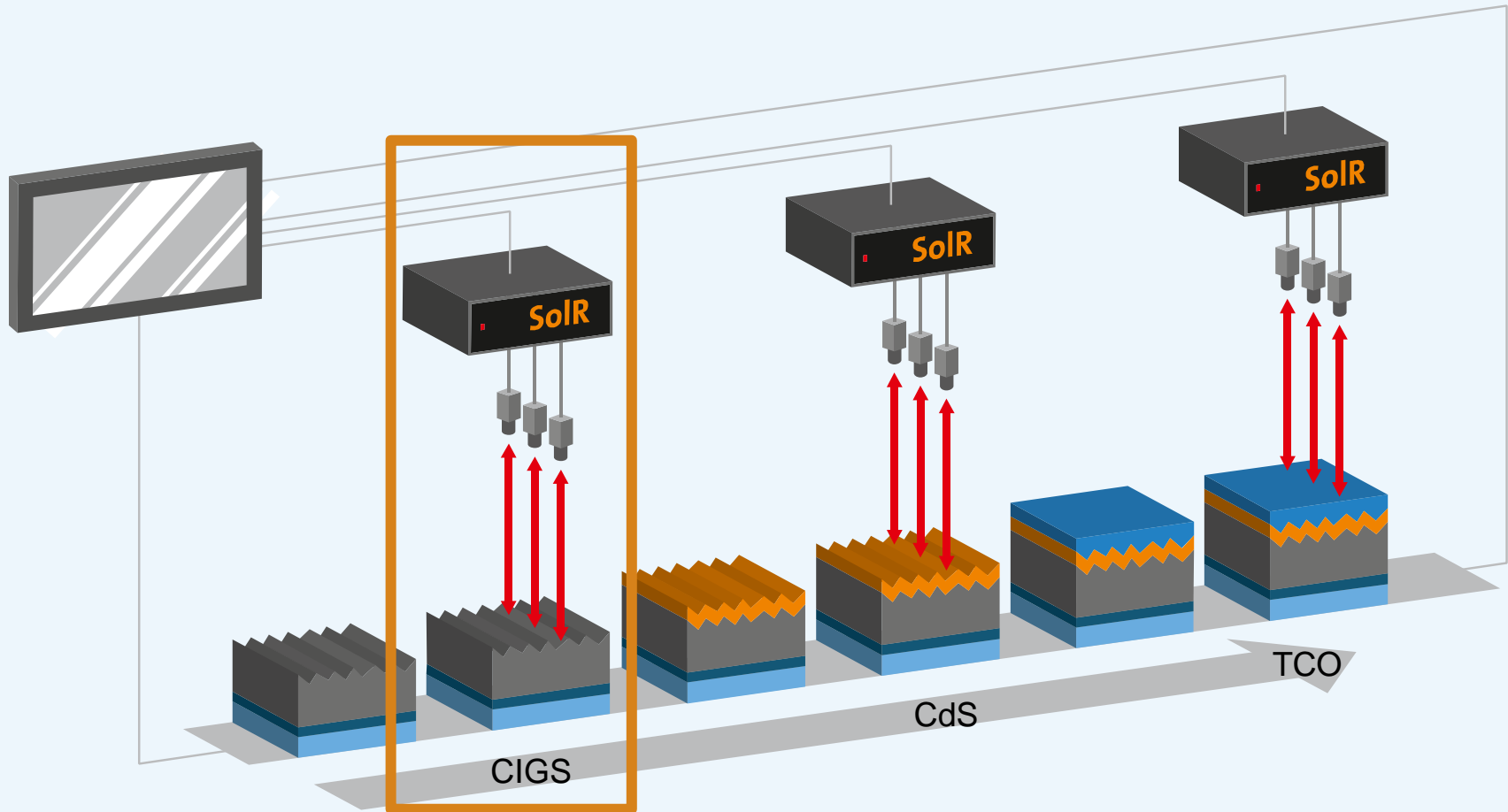
➤ **complete control of the whole PV layer deposition process!**

In-line & roll-to-roll applications

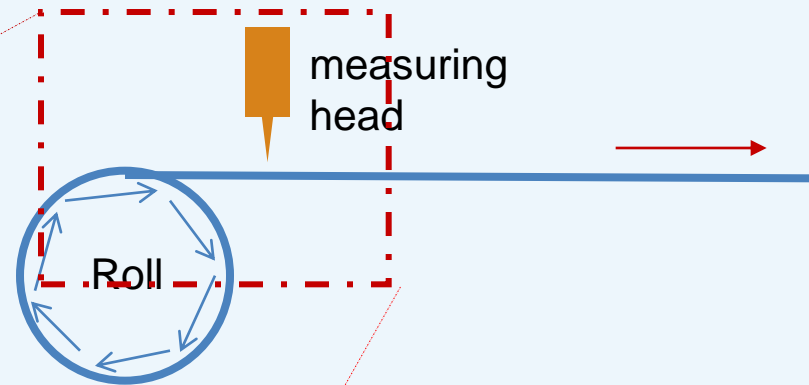
- adaptable to every in-line process via customized mounts and optical heads
- spatially resolved information by multiple head concept
- fast data acquisition for in-line measurements on moving substrates
- automated film-thickness analysis (incl. algorithms for rough layers and LayTec dispersion data base for PV materials)
- software integration in PV-line via Profibus/ Ethernet/ TCP/IP or others for automated operation



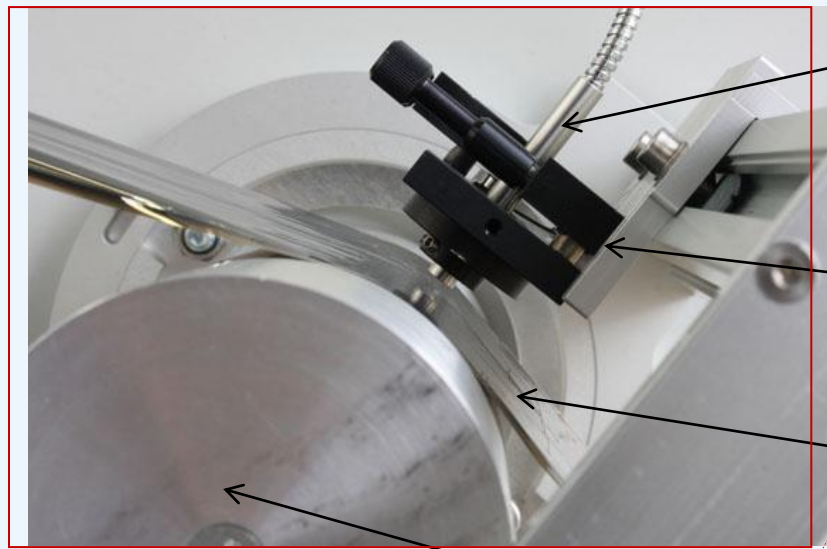
CIGS process monitoring



Parts of SolR system



SolR optical head
on roll-to-roll system



Sensor head

Clamp
mechanism

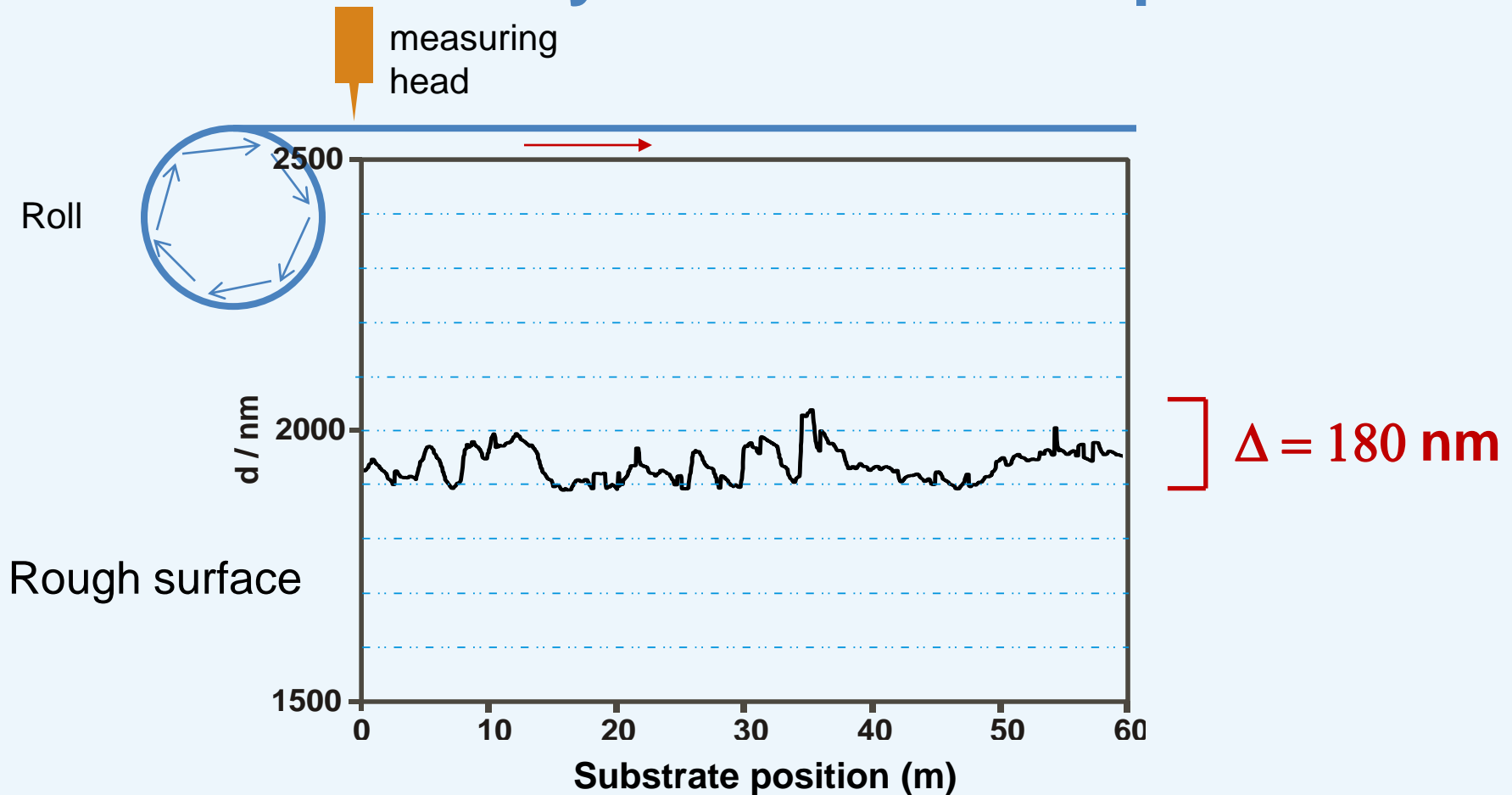
Foil

Roll

SolR
electronic unit

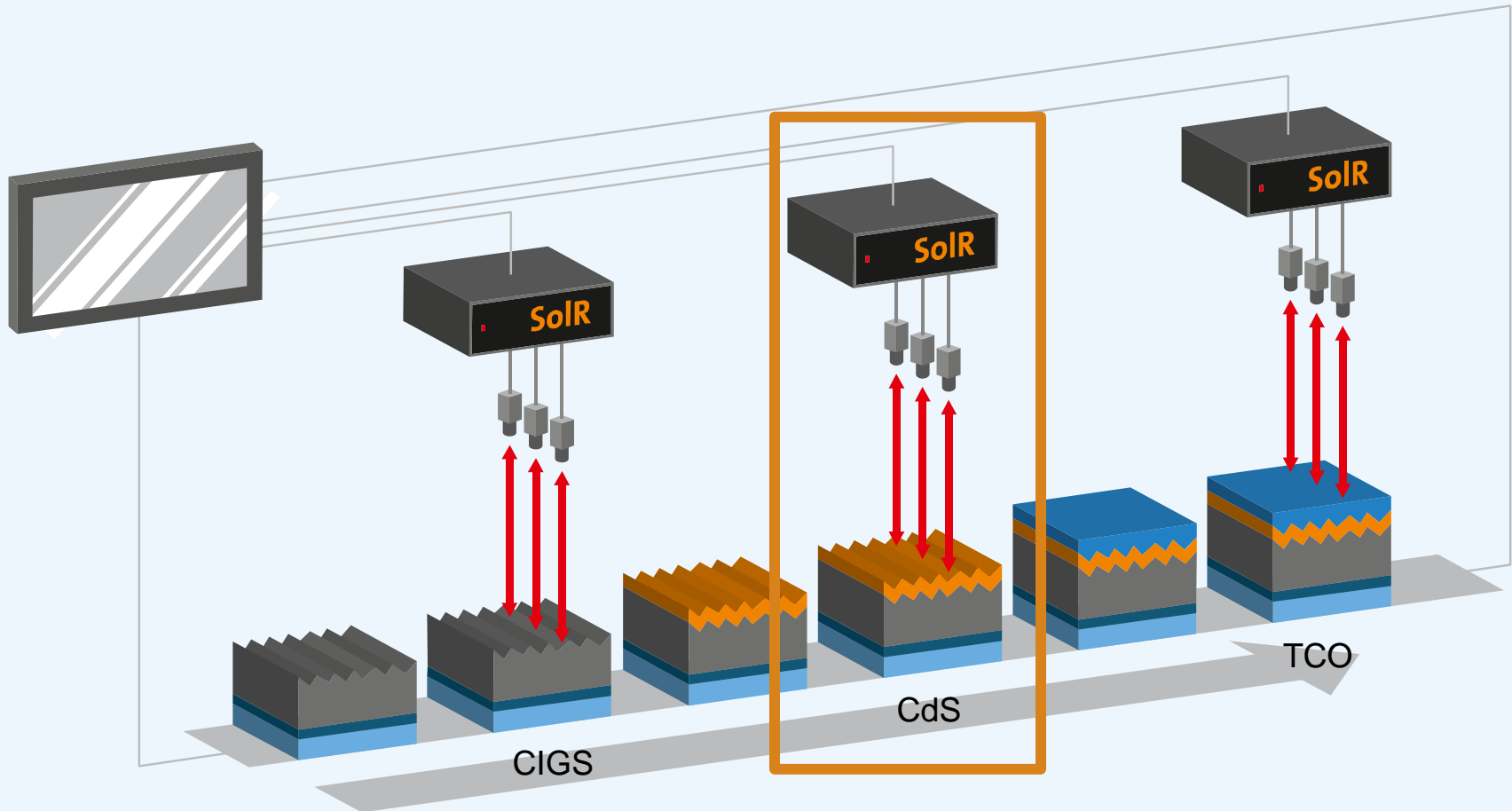


CIGS absorber layer thickness vs. position

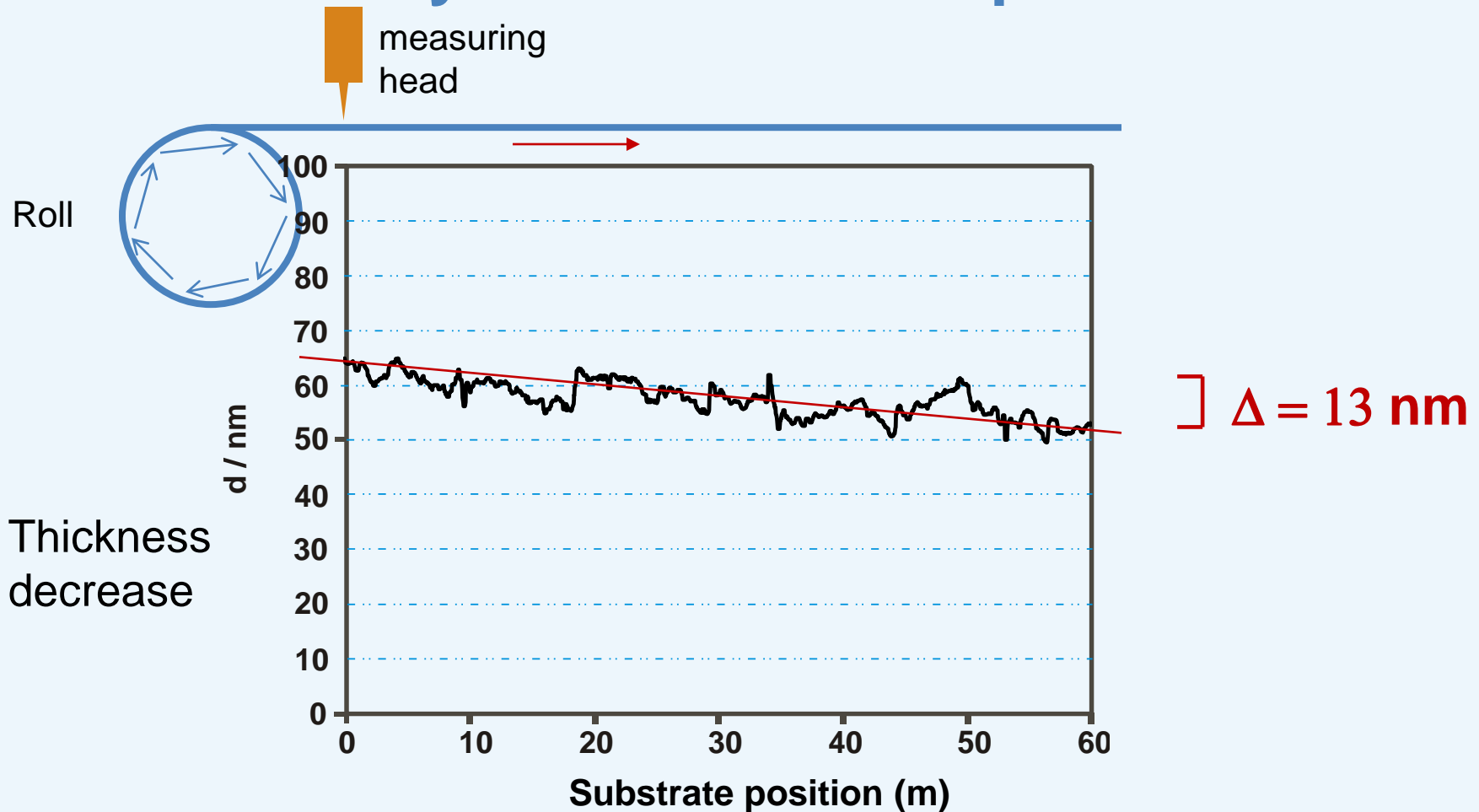


➤ Lateral CIGS thickness monitoring

CdS process monitoring

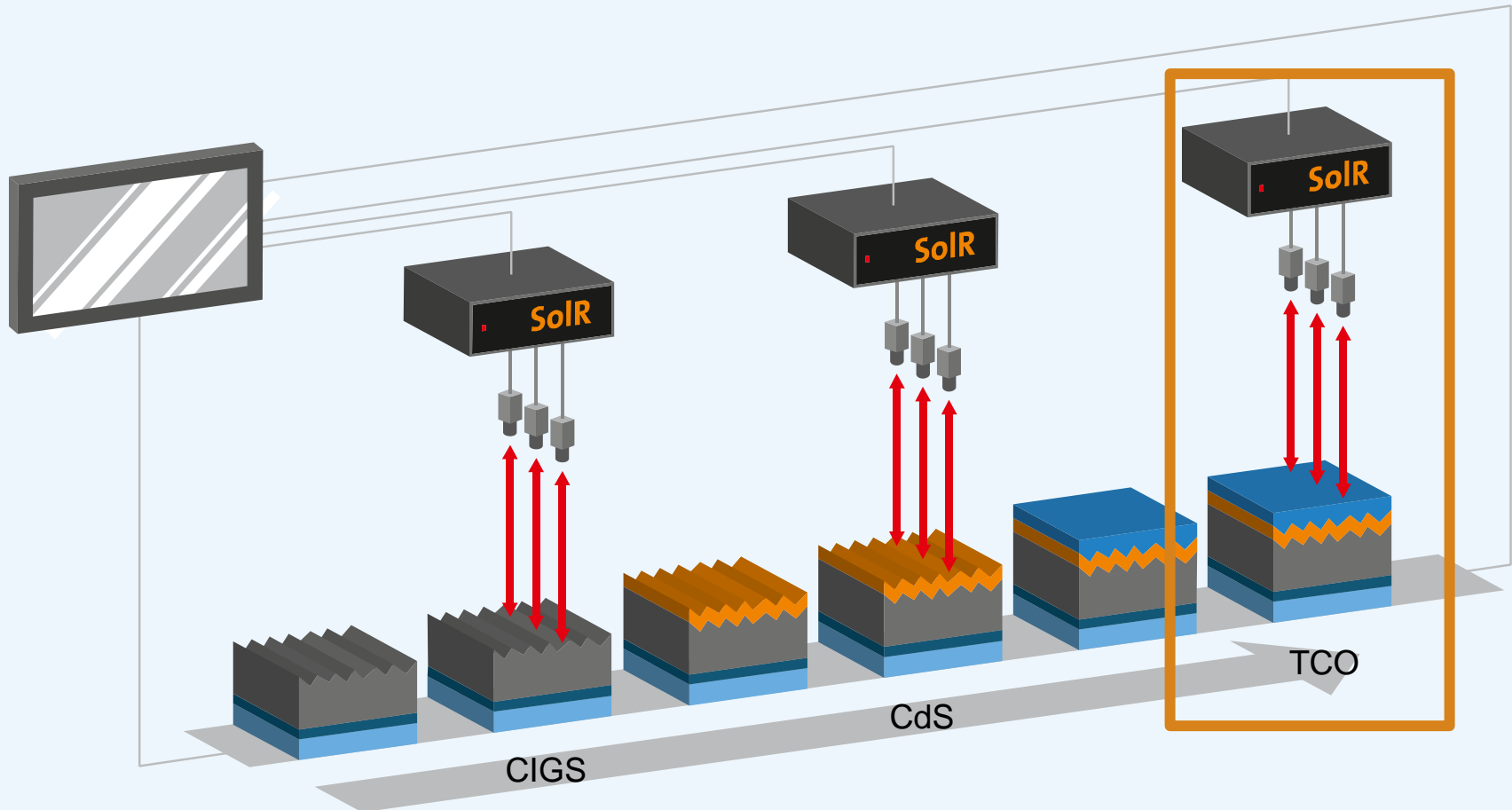


CdS buffer layer thickness vs. position

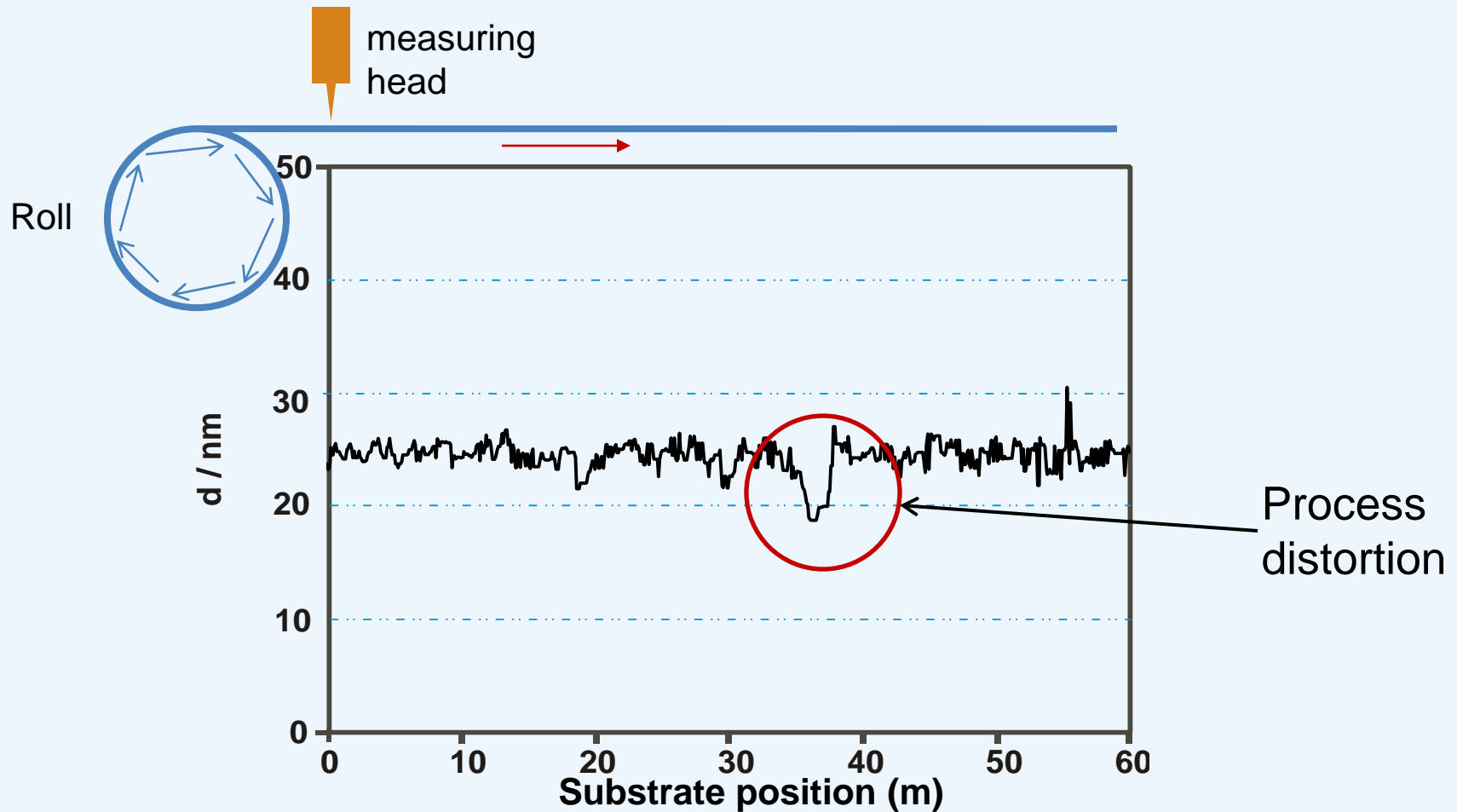


➤ **Chemical bath depletion can be monitored**

TCO process monitoring

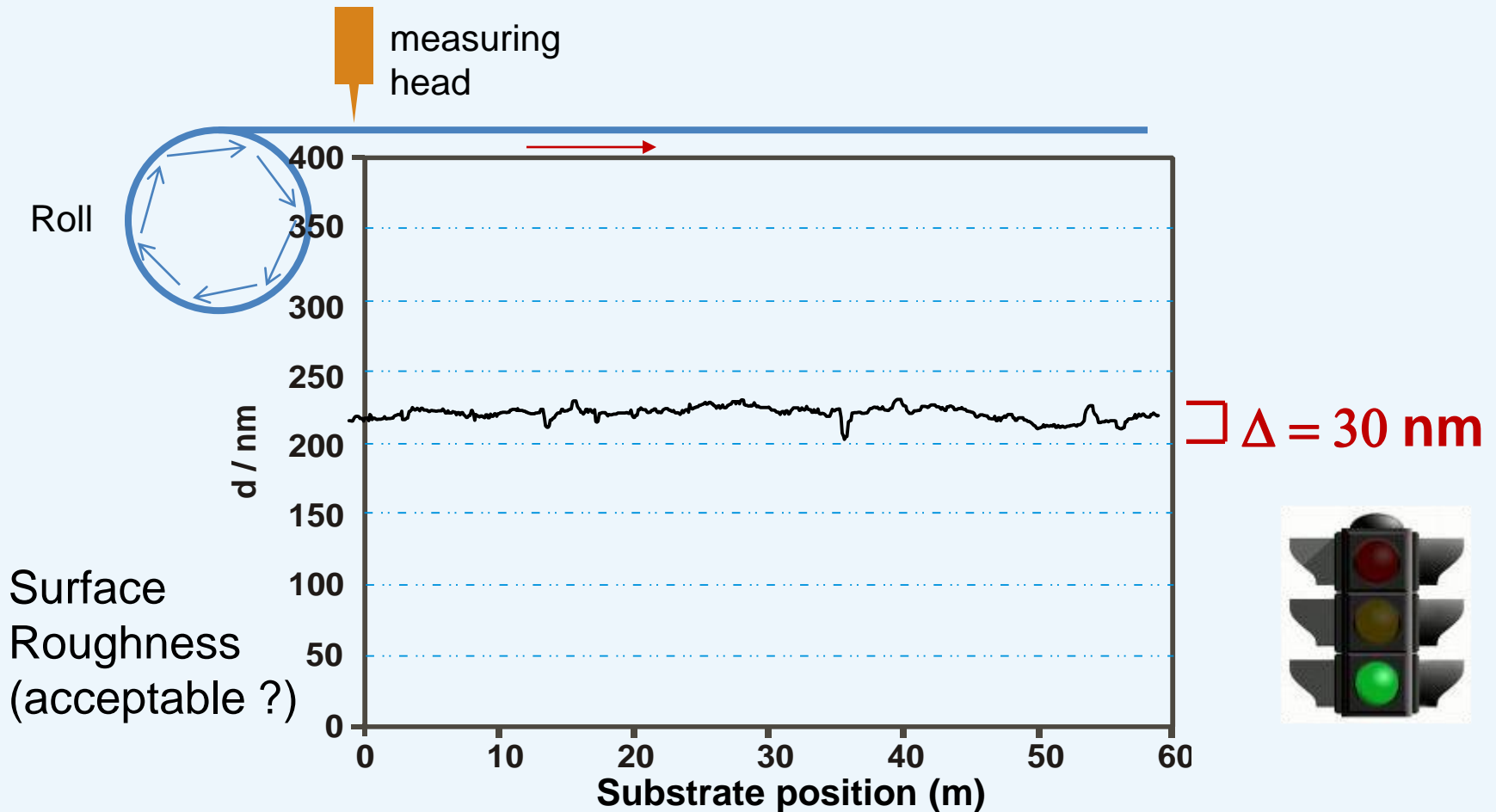


TCO - iZnO thickness vs. time



➤ **Process deviations can be tracked on-line**

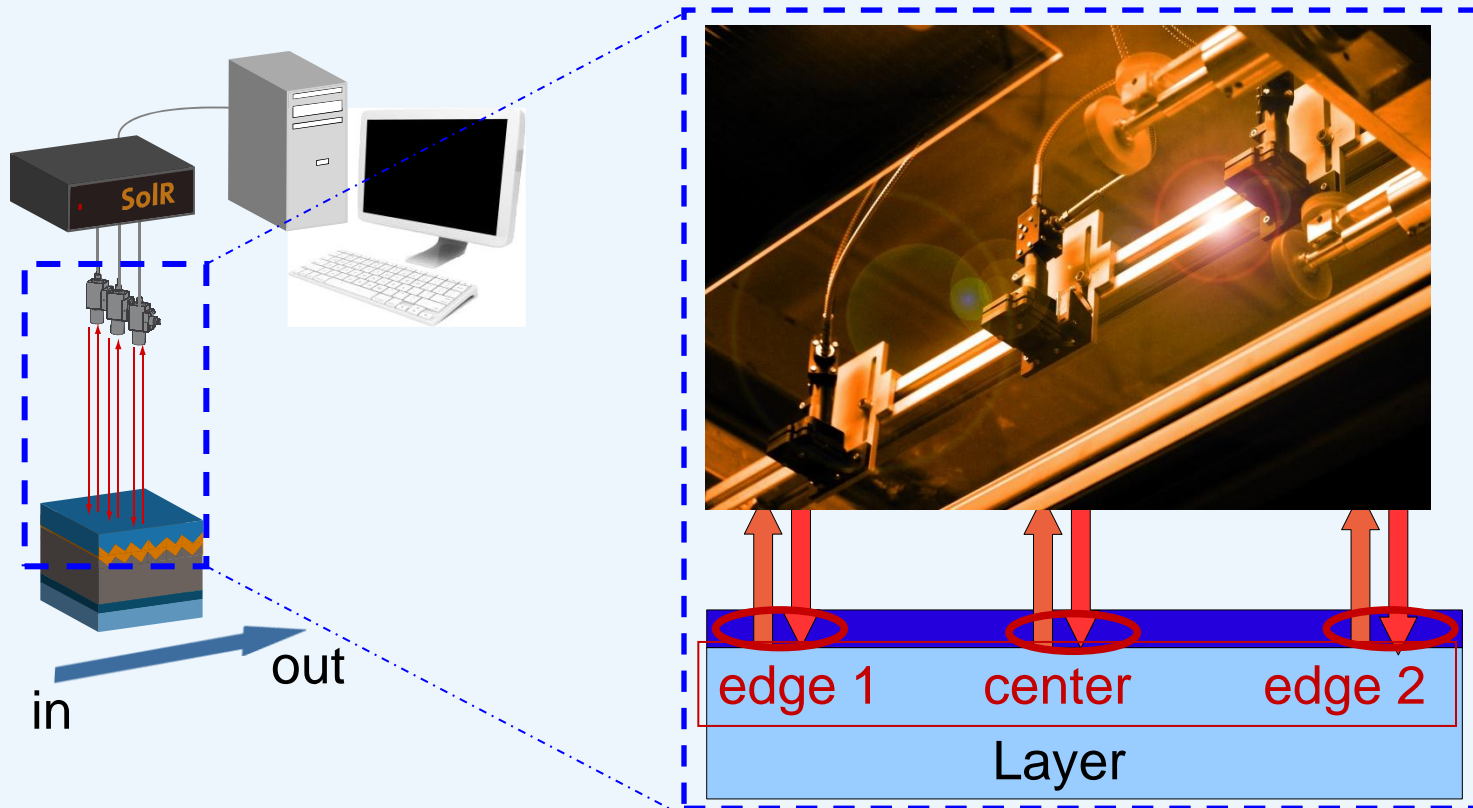
TCO – ZnO:Al thickness vs. time



➤ Status information is provided to the operator

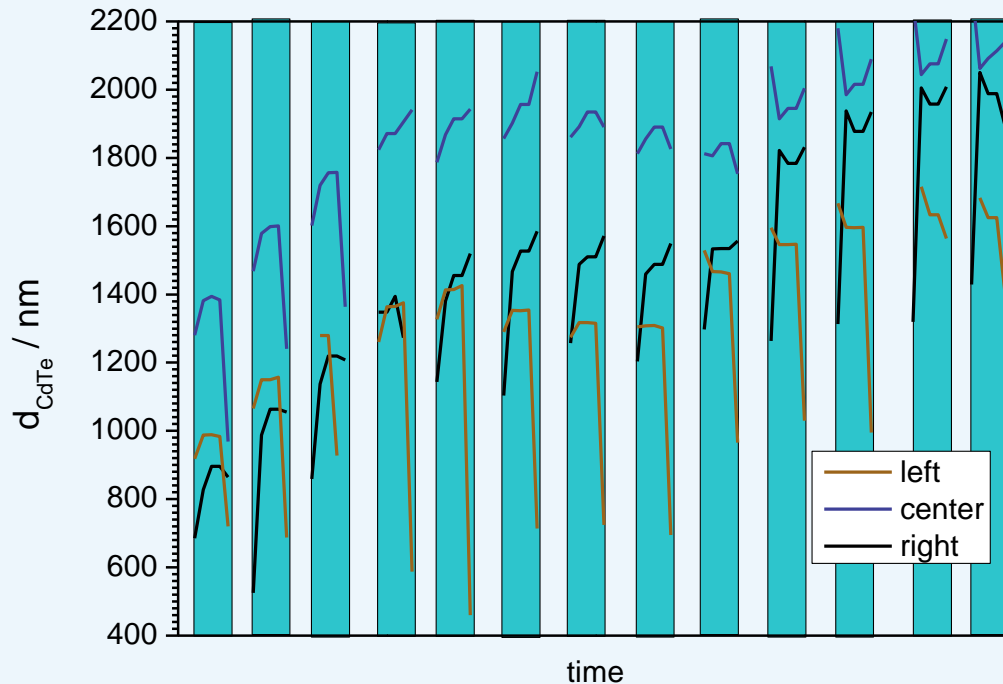
Lateral resolution

- Lateral resolution can be refined by multi head concept
- Homogeneity information derived in-line



➤ **Modular and scalable system by multiple head concept**

Ramp-up of CdTe deposition



Reflectance measurement monitors thickness variation with time and homogeneity over individual modules in real-time.

- **If measuring spots match heater zones: real time optimization of heaters.**

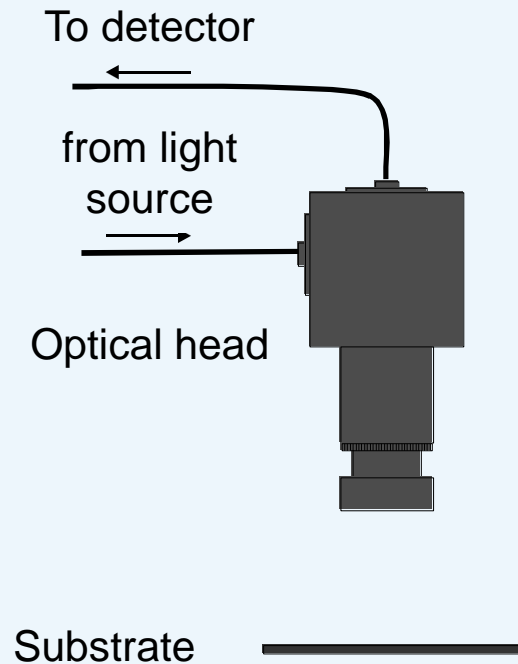
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Principle

- laser light is irradiated to the surface at wavelength λ_1
- absorber layer absorbs the light and emits PL light at wavelength $> \lambda_1$

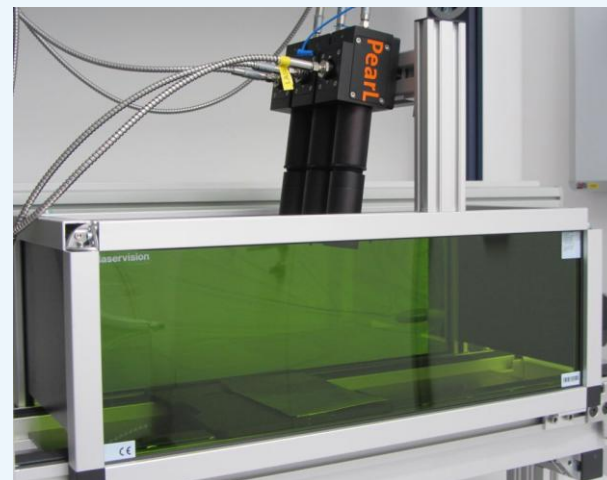
PL spectrum gives information on:

- bandgap
- material composition
- homogeneity

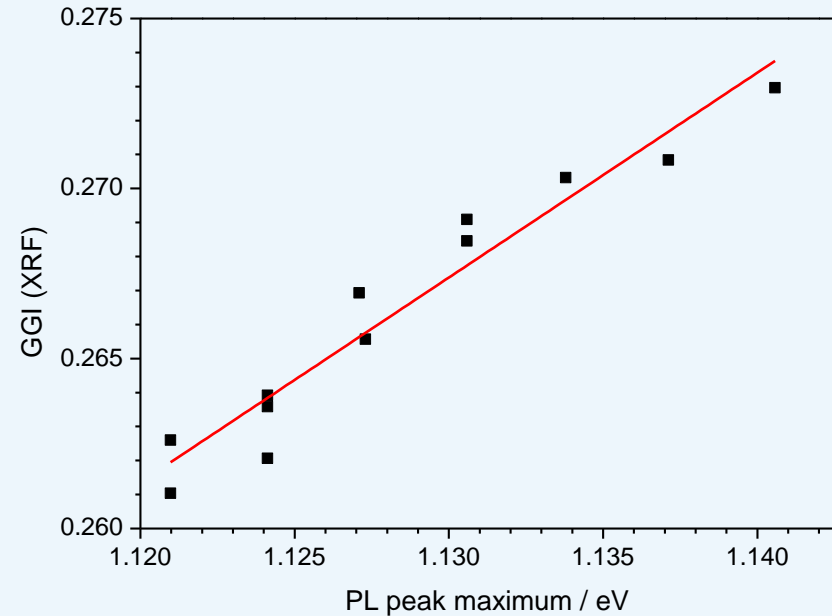
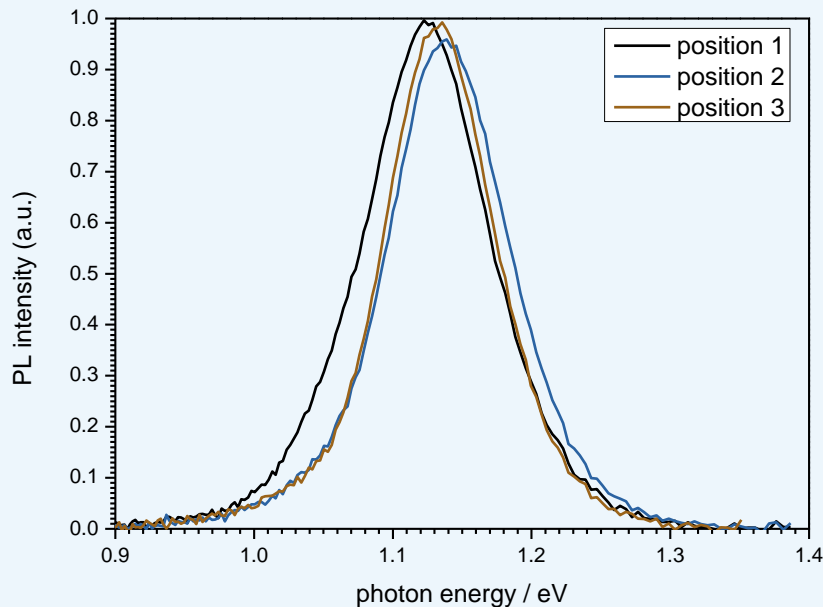


Set up

- hardware is similar to in-line reflectance platform – reliable design ready for production environments
- reflectance and PL measurement can be integrated into one setup – single user access for all layer information
- Excitation at 808nm, other wavelengths on request
- Measurement time 100ms on 3 traces



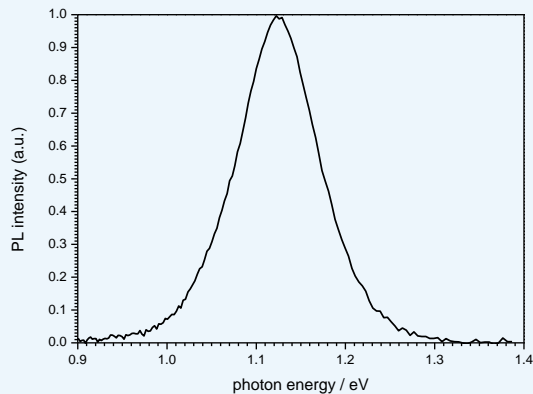
PL spectra from CIGS: sensitivity to GGI



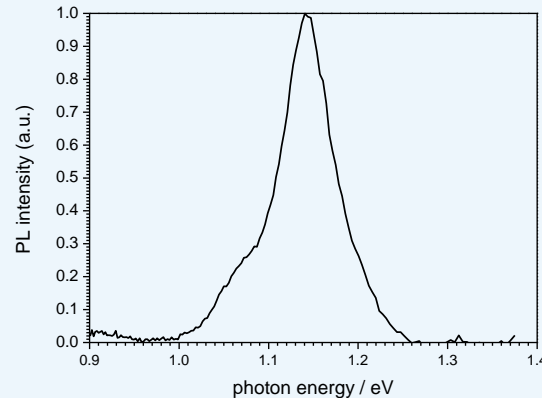
clear correlation between peak position and XRF measured GGI

➤ accuracy better than 0.01 in GGI

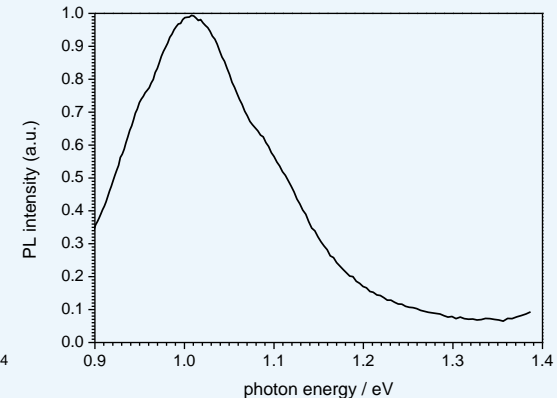
CIGS PL spectra from different processes



„simple“ peak correlates with Ga content



additional shoulder hints at Cu content

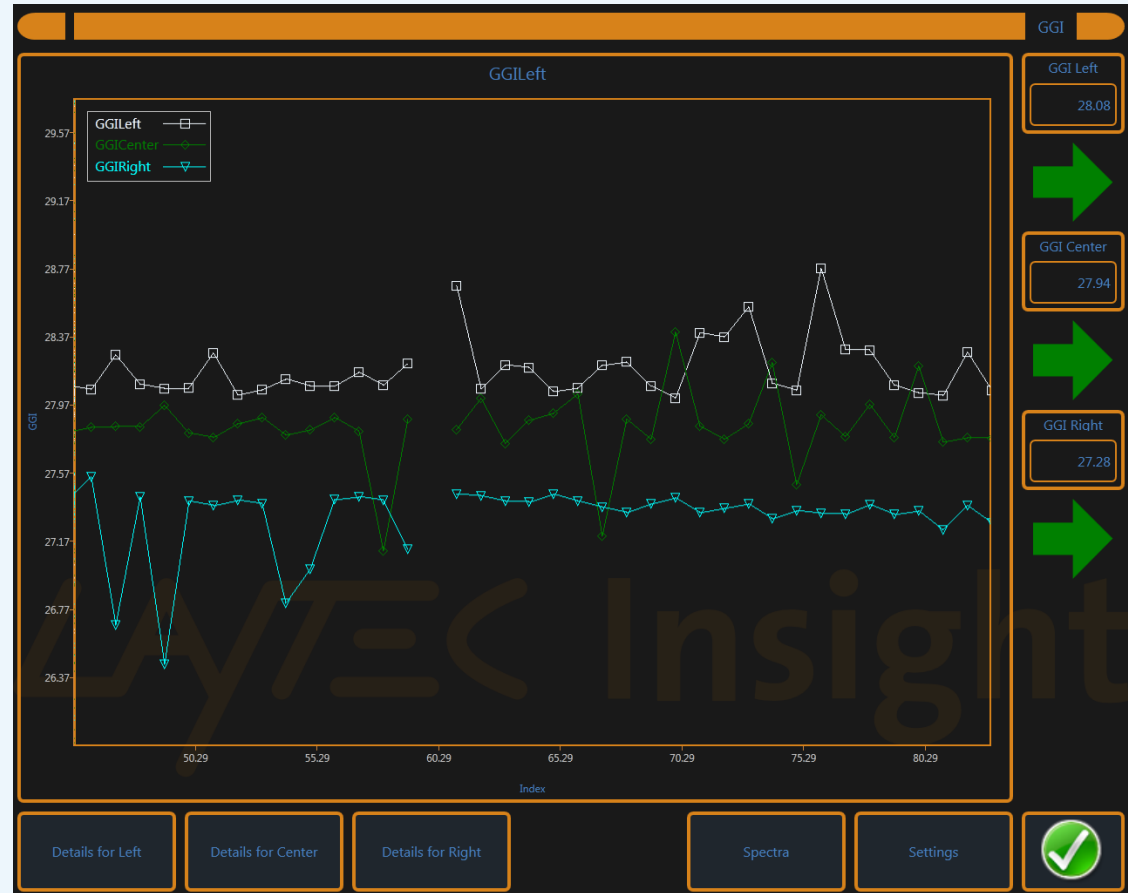


broad peak with shoulders, correlations not yet interpreted

- **shape of spectrum depends on production process**
- **customized data analysis gives additional information**

LayTec Insight software

- well structured
- configurable
- touch screen
- operator view vs. engineer view



➤ **Gallium to Gallium Indium ratio on three traces**

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In-line metrology supplies information about

- **Thin layers in solar cells:**
 - CIGS
 - CdTe
 - a-Si/ μ c-Si
 - ARC coatings
- **Properties:**
 - reflectance
 - film thickness
 - bandgap / layer composition
 - conductivity
 - haze
 - roughness / texture
- **Adaption to any PV process:**
 - in-line or in-situ
 - batch or roll-to-roll
 - on glass or flexible substrates

In-line measurements for TF-PV:

- specular reflectance method ideally suited for film thickness measurements on all layers
- setup and data analysis must be customized
- complete control established for in-line and roll-to-roll production lines
- in-line PL spectrometry gives access to Ga content
- precise layer thickness, homogeneity and composition characteristics – all at once and in-line!

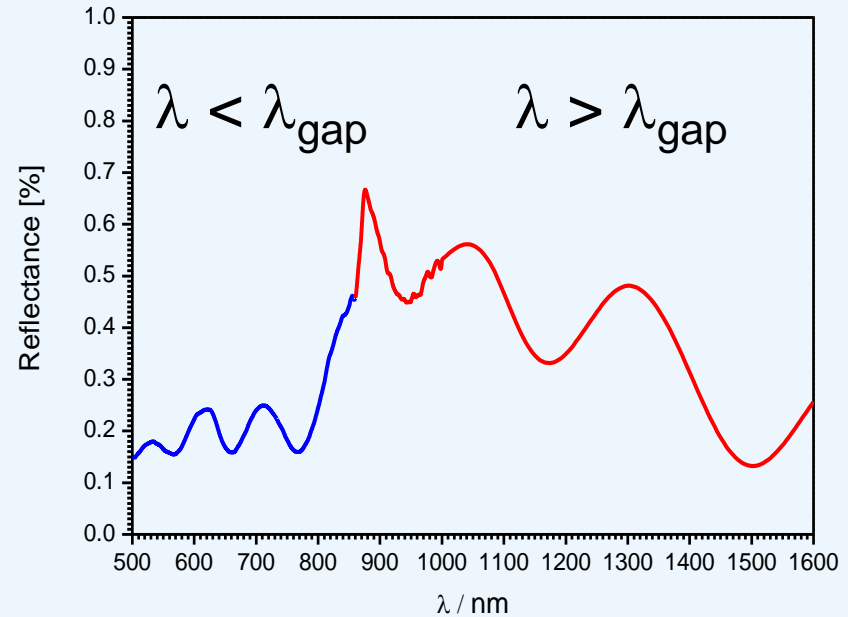
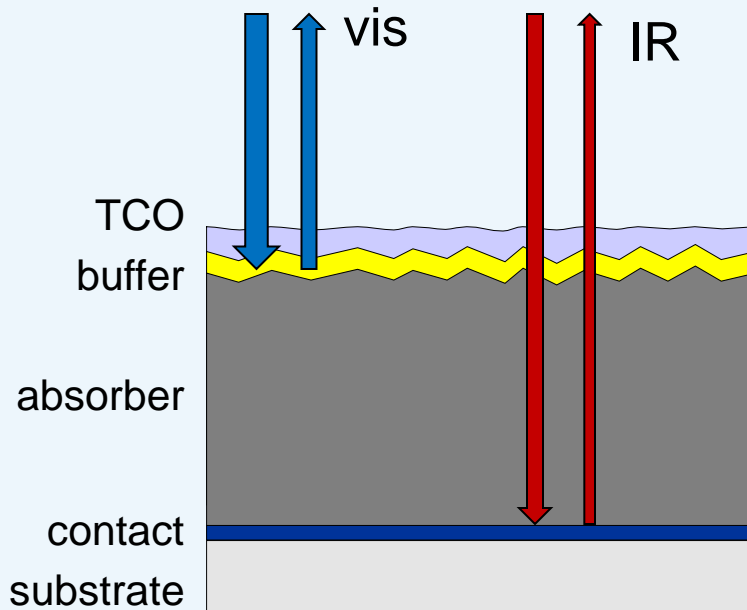
Turn sun
into
gold



www.laytec.de

LAYTEC
in-line metrology

Reflectance spectrum of a complete stack



- $\lambda < \lambda_{\text{absorber-bandgap}}$: sensitive to TCO and buffer layer
- $\lambda > \lambda_{\text{absorber-bandgap}}$: probes the whole stack