Evaluation of Thin-Film CIGS (Copper,Indium, Gallium, Selenium) Solar Cells using FISCHERSCOPE ® X-ray equipment for inline-process or offline-testing applications:

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Why use CIGS thin film for solar cells?

There is a potential to reduce the costs of manufacturing with only a small amount of photovoltaic material. Forecasted shortage of silicon material is providing an incentive for investment in alternative thin-film CIGS technologies. Fundamental research promises to improve the light-to-power efficiency of CIGS-coatings (in 2007 for 13% in production and and 19% in the lab). The efficiency of a CIGS-coating can be influenced by a variation of the element concentrations of Cu,In,Ga,Se, which may result to a better spectrum absorption of the sunlight.

CIGS solar cells processes:

Three categorical approaches have emerged so far: using evaporation, nano particles and PVD "sputtering" with targets. Manufacturers develop their own "secret" processes in order to optimize efficiency and cost of CIGS-cells.

Why measure coating thicknesses and element concentrations of CIGS-materials?

In order to fulfill the specified electrical features of a photovoltaic pane,l the manufacturer has to make sure that the solar cell process will be kept within a narrow tolerance band for the CIGS absorption coating thickness as well as for the Cu,In,Ga,Se concentrations which define the efficiency of the photovoltaic process. Not only the correct stoichiometry has to be measured but also the homogeneity of the CIGS layer. FISCHERSCOPE ® X-ray equipment is using the energy dispersive X-ray fluorescence (EDXRF) method – an ideal physical principle to solve this job with non-destructive and contactless measurements. Some manufacturers decide to install X-Ray equipment for inline-process, with a chance to correct any deviations from specification immediately by process-control. Other manufacturers use offline-testing X-ray devices – in a by-pass line or the quality laboratory – in order to check the quality parameters of their solar panels.

FISCHERSCOPE ® X-ray equipment for inline-process applications:

For a production-engineer it is desirable to get quality-data (as thickness, concentrations, homogenity of the CISG-coating) soon after the coating process, so he has a chance to improve the production parameters if something shows wrong with the data. The only way to manage such a quick supply of quality-data is to install the X-ray measuring equipment in-line into the process. Fig.1 and Fig.2 show the principal design of CIGS solar cells plants – for horizontal glass panels and roll-to-roll polyimide foils. For both plant-designs the X-ray coating measurements are made at the end of the process-cycle. Fig.1 and Fig.2 show how the inline X-ray equipment has been integrated into production lines, it is evident that inline X-ray equipment always has to be adapted to special process conditions like: high temperature, vacuum, limited space, chemical contamination.

Fig.3 CIS-coating laboratory device by ZSW Germany. Downward evaporation for glass panels with 120 cm length.

In Fig.3 one can see on the left hand side a glass panel with the grey shining CIS-coating on it – the panel had been horizontally moved through all process stages as explained in Fig.1

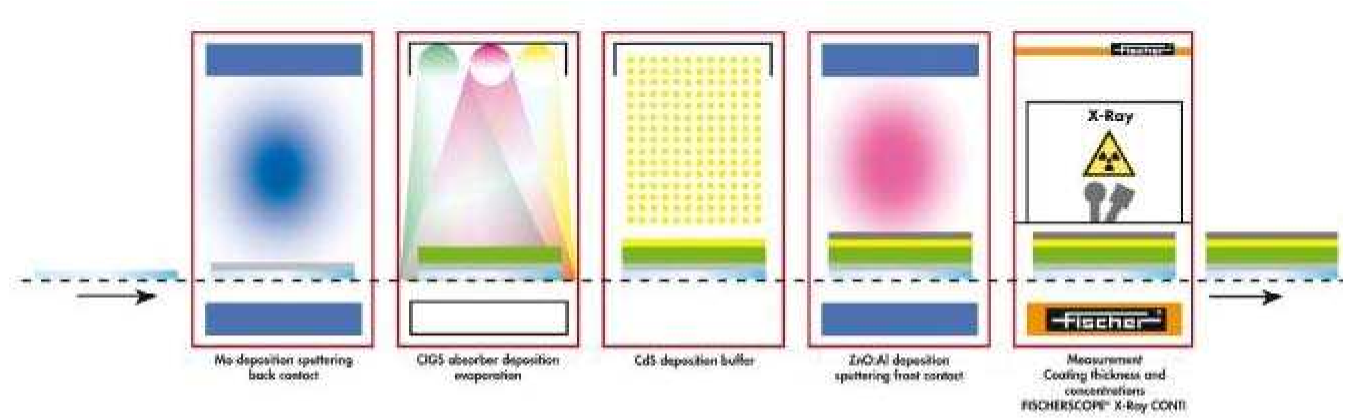

Fig. 1: Multi-stage flat glass CIGS panel technology, basic concept for continous deposition of Mo, CIGS, CdS, ZnO layers and measuring chamber for inline FISCHERSCOPE® CONTI 4000-V. Horizontal step-by-step transport of glass panels through different deposition processes.

A possible solution for EDXRF equipment which is designed to measure inline in a evaporation process chamber can be seen on Fig.4. Water cooling, heat shielding, X-ray vacuum flanges are part of that measuring device. If necessary, there is an easy mechanical access to the equipment.

Fig.4 FISCHERSCOPE® CONTI 4000-V for downward installation into a CIS-coating plant (horizontal moving CIS-panels below the cylindrical EDXRF equipment, see Fig.1)

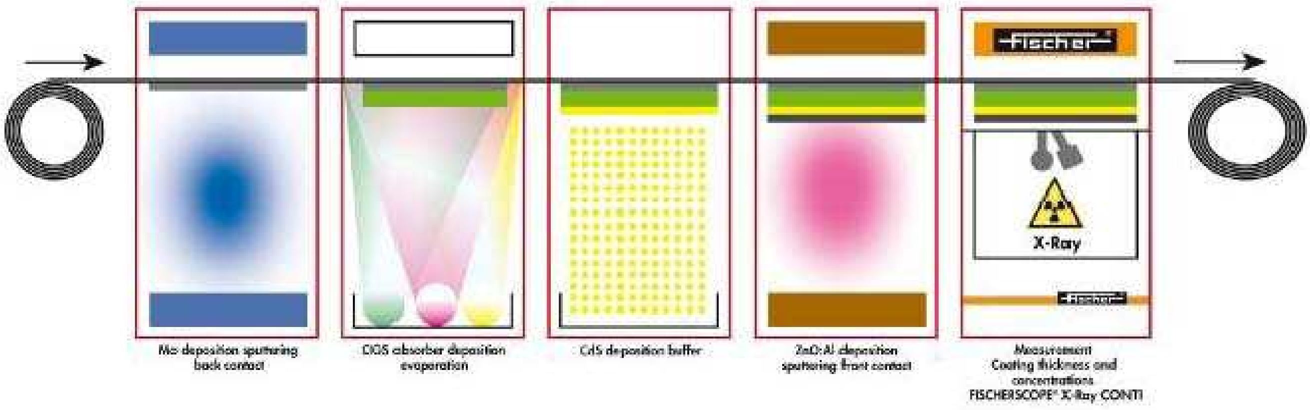

Fig.2: Basic concept of roll-to-roll technology for flexible CIGS solar foils. Continous deposition of Mo, CIGS, CdS, ZnO layers and measuring chamber for inline FISCHERSCOPE® CONTI 4000-V. Concept allows depositions on plastic foils at high speed.

Fig. 2 is an example for the installation of FISCHERSCOPE® CONTI 4000-V equipment into a plant using roll-to-roll technology for flexible CIGS solar cells. With this technology, polyimide foils will be continously coated with the described sequence of Mo/CIGS/CdS/ZnO coatings, the EDXRF equipment is operated bottom-up as an adapted inline device.

FISCHERSCOPE ® X-ray equipment for offline applications:

a) CONTI 4000 -DPP

Usually for inline CONTI 4000-V equipment, the measuring spot will be fixed and due to the transport of the panel or the foil we will get a measuring line (with thickness and concentration values) along the length of the CIGS-product. Offline equipment – not dealing with the usual inline difficulties of vacuum, heat, limited access space etc. – is well prepared to X-Y- scan over the CIGS-coating and can present valuable information about the homogeniety of such a coating. If one is interested to measure the coating parameters on large CIS-panels or CIS-coatings on long sheets, the CONTI 4000-DPP can be adapted in various modifications. Max. width of sheets 1000 mm, length of panel or sheet up to infinity.

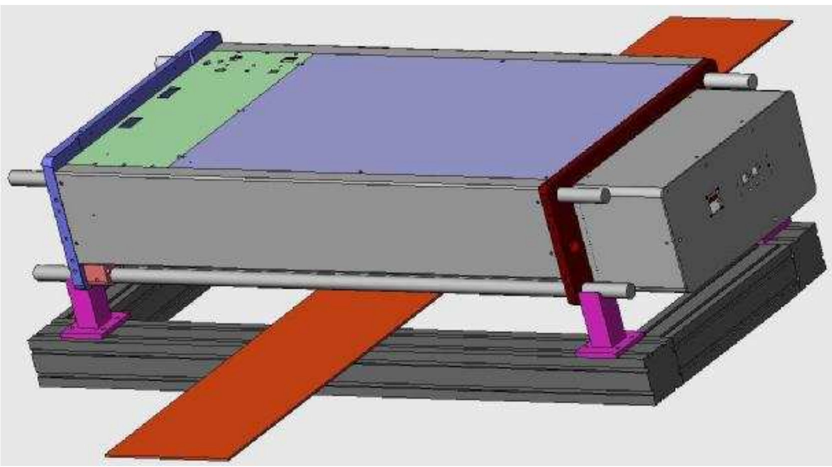

Fig. 5 Schematic view of a FISCHERSCOPE® X-Ray CONTI 4000-DPP measuring head. Moving strip or sheet with CIGS-coatings on it (marked with brown colour). Measuring X-ray beam downwards focused on the CIGS-surface

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Fig.6 Calibration adapter for X-ray calibration standards of measuring head CONTI 4000DPP. Calibration mode possible even during continous production process.

Fig.7 FISCHERSCOPE® X-Ray CONTI 4000-DPP measuring head (see also Fig.5 schematic view)

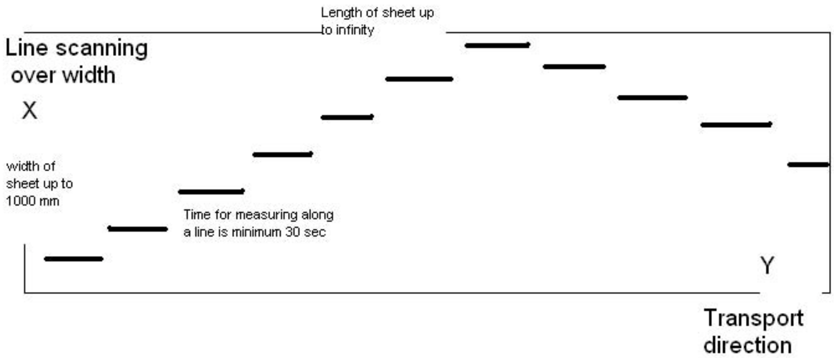

Fig.8 Principal sketch for measuring CIGS thicknesses and concentrations of large panels. The CONTI measuring head can be freely programmed to X-coordinates along the panel-width. As a result there will be measuring lines along the transport direction Y. The minimum measuring time of a scanning line is t = 30 sec due to the precision requirements. Typical speeds of the panels/sheets are some meters per minute.

b) Offline standard equipment (table-top) FISCHERSCOPE ® X-ray XDV®

Each CIGS solar cell production plant usually has one or more quality laboratories because for a stable process, a lot of chemical and physical parameters have to be monitored. For quick offline analysis of smaller sized CIGS parts, the table-top X-ray XDV® is ideal. For precision of XDV measurements see Table.1 below. For smaller panels up to 250 x 250 mm, it is convenient to measure with a standard table-top instrument like the FISCHERSCOPE ® X-Ray XDV, which has a fast motorized X-Y-table to scan the surface of CIGS coatings for homogeneity (thicknesses and stoichiometry).

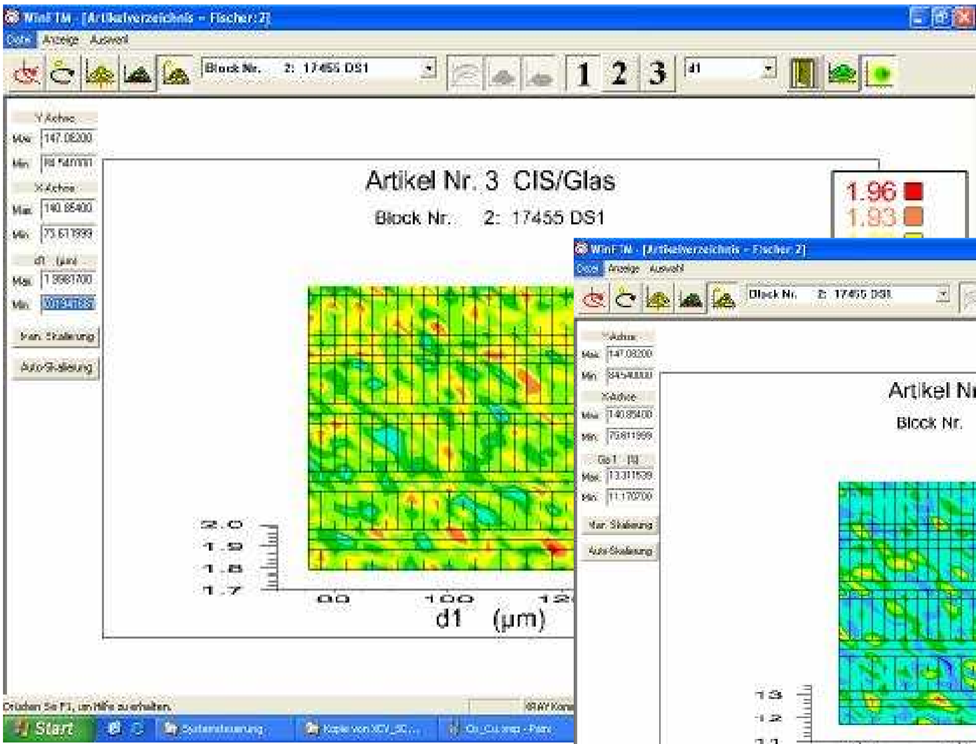

Fig.9 two-dimensional X-Y scan of CIS-coating thickness (1,7 – 1,96µm)

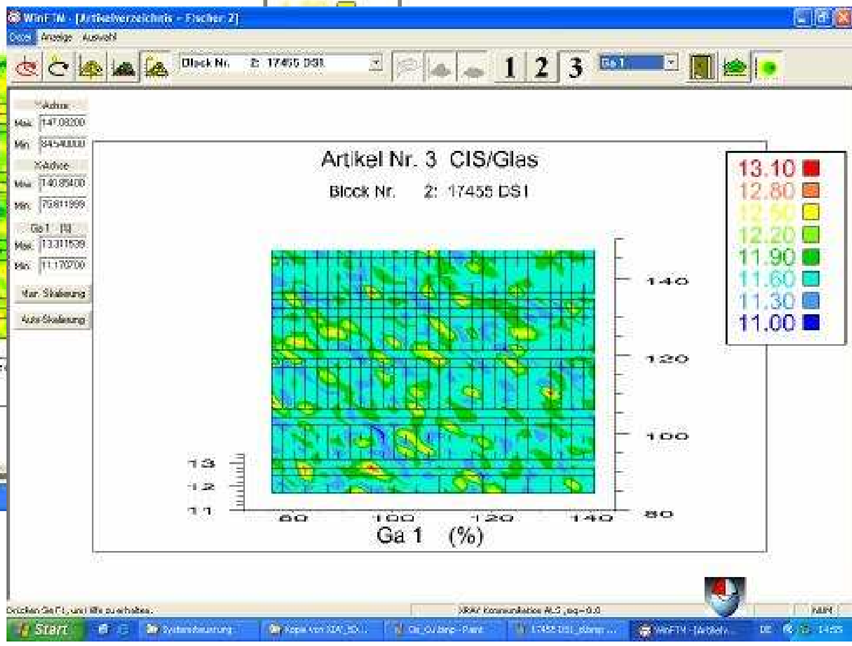

Fig 10 Two dimensional X-Y scan of Ga-concentrations

WinFTM ® - Software: definition of measuring tasks and calibrations

All FISCHERSCOPE ® X-Ray equipment – inline as well as offline use – are operated with the same powerful WinFTM ® - Software . WinFTM ® uses fundamental parameter routines to simulate all relevant physical interactions inside a CIGS-coating – but as an additional advantage also allows the user to calibrate the EDXRF-equipment with CIGS reference samples with known values for thicknesses (CIGS,CdS,Mo) or concentrations atomic % (Cu,Ga,Se,In). Typically the producer is supplying the reference samples from his CIGS-production process and Fischer will recommend the best parameters for those reference samples. WinFTM ® calculated results, using the FP-mode without given reference samples, usually fit reasonably well with known values of CIGS reference samples used for calibration.

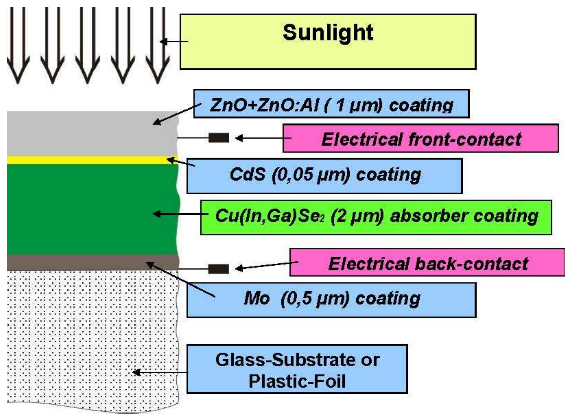

Fig. 8: Basic Concept of a CIGS Solar Cell as multi-layer thin film composites

The powerful WinFTM® software allows the definition of a measuring task (DefMA) for the FISCHERSCOPE® X-Ray instruments which specifies the task by:

1) Upper layer: ZnO alloy
2) Buffer layer: CdS alloy
3) CIGS absorber: CuInGaSe alloy
4) Mo back contact: Mo single element
5) Substrate (glass or plastic)- specif

With this set of information the WinFTM® can already measure the layer properties without using calibration samples (so called standard free mode). Of course as usual the trueness of measurements require calibrated reference standards with the producer has to supply by other physical means.

Table 1: precision results for CIGS coatings Fig.6: Typical X-Ray spectrum for CIGS-solar cell – multi layered thin-film composites.The measured countrates correspond to a CIGS layer thickness of 2,8 µm, Mo back-contact

Measured Element	*Measured mean value (average over 20 readings, t=100 sec)*		*Repeatability XDV or CONTI Standard deviation s*	
Thickness Mo (µm)	0,7		0,002	
Thickness CISG (µm)	2,8		0,005	
Concentr. Cu (atomic - %)	19		0,07	
Concentr. Ga (atomic - %)	10		0,04	
Concentr. Se (atomic - %)	54		0,07	
Concentr. In (atomic - %)	17		0,07	
Scanning range for CIGS-panel (mm)			250 x 250 XDV (X-Y direction) CONTI X <1000 mm Y up to infinity	

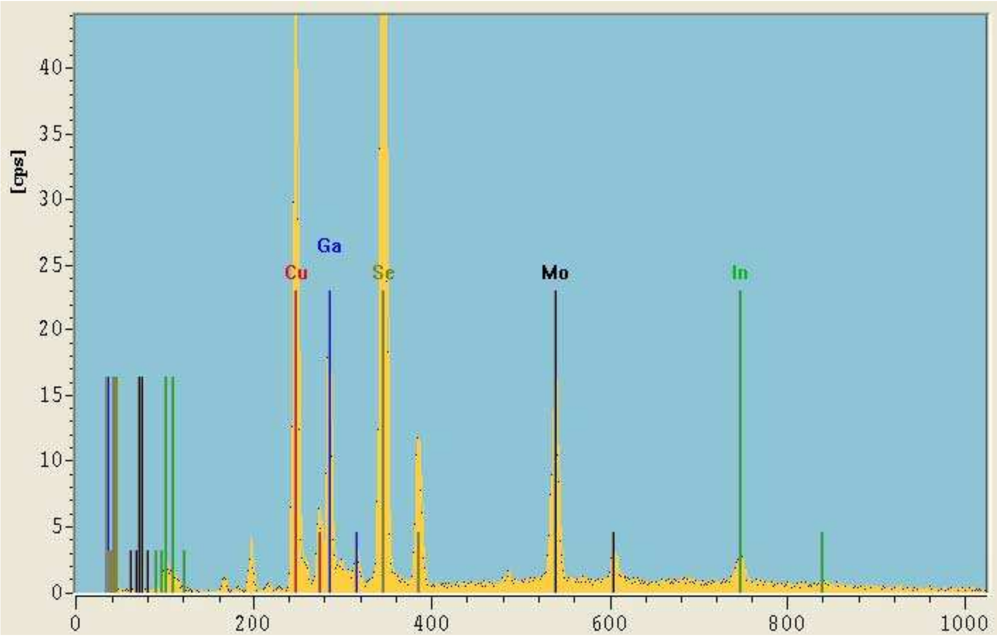

Fig 6: Typical X-Ray spectrum for CIGS-solar cell – multi layered thin-film composites. The measured concentrations correspond to a CIGS layer thickness of 2,8 µm, Mo back-contact 0,7 µm thickness, typical concentrations for Cu,Ga,Se,In vary between 10 and 50 atomic% depending on the stoichiometry of each producer.

Helmut-Fischer GmbH are measurement technology experts with over 50 years in the field, counting among the global leaders in coating thickness measurement, materials analysis and micro-hardness determination. The solar panels application demonstrates how versatile and powerful Fischer's instrumentation range is. Fischer's instrumentation is widely across production shop floors and laboratories throughout the world.