

PearL – spectroscopic in-line photoluminescence of solar cell materials

LayTec has developed a new in-line monitoring system which is capable of measuring the spectroscopic photoluminescence of layers throughout the solar cell manufacturing process. In contrast to integrating imaging technologies the spectroscopic approach reveals detailed information about the recombination mechanism involved. Observing photoluminescence gives direct access to the band gap and to the composition of binary and multinary compounds.

Material properties of semiconductors are directly correlated to their electronic structure. Spectroscopic photoluminescence (sPL) is a sensitive method to observe related electronic transitions. Thus, photoluminescence can be used to detect intentional variations in material properties or unintentional variations due to process instabilities.

With PearL LayTec now makes sPL available as an in-line tool. In a production environment, the continuous recording of photoluminescence spectra is a valuable measure for quality control and process window adherence. In this paper we present results from thin Cu(In,Ga)Se₂ layers as one of many attractive applications.

PearL is based on LayTec's proven modular platform for in-line optical set-ups (Fig. 1 and Fig. 2).

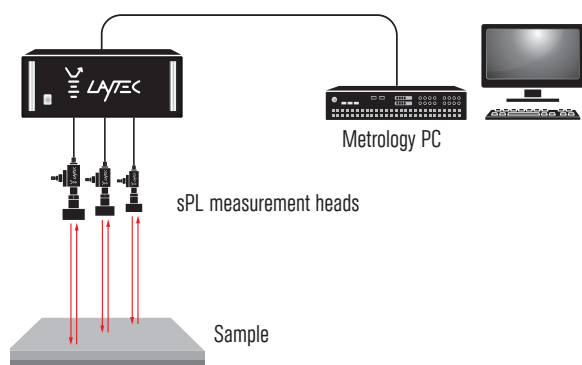


Fig. 1: Set-up of the PearL spectroscopic photoluminescence (sPL) measurement system.

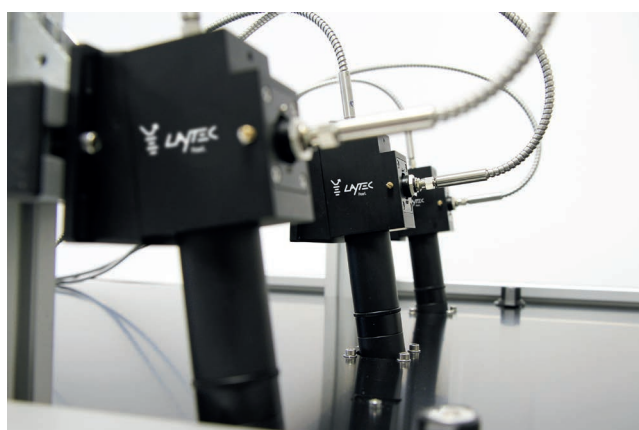


Fig. 2: Optical heads of the PearL system.

As each material needs a dedicated excitation wavelength for optimal PL intensity, a variety of lasers is available. The components are optimized for a good signal-to-noise ratio even in a temperature range from room temperature to 200 °C. The analysis software unfolds the measured spectrum in real time and performs the data analysis.

The Cu(In,Ga)Se₂ solar cell is the prime example for a defective-controlled system in photovoltaics. The position of the band edge can be steered by purposeful incorporation of Gallium as iso-valent Indium substituent. The widening of the band gap is not expected to increase the efficiency since the smaller photo current compensates the profit in open circuit voltage. However, the Gallium incorporation affects the phase formation and crystallization of the absorber layer.

Improved crystallinity and a lower defect concentration lead to a disproportionately high photo current. In result, the conversion efficiency is increased in comparison to the ternary system. The incorporation and control of the Gallium content in $\text{Cu}(\text{In,Ga})\text{Se}_2$ solar cells therefore is of central importance and can be controlled by means of photoluminescence measurements.

A series of photoluminescence-spectra taken from samples with varying Gallium content was recorded with PearL and is shown in Fig. 3. The spectra feature a pronounced main peak and a weak side band. The spectra are unfolded and the position of the main peak is determined. The shift in peak energy is proportional to the Gallium content of the absorber.

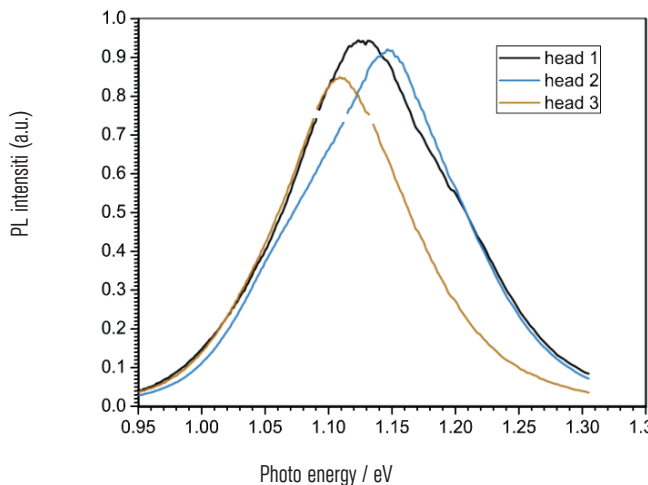


Fig. 3: Photoluminescence spectra of a series of $\text{Cu}(\text{In,Ga})\text{Se}_2$ layers with varying Ga-content.

For reference, x-ray fluorescence analysis was performed on a set of samples. The results plotted against the photoluminescence peak energy as shown in Fig. 4. The straight correlation line demonstrates impressively the correlation of the peak position and the Gallium content. Exploiting this dependency, PearL is capable of measuring the optical effect of the Gallium incorporation. With PearL LayTec offers a robust solution for controlling the optical band-gap of layers in an industrial environment. PearL can be applied for other material systems e.g. CdTe as well.

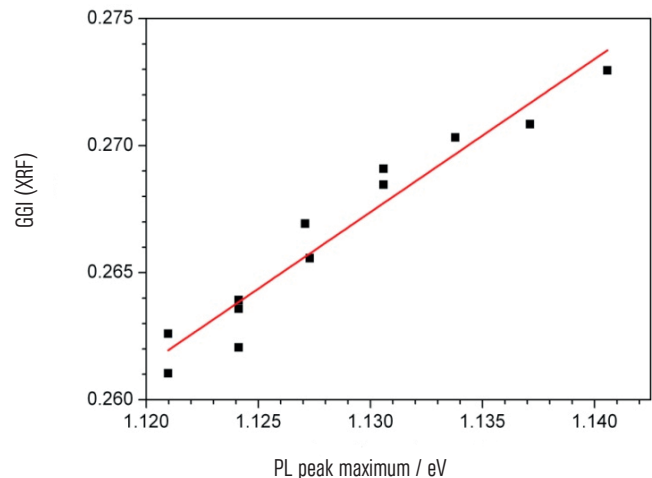


Fig. 4: Analysis of the PL: main PL peak maximum shows a clear correlation with the $\text{Ga}/(\text{Ga}+\text{In})$ ratio GGI.

For more information please visit www.laytec.de/pearl or contact info@laytec.de.