PearL – spectroscopic in-line photoluminescence of solar cell materials

LayTec has developed a new in-line monitoring system that 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 PL 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 PL spectra is a valuable measure for quality control and process window adherence. In this paper we present results from thin Cu(In,Ga)Se_2 layers as one of many attractive applications. **PearL** is based on LayTec's proven modular platform for in-line optical set-ups **(Fig. 1)**. A controller unit contains all optical and electronical components including a real-time embedded controller for highest reliability. Slim optical fibers guide the measurement light between the controller unit and the measurement positions. Miniaturized measurement heads provide optimum optical performance with low foot-print. Sophisticated automated analysis, monitoring, and storage of the data are provided by a metrology PC connected to the controller unit. Optionally, PearL integrates with production machines and software systems by a large variety of protocols like OPC, Ethernet, ProfiBus, and others.

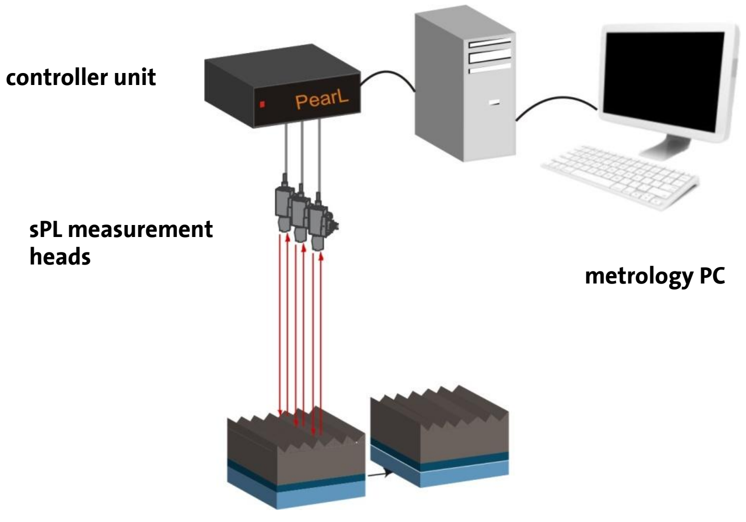

Fig. 1: Set-up of the PearL spectroscopic photoluminescence (sPL) measurement system.

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As each material needs a dedicated excitation wavelength for optimal PL intensity, a variety of lasers is available. The components are laid out in such a way that at room temperature a good signal-to-noise ratio is obtained. The analysis software unfolds the measured spectrum in real time and performs the data analysis.

The Cu(In,Ga)Se_2 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. Actually 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 disproportionally 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 Cu(In,Ga)Se_2 solar cells therefore is of central importance and can be controlled by means of photoluminescence measurements. A series of PL-spectra taken from samples with varying Gallium content was recorded with **PearL** and is shown in **Fig. 2**. 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. For reference, x-ray fluorescence analysis was performed on a set of samples. The results plotted against the PL peak energy as shown in **Fig. 3**.

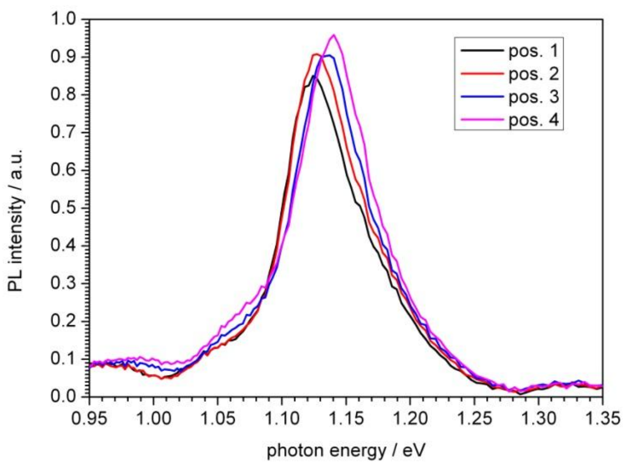

Fig. 2: Photoluminescence spectra of a series of Cu(In,Ga)Se_2 layers with varying Ga-content.

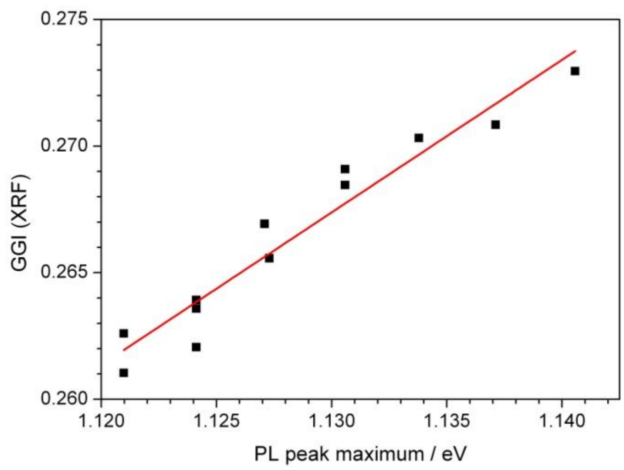

Fig. 3: Analysis of the PL: main PL peak maximum shows a clear correlation with the Ga/(Ga+In) ratio GGI.

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 industry environment. **PearL** can be applied for other material systems e.g. CdTe as well.

For more information please visit www.laytec.de or contact mail@laytec.de.

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