In-situ thickness measurements in OLED evaporation processes

Large area OLED manufacturing process technology still lacks a robust in-situ tool to measure layer thickness during the deposition. In close collaboration with Fraunhofer Institute for Photonic Microsystems in Dresden (Germany) LayTec has adopted its versatile spectral reflectometer EpiR DA to an OLED in-line evaporation system to monitor UV-VIS reflectivity spectra of individual layers during production process [1].

Typical OLED structures consist of extremely thin layers of a few nanometers only. In large area OLED manufacturing, linear evaporation sources are usually applied. Due to their rather direct beams, the expensive raw materials are used more efficiently. However, the conventional method of thickness monitoring, in which separate probes like quartz crystal are used, is not applicable to the directed beam evaporation to large substrates.

In such systems, LayTec's spectral reflectometer **EpiR DA** has proved to be an ideal tool for a direct in-situ monitoring of thin-film optical properties on the substrate itself. Since it is a non-destructive optical method, the sensor obtains information right from the individual layers of the OLED structure inside the in-line evaporation system. In the set-up shown in Fig. 1 the sensor was attached to a quartz optical view port at the transfer chamber. After each deposition step the substrate was moved to the measurement position and a full reflectance spectrum was taken. Such sprectra are called "single-shot" spectra because they are not taken continuously during the deposition but as separate spectra individually just after the respective deposition steps.

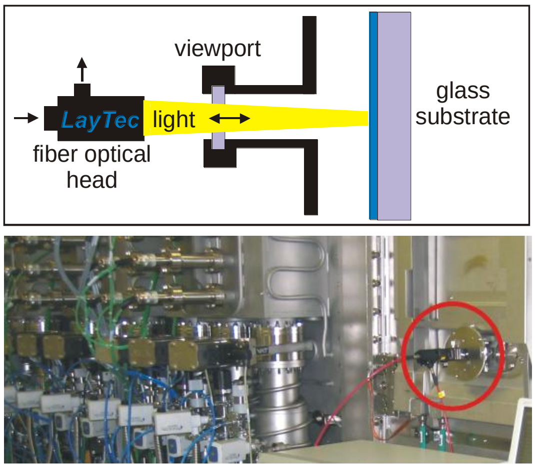

Fig. 1: Side view and picture of the set-up a vertical in-line evaporation system with a sensor attached to a quartz optical view port at the transfer chamber.

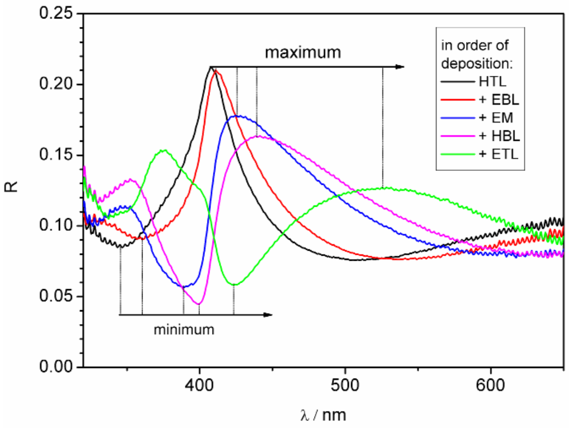

Fig. 2: Evolution of the spectral reflectance during the deposition of an OLED stack of five layers (see the insert with colour codes).

The reflection spectra in Fig. 2 were taken during an OLED process in which five layers were stacked on the substrates: a hole transport layer (HTL), an electron blocking layer (EBL), an emitter layer (EM), a hole blocking layer (HBL) and an electron transport layer (ETL). The spectra were measured after each layer deposition.

The most dominant features common to all the spectra are the maximum and the minimum shifting towards higher wavelengths with the increasing total thickness of the multi-layer stack. These spectra can already serve as fingerprint signatures for established processes. However, they also allow calculating an accurate thickness of each individual layer by using appropriate multi-layer analysis algorithms.

In order to obtain the layer thicknesses from single-shot reflectivity measurement, the whole spectrum must be analyzed in detail. This requires the precise knowledge of the n,k dispersion of all materials over the whole monitored spectral range. To obtain these data, single layers of all materials were deposited onto glass probes and reflectance spectra were taken. Then, the single layers were characterized by ex situ profilometric thickness gauging and optical transmission spectroscopy under nitrogen atmosphere. These reflection and transmission spectra were analyzed to determine related n and k spectra of all OLED materials in the 300nm – 700nm wavelength range. The thickness d measured by ex situ profilometry was used as one of the starting parameters of the fitting procedure. The reflection data is basically dominated by the index of refraction, whereas the transmission data is mainly influenced by absorption. As an example, the reflection and transmission data for the HTL layer is depicted in Fig. 3 together with the derived n and k dispersions.

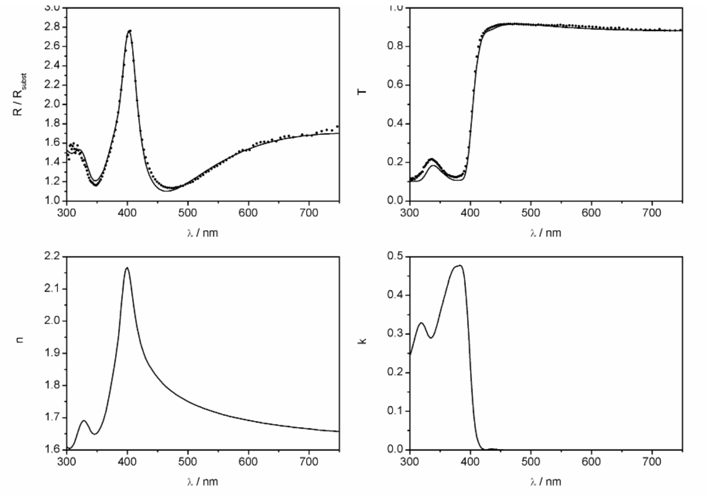

Fig. 3: Spectral reflectance normalized to the substrate reflectance (R/R_{subst}) and transmittance of an HTL layer (T) together with the derived n and k dispersions. Points represent measured values, curves are fit results.

	d_{refl}/ nm	d_{prof}/nm
HTL	143 ± 1	150 ± 5
+ EBL	7 ± 1	10 ± 5
+ EM	30 ± 1	24 ± 5
+ HBL	9 ± 1	10 ± 5
+ ETL	37 ± 1	39 ± 5

Table 1: Film thicknesses measured in a stack of five layers. d_{refl} are values derived from in situ reflectivity measurement, d_{prof} from ex situ profilometry.

Knowing the n,k dispersions of the OLED materials, the thicknesses of individual layer in a multi-layer stack can be calculated from the in-situ reflection spectra. For each new layer in the stack, the thicknesses of all previous layers beneath must be known. Table 1 shows the thicknesses of the layers in the stack as obtained from the spectra in Fig. 2. The values are compared to those measured by ex situ profilometry and demonstrate a good agreement, whereas the accuracy of the in-situ measurement is significantly better.

The presented set-up (Fig. 1) is the first step towards a multi-sensor system, in which there will be one sensor head after each deposition module. LayTec's goal is to develop a complete multiple optical head system for production line monitoring. In in-line and roll-to-roll production tools, where the substrate cannot be transferred backwards, the method allows for continuous quality control and enables reacting to long time drift effects or detecting major faults as soon as they occur.

As for cluster tools, we expect that already the single optical head spectroscopic reflectance technique as presented here is fully sufficient. In such cluster tools, even direct thickness control by a two-step deposition of each layer should be possible.

[1] Further reading: Steffen Uredat, Thomas Trepk, Michael Eritt, Christian May, Michael Toerker, P. Ressel, J.-Thomas Zettler: **In-situ Layer Thickness Measurement in OLED and Sputter Processes,** presented at the 50th SVC Annual Technical on April 28-May 3, 2007

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