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AUGUST 2005

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SPECIAL REPORT

Tiny tech makes big business

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Manufacturers' Product Showcase

Reflection, transmission spectrophotometry characterizes OLED materials

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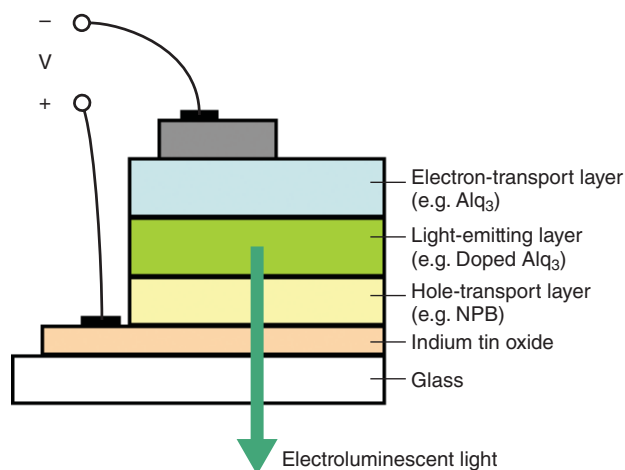


FIGURE 1. Electroluminescent light is produced in an organic light-emitting device when electrons and holes recombine in the light-emission layer. The accuracy, repeatability, and uniformity of the organic film thicknesses are important manufacturing issues to which reflection and transmission spectroscopy can be applied.

The spectacular growth of the organic-light-emitting-device (OLED) industry over the past couple of years has highlighted the technical challenges faced in the manufacturing of these devices. The accuracy, repeatability, and uniformity of the organic-layer thicknesses is a critical manufacturing issue for OLED displays because these parameters directly affect the brightness and color uniformity of pixels in the display. Furthermore, knowledge of the optical properties of the organic layers is necessary for optimizing the design of the OLED display, including the design of microcavities, and in understanding device properties such as external light-coupling efficiency. Reflection and transmission spectrophotometry is a fast, noncontact, and nondestructive characterization method that is ideally suited for these OLED manufacturing challenges.

Contending with OLED absorption
Optical-metrology methods, including reflectometry and spectroscopic ellipsometry, have found widespread use in the silicon industry for monitoring layer thicknesses and

An advanced metrology tool characterizes multilayer thin-film OLED structures based on power-spectral-density analysis of spectroscopic multiangle polarized reflection, polarized transmission, and spectroscopic ellipsometric data.

optical constants (refractive index n and extinction coefficient k). These techniques, however, have limitations when applied to OLED-related applications in which the organic films of interest tend to be thin and highly absorbing in the UV range and are deposited on transparent substrates. Although reflectometry (reflection spectrophotometry) methods can readily determine film thickness (t) if the optical constants of

the film are known (fixed), the technique does not inherently contain enough measured information to solve n , k , and t of the film independently.

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Spectroscopic ellipsometry, on the other hand, measures the polarization states of collimated monochromatic light before and after reflection from a surface to obtain the ratio of the complex *p*- and *s*-polarization reflection coefficients and provides twice as much information in the experimental data as does reflectometry; however, accurate determination of the extinction coefficient can be difficult without transmission data.

As a result, slightly more-involved analysis, such as the use of multiple sample data sets and/or determining thickness first in a nonabsorbing wavelength region, may be necessary to arrive at a unique solution for *n*, *k*, and *t*. The partial reflection from the backside of the transparent OLED substrate and the birefringence of some polymer OLED substrates (for example, polyethylene terephthalate films) adds additional complexity to the collection and analysis of spectroscopic ellipsometric data for OLED applications. Although these two unknown effects can be incorporated in the optical model, they introduce uncertainty in the uniqueness of the solution of the optical parameters.

Alternatively, transmission spectrophotometry is an ideal technique for measuring absorption and provides better resolution of the film's extinction coefficient compared with spectroscopic ellipsometry. Combining reflection and transmission spectrophotometry in a single instrument provides two data sets with enough information content to uniquely determine the thickness and optical constants of thin absorbing films on transparent substrates.

System design

We have developed advanced metrology tools based on a new optical technique that uses power-spectral-density analysis of spectroscopic multiangle polarized reflection, polarized transmission, and spectroscopic ellipsometric data. For the purpose of analyzing the OLED samples described here, we have limited our analysis to normal-incident spectroscopic reflection and transmission data. We have found that this method allows for fast and accurate material analysis and thickness determination of films during the production of OLED devices.

The instrument (called the FilmTek 3000) used to measure and analyze the

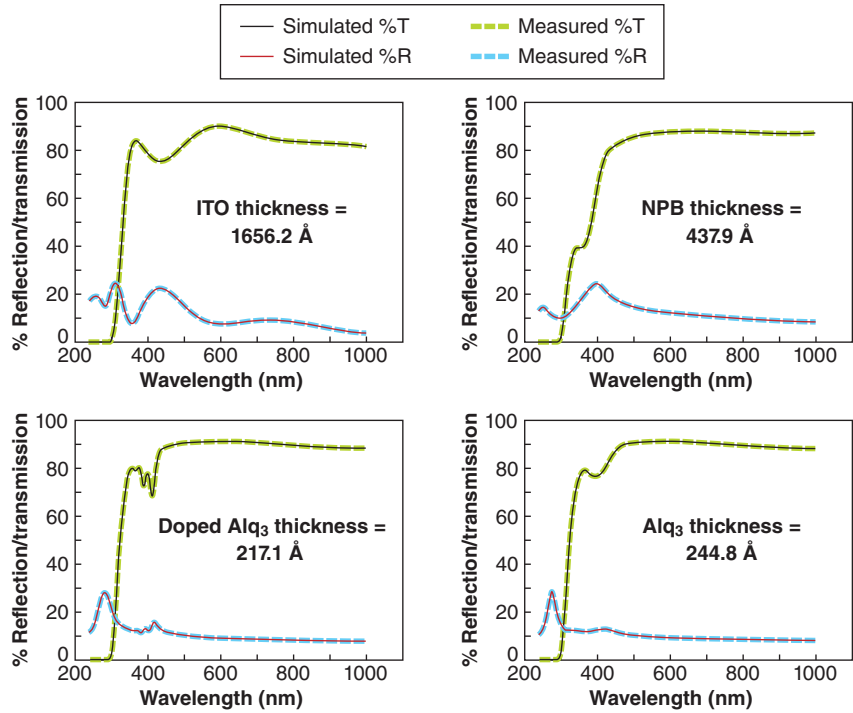


FIGURE 2. The modeled reflection and transmission spectra of single-layer OLED films on glass are in good agreement with measured data. The OLED layer thicknesses and optical constants are determined simultaneously. By using a general dispersion model that covers the entire wavelength range of the measurement, the number of parameters required to model optical response is reduced, eliminating the potential for multiple solutions.

OLED samples is a fiber-based system with a tungsten-deuterium light source and fixed-grating CCD-array spectrometers. Absolute reflection and transmission spectra are obtained by collecting reflection and transmission spectra from

ANALYSIS OF THE REFLECTION AND TRANSMISSION DATA GIVES ACCURATE THICKNESS VALUES AS WELL AS THE REFRACTIVE INDEX AND EXTINCTION COEFFICIENTS.

the sample of interest in ratio to reflection and transmission spectra from known samples (bare silicon for reflection and air for transmission). Reflection and transmission spectra can be measured from the deep-UV to near-IR, with acquisition time taking a fraction of a sec-

ond. Various optical configurations allow for a measurement spot size that ranges from 3.5 mm to 2 μ m.

Accompanying software simultaneously solves for refractive index $n(\lambda)$, extinction coefficient $k(\lambda)$, and thicknesses of multilayer film structures. A self-consistent solution is obtained by using a generalized dispersion formula developed at Scientific Computing International to model fitted values of the dielectric function $\epsilon(\lambda)$ to the measured reflection and transmission data. The dispersion formula is a self-consistent model that is derived from quantum-mechanical principles and correctly obeys the Kramer-Kronig relationship. It is applicable to metallic, semiconductor, amorphous, crystalline, dielectric, and organic materials.

By using a general dispersion model that covers the entire wavelength range of the measurement, the number of variables or parameters required to model optical response is reduced, eliminating the potential for multiple solutions. This approach allows the user to model complex multilayer structures with reflection and transmission data. Global-optimiza-

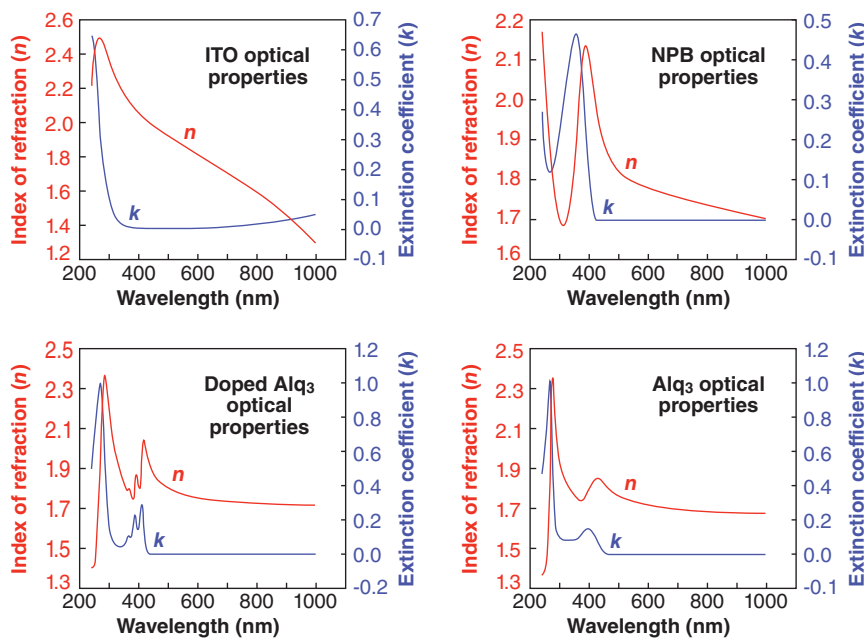


FIGURE 3. Fitted optical constants are determined from analysis of the reflection and transmission spectra obtained from single-layer OLED films on glass.

tion methods are used to obtain the best solution while avoiding local minima and minimizing sensitivity to the user's initial guess of fitted parameters (for example, layer thickness). The software optimizes the reflection, transmission, and the power-density-spectrum (fast-Fourier-transform) data simultaneously. This allows for accurate thickness determination over a wide range of thicknesses from 3 nm to 350 μm .

Application to OLED thin-film structures

Light is produced in OLEDs when an appropriate voltage is applied across the electrodes, causing electrons and holes to recombine in the light-emission layer (electroluminescence). The most commonly used emitter material is tris (8-hydroxyquinoline) aluminum (Alq_3). Changing the composition of the organic layers tunes the OLED emission colors across the visible spectrum. For example, by doping the Alq_3 layer with other organic molecules, energy transfer from the Alq_3 to the dopant results in lower energy (redder) emission. Also, substantial shifts in the electrolu-

minescent wavelength can be achieved by controlling the number and chemical nature of the quinolate ligands in Alq_3 . With these approaches, devices with electroluminescent emission in the red, green, and blue spectral regions have been demonstrated.

A typical OLED structure consists of organic layers grown on a glass or plastic substrate to form a multilayer struc-

Alq_3	252.2 Å
Doped Alq_3	201.3 Å
NPB	448.6 Å
ITO	1574.2 Å
Glass	

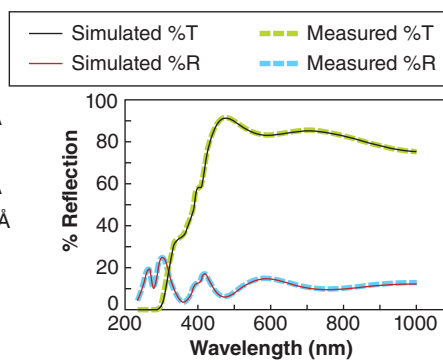


FIGURE 4. The modeled reflection and transmission spectra of a multilayer OLED film stack on glass are in good agreement with the measured data. The multiple OLED layer thicknesses can be determined simultaneously, with combined measurement and analysis time of one to two seconds per point.

ture about 1000 to 2000 Å thick (see Fig. 1). Small-molecule OLEDs are deposited under vacuum by thermal sublimation, while polymer-based OLED films are spin-coated and heat-treated. The sub-

strate is first coated with a conducting transparent electrode such as indium tin oxide (ITO), which serves as the anode. This layer is followed by a hole-transporting layer (HTL) such as naphthylphenylbiphenyl (NPB). An organic light-emitting layer (EML), such as doped Alq_3 , is then deposited on the HTL surface. A similar material is often used for the electron-transporting layer (ETL) that is deposited on the EML surface. The device is completed by depositing a low-work-function metal cathode such as magnesium-silver alloy.

The optical properties of OLED materials are essentially dependent on their complex dielectric functions, which are related to the refractive index n and extinction coefficient k . The nature and thickness of the organic layers in the OLED structure can be optimized for efficient charge migration, recombination, and light emission.

In routine use

Reflection and transmission spectrophotometry is a powerful technique for characterizing the organic-film thicknesses and optical constants of multilayer OLED thin-film structures. The FilmTek 3000 is routinely used for the noncontact optical characterization of multilayer OLED structures on glass substrates. In one example, the reflection and transmission spectra of single-layer OLED films on

glass are obtained from 240 to 1000 nm (Fig. 2). Analysis of the reflection and transmission data gives accurate thickness values as well as the refractive index and extinction coefficients over the same wavelength range (see Fig. 3). The layer thicknesses of a multilayer OLED structure on glass can also be determined accurately and simultaneously (see Fig. 4).

When reflection and transmission spectrophotometry is used for high-throughput large-area flat-panel-display applications, large custom stages

and small measurement-spot sizes allow the simultaneous determination of layer thicknesses and optical properties—key performance metrics in the manufacture of OLEDs. □