Time-resolved photoluminescence and electroluminescence characterization of a quantum dot LED using the FluoTime 300 spectrometer

Eugeny Ermilov, Maria Loidolt-Krüger, Bita Rezania, Asim Önal, Sedat Nizamoglu

PicoQuant GmbH, Rudower Chaussee 29, 12489 Berlin, Germany, info@picoquant.com

Department of Electrical and Electronics Engineering, Koc University, Rumelifeneri Yolu 34450
SarıyerIstanbul,Turkey, gsse@ku.edu.tr

Advancing the energy efficiency and color quality of LEDs with quantum dots

Current materials science research aims to advance the energy efficiency, color quality, and stability of LEDs. One approach towards efficient lighting that has attracted significant attention is the incorporation of colloidal quantum dots (QDs), as these can reach a high quantum yields of over 80 %. Moreover, QDs feature a tunable emission bandwidth, as well as the ability to fine-tune the emission spectrum by simply changing their size and composition. This promises the development of devices with superior color quality. In order to optimize the luminous properties, it is necessary to characterize the electroluminescence and photoluminescence of new materials and devices during development.

Methods for characterizing electroluminescent and photoluminescent properties

A toolbox full of methods for investigating the luminescent characteristics of materials exists. Commonly used methods include:

- **Electroluminescence spectroscopy** to analyze the emission spectrum of LEDs under electrical excitation with a photoluminescence spectrometer.
- **Time-resolved electroluminescence** to understand carrier dynamics, evaluate the temporal response of the LED, and to monitor changes in carrier lifetimes and recombination dynamics during aging and degradation.
- **Photoluminescence spectroscopy** to study the emission spectra of LEDs upon excitation with light, either a cw lamp or a laser, using a photoluminescence spectrometer.
- **Time-resolved photoluminescence** upon excitation with a pulsed (typically picosecond) laser to investigate the dynamics of excited states, recombination processes, and carrier lifetimes, employing a time-resolved photoluminescence spectrometer or microscope.
- **Photoluminescence quantum yield measurements** to determine the efficiency of photon emission from the material upon light excitation using an integrating sphere.

All of these methods are available with the FluoTime 300 time-resolved photoluminescence spectrometer.

FluoTime 300

This application note will showcase time-resolved photoluminescence and electroluminescence measurements of a quantum dot LED with the FluoTime 300 spectrometer.
The samples were kindly provided by the Nizamoglu group, Department of Electrical and Electronics Engineering, Koc University Istanbul, Turkey.

Results: optical characterization

Steady-state emission spectra are acquired to identify peak wavelengths of a material, to evaluate the spectral shape, i.e. spectral purity, and to detect secondary peaks or shoulders which could indicate defects in the material.
Fig. 1 shows the emission spectra of both individual components, the QDs emitting green light around 525 nm, and the LED die emitting blue light around 450 nm. The hybrid QD-LED`s total emission spectrum`s highest peak corresponds to the QD emission, which is slightly red-shifted compared to the solution. The emission between 425 and 500 nm corresponds to the LED die while the structure and intensity of the emission bands are different in the hybrid device compared to the standard LED die.

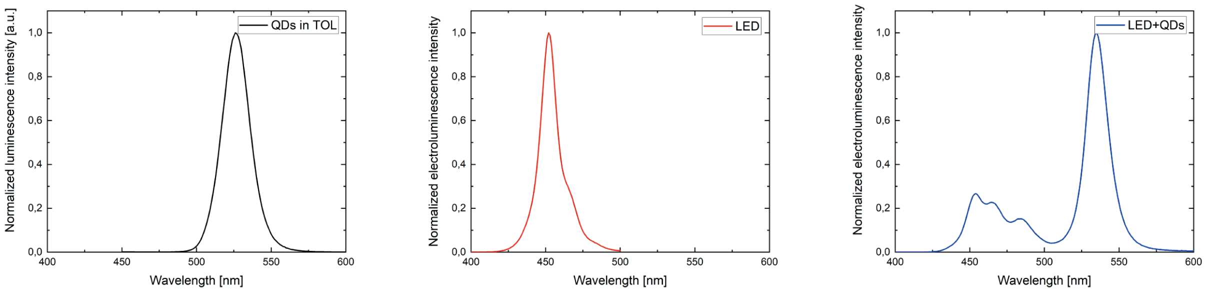

Figure 1: Emission spectra of QDs in solution (left) after excitation at 440 nm, and electroluminescence spectra of the LED (middle) and the hybrid QD-LED (right) with electrical excitation.

Next, we transferred the emission spectrum into chromaticity coordinates for plotting on a chromaticity diagram. The chromaticity diagram in Fig. 2 shows the perceived color of the emitted light from the QD-LED shifted to the green, compared to the blue emission of the LED die alone. This information can be used to tune the emission spectrum and the concentration of the quantum dots further and to calculate the correlated color temperature, which is the hue of white light.

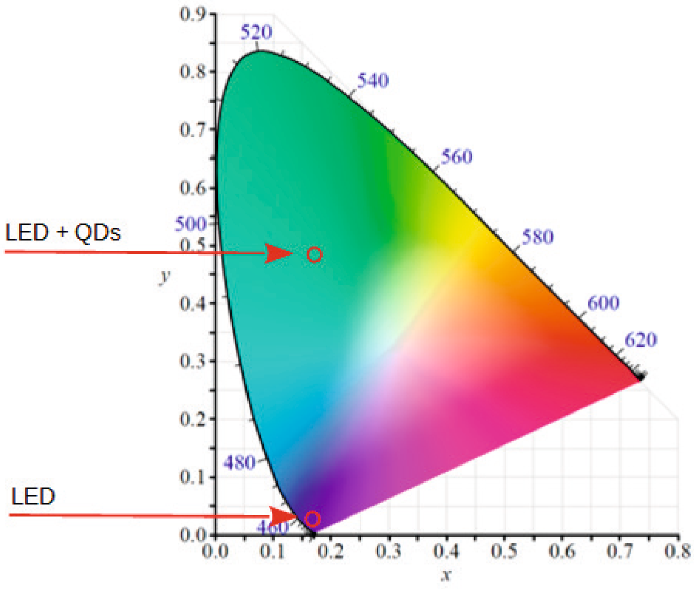

Figure 2: Spectrum of LED die and hybrid QD-LED indicated on CIE 1931 chromaticity diagram.

With the FluoTime 300 we also characterized the time-resolved photoluminescence of the QD-LED device. Fig. 3 shows the complex decay pattern of the QDs in solution, which can be fitted with 4 exponentials. When the QDs are incorporated into the hybrid LED, the electroluminescence is much longer and dominated by the longest components of the QD luminescence, whereas the electroluminescence of the LED alone is extremely short-lived.

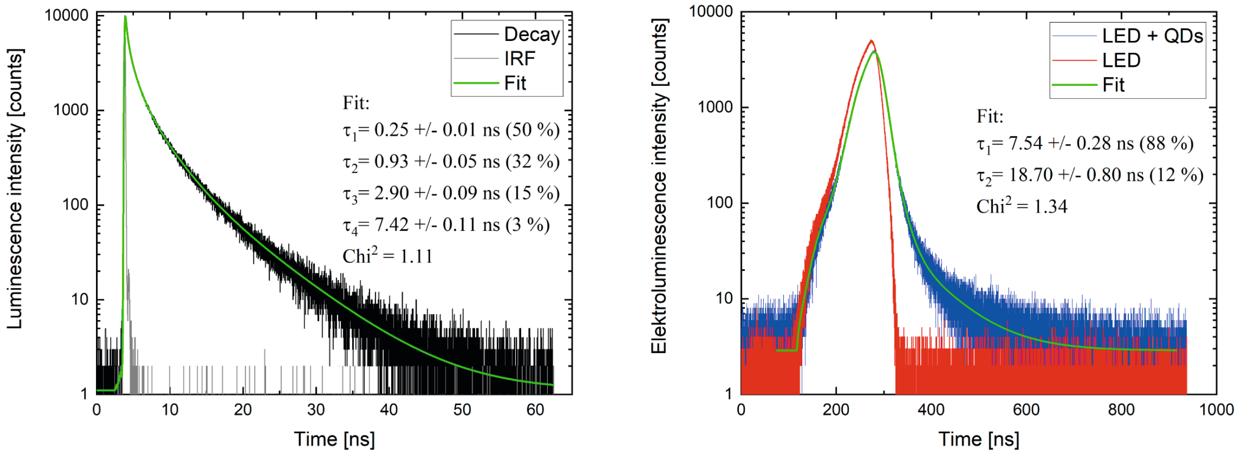

Figure 3: Left: Time-resolved photoluminescence decay of QDs in solution at 530 nm after pulsed excitation with 438 nm. The photoluminescence lifetimes obtained from a 4-exponential decay fit are noted.
Right: Time-resolved electroluminescence decays of the LED (red) and the QD-LED device (blue). The lifetimes obtained from a bi-exponential fit are noted.

By fitting the decay curves to appropriate models, e.g. single or multi-exponential decays, one can extract carrier lifetimes and investigate carrier recombination dynamics.

Outlook

With a micro-photoluminescence upgrade, one can access additional spatial information with a microscope, to study local variations in the material or visualize carrier diffusion.

Furthermore, time-resolved photoluminescence can reveal the presence of trap states by showing delayed emission components.