Eastman Kodak Company
Final Technical Report
OLED Lighting Device Architecture

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EXECUTIVE SUMMARY

Lighting consumes more than 20% of electricity generated in the United States. Solid state lighting relies upon either inorganic or organic light-emitting diodes (OLEDs).

OLED devices because of their thinness, fast response, excellent color, and efficiency could become the technology of choice for future lighting applications, provided progress is made to increase power efficiency and device lifetime and to develop cost-effective manufacturing processes.

As a first step in this process, Eastman Kodak Company has demonstrated an OLED device architecture having an efficacy over 50 lm/W that exceeds the specifications of DOE Energy Star Program Requirements for Solid State Lighting.

PROJECT OBJECTIVE

The project included work designed to optimize an OLED device, based on a stacked-OLED structure, with performance parameters of: low voltage; improved light extraction efficiency; improved internal quantum efficiency; and acceptable lifetime.

The stated goal for the end of the project was delivery of an OLED device architecture, suitable for development into successful commercial products, having over 50 lum/W power efficiency and 10,000 hours lifetime at 1000 cd/m^2.

ACCOMPLISHMENTS

During the project, Kodak developed and tested a tandem hybrid IES device made with a fluorescent blue emitter, a phosphorescent yellow emitter, and a phosphorescent red emitter in a stacked structure that had the following performance parameters:

Brightness: 1183 cd/m^2
Voltage: 5.7 V
Current Eff.: 118.3 cd/A
EQE: 54.1%
Efficacy: 64.7 lm/W
CIE-x: 0.417
CIE-y: 0.398
CCT: 3287 K
DC: 0.00079
CRI: 86.1

The estimated lifetime for this device was 10,000 hours +/- 10%.

In addition, Kodak developed and tested tandem hybrid EES devices with the following performance parameters:

Brightness: 982 cd/m^2
Voltage: 5.7 V
Current Eff.: 98.2 cd/A
EQE: 45.2%
Efficacy: 54 lm/W
CIE-x: 0.420
CIE-y: 0.409
CCT: 3290 K
DC: 0.0052
CRI: 77.7

The estimated lifetime for these devices was lower than the IES devices.

PROJECT ACTIVITIES

The challenge was to find low voltage materials that do not absorb excessive amounts of emitted light when the extraction enhancement structure is applied. Because an extraction enhancement structure forces the emitted light to travel several times through the OLED layers before it is emitted, it exacerbates the absorption loss. A variety of ETL and HTL materials was investigated for application in the low voltage SSL device structure. Several of the materials were found to successfully yield low operating device voltages without incurring excessive absorption loss when the extraction enhancement structure was applied.

An internal extraction layer comprises two essential components: a light extraction element (LEE) that does the actual extraction of emitted light and a light coupling layer (LCL) that allows the emitted light to interact with the extraction element. Modeling results show that the optical index of the LCL needs to be high, preferably higher than that of the organic layers with an n value of ~1.8. In addition, since the OLED structure needs to be built on top of it the LCL needs to be physically and chemically benign. During the first year of the project, efforts were spent to develop the LCL.

The LEE was fabricated using a proprietary 2P process developed prior to the start of the current project. Kodak successfully integrated the LEE with the LCL and produced an OLED compatible IEL.

In addition to the IEL, we also improved the efficiency of our external extraction layer (EEL). We achieved an EQE of 11% for fluorescent devices incorporating our EEL. Although less efficient, the EEL costs less to produce than the IEL. It might be adequate for many applications as improvements are made in the IQE of our emitters.

After analyzing several different possible configurations for constructing a hybrid white device we decided to focus on the hybrid-by-exciton-sharing (HBES) scheme. A HBES device comprises a fluorescent light emitting zone and a phosphorescent light- emitting zone. The device is designed such that excitons as a result of the recombination of electron and holes are produced in both the fluorescent emitting layers and the phosphorescent emitting layers. A charge-throttling layer is used to ensure the emission of proper proportions of photons of different colors to achieve the desired white color.

(Note that by having good color we mean color coordinates that fall in the Energy Star tolerance quadrangles and CRI values higher than 80. This color specification is very stringent and it adds significantly to the challenge in device design. If we ignored the color requirement as most reports in the published literature do, much higher power efficiency values could be achieved.)

We fabricated devices having nearly 30 lum/W power efficiency with good color within a few months from the start of the project. We soon discovered, however, that the lifetime of these devices was very short and the T50 (time to reach 50% of initial luminance) was much less than 100 hours. The culprit was determined to be the materials set that we used. By replacing the materials with more stable ones we were able to gradually improve the T50 lifetime.

In addition to the hybrid devices, we also significantly improved the all-fluorescent white devices. The major benefit over the hybrid devices is the improved lifetime. By the end of 2007, our analysis showed that the overall project goal of 50 lum/W is achievable using fluorescent devices by making further improvements in the IQE of the emitters and the extraction efficiency of the IEL's.

Throughout 2008, improvements were made in the performance of both the all-fluorescent white devices and the hybrid IES devices composed of a fluorescent blue emitter, a phosphorescent yellow emitter, and a phosphorescent red emitter in a stacked structure to achieve the accomplishments described above. For the hybrid device, a new host material for the blue fluorescent emitting layer was developed and new red phosphorescent and red and yellow triplet dopants were utilized. In addition, a new electron injection material was utilized to improve both the manufacturing process and the expected lifetime of the device.

In 2009, we focused on improving the lifetime of the devices, along with improvements in fabricating processes.

During the term of the project, Mr. Tyan made multiple presentations regarding the progress of Kodak's research and design activities. Copies of those presentation were submitted to DOE.

As the project concluded, our focus was on the tandem hybrid device, which proved to be the more efficient architecture. Cost-efficient device fabrication will provide the next challenges with this device architecture in order to allow this architecture to be commercialized.

PATENT APPLICATION

Patent application (D93593 or US 11/746,820) entitled "OLED Device Architecture for enhanced light extraction efficiency & lifetime" is still in prosecution.