<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>White light emission from InGaN/organic molecule light-emitting diode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Yue, Z; Cheung, YF; Choi, HW; Zhao, Z; Tang, BZ; Wong, KS</td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td>The 2013 Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR), Kyoto, Japan, 30 June-4 July 2013. In Conference Proceedings, 2013, paper no. TuPH-6</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>2013</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/202306">http://hdl.handle.net/10722/202306</a></td>
</tr>
<tr>
<td><strong>Rights</strong></td>
<td>International Conference on Quantum Electronics (IQEC) Proceedings. Copyright © IEEE.; ©2013 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.; This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.</td>
</tr>
</tbody>
</table>
White Light Emission From InGaN/organic Molecule Light-Emitting Diode

Zhounan Yue\textsuperscript{a}, Yuk Fai Cheung\textsuperscript{b}, Hoi Wai Choi\textsuperscript{b}, Zujin Zhao\textsuperscript{c}, Ben Zhong Tang\textsuperscript{d}, Kam Sing Wong\textsuperscript{a,*}

\textsuperscript{a}Department of Physics and Institute of Molecular Functional Materials, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong. * email: phkwong@ust.hk
\textsuperscript{b}Department of Electrical and Electronic Engineering, University of Hong Kong, Pokfulam Road, Hong Kong
\textsuperscript{c}Department of Chemistry and Institute of Molecular Functional Materials, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

Abstract

Aggregation-induced emission (AIE) organic molecule 4,7-Bis[4-(1,2,2-triphenylvinyl)phenyl]benzo-2,1,3-thiadiazole (BTPETD) was used as a top emitter on GaN-based light-emitting diode (LED) to produce white light. The fabricated hybrid organic/inorganic LED shows CIE coordinates of (0.32, 0.33) and 45.4% optical extraction efficiency from BTPETD layer with pump leakage of 17.3%. At driving current of 30 mA, the highest luminous efficacy of 123.8 lm/W was obtained for the hybrid devices which corresponded a luminance of $1.4 \times 10^5$ cd/m\textsuperscript{2}. This result shows an effective and simple way to produce white LED for solid state lighting application.

I. INTRODUCTION

There is tremendous effort to search for new and efficient light sources since lighting applications consume about 20% of global energy [1]. LEDs which can convert electrical energy directly to light, are considered to be the ultimate lamp, because of their high electroluminescence (EL) efficiencies. Among these LEDs, Gallium nitride (GaN)-based LEDs are almost ideal devices for next-generation white light sources due to their customized direct band-gaps in the ultraviolet to visible spectral range [3]. By coating with a yellow emitting overlayer, the GaN-based LEDs can achieve white light emission by mixing the original blue emission with secondary (yellow) luminescence generated from the overlayer. One normally use inorganic phosphor such as “YAG” for this yellow emitting top layer [3]. However, higher prices and shortage of phosphors are expected as demand for solid state lighting grows. Thus, search for alternative materials for white light emitting is important. Organic conjugated polymers with high photoluminescence yield have also been studied to generate white light as well [4]. Other than conjugated polymers, aggregation-induced emission (AIE) organic molecules are another group of organic materials with very high quantum efficiencies (normally exceed 50%) [5-6]. As their name suggests, the aggregation of AIE molecules induces the light emission rather than quenches the emission, which means they can be used in high concentration, and makes them good candidates for the hybrid white light emitters. In general, AIE molecules have very high quantum efficiencies (i.e., many close to 100%) and quite stable in air, furthermore one can modify their molecular structures by molecular engineering endeavor to give new luminophors with different emission colors [6]. Thus, AIE molecules are excellent candidate for display device applications. In this study, we report on fabrication and the properties of hybrid white light emitters with GaN-based LEDs and AIE molecule BTPETD.

II. EXPERIMENTAL RESULT AND DISCUSSION

The blue emitting (460nm) commercially-sourced InGaN/GaN LED wafers were used. The LED chips are diced by ultraviolet nanosecond laser micro-machining and die-bonded onto TO-headers, followed by Al wire-bonding. BTPETD was synthesized according to our previous publication [6]. The hybrid white light emitters were fabricated by dropping BTPETD toluene solution with concentration of 20 mg/mL on top of the bare InGaN LED to form a thin overlayer of BTPETD. The thickness of this down conversion layer was carefully adjusted to achieve overall white emission from the hybrid devices through the combination of blue emission from InGaN LEDs and down converted yellow emission from BTPETD. In addition to the BTPETD down conversion layer, the hybrid devices were later encapsulated with an epoxy coating to improve their stability.

![FIG. 1. (a) Molecular structure of BTPETD. (b) Normalized absorption and PL spectra of BTPETD in THF solutions and EL spectrum of GaN-based LED.](image-url)
(PL) spectra of BTPETD are also shown in Fig. 1(b). For hybrid devices with radiative energy transfer, there are two requirements in the luminescence down-conversion process. One is that there should be spectral overlap between the EL emission spectrum of LED and absorption spectrum of BTPETD. The other one requires the BTPETD molecule to convert absorbed photons into photons at longer wavelengths. The emission spectrum of LED shows a single peak at 460 nm with a narrow linewidth of 20 nm, and its left shoulder coincides with the absorption tail of BTPETD. Although it would be better if the EL spectrum of LED overlapped with the absorption maxima rather than presented absorption tail of the chromophore, the reason why BTPETD is still chosen to be the down-conversion material, is due to the fact that the PL of BTPETD and the blue emission from LED are complementary colors. Thus, by combining the blue EL emission and the yellow PL emission, white light emission from the hybrid devices can be achieved.

By carefully adjust the coating condition of BTPETD toluene solution onto the GaN-based LED Chip, white light emission from the hybrid devices is observed with CIE coordinates of (0.32, 0.33) (Fig. 2), which is close to the ideal white color. The spectrum of such a device is shown in Fig. 3 with driving current I=2mA. However, at high current, the color tends toward the blue.

Fig. 2 The dependence of CIE chromaticity coordinates on the driving current. The direction of arrow shows the direction in which driving current increases.

For those devices with epoxy encapsulation, the device is more stable than un-encapsulated one both in term of emitted intensity as a function of time and under high intensity photon pumping. It seems that the epoxy layer well insulates the BTPETD molecules, which prevents them from being oxidized by air. The luminance of the GaN-based LED can be up to 1.57×10^5 cd/m^2 with driving current up to 80mA, and shows no degradation within such range of driving current. The luminance of emission from the hybrid devices is higher than the LED due to the overlap between the PL emission and the standard luminosity function, and shows a maximum of 2.69×10^5 cd/m^2 at I=80 mA. However the BTPETD molecules degrade at intense photon pumping, which leads to the saturation at high driving current.

Fig. 3 The spectrum of white light emission from hybrid device with BTPETD at I=2mA.

III Conclusions

In summary, hybrid white light emitters constructed with InGaN LED and AIE molecule BTPETD are demonstrated. The fabricated device shows CIE coordinates of (0.32, 0.33) and optical extraction efficacy of 45.4% with leakage fraction of 17.3%. At a driving current of 30mA, the hybrid device shows the highest luminous efficacy 123.8 lm/W, which corresponded to a luminance of 1.4×10^5 cd/m^2. However, a maximum of 2.69×10^5 cd/m^2 at I=80mA was achieved which is sufficiently intense for lighting application.

ACKNOWLEDGMENT

Financial support from the Research Grants Council of Hong Kong (project # HKUST2/CRF/10) and the University Grants Committee of Hong Kong (project # AoE/P-03/08) is acknowledged.

REFERENCES