Applied Physics Letters ARTICLE scitation.org/journal/apl

Photovoltaic characterizing method of degradation of polymer light-emitting diodes based on ideality factor and density of states

Cite as: Appl. Phys. Lett. **119**, 123301 (2021); doi: 10.1063/5.0057615
Submitted: 22 May 2021 · Accepted: 2 September 2021 ·
Published Online: 21 September 2021

View Online Export Citation CrossMark

Jaehoon Kim,[a] Taesoo Lee, Jeonghun Kwak, and Changhee Lee[a]

AFFILIATIONS

Department of Electrical and Computer Engineering, Inter-university Semiconductor Research Center, Seoul National University, Seoul 08826, South Korea

[a]Authors to whom correspondence should be addressed: jplane@snu.ac.kr and chlee7@snu.ac.kr

ABSTRACT

Polymer light-emitting diodes (PLEDs) possess several unique advantages over competitive technologies, including solution processability, broad applicability, and low-cost fabrication. However, their commercialization is delayed due to the relatively low operation stability compared to current display techniques. To provide fundamental insight into the degradation mechanism and enhance the stability, we discuss unique analysis methods of PLEDs' degradation using photovoltaic impedance characteristics. In particular, we report the method to determine the energetic disorder or density of states (DOS) of PLEDs using light intensity (P_{light})-dependent open-circuit voltage (V_{OC}) and Cole–Cole plot measurement. Based on the method, it was found that PLED degradation results in a shift of the center of DOS rather than broadening. Furthermore, we extrapolated equivalent ideality factor (n) values from the P_{light}-dependent V_{OC} and dark current density–voltage (J–V) characteristics, which implied trap-assisted recombination throughout the degradation process. Thus, we believe that the results will provide helpful and comprehensive insight into understanding the degradation of PLEDs.

Polymer light-emitting diodes (PLEDs) are one of the candidates for next-generation display due to their solution-processability,[1,2] broad applicability,[3,4] and low-cost fabrication.[2,5,6] Since the PLED was reported in the field, various studies have been conducted to improve the performance. In particular, the synthesis of efficient polymers,[7,8] interfacial engineering,[9] and structural modification[10,11] has contributed to a significant enhancement of the PLEDs' efficiency. However, the commercialization of the PLED has been hindered due to the relatively low operational stability compared to the current display technologies such as thermally evaporated small molecule organic light-emitting diodes (OLEDs).[12,13] The primary reasons for the PLEDs' lower performance than OLEDs or inorganic light-emitting diodes (LEDs) are mainly based on the susceptible degradation of polymers.[14–17] In addition, the impurities and particles in the solutions act as defect sites, limiting the performance of the solution-processed devices.[18] Though many articles reported diverse stability-enhancing methods such as interfacial engineering[19] and stable polymers,[20] systematic analysis on the PLEDs' degradation has been lacking. Specifically, regarding the PLEDs, effective analysis methods have been lacking compared to the solar cells' field, where impedance spectroscopy provides various analysis methods.[21–27]

In this article, we discuss a unique method of analyzing the PLED degradation with photovoltaic properties. Although the PLEDs generally adopt materials with significantly lower charge carrier mobility than organic solar cells' case,[28,29] it is revealed that the photovoltaic measurement methods are applicable to PLEDs, where they provided unique analyzing methods. In particular, comprehensive studies, including the photovoltaic properties and impedance spectroscopy, effectively provided the density of states (DOS) properties of PLEDs. While the characterizing method has been frequently reported in the solar cells' case,[23–27] its application to the PLED has been missing, which would make interesting and valuable tools in PLED studies. As it is reported in the solar cell articles,[23] the capacitance components of the emissive layer (EML) (an active layer in the case of solar cells) were extrapolated from the Cole–Cole plots under diverse open-circuit conditions with various light intensity (P_{light}) circumstances. The capacitance as a function of the bias V_{OC} generally shows an apparent Gaussian-shaped DOS, providing essential insight into the organic solar cells' (OSCs) energy level characteristics. Similarly, it is found that the method applies to the PLED as well, where the variation in DOS, a significant shift of the center of DOS, was measured upon degradation. In addition to the DOS-related analyses, we also offer a