Voltage dependent capacitances of organic light emitting devices

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Various structures of organic light-emitting devices (OLEDs) including electrophosphorescence were measured for their capacitances. The zero bias capacitances were in inverse proportion to the total thickness of organic layers. Positive bias voltage only affected the capacitances. It is suggested that Joule heating of organic layers caused the dependences of the capacitances on voltage. The maximal capacitances were scattered from 7 to 34 nF/cm² and in inverse proportion not only to the total thickness, but also to the single layer thickness of Alq. The similarity of these proportionality factors suggested that the dielectric constants of the hole transports and Alq were not so different, and the contribution of Alq layer was dominant for the maximal capacitance. The capacitances of OLEDs were roughly estimated from total thickness without respect to the difference of dielectric constants of whole layers.

Keywords: light-emitting device, capacitance, voltage dependence, thickness

1. Introduction

Organic light-emitting devices (OLEDs) have been expected as new type of full color ultra-thin displays because of their high quality and efficiencies. In order to achieve higher efficiency, it is important not only to improve materials, but also to optimize driving scheme. Passively addressed OLED displays are driven by peripheral driving ICs. Design of driving circuit for passive display is independent of display design because both sizes are separately variable. On the other hand, in the case of active matrix OLED display using thin film transistors (TFT), emitting pixels and driving transistors should co-exist within a limited area. Therefore, coordination of pixel area and transistor size becomes important. In other words, size of transistors must be minimized to maximize emitting area of OLED pixels.

Electrostatic capacities of passive OLED displays are less important [1] because external driving circuits having large current flowing capability are available. In contrast, capacitances of active OLEDs are important because current flowing capability of small sized thin film transistors, which drive each pixel, is limited. Eshima et al. reported temperature dependent capacitance of an OLED having structure of ITO/CuPc/NPB/Alq/LiF/Al [2]. However, less information for various structures of OLEDs has been reported.

In this study, capacitances were measured for various structures of OLEDs including electrophosphorescence. Dependences of the capacitances on voltage, luminance and thickness are discussed.

2. Experimental

OLEDs were prepared by vacuum evaporation method (0.1 mPa) onto glass substrates with 10 ohm/square indium tin oxide (ITO) anodes. Cathodes were evaporated up to a thickness of 200 nm from a mixture containing 90% of magnesium and 10% of indium by weight. An effective area of the electrodes was 4mm². Each OLED had a tris(8-hydroxyquinoline) aluminum (Alq) layer, which contacts to the cathode. OLED may be comprised of a hole injection layer (HIL), 4,4'-bis [N-(1-napthyl)-N-phenyl-amino] biphenyl (NPB) hole transport layer (HTL), 7 weight percent of tris(2-phenylpyridine) iridium (Ir(ppy)) doped in 4,4'-bis(carbazol-9-yl)-biphenyl (CBP) electrophosphorescence layer (IrL), 2,9-dimethyl-
4,7-diphenyl-1,10-phenanthroline (BCP) hole blocking layer. Organic Layer structures of fabricated OLEDs were as follows: 

A: NPB(50nm)/Alq(50nm),
B: HIL(15nm)/NPB(13nm)/Alq(31nm),
C: HIL(15nm)/NPB(13nm)/Alq(16nm),
D: Alq(32nm),
E: NPB(14nm)/Alq(32nm),
F: HIL(7nm)/NPB(14nm)/Alq(32nm),
G: NPB(25nm)/IrL(14nm)/BCP(10nm)/Alq(19nm),
H: NPB(25nm)/IrL(14nm)/Alq(19nm),
I: HIL(18nm)/NPB(15nm)/IrL(15nm)/Alq(30nm).

Capacitances and parallel conductances were measured with an Agilent-HP 4192A LF Impedance Analyzer using 1 kHz probe wave of 1 V r.m.s. A model of capacitor in parallel with resistor was assumed for OLED equivalent circuit. Light emission was measured with a Topcon BM-5 luminance meter. All measurements were carried out at room temperature.

3. Results and discussion

Figure 1 shows characteristic bias voltage dependences of the capacitances for an area. The zero bias capacitances, which mean the capacitances without bias voltage, were ranging from 7 to 25 nF/cm². The capacitances depended on positive bias voltages, however, negative bias does not affect. The maximal capacitances were scattered from 7 to 34 nF/cm², where the bias voltages for the maxima were ranging from 5 to 19 V. In the higher bias region, each capacitance approached to zero, in contrast, the thickest A device maintained its capacitance up to 25 V. Single-layered and the thinnest D device had the largest maximal capacitance. These results suggested that Joule heating of organic layers caused the dependences of the capacitances on voltage, because thinner layer is sensitive to be heated by Joule heating.

Figure 2 shows luminance dependences of the capacitances. Most of the maximal capacitances were obtained in a luminance range from 20 to
2000 cd/m², which range is important for display applications. Therefore, estimation of capacitance is necessary for obtaining optimal design of driving circuit.

The zero bias capacitances were plotted against inverse of the total thickness of the whole organic layers as shown in Fig. 3. These capacitances were in inverse proportion to the total thickness. The inverse proportionality factor was $7.6 \times 10^{-14}$ F/m, and the intercept was almost zero. Square of the correlation factor for all devices was 0.78, this seemed to a fairly good proportionality. Whenever
to start display, driving circuits encounter the zero bias capacitances as initial capacitance values. These important capacitances were possible to be roughly estimated from the total thickness.

The maximal capacitances are also important to design optimal driving circuits. Most of the maximal capacitances also were in inverse proportion to the total thickness as shown in Fig. 4. The inverse proportionality factor was 7.4 x 10^{-14} F/m, and the intercept was about 12 nF/cm². Square of the correlation factor for 6 devices was 0.90. The difference between two intercepts corresponds to an average of differences between zero bias capacitance and maximal capacitance for each devices. The inverse proportionality factors for two plots were very close. These results suggested that the dielectric constants of the hole transports and Alq were not so different, and the zero bias capacitances and the maximal capacitances can be roughly estimated from the total thickness.

Figure 5 shows most of the maximal capacitances were also in inverse proportion to the single layer thickness of Alq. The inverse proportionality factor was 5.1 x 10^{-14} F/m, and the intercept was almost zero. Square of the correlation factor for 7 devices was 0.93. Such similarity of those inverse proportionality factors suggested that the contribution of Alq layer was dominant for the maximal capacitance.

4. Conclusion
Various structures of OLEDs were measured for their capacitances. The zero bias capacitances were in inverse proportion to the total thickness of the whole organic layers. Positive bias voltage only affected the capacitances. It is suggested that Joule heating of organic layers caused the dependences of the capacitances on voltage. The maximal capacitances were in inverse proportion not only to the total thickness, but also to the single layer thickness of Alq. The proportionality factors for those plots were similar. Thus, the capacitances of the OLEDs can be roughly estimated from the total thickness without respect to the difference of dielectric constants of whole layers.

References