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Influence of layer thickness to the emission spectra in microcavity organic light emitting diodes

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Abstract - Microcavity organic light emitting diodes (OLEDs) have attracted great attention because they can reduce the width of emission spectra from organic materials, enhance brightness and achieve multipeak emission from the same material. In this work, we have fabricated microcavity OLEDs with widely used organic materials, such as N,N′-di(naphthalene-1-yl)-N,N′-diphenylbenzidine (NPB) as a hole transport layer and tris (8-hydroxyquinoline) (Alq) as emitting and electron transporting layer. These organic materials are sandwiched either between two thick silver mirrors or one thin copper and one thick silver mirrors. The influence of total cavity length (from 164 nm to 243nm) and the cavity Q-factor to the emission behavior has been investigated. In all cases, an OLED without bottom mirror, i.e. with the organic materials sandwiched between indium tin oxide and a thick silver mirror, has been fabricated for comparison. We have characterized the devices with photoluminescence, electroluminescence, and reflectance measurements. Multiple peaks have been observed for some devices at larger viewing angles.

Keywords- microcavity, OLED

I. INTRODUCTION

Organic materials have been found useful in applications, such as organic light emitting diodes (OLEDs). However, the emission spectrum of organic materials is typically broad. For example, the emission spectrum of Alq covers the range from 480 nm to 650 nm. Microcavity OLEDs have been attracting lots of attention in order to achieve spectral narrowing, brightness enhancement, or multipeak emission from the same emitting layer [1-6].

In this work, we have demonstrated multipeak emission with commonly used materials, N,N′-di(naphthalene-1-yl)-N,N′-diphenylbenzidine (NPB) as hole transporting material and tris (8-hydroxyquinoline) (Alq) as emissive/electron transporting material. The two materials are sandwiched between two mirrors, either thin Cu and thick Ag mirrors or two thick Ag mirrors. Devices with different thickness of organic materials have been fabricated. The devices are characterized by photoluminescence (PL), electroluminescence (EL), and reflectance measurements. We found that both EL and PL spectra are significantly affected by the cavity length (organic layer thickness) and the cavity Q-factor.

The paper is organized as follows. Experimental details are described in Section II followed by Results and discussion. Finally conclusions are drawn.

II. EXPERIMENTAL DETAILS

A. *Sample and device fabrication*

High purity NPB and Alq were purchased from H. W. Sands Corp. They were further purified by sublimation before device fabrication. The microcavity OLEDs were fabricated on cleaned quartz substrates by thermal evaporation under high vacuum (~10^{-6} Torr). The thickness of the films was monitored by a quartz thickness monitor during deposition, and verified by step profiler and spectroscopic ellipsometry after deposition. Different bottom mirrors, thin Cu (25 nm) and thick Ag (80 nm), were fabricated on top of the quartz substrates as anode. The different thickness of NPB and Alq filmswere deposited. Then the devices were completed with 70 nm Ag cathode. The devices with different bottom mirrors were fabricated at the same time in order to eliminate possible effects of the thickness variation of the organic layers. Microcavity OLEDs containing Alq layer only with the same total thickness were also fabricated in order to exclude possible effects of NPB and confirm that the observed emission originates from the interplay of a cavity and Alq.

B. *Measurement and characterization*

Photoluminescence (PL), reflectance, and electroluminescence (EL) for the devices have been measured. The excitation source for PL measurements was HeCd laser (325 nm). The PL spectra were collected using a double monochromator (1.4 m Oriel 77225) with Peltier-cooled photomultiplier detector (Hamamatsu R636-10). A deuterium-tungsten lamp was used as an excitation source for reflectance measurements, and the spectra were collected using the same system as for the PL. The OLEDs were biased with Keithley 2400 source-measurement unit and the electroluminescence spectra are measured with using a fiberoptic spectrometer PDA-512-USB (Control Development Inc).

III. Results and Dicussions

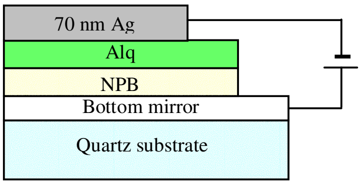

Figure 1. Structure of microcavity OLED, the bottom mirror is either 25 nm Cu or 80 nm Ag.

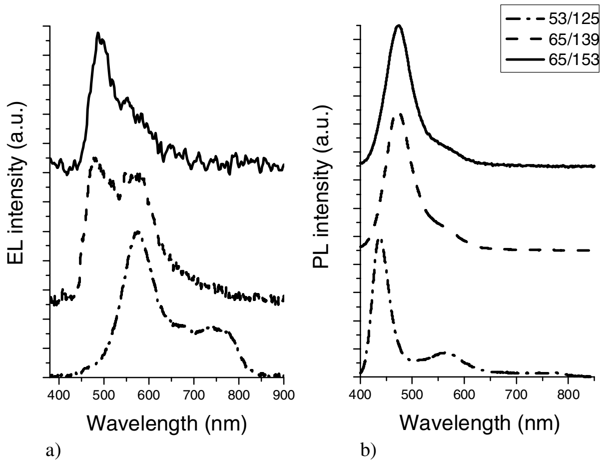

Figure 2. a) EL and b) PL spectra of MOLEDs with different NPB and Alq thickness sandwiched between 25 nm Cu bottom mirror at normal incidence from the bottom mirror.

The device structure is shown in Figure 1. The microcavity devices are labeled according to the NPB and Alq3 thickness, i.e 53/125 represents device with 53 nm NPB and 125 nm Alq. Figure 2 shows the EL spectra and PL spectra of devices with different thickness of NPB and Alq. Multiple emission peaks have been observed for all the devices, which is not expected since emission from Alq films exhibits a single peak at ~540 nm. One of the devices (53/125) also exhibits emission in the near-infrared spectral range, which is surprising considering the fact that Alq emission above 700 nm is negligible. The PL spectra consist of the emissions from both NPB and Alq. Both EL and PL spectra are strongly affected by the thickness of the organic layers, which is expected as the cavity mode emission is dependent on the cavity length between the two mirrors.

We have also investigated the influence of cavity Q-factor on the emission spectra of the devices by using different bottom mirrors. Since 53/125 device shows the strongest EL intensity which extends to IR range, we have chosen this device for further investigation. Angular dependence of the EL spectra of 53/125 devices with 25 nm Cu bottom mirror, 80 nm Ag bottom mirrors, and ITO are shown in Figure 3. With low cavity Q-factor (25 nm Cu bottom mirror), the yellow emission peak (~574 nm) can couple out of the microcavity. The cavity mode (~750 nm) emission exhibits blue shifting with increasing viewing angle. When 80 nm Ag is used, the emission is dominated by the near-infrared resonant cavity mode which shows blue shift with the increasing viewing angle, similar to the devices with thin Cu mirror. On the other hand, the emission of the non-cavity devices is dominated by the yellow emission peak and no near infrared emission can be observed.

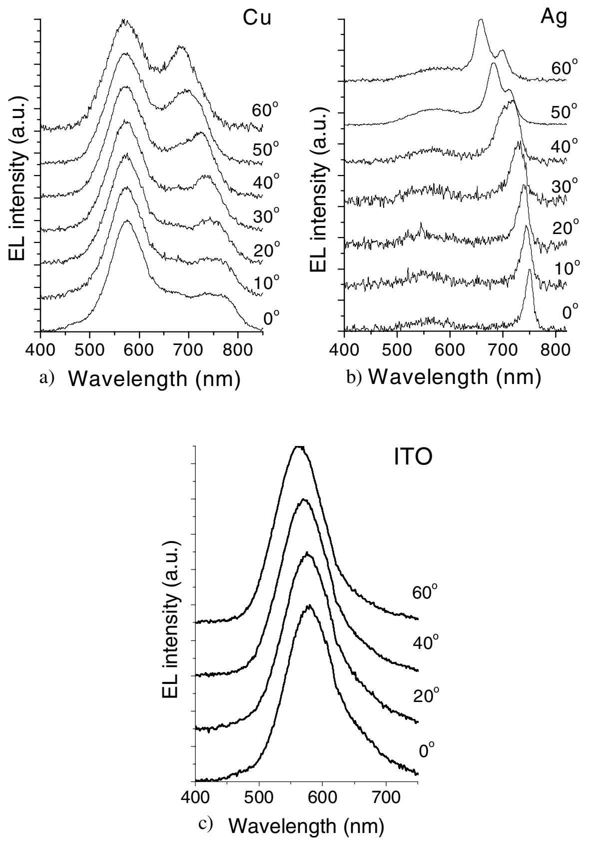

Figure 3. Angular dependence of the EL spectra for 53/125 devices with different bottom mirrors, a) 25 nm Cu bottom mirror, b) 80 nm Ag, and c) ITO.

Figure 4 shows the angular dependence of the PL spectra of 53/125 devices with different bottom mirrors. In this case, the emission is dominated by the blue emission peak from the NPB layer. The fact that this peak originates from the NPB is confirmed by the absence of the blue emission in the cavities containing Alq only. Apart from the absence of the NPB emission, the cavities with Alq only exhibit very similar behavior to those with NPB/Alq layers, so that it can be concluded that the yellow and near infrared emissions arise from the interplay of the Alq and the cavity.

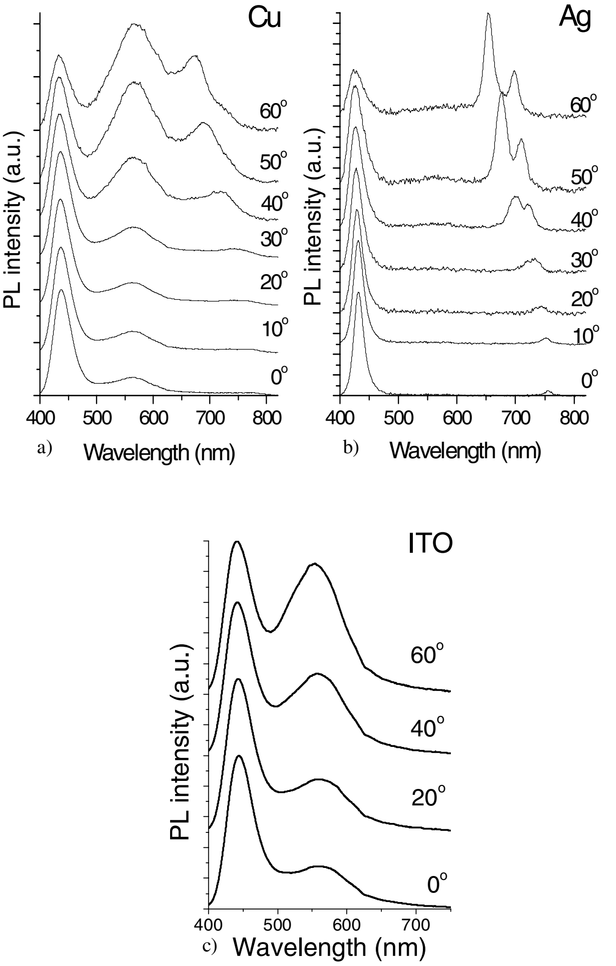

Figure 4. Angular dependence of the PL spectra for 53/125 devices with a) 25 nm Cu bottom mirror, b) 80 nm Ag bottom mirror and c) ITO.

To further investigate unusual behavior of these devices, reflectance measurements were performed. Figure 5 shows the reflectance of 53/125 devices with 25 nm Cu bottom mirror. Since the reflectance of 80 nm Ag is very high in the visible range, we did not measure the reflectance of Ag devices. Three reflectance dips can be resolved in the devices with thin Cu mirrors, in agreement with three peaks observed in the photoluminescence. The origin of these peaks, however, is not fully clear. Even though the emission from the Alq is broad, the emission above 700 nm is negligible and thus the dominant emission at ~750 nm from cavities with two Ag mirrors in unexpected.

The multiple peak emission in microcavities can originate from several different causes, such as wide angle interference [7], TE-TM mode splitting [8], and strong coupling [9]. The interference phenomena could not fully explain the obtained experimental results in NPB/Alq based non-cavity OLEDs. TE-TM mode splitting is responsible for the near infrared peak splitting at larger viewing angles in the devices with two thick Ag mirrors, which is supported by the polarization dependent measurements. On the other hand, the yellow emission peak and the corresponding reflectance dip ~560-570 nm cannot be explained by the polarization mode splitting. There are two possible causes for the yellow emission: one is the uncoupled emission from Alq modified by the transmission of the bottom mirror, while the other is polariton emission. Polariton emission in organic materials was demonstrated previously [10-13], but the studies have been confined to the materials with narrow excitonic resonance. However, it should be noted that, from the expression for the splitting, a finite positive Rabi splitting will exist in the microcavities where the width of the exciton and photon modes are equal [13]. However, this splitting could be observed only if it is larger than the sum of the broadenings of the exciton and photon modes [9]. Therefore, further study is needed to establish whether such phenomena contribute to the unusual spectra observed in the microcavities with thin Cu mirror. Also, the origin of the near infrared emission, in particular clarification of the role of the defect states and subband gap absorption in Alq, requires further study.

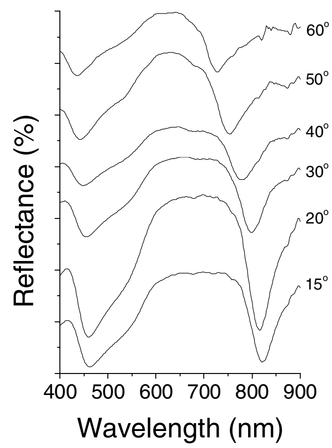

Figure 5. Angular dependence of the reflectance of 53/125 devices with 25 nm Cu bottom mirror.

IV. Conclusions

In conclusion, we have demonstrated multipeak emission from MOLEDs using conventional bilayer structure with NPB and Alq. The bottom mirror is either 25 nm Cu or 80 nm Ag and the top mirror is 70 nm Ag. The emission properties were strongly dependent on the thickness of organic layers and the Q-factor of the cavity. The origin of the multiple peak emission in some of the devices requires further study.

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