Response to "Comment on 'Change of the emission spectra in organic light-emitting diodes by layer thickness modification'" [Appl. Phys. Lett. 86, 186101 (2005)]

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In our recent paper,[1] we presented the study of the emission spectra of tris-(8-hydroxyquinoline) aluminum (Alq) based organic light-emitting diodes (OLEDs) as a function of organic layer thickness. Both calculations and experimental results were presented. The discrepancy between the calculated and measured emission spectra was noted, and possible reasons were discussed. Finally, it was concluded that further study is needed to conclusively establish whether any other phenomena in addition to simple interference play a role in the obtained results. In his recent comment,[2] Shore claimed that our experimental data can be entirely explained by simple interference phenomena, and presented calculations which qualitatively "reproduce" basic behavior of our devices.

However, the calculations in our work [Fig. 1(b)][1] also show similar behavior as those presented in the comment by Shore (Fig. 2).[2] Since Shore[2] changed only the Alq layer thickness, while we considered devices with different N, N′-di(naphthalene-1-yl)-N,N′-diphenylbenzidine (NPB) and Alq thicknesses, direct comparison can only be made for the device with 65 nm NPB and 139 nm Alq. It is obvious from Fig. 1(b) in our letter[1] and Fig. 2 in the recent comment[2] that both calculations show essentially the same features. Yet, quantitative agreement between the experimental data and the calculated results is lacking. Since the thicknesses of organic layers were verified by step profiler and spectroscopic ellipsometry after deposition, thickness errors in the fabricated devices are unlikely. Another possible reason for the discrepancy, as correctly identified by Shore,[2] is different emission region thickness. Figure 1 illustrates the influence of the assumed emission region thickness on the calculated electroluminescence (EL) spectra. Further studies with confined emitting layers of known thickness are in progress to experimentally establish the influence of the emitting layer thickness.

We would also like to point out that, regardless of the assumed emission layer thickness, the calculated spectra always show two peaks, while some of the experimental spectra showed clear shoulders in addition to two peaks. Comparison between the calculated and the experimental spectra for the 65/153 (65 nm NPB and 153 nm Alq) device is shown in Fig. 2(a). It can be observed that the calculated spectrum, exhibiting a two-peak structure, does not describe the experimental spectrum well. The calculation for the same

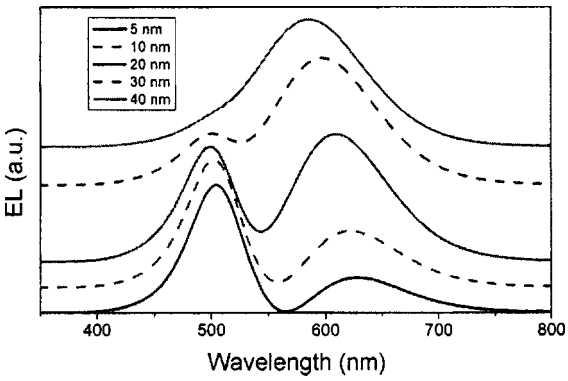

FIG. 1. Influence of the emitting layer thickness. The spectra have been normalized and shifted for clarity.

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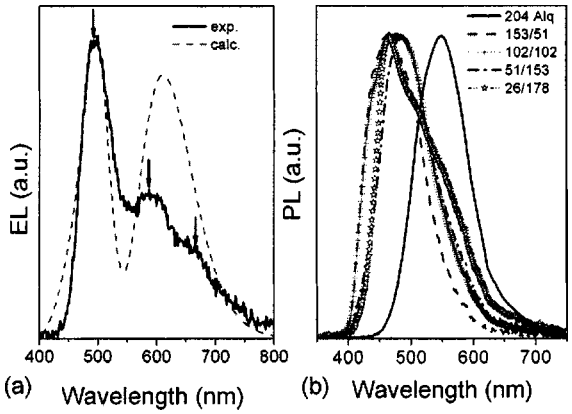

FIG. 2. (a) Comparison between the experimental and the calculated EL spectra for the device with 65 nm NPB and 153 nm Alq. Arrows indicate positions of the Gaussian peak fit. (b) PL spectra in a device with total organic thickness of 204 nm for different positions of NPB/Alq interface. PL spectrum from 204 nm Alq film is also shown.

device, shown in Fig. 3 in the comment by Shore,[2] shows the same two-peak structure, although with a different ratio of the peak intensities which is likely due to the emission region width of 30 nm, instead of more commonly used 20 nm.[3]

It should also be noted that the claim by Shore[2] of the NPB thickness variation being less important disagrees with both experimental and calculated results [Fig. 1b in Ref. 1] in spite of the similar optical functions of NPB and Alq above ~450 nm, since the distance of the light emitting layer, i.e., NPB/Alq interface, from the cathode plays a significant role in the devices with the same total thickness. This is also the case for the photoluminescence (PL) spectra, as shown in Fig. 2(b), which is in disagreement with the claim by Shore[2] that any interference effects are cancelled in the PL. Therefore, it is still necessary to improve the agreement between the experimental results and calculated emission spectra (which is the case both for our calculations and calculations by Shore[2] which exhibit essentially the same features), and further experimental and simulation studies are in progress to positively identify the causes of discrepancies between calculated and experimental spectra.

[1]C. H. Cheung, A. B. Djurišić, C. Y. Kwong, H. L. Tam, K. W. Cheah, Z. T. Liu, W. K. Chan, P. C. Chui, J. Chan, and A. D. Rakić, Appl. Phys. Lett. **85**, 2944 (2004).
[2]J. D. Shore, Appl. Phys. Lett. **86**, 186101 (2005), preceding paper.
[3]A. Dodabalapur, L. J. Rothberg, and T. M. Miller, Appl. Phys. Lett. **65**, 2308 (1994).