

Novel host and electron blocking materials for efficient and long lifetime phosphorescent OLEDs

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Abstract

In order to improve the performance in green phosphorescent OLED devices, Merck has developed novel host and electron blocking materials. The newly developed host materials improve the device lifetime by a factor of 3. The newly developed electron blocking materials having not only electron but also exciton barrier properties increase the efficiency of the device by a factor of 1.4. Comparable results were achieved in phosphorescent red systems with further host materials.

1. Introduction

Active and passive matrix OLED displays are widely used in mobile and automotive applications.

OLEDs employing phosphorescent (triplet) emitters [1,2,3,4,5] have generated enormous research activities and industrial display interest due to their high electric current to light conversion efficiency. In the past, commercial applications with green triplet materials have been restricted by the overall performance of these devices and their deficiencies with respect to lifetime and efficiency. Whereas the emitter structures are seen as relatively stable compounds, the required host, transport and blocking materials have formed a bottleneck. In particular their stability and operational lifetime performance are limited. Merck has been working on the development of all of these types of materials for phosphorescent OLED devices with significant progress: Triplet emitters, host and blocking materials for red and green devices have been synthesized for highly efficient and long lifetime OLED displays.

It has been often pointed out that phosphorescent devices have problems like an operational lifetime that is shorter than that of fluorescent devices. Hence, the combination of long lifetime and high efficiency is required.

For the lifetime issues, the host (matrix) materials

and hole transport materials (electron or exciton blocking materials) should be carefully selected from the material stability point of view. For highest efficiency, the hole transport materials have to act as electron or exciton blocking materials in addition to having good hole transport ability. For this purpose, we have focused on efficient and long lifetime host and electron blocking materials for triplet emitters.

2. Experimental

The basic device structure used for the performance evaluation of the materials is as follows: Glass/ ITO/ HIL/ HTL/ (EBL)/ RGB Emitter + Matrix/ ETL/Cathode. The device configuration with standard materials was compared with new devices, in which the standard host was replaced by the new matrix material and/or an additional electron blocking layer was included. The devices were fabricated by successive evaporation of these materials and transferred to the measuring glove box filled with high purity argon without exposing them to ambient atmosphere.

	Cathode	LiF/Al
20 nm	ETL	Alq
40 nm	EML	TMM-004 or TMM-086: Ir(ppy) ₃ = TEG-341 (15%)
(15 nm)	HTL or EBL	HTM-040 optional
20 or 5 nm	HTL	NPB
20 nm	HIL	HTM-014
	ITO	

Fig. 1. Device structure for phosphorescent green devices.

3. Results and discussion

In order to evaluate host and electron blocking materials for green phosphorescent devices, we used the device structure as shown in the Fig. 1.

The HIL consists of a conventional Merck hole injection material. In the HTL NPB is employed, which is the abbreviation of 4,4'-bis (1-naphthyl-N-phenyl-amino)-biphenyl. Alq is the well known aluminium-tris-hydroxyquinoline. The green phosphorescent emitter named TEG-341 is fac tris(2-phenylpyridine) iridium ($\text{Ir}(\text{ppy})_3$) having a purity of 99.9 % by NMR analysis.

The overall organic layer thickness was kept constant at 100 nm. Three different device structures were compared, where the structure with the host material TMM-004 is the reference device structure. In one set of test devices, the matrix material TMM-004 was replaced by TMM-086. In further experiments an additional layer of HTM-040 was placed between the EML and HTL as a second HTL, the overall thickness of NPB(5 nm)/HTM-040(15 nm) was kept constant at 20 nm.

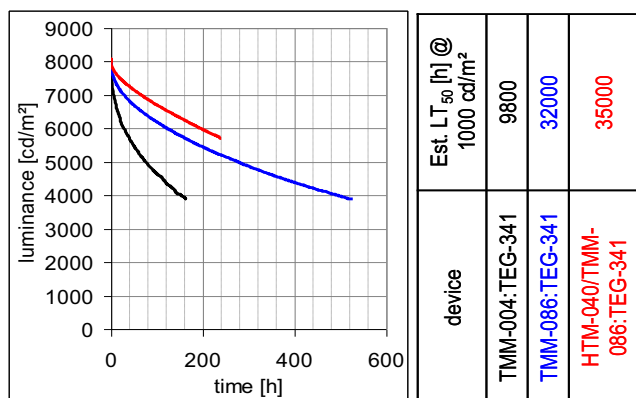


Fig. 2. Lifetime measurement curves (under constant current mode) of the three different device structures.

The results are shown in Fig. 2 and Fig. 3, respectively. As can be seen, TMM-086 mainly improves the lifetime (by a factor of more than 3), whereas HTM-040 mainly improves the efficiency (by about 50%) with respect to the standard device including TMM-004.

The operational lifetime with TMM-086 shows a remarkable improvement to the TMM-004 reference device as indicated in the Fig. 2, where the operational lifetime (half brightness life) of the TMM-086 is more than 3 times longer than that of TMM-

004 in the accelerated life test mode with an initial brightness of 8000 cd/m². The estimated lifetime at 1000 cd/m² is about 32000 h (TMM-086:TEG-341) and 36000 h with HTM-040 as an additional layer, respectively (calculated with an acceleration factor of $n=2$). HTM-040 obviously acts as an efficient electron and exciton blocking material. This is also indicated by the electroluminescence spectrum from the reference device where NPB is in direct contact with the emission layer. Taking a closer look on the EL spectrum, it reveals a small contribution of NPB.

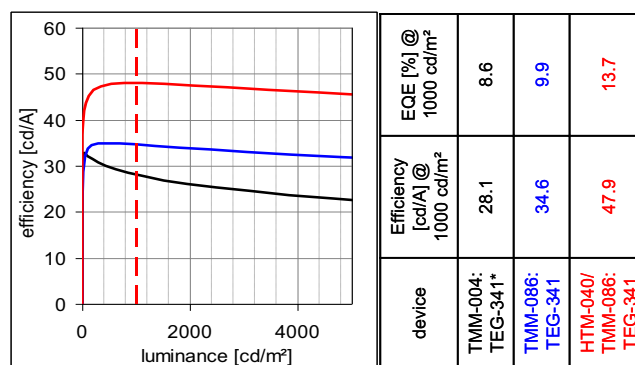


Fig. 3. Current efficiency as function of the luminance for the three different device structures.

The calculated HOMO-LUMO level diagram (Fig.4) including calculated T1 levels can be used for an explanation of the observed behavior.

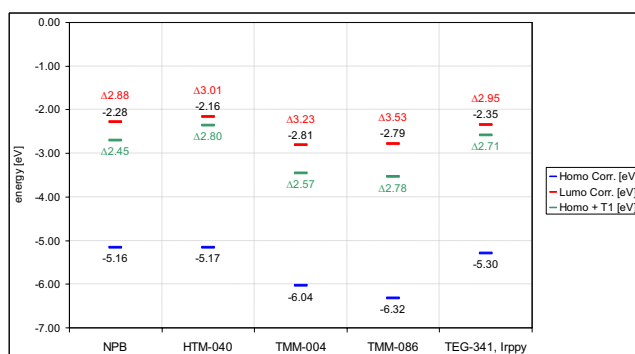


Fig. 4. HOMO/LUMO levels, energy gap and T1-energy calculated with TD-DFT of the used materials.

The significant improvement in efficiency of the device with HTM-040 with respect to the standard device results from the higher triplet level of HTM-040 with respect to NPB. It is very likely that triplet excitons are transferred to the triplet level of the NPB layer and decay non-radiatively there, which results in

a direct loss of efficiency. Making use of a hole transport material with an appropriately high triplet level like HTM-040 results in an increase in efficiency.

As an additional effect, it probably helps that HTM-040 also has a higher LUMO level than NPB. We speculate that an injection of electrons into NPB might occur because there is only a moderate barrier between the emission layer and NPB.

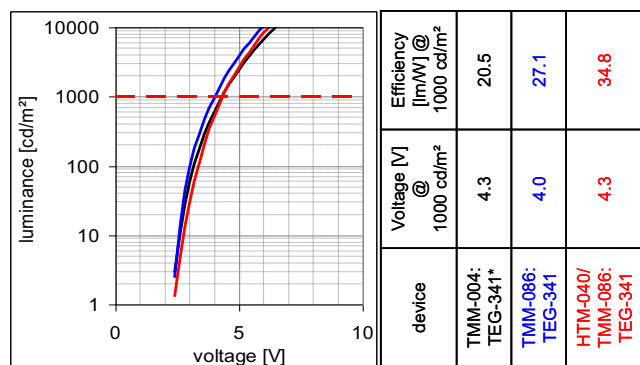


Fig. 5. Luminance versus voltage of the three different devices.

TMM-004 is well known as a host material for green phosphorescent emitters resulting in very low voltages. This big advantage compared to most of the common matrix materials is also shown by TMM-086.

The L/V characteristics (Fig. 5) shows that the voltage of all devices is on a very low level of about 4 volt. With the help of a better ETM than Alq a further reduction would be possible. The resulting high power efficiency of 27.1 lm/W with only TMM-086 and 34.8 lm/W with the additional HTM-040 electron blocking layer is a big improvement compared to the 20.5 lm/W in the TMM-004 reference device.

In red phosphorescent systems Merck developed host materials exhibiting comparable achievements to phosphorescent green systems. With the new red host TMM-080 the lifetime was doubled compared to conventional host materials like BALq, values beyond 40000h @ 1000 cd/m² were achieved.

4. Summary

Merck's newly developed matrix TMM-086 for phosphorescent green dopants shows excellent current efficiencies in combination with HTM-040 and long lifetimes. These new materials will contribute to the commercialization of phosphorescent AMOLED.

5. References

1. M.A. Baldo, D.F. O'Brien, Y. You, S. Silbey, M.E. Thompson, and S.R. Forrest. *Nature* 395, 151-154 (1998).
2. M.A. Baldo, S.Lamansky, P.E. Burrows, M.E. Thompson and S.R. Forrest. *Appl. Phys. Lett.* 75, 4-5 (1999).
3. H. Vestweber, I. Bach, H. Becker, R. Fortte, O. Gelsen, A. Gerhard, S. Heun, P. Stoessel, ICEL-4, O21 (2003).
4. H. Becker, H. Vestweber, A. Gerhard, P. Stoessel, R. Fortte; *SID Digest*, 796 (2004).
5. H. Vestweber, H. Becker, R. Fortte, A. Gerhard, S. Heun, J. Kroeber, P. Stoessel, *IDMC-05*, 211-213 (2005).