RESEARCH FOR **LOW COST**
FLEXIBLE LIGHTING SOLUTIONS

Deliverable 2.6
"Demonstration of a flexible LEC with turn-on time < 20 s, system efficiency > 25 lm/W and stability > 5000 hours"

Delivery date: M33
Submission date: 30.09.2012

EU founded FP7-Strep project CELLO, 248043
Cost-Efficient Lighting devices based on Liquid processes and ionic Organometallic complexes
Date: 30-09-2012
Lead contractor: P2 (SIEMENS)
Revision: Final
Dissemination level: Public

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SEVENTH FRAMEWORK PROGRAMME

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1. Introduction

CELLO aims at preparing light emitting electrochemical cells (LECs) with significantly improved performances using solution processing on flexible substrates.[1]

For this reason CELLO developed LECs with fast turn-on times (< 20 seconds), high luminance (1000 cd/m2) and long stability (time to reach 50 % of luminance > 5000 hours). Additionally, power efficiencies of 17 lum/W has been achieved.

2. Results and discussion

In the following sections results will be shown considering device lifetime, devices on flexible substrates and efficiency.

Turn-on time and lifetime:

Typical light-emitting electrochemical cells (LECs) used for liftetime studies were prepared by spin-coating and consisted of the following layout:

- Indium Tin Oxide (ITO) anode pre-patterned on a glass substrate.
- Hole injection/transport (HIL/HTL): poly(3,4ethylenedioxythiophene)poly (styrenesulfonate) (PEDOT:PSS) 100nm thin layer.
- A 100nm thin layer of an ionic iridium complex, for the example shown below bis(2phenylpyrdineC,N)(4(3,5dimethoxyphenyl)6phenyl2,2'bipyridineN,N')iridium(III) hexafluorophosphate,[Ir(ppy)2(Meppbpy)][PF6] (= SG069),[2] (Figure 1) mixed with the ionic liquid 1butyl3methylimidazolium tetrafluoroborate, [BMIM+:BF4–] at a molar ratio of 3:1. The iridium complex was highly purified at Siemens.
- A 150nm aluminium evaporated cathode.

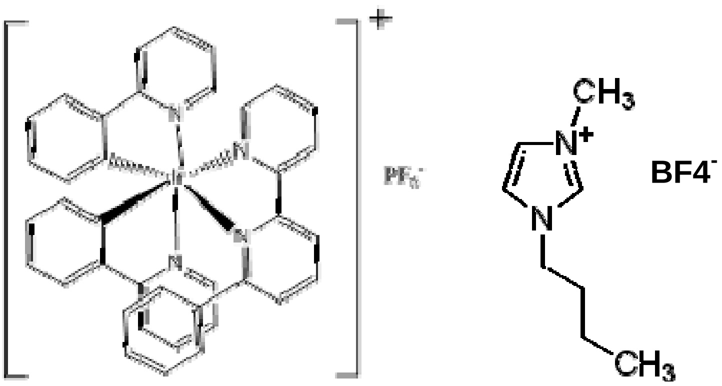


Figure 1. Chemical structures of the active emitting complex $[Ir(ppy)_2(Meppbpy)][PF_6]$, SG069 and the Ionic Liquid $[BMIM_+:BF4_4]$.

The LECs were driven under a block-wave pulsed current with 30% duty cycle and an average current density of 25mA/cm². The choice of a pulsed current driving scheme is not arbitrary as the pulsed wave allows a higher stabilization of the doped regions which leads to longer lifetimes.[3]

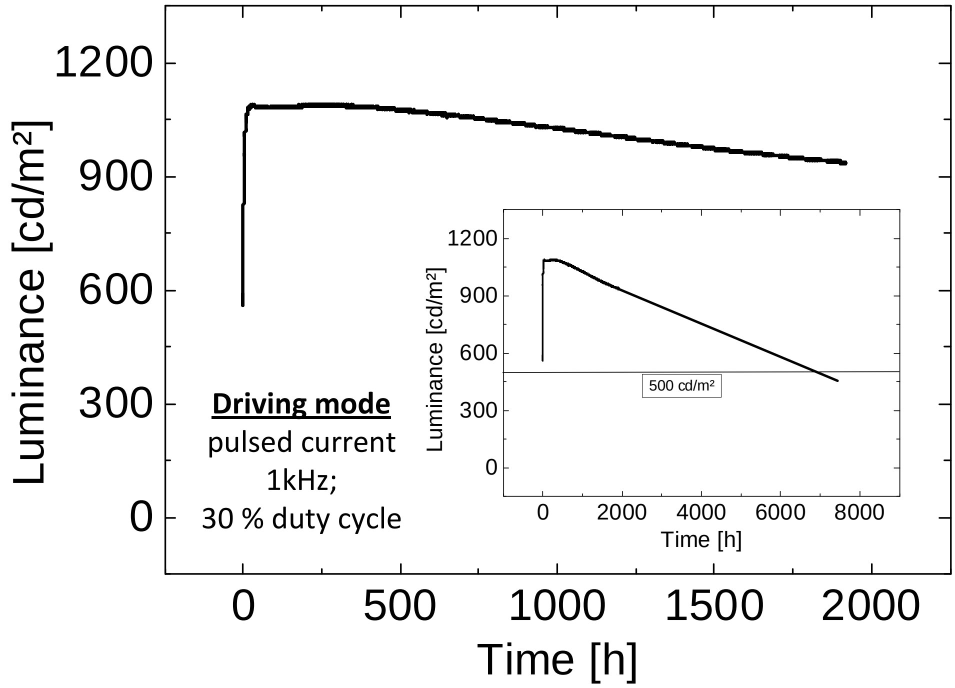


Figure 2. Luminance versus time for a SG069 based LEC. Inset shows extrapolation up to 50 % of the initial luminance.

In Figure 2 the luminance of the above mentioned LEC is depicted versus operational time. The LEC was encapsulated with a glass cover and evaluated in a temperature controlled test facility in air.
The turn-on time is less than 1 second as the first measurement point the luminance is > 400cd/m². The luminance rapidly rises until a maximum above1000 cd/m².
Its operation is very stable and after approximately 2000 hours the luminance has dropped to 950 cd/m^2. When applying a conservative linear extrapolation this leads to a lifetime (time to reach 50 % of the maximum luminance) in the order of 7000 hours.

Efficiency:
Highest efficiency values achieved for SG069 for current as well as power efficiency at a luminance level of 1000cd/m² are 5.50 cd/A and 2.24 lm/W, respectively.
Achieved values for the external quantum efficiency (EQE) are thereby 2.72 %. Considering a perfect charge balance, 20% outcoupling efficiency, ~ 20% photoluminescence quantum efficiency and no exciton quenching losses the theoretical limit of the EQE for SG069 is about 4 %. Hence, the observed EQE is close to its theoretical limit of this emitter.

Using ionic iridium complexes with higher photoluminescence quantum efficiencies it is possible to enhance the device performance. Best efficiencies obtained were 28.2 cd A^{-1} and power efficiencies of 17.1 lm W^{-1} at luminance levels around 600 cd m^{-2} when the complex JF326 (see Figure 3 below) was used. More importantly is that the obtained efficiencies were stable over time and not just reached in the initial phase of the operation.

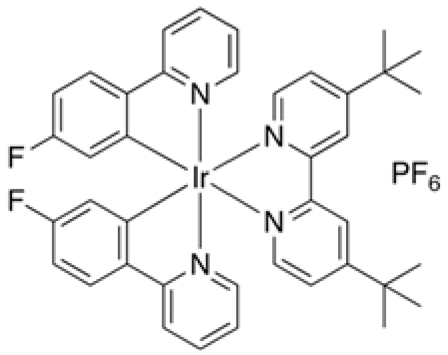
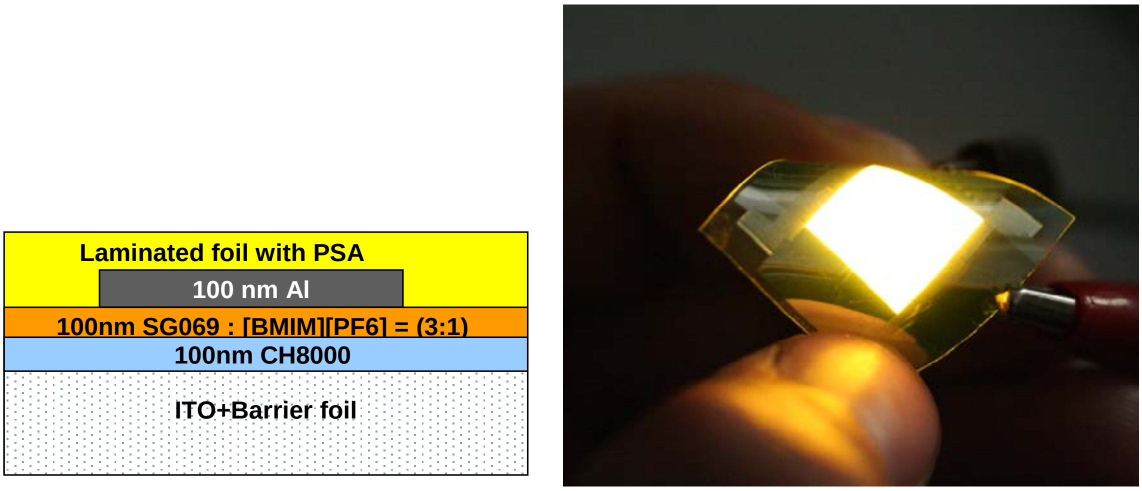


Figure 3. Chemical structure of the very efficient ionic iridium complex JF326.

Flexible devices:

LEC are also easily prepared on flexible substrates. The commercially available ITO coated foils, however do have inferior roughness and conductivity properties compared to glass substrates. Nevertheless, very bright and stable LECs can be prepared. Figure 4 shows a fully solution processed LEC device on a flexible ITO substrate and flexible encapsulation under ambient air conditions.



Active area ~ 1.5 cm²

Figure 4. Device layout and image of an operating encapsulated flexible LEC.

3. Conclusion

We have demonstrated that it is possible to achieve LECs with subsecond turn-on times and lifetimes in excess of 6500 hours when operated at 1000 cd/m^2. Additionally, LECs were obtained with an efficiency around 17 lm W^{-1} at luminance levels around 600 cd m^{-2}. Although these results were obtained on rigid substrates due to the lack of good quality flexible substrates, we were also able to obtain efficient and bright LECs using ITO coated PET foils.

4. References

[1] R. D. Costa, E. Orti, H. J. Bolink, F. Monti, G. Accorsi, N. Armaroli, *Angew. Chem. Int. Ed.* **2012**, *51*, 8178.
[2] H. J. Bolink, E. Coronado, R. D. Costa, E. Ortí, M. Sessolo, S. Graber, K. Doyle, M. Neuburger, C. E. Housecroft, E. C. Constable, *Adv. Mater.* **2008**, *20*, 3910-3913.
[3] D. Tordera, S. Meier, M. Lenes, R. D. Costa, E. Orti, W. Sarfert, H. J. Bolink, *Adv. Mater.* **2012**, *24*, 897.