Modeling electrothermal feedback in OLEDs by a 2D thermistor network comprising negative differential resistance

Axel Fischer(1), Thomas Koprucki(2), Annegret Glitzky(2), Matthias Liero(2), Klaus Gärtner(2), Daniel Kasemann(1), Bjrn Lüssem(1), Karl Leo(1), and Reinhard Scholz(1)

(1) Institut für Angewandte Photophysik, Technische Universität Dresden, 01062 Dresden

(2)Weierstraß-Institut (WIAS Berlin), Mohrenstraße 39, 10117 Berlin

e-mail: `axel.fischer@iapp.de`

For lighting applications, OLEDs need much higher brightness than for displays, causing substantial self-heating. It is well known that this is accompanied by unpleasant brightness inhomogeneities. Although the relevance of electrothermal interplay has been recognized, the fundamental understanding of its origin is still missing [1, 2]. For example, there is no explanation why regions with the highest temperatures shift to the device borders albeit the heat conduction is worst at the center of the substrate. Furthermore, lighting tiles can show a saturation of brightness around their mid position at elevated self-heating.

Recently, it has been shown that the temperature-activated transport in organic semiconductors favors thermal runaway and the occurrence of negative differential resistance (NDR) of 'S'-shape type. This is demonstrated by reversible thermal switching of an n-doped/intrinsic/n-doped C60 device [3]. The effect can be explained by purely thermal effects arising from the positive feedback loop between the temperature dependent conductivity and power dissipation. Such a behavior is well-known for thermistor devices with a negative temperature coefficient (NTC). Thus, organic semiconductor devices have to be understood as NTC-thermistors.

Here, we show by experiment and simulation that OLEDs produce such a strong electrothermal feedback that S-shaped NDR occurs, but with the crucial difference that the OLED comes along with a laterally extended crossbar architecture. Under rising voltage applied to the contacts, self-heating combined with the series resistance of the transparent electrode produces regions with decreasing voltage across the organic layers. Even more interestingly, a part of these regions shows even decreasing currents. Hence, the current density becomes extremely inhomogeneous because regions with increasing and decreasing currents can occur in different parts of the device, leading to strong local variations in luminance. As a result, regions with either S-NDR or switched-back behavior occur in a stable manner, and the interface between these regions propagates through the device for an increase of the total device current.

To model this effect, we use a SPICE network simulation. A cubic lattice of thermistor devices represents the active OLED layer system linked by two resistor networks accounting for the anode and the cathode. A third resistor network corresponds to the thermal properties of the glass substrate which is conducting most of the heat. Thus, we can describe the steady state IV curve up to the point where degradation starts.

An accurate understanding of nonlinear electrothermal feedback will be essential for predicting device function for different geometries, contacting, and materials. Thus, our results are important for further progress in this field.

References

[1] Slawinski, M.; Bertram, D.; Heuken, M.; Kalisch, H. & Vescan, A.: Electrothermal characterization of large-area organic light-emitting diodes employing finite-element simulation, *Org. Electron.*, 2011, **12**, 1399-1405

[2] Pohl, L.; Kollár, E.; Poppe, A. & Kohári, Z.: Nonlinear electro-thermal modeling and field-simulation of OLEDs for lighting applications I: Algorithmic fundamentals, *Microelectronics Journal, THERMINIC 2010*, 2012, **43**, 624

[3] Fischer, A.; Pahner, P.; Lüssem, B.; Leo, K.; Scholz, R.; Koprucki, T.; Gärtner, K. & Glitzky, A.: Self-Heating, Bistability, and Thermal Switching in Organic Semiconductors, *Phys. Rev. Lett.*, 2013, **110**, 126601

[4] Shaw, M. & Yildirim, N.: *Thermal and Electrothermal Instabilities in Semiconductors*, Academic Press, 1983, Volume 60, 307

[5] Fischer, A.; Koprucki, T.; Gärtner, K.; Tietze, M. L.; Brückner, J.; Lüssem, B.; Leo, K.; Glitzky, A. & Scholz, R.: Feel the Heat: Nonlinear Electrothermal Feedback in Organic LEDs, *Adv. Funct. Mater.*, 2014, **24**, 3367