TECHNISCHE UNIVERSITÄT DRESDEN

School of Science Department of Physics

Multi-physics simulation of organic devices using LTspice for first principle understanding

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DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

ECMI 2016, Santiago de Compostela

Motivation

- Explaining new unexpected measurements
- Feasibility analysis of new ideas and strategies
- Short development time (~ days – weeks)
- Playground to improve understanding, basic optimization rules
- Multi-physics (charge flow, heat flow, ...)
- Design rules for sophisticated simulation tools

LTspice

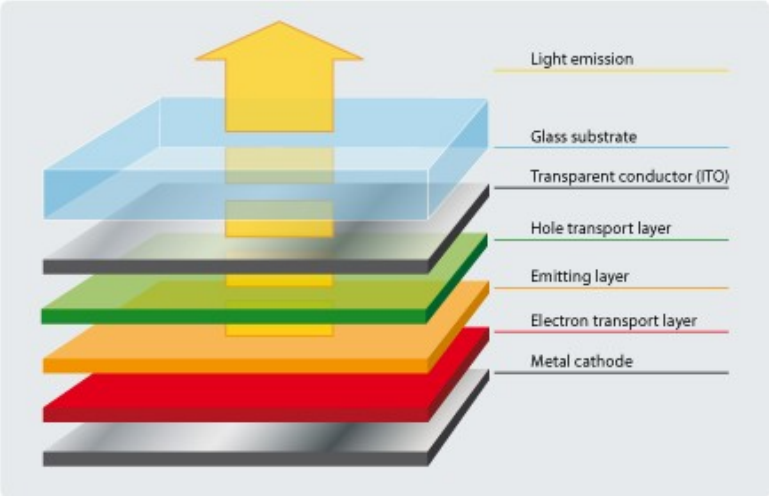
http://www.linear.com/designtools/software/

- SPICE (Simulation Program with Integrated Circuits Emphasis)
- Commonly used for analog electronic circuits
- Freely available (Ltspice, Ngspice,...)
- Netlist can be generated by scripts, Data output by ASCII file
- Arbitrary current and voltage sources allow for adapting problems

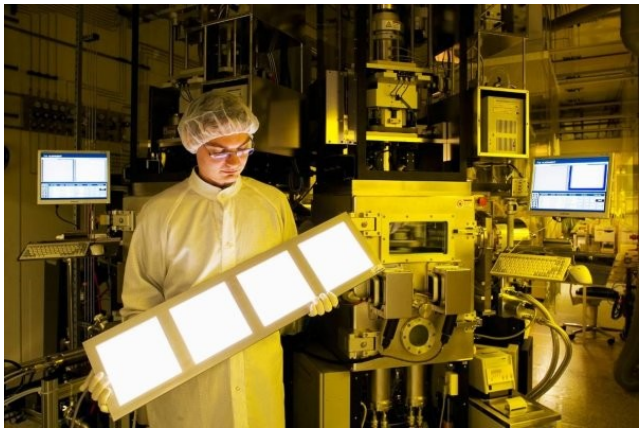
Outline

1. Electrothermal feedback in OLEDs
2. A new concept for organic semiconductor lasers

Organic light-emitting diodes



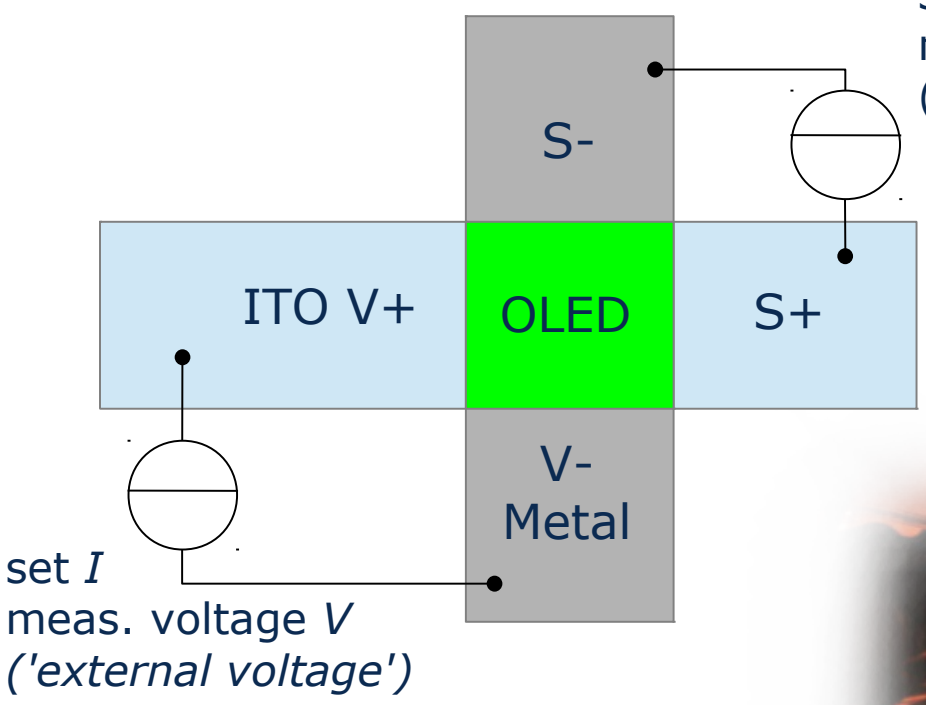
from novaled.com



Fraunhofer COMEDD, Dresden
Lighting panel

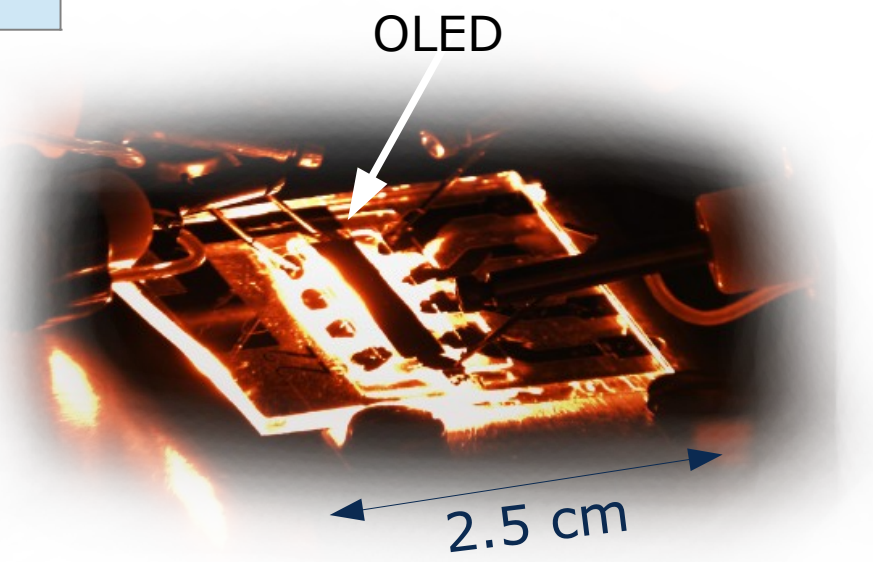
- OLEDs are multi-layer devices composed of organic molecules
- OLEDs can be fabricated on large areas as lighting panels

Organic light-emitting diodes



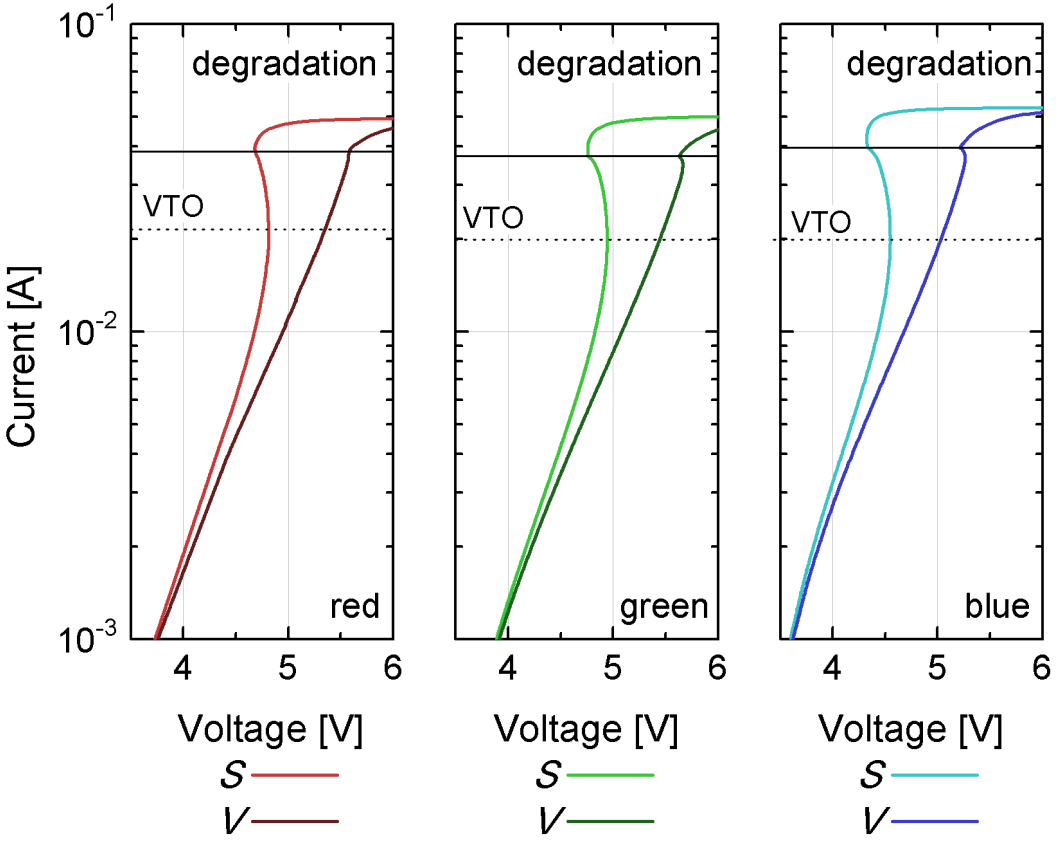
set *I* = 0 A
meas. voltage *S*
(*'sensed voltage'*)

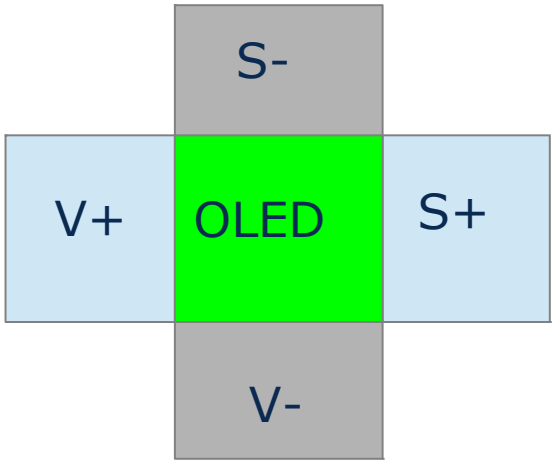
set *I*
meas. voltage *V*
(*'external voltage'*)

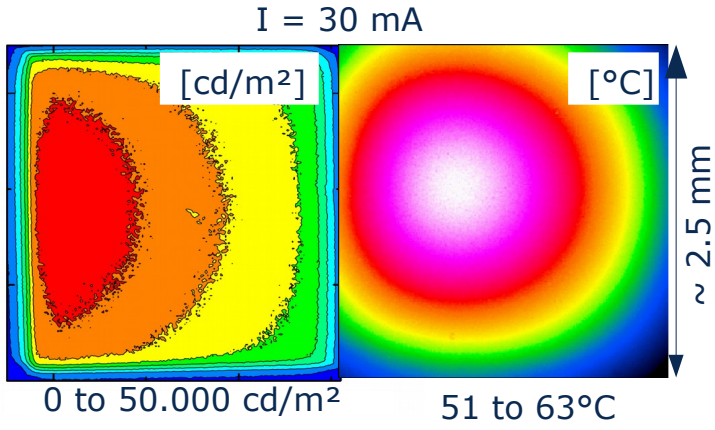


- 4-wire crossbar measurement
- Strong reduction of the series resistance

Organic light-emitting diodes







- NDR present for red, green, and blue OLED
- Standard pin-OLED stacks used
- VTO = voltage turnover

Fischer et al., Adv. Funct. Mater. 24, 2014

Organic light-emitting diodes

$$\sigma = \sigma_0 \exp(-E_a/k_B T)$$

(conductivity)

$$V = \text{const.}$$

Thermistor shows a positive feedback loop between heat dissipation and conductivity

Shaw, M. & Yildirim Thermal and Electrothermal Instabilities in Semiconductors 1983
Fischer et al., Phys. Rev. Lett. 110, 2013

Organic light-emitting diodes

$$\sigma = \sigma_0 \exp(-E_a/k_B T)$$

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Organic light-emitting diodes

$\sigma = \sigma_0 \exp(-E_a/k_B T)$

(conductivity)

V = const.

$j = \sigma F$

(current)

$P = jAV$

(power)

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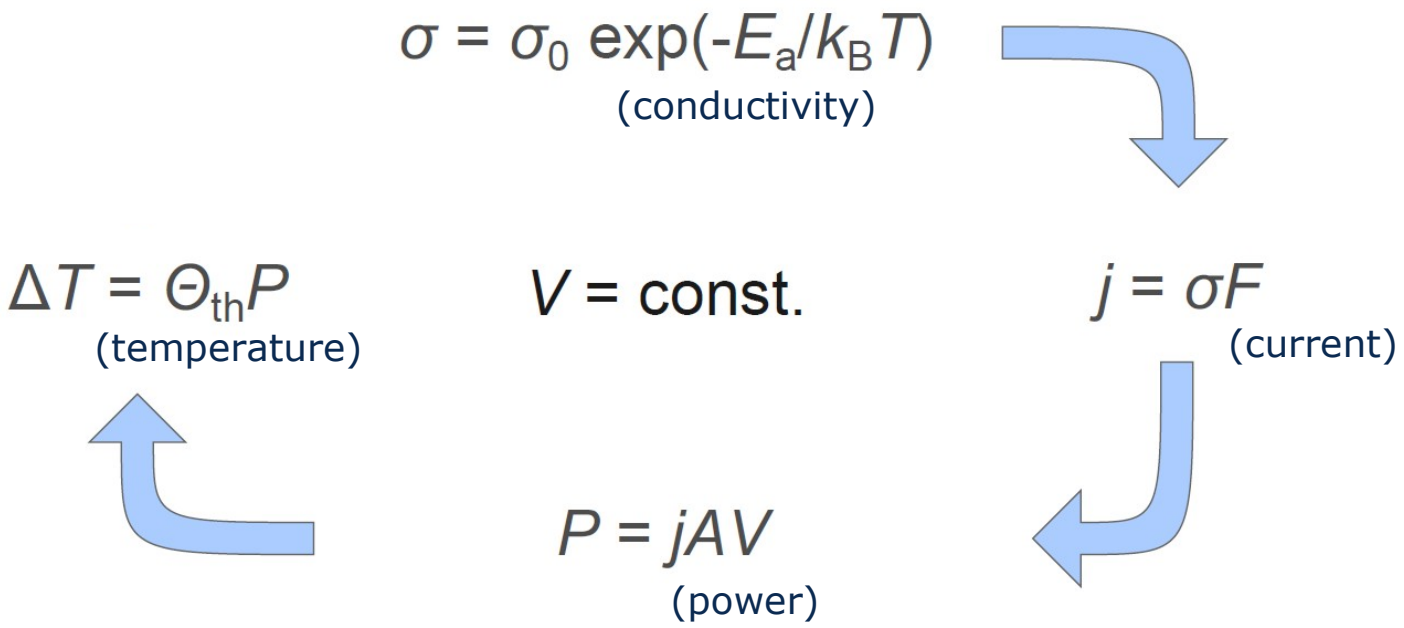
Organic light-emitting diodes



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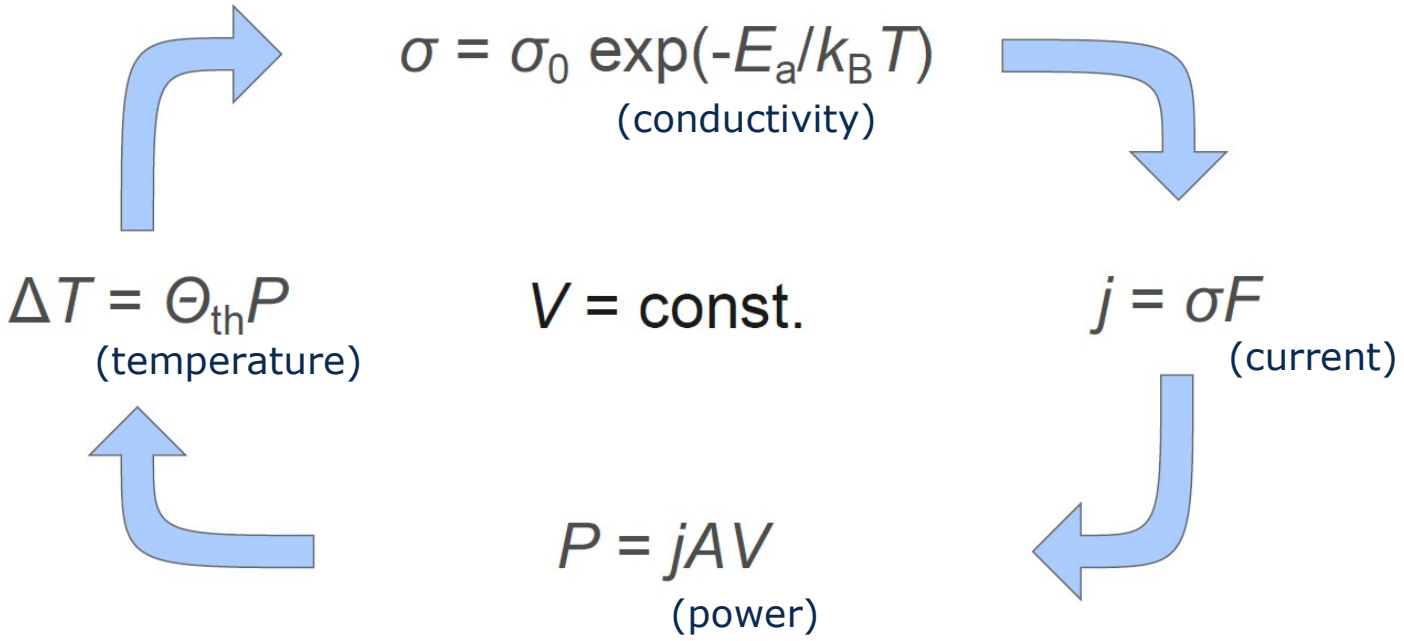
Organic light-emitting diodes



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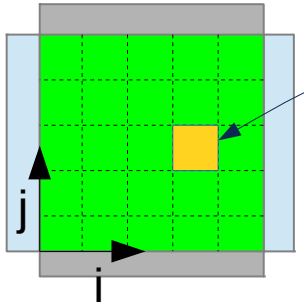
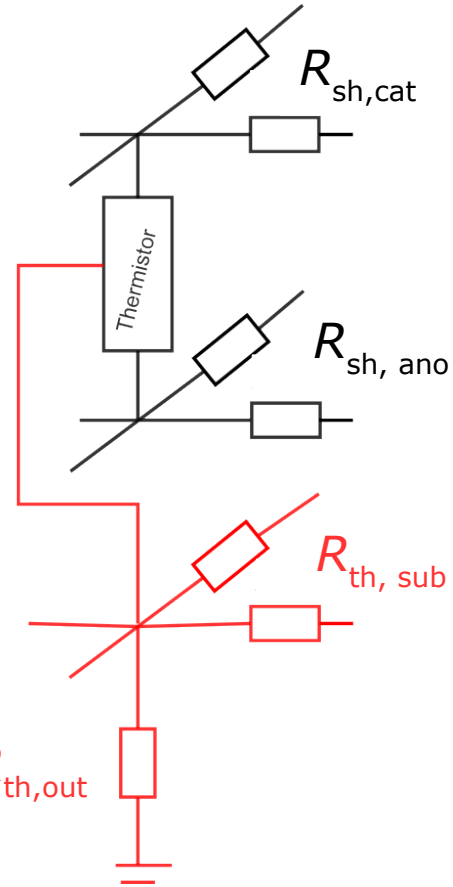
Fischer et al., Phys. Rev. Lett. 110, 2013

OLED



equals

Simplified scheme:



$P_{th} \sim P_{el}$

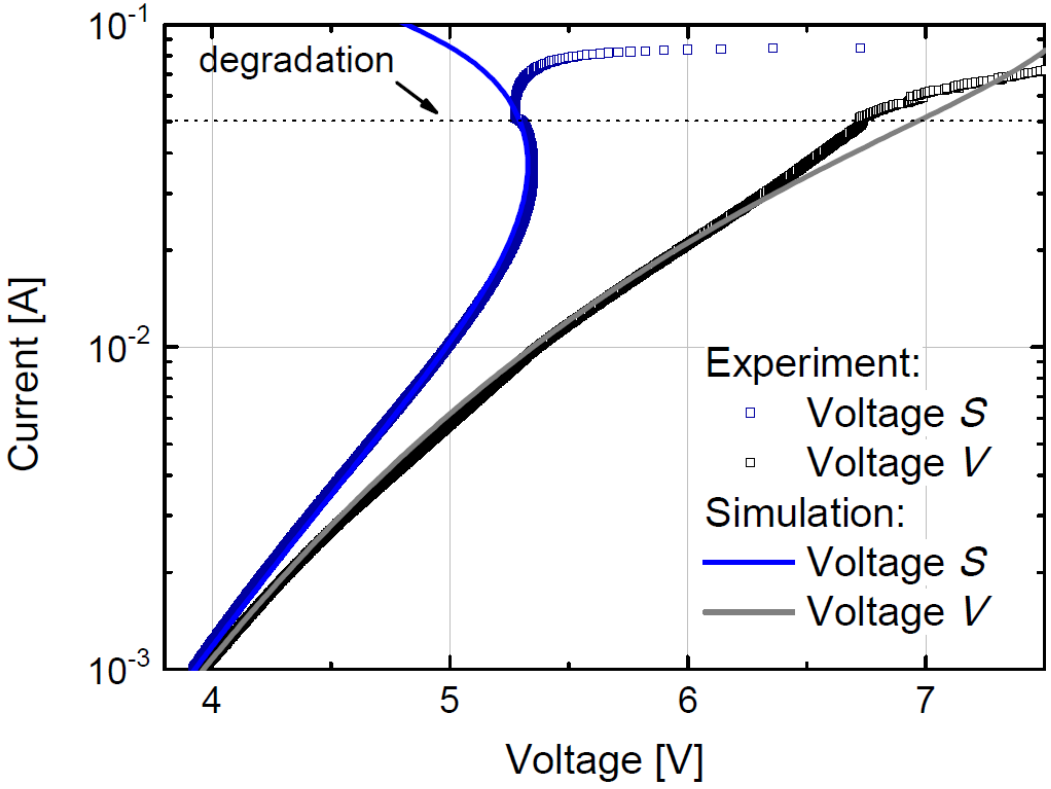
$$I(V,T) = \sim V^a \exp[-E_{act}/(k_B T)]$$

$P_{th} \sim P_{el} = I \times V$

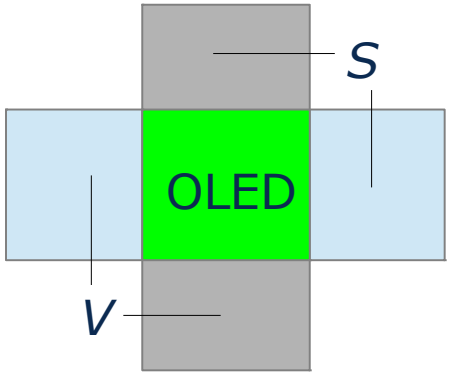
$\Delta T = P_{th} \times R_{th}$

OLED = thermistor, interface between electrical and thermal network

Organic light-emitting diodes



- Experimental data can be fitted until degradation starts



Fitting parameter:

E_{act}=25 $k_B T$

Exponent = 8.9

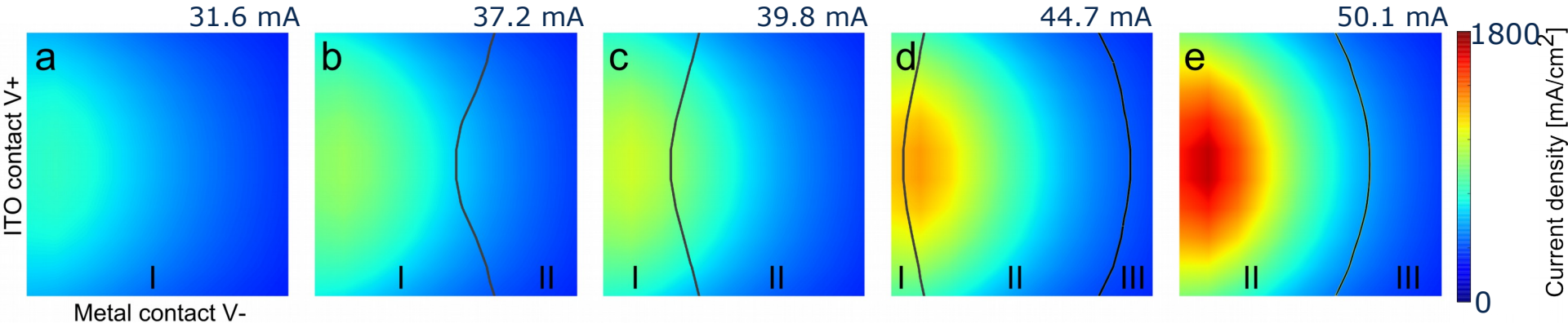
Fixed parameters:

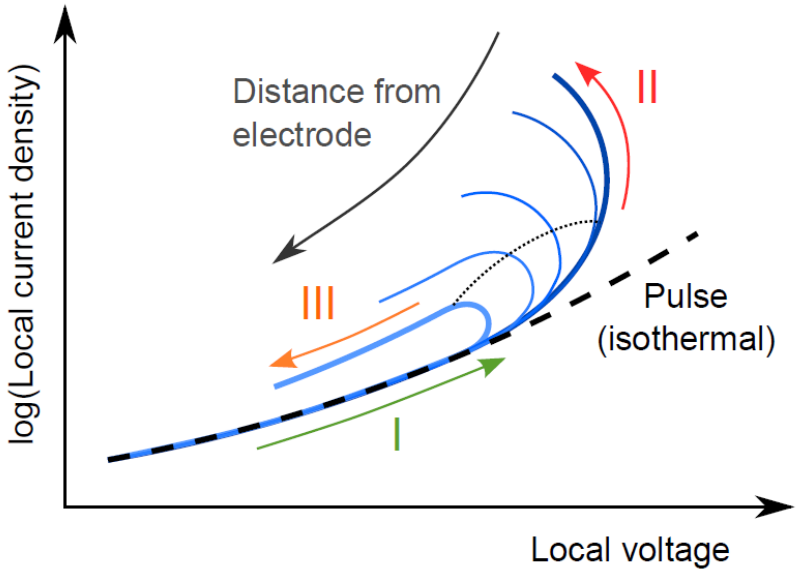
R_{sh} = 26.5 Ω (experiment)

V_{ref}, I_{ref} = 3.9 V, 1 mA

λ_{glass} ~ 1.8 W/m/K

Fischer et al., Adv. Funct. Mater. 24, 2014





current \ voltage	$\frac{dV_{ij}}{dI} > 0$	$\frac{dV_{ij}}{dI} < 0$
$\frac{dI_{ij}}{dI} > 0$	$\frac{dV_{ij}}{dI_{ij}} > 0$ normal (I)	$\frac{dV_{ij}}{dI_{ij}} < 0$ S-NDR (II)
$\frac{dI_{ij}}{dI} < 0$	$\frac{dV_{ij}}{dI_{ij}} < 0$ N-NDR (not present)	$\frac{dV_{ij}}{dI_{ij}} > 0$ switched-back (III)

Fischer et al., Adv. Funct. Mater. 24, 2014

Outline

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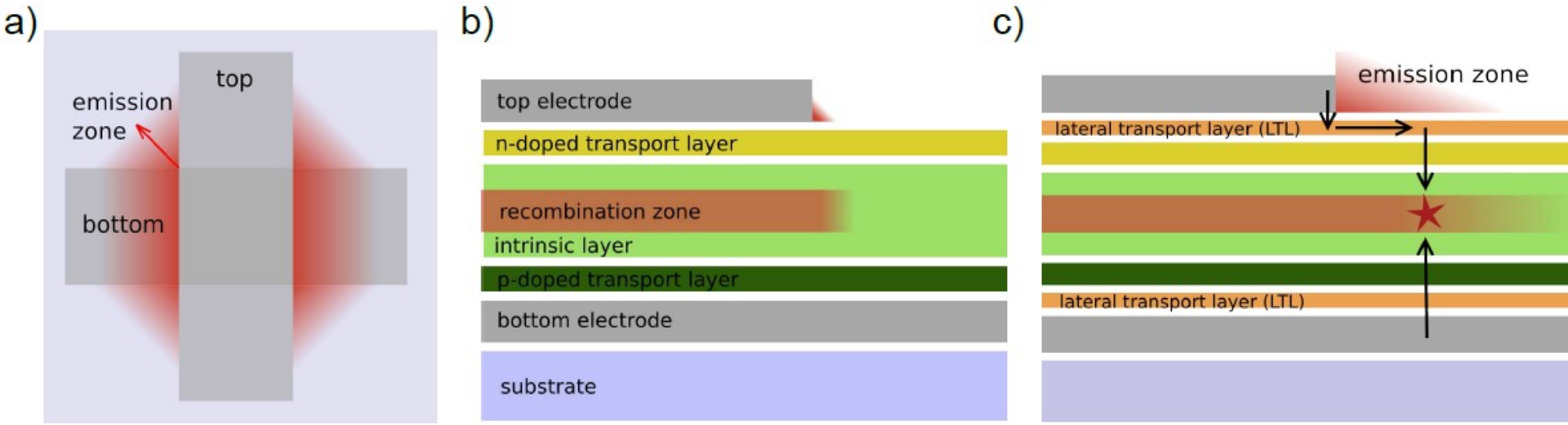
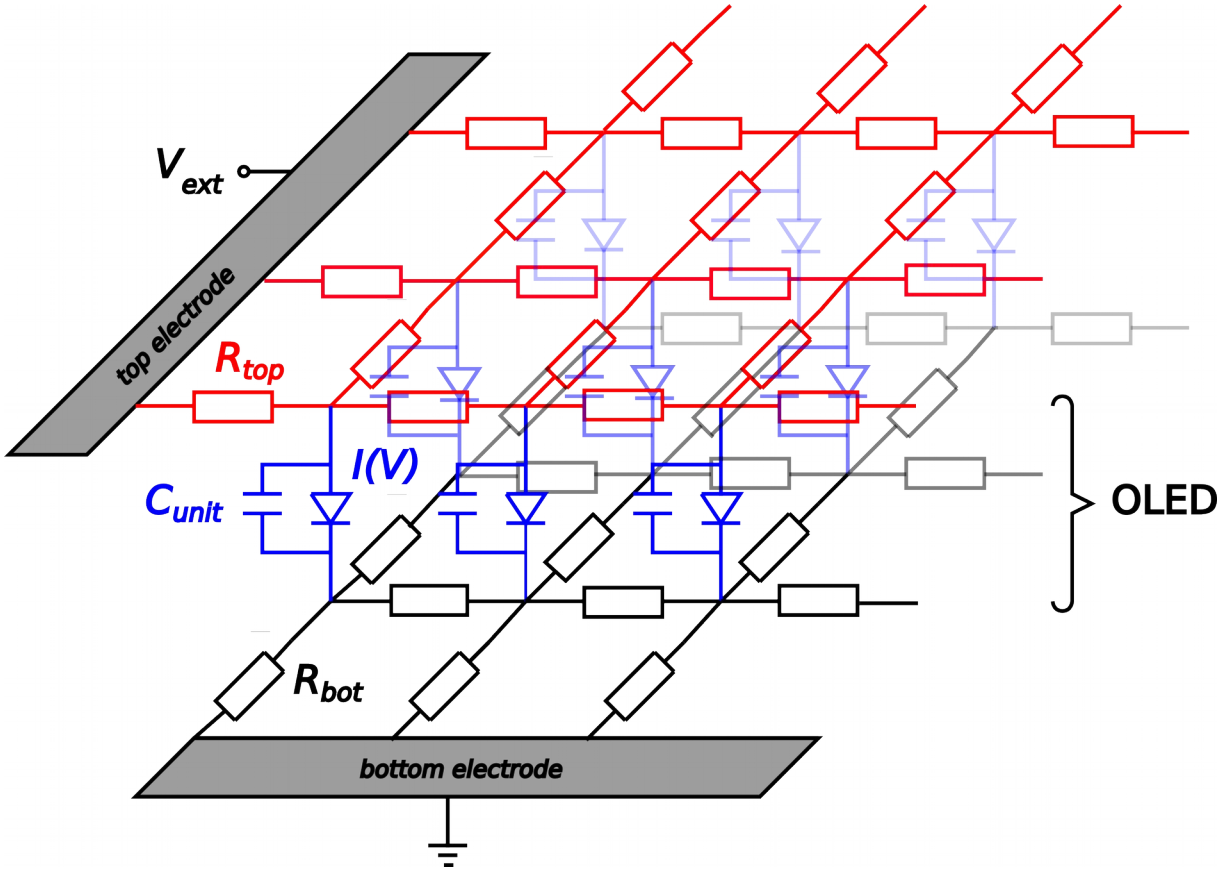
Organic laser

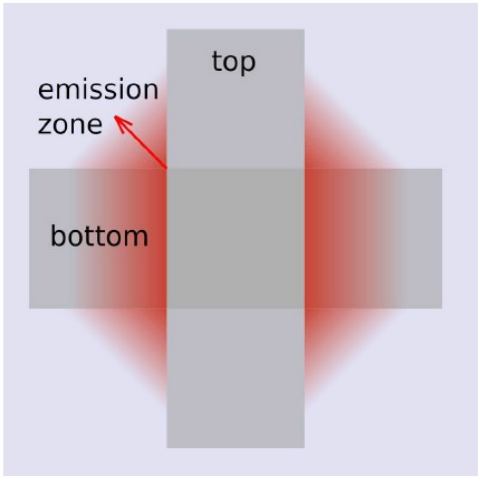


- New structuring concept for organic semiconductor laser
- Idea: Enhance light emission outside the „active area"
- Use of highly conductive layer: n-doped C60 (~10 S/cm)

Slowik et al., Proc. SPIE 9895, Organic Photonics VII 2016

Organic laser

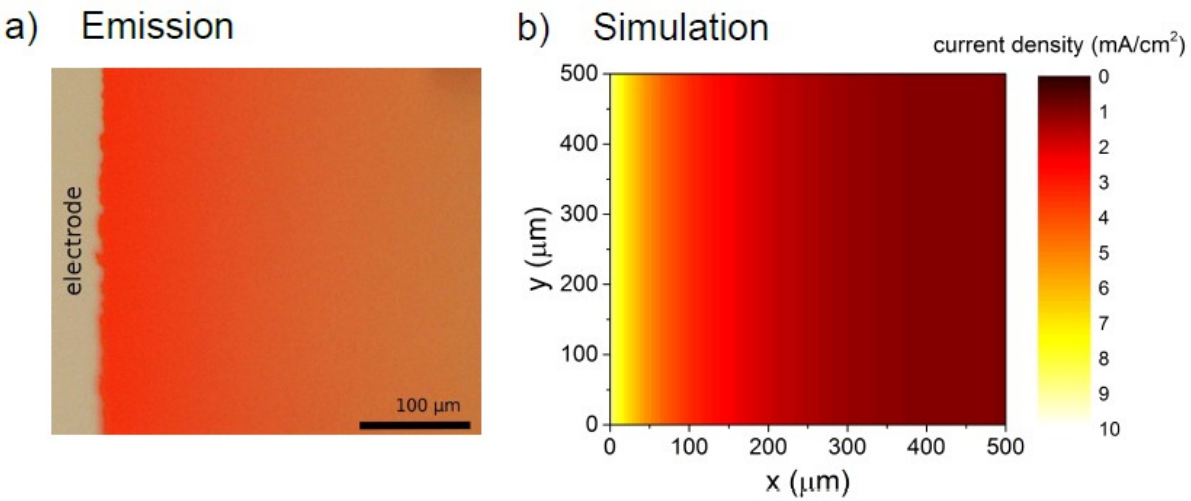




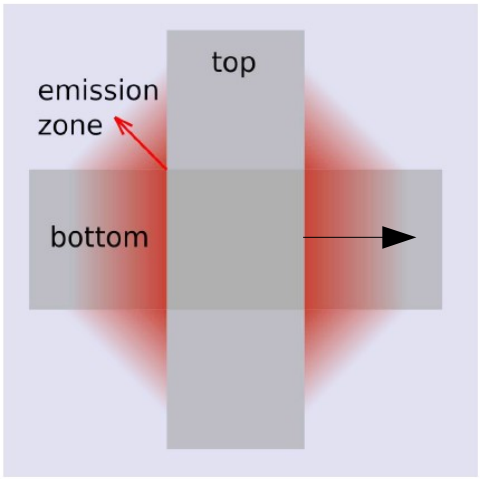
- Diodes = vertical current flow through OLED layer stack
- Resistors = lateral current flow by highly doped layers (n-doped C60)

Slowik et al., Proc. SPIE 9895, Organic Photonics VII 2016

Organic laser

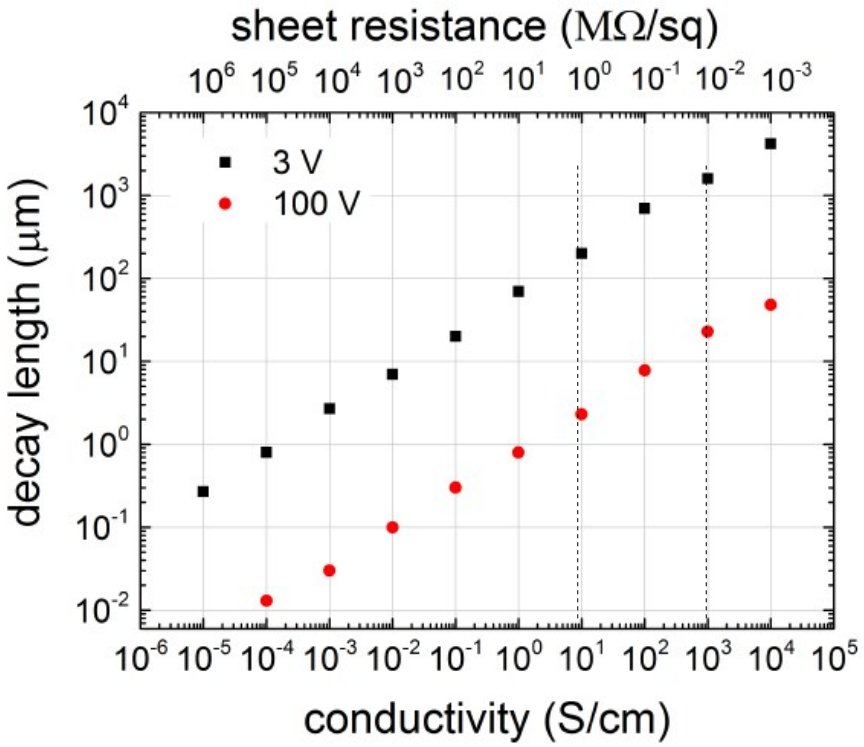


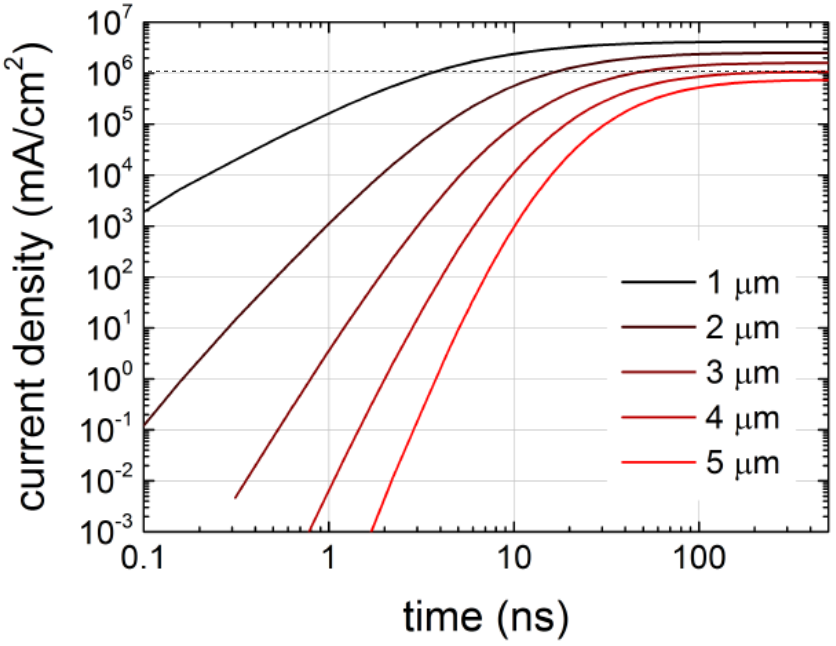
- Simulation reproduces decay profile of emission outside the electrode overlap



Slowik et al., Proc. SPIE 9895, Organic Photonics VII 2016

Organic laser

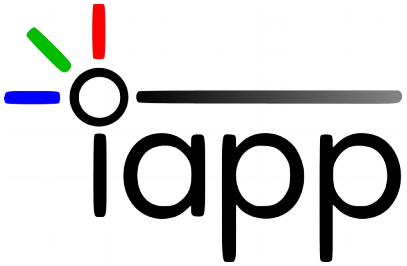




- Relevant current densities are reached at >100 V
- After 40 ns, 1 kA/cm² are achieved within a distance of 3 µm
- Higher conductivity desirable → PEDOT:PSS 1000 S/cm

Slowik et al., Proc. SPIE 9895, Organic Photonics VII 2016

Acknowledgment



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