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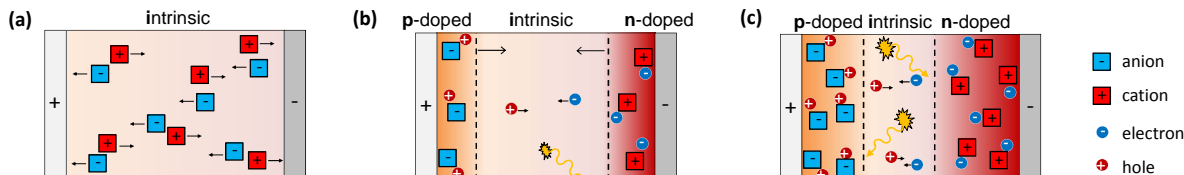
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Introduction

Organic light-emitting electrochemical cells (LECs) were invented as an easy-to-fabricate and electrode-insensitive alternative to the more famous organic light-emitting diodes (OLEDs). The emissive layer is a semiconducting material that

has to be able to transport both ionic and electronic charges. Their peculiar operation mechanism is explained by the electrochemical doping (ECD) model. Upon applying a voltage the ions drift to the respective electrode (a) where they

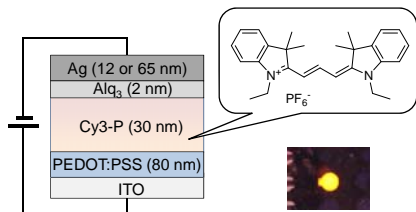
facilitate electronic charge injection. This causes p- and n-doped regions that grow towards each other with time (b). Light emission originates from the central intrinsic region where electronic charges recombine radiatively (c).



Results

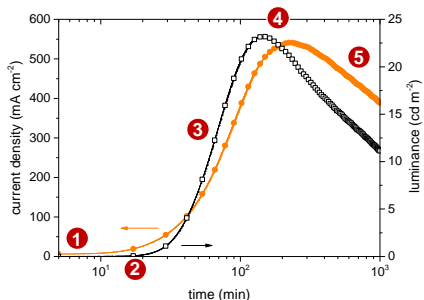
Materials and device structure

- The active component is a trimethine cyanine dye with a mobile PF₆⁻ counter ion (Cy3-P)
- The emission of the final device is orange (see photograph)



Operation mechanism

- A typical luminance and current transient for constant 3V operation is shown below

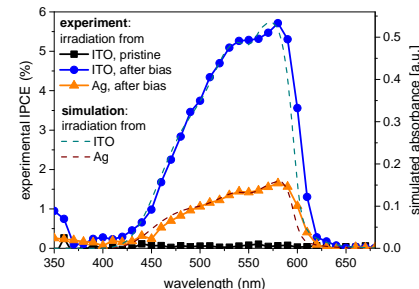
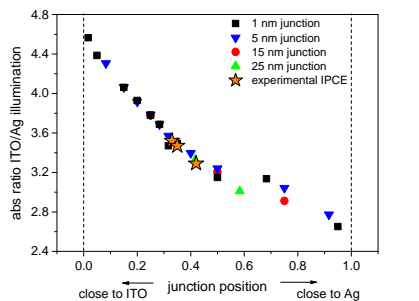


- The behaviour of all points in time (1-5) are explained by the ECD model:

- Ions drift to the electrode
- Charges are injected and start to recombine causing light emission to start
- Doped regions grow increasing current and luminance
- Doped regions grow further which deteriorates the luminance because of too much exciton quenching
- Unspecific degradation of the active material

Junction position determination

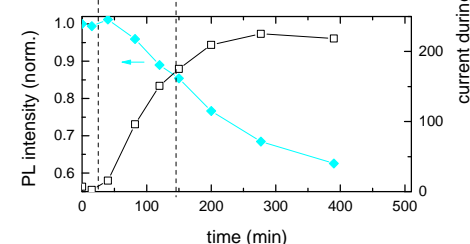
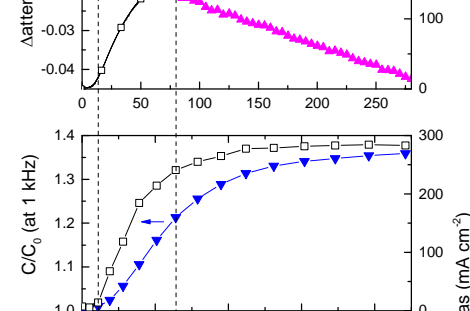
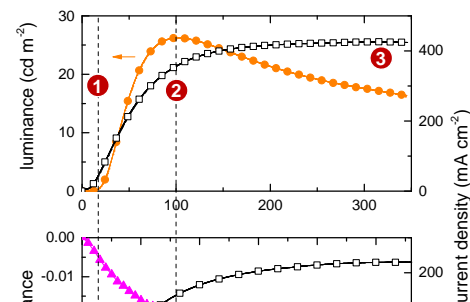
- The developed p-i-n structure is able to split excitons thus we can measure its photovoltaic response
- As p- and n-doped regions quench excitons the extracted charge originates from the intrinsic region only
- A semi-transparent Ag electrode enables to measure IPCE with illumination through either ITO or Ag
- Optical simulations for the full device dividing the active layer in a p-, n- and an i-region have been performed to determine the intrinsic layer absorption
- The ratio of the simulated intrinsic layer absorption through both illumination sides can directly be compared to the ratio of the experimental IPCE



- Simulated absorption ratios do not depend on the thickness of the intrinsic region
- The centre of the junction was determined to be ~37% of the total Cy3-P layer away from the ITO contact

Dynamic doping and junction evolution

- Luminance + Current: Follow the state of the LEC
- Absorption: The cyanine monomer species is consumed to form n- and p-doped species. In the absence of side reactions this decrease is equal to the sum of all dopants.
- Capacitance: As the doped regions are highly conductive the device capacitance is given by the intrinsic region.
- Photoluminescence (PL): Doped regions do not show PL because excitons are quenched. Thus the remaining PL enables us to calculate the thickness of the intrinsic region.



Parameter	1	2	3
Doping conc.		2.6 ± 0.6 %	4.4 ± 1.7 % *
d _{int} (from cap.)	99 % (of d ₀)	83 % (of d ₀)	72 % (of d ₀)
d _{int} (from PL)	100 % (of d ₀)	85 % (of d ₀)	65 % (of d ₀)

* Using d_{int} and the junction position individual n- (0.08) and p-doping (>0.6) concentrations can be calculated.

Conclusions

- Cyanine dye is used as active component in an LEC
- IPCE and optical simulation was used to determine the centre of the junction to be at ~37% of the total Cy3-P layer away from the ITO contact
- Transient luminance, attenuation, capacitance and PL signals were used to estimate doping concentrations and calculate junction layer thicknesses for every point during operation
- Together, these data give a full picture of the operating device (sketch on the right illustrates the situation at maximum current)

