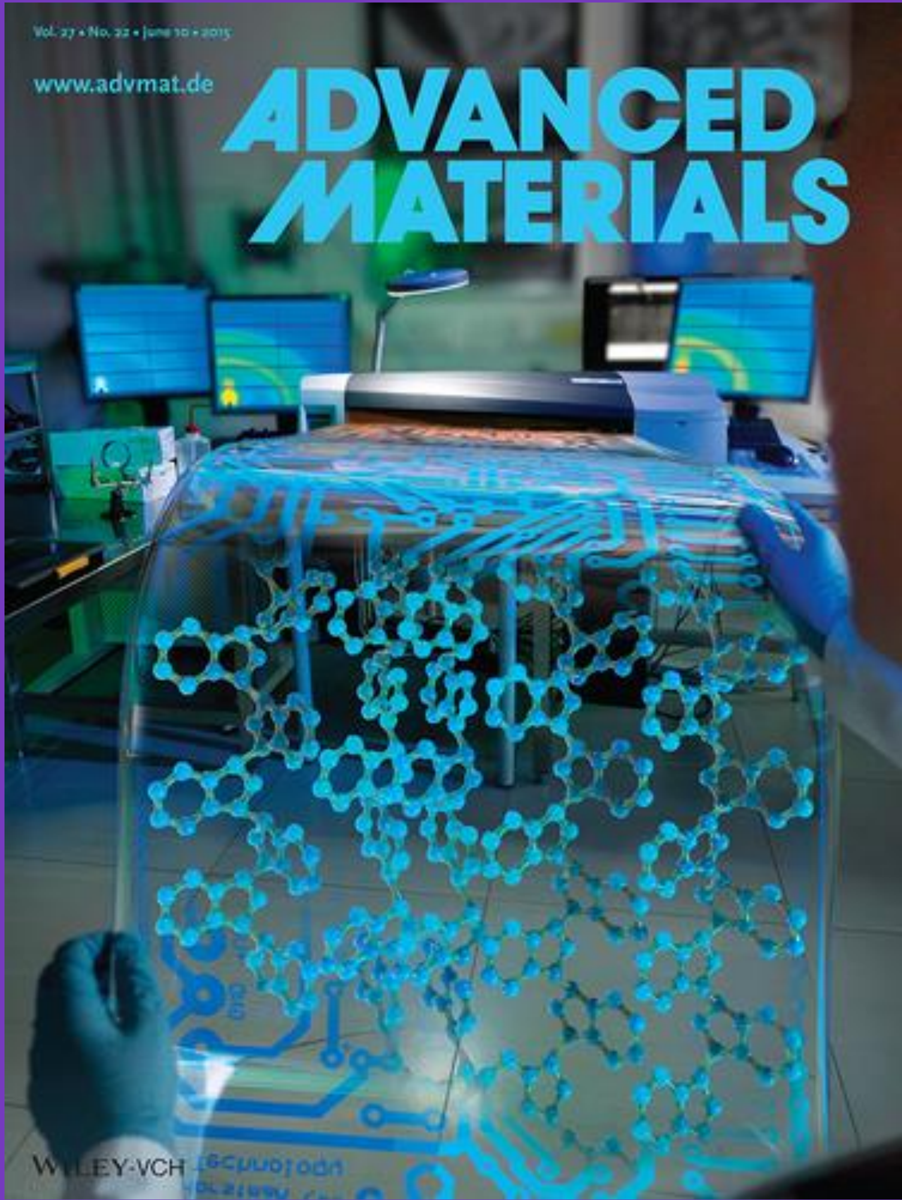
ELEC-E9210 Organic Electronics: Materials, Devices & Applications

Organic Light Emitting Transistors I

Aalto University
School of Electrical
Engineering

organicelectronics.aalto.fi



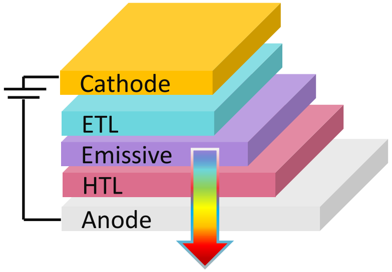
Today´s Class

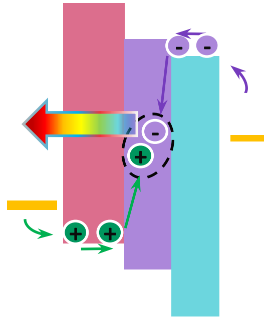
Previously…

OLED

- charge transport/injection/blocking layer
- host-guest for efficient emission
- phosphorescent/fluorescent dyes/TADF molecules

- OLED as light-source for lighting and display applications





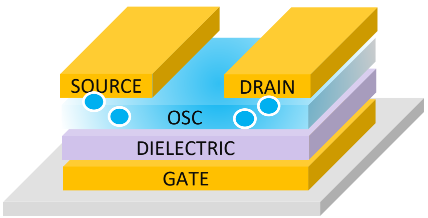
Today: Organic Light Emitting Transistors

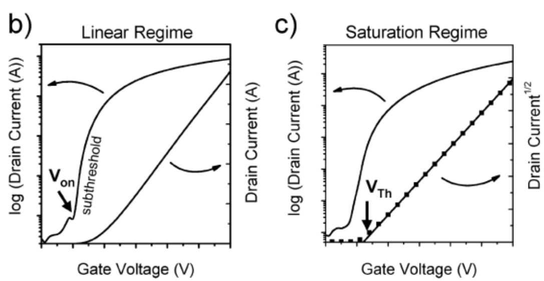
- Organic light emitting transistors: basic working principles & mechanism

Organic Light Emitting Transistors (OLET)

Organic Light Emitting Transistors are ***field-effect transistors*** capable of ***emitting light***

organic field-effect transistor (OFET)



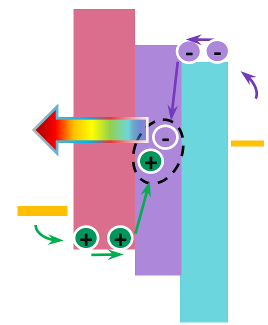


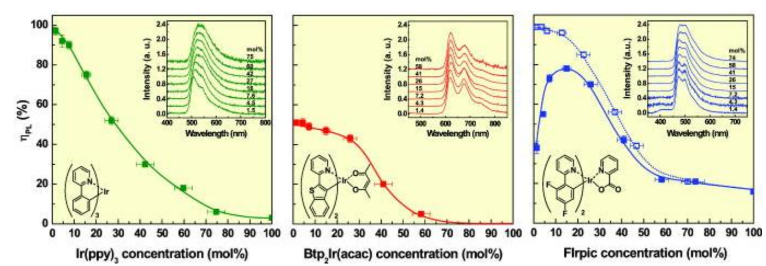
$$I_{D,lin} = \frac{W}{L}\,\mu\,C_i(V_G - V_{th})\,V_D$$

$$I_{D,sat} = \frac{W}{2L}\,\mu\,C_i(V_G - V_{th})^2$$

+

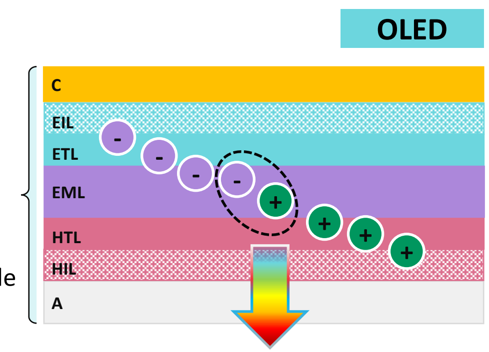
light emission (OLED materials)

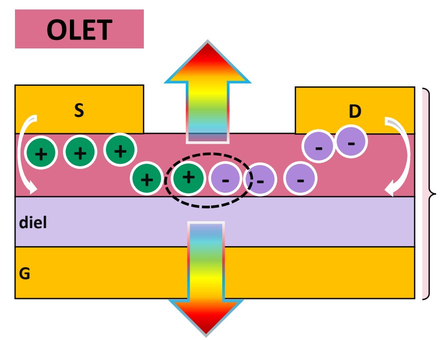




OLET *vs.* OLED: General Considerations

- ***Diode*** characteristics
- ***vertical nanoscale*** transport
- ***2 terminals*** (C,A)
- ***one transparent*** electrode





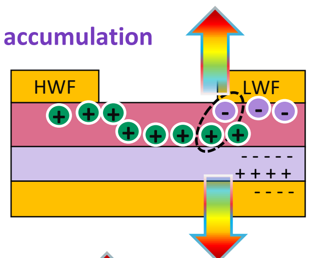
- ***Transistor accumulation*** regime
- ***Horizontal μ-scale*** transport
- ***3 terminals*** (S, D, G)
- ***no need for transparent*** electrode

- ***materials*** and ***energy consideration***
- ***processes***
  - light emission (fluorescence, phosphorescence, ISC,..)
  - absorption
  - charge transport and injection
  - exciton dynamics
- ***lifetime, stress*** (depending on device operation)

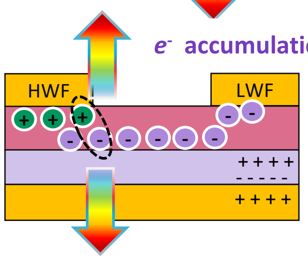
OLET: Unipolar *vs.* Ambipolar Regime

unipolar *vs.* ambipolar regime

***h^+* accumulation**

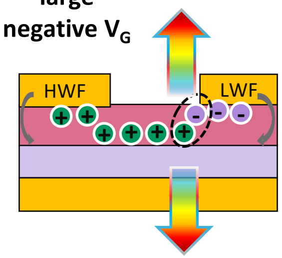


***e^-* accumulation**

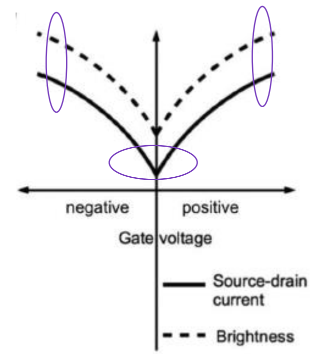


h^+ (e-) are injected into the device from source (drain), but only holes (electrons) accumulate in the channel. ***Light emission occurs next to the e-injecting electrode with low (high)*** working function

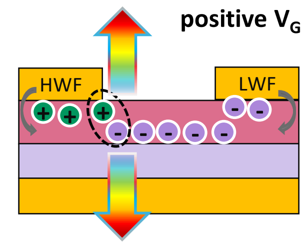
large negative V_G



h^+ accumulate in the channel and light emission occurs close to the LWF (*e*-injecting electrode)

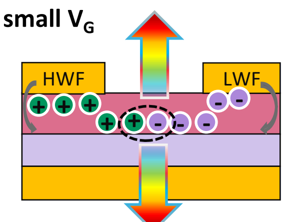


large positive V_G



e^- accumulate in the channel and light emission occurs close to the HWF (*h*-injecting electrode)

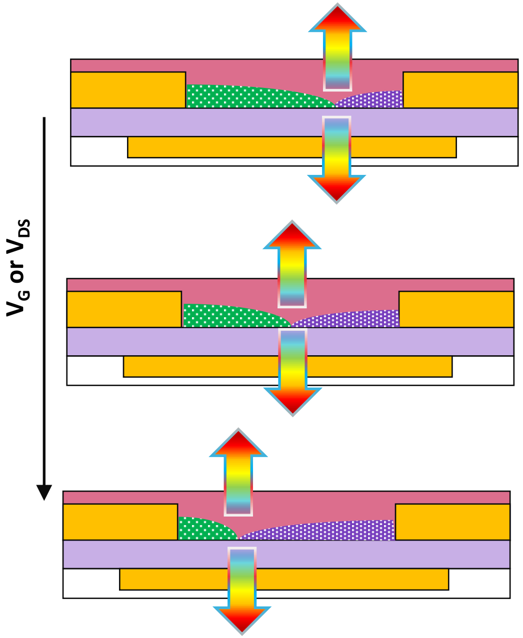
small V_G

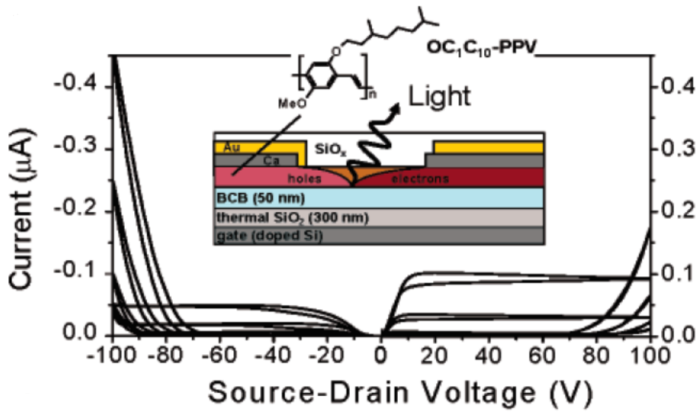


h^+ accumulation increases and charges recombines in the channel (far from electrodes)

Light Emission in Organic Light Emitting Transistor

Light emission occurs at the boundary of the holes and electrons charge distributions (where exciton forms and decays emitting radiation)

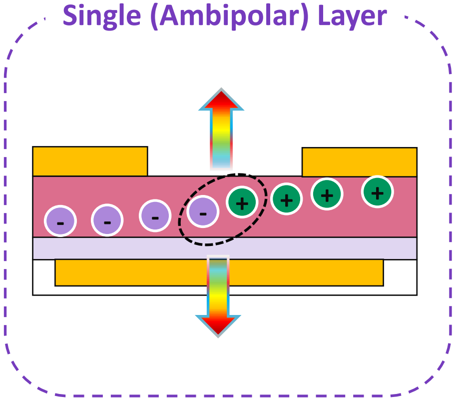


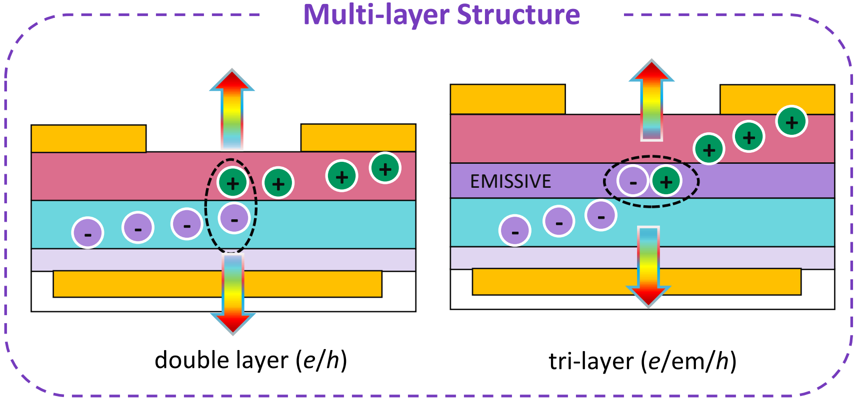


Nat. Mat. **5**, 69 (2006)

Gate bias is used to:
- balance between charge carrier currents
- reduce *exciton-charge quenching*
- control the *position of the emission zone*

OLET: Single Layer *vs.* Multi-layer





very low brightness, mainly due to the low drain current (low mobility OSC)→ device geometry can improving brightness (increasing L/W ratio)

exciton-charge quenching:

- *exciton-exciton/exciton-charge* (within layer)
- *exciton-charge* at metal interface

multi-layers structures assign charge transport and light emission to individual layer (engineered for that), so that device electrical and optical output can be addressed individually.

In case of multi-layers structures energetics, ***interfaces***, ***materials*** compatibility are crucial

2L → *exciton-charge quenching* at interface and metal interface

3L → ***exciton quenching is prevented***

OLET Materials

(Organic) materials are shared with the OFET/OLED field

dielectric layer
- polymeric
- oxide
- SAMs

active layer(s)
- *p/n* -type carrier
- ambipolar layer
- injection/barrier

emissive layer
- single emissive layer
- host-guest
- phosphorescent emitter
- fluorescent emitter
- TADF emitter

electrode(s)
- metal (no need for transparent electrodes)
- ITO (as gate electrode)
- doping (to enhance injection)

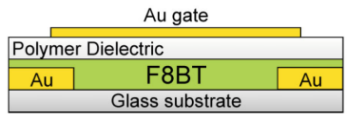
advantages
- scalable to large areas (printing)
- high throughput
- flexible & foldable
- light-weight
- (potentially) low-cost
- broad color gamut

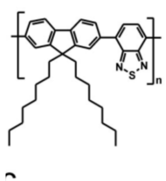
challenges
- "deep" colors
- power consumption
- lifetime & stress (R, G, B)
- moisture & humidity

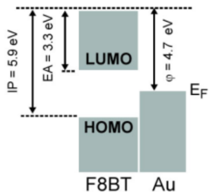
OLET based on Light Emitting Polymers (LEPs)

F8BT

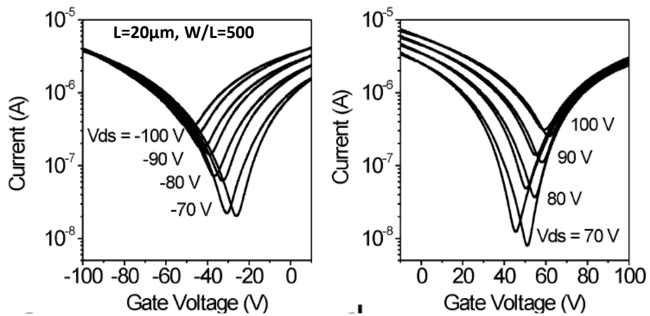
(green OLET)



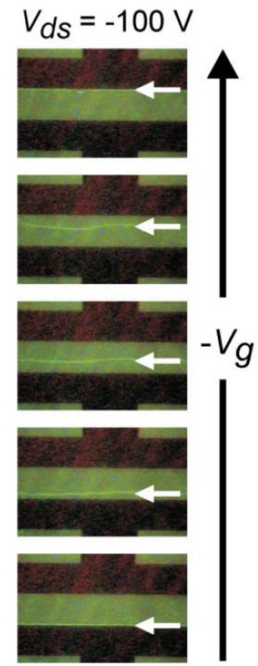


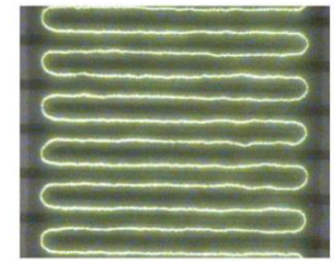


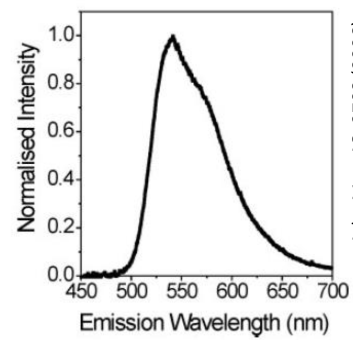
F8BT chemical structure and corresponding energy diagram/device configuration (BC-TG)



Transfer curve of ambipolar F8BT transistor (diel: PMMA) at different negative and positive V_D. The device is characterized by balance transport and saturation mobilities.







Adv. Mat. **18**, 2708 (2006)

Optical images of the recombination and emission zone (L=100µm, W=4mm) in a transfer curve at V_D=-100V for different gate bias (-50V<V_G<-35V) and (right) interdigitated electrodes configuration. EL spectrum of light emitting F8BT OLET.

Polymer OLET: Limitations

- Conjugated-polymer-based light emitting field-effect transistors (LEFETs) have low mobilities (10^{-5}-10^{-3} cm^2/Vs)

  → fast carrier transport is needed for high-frequency operation

- Interfaces (in hetero-structure) becomes very critical

  → *materials compatibility*

  → *interface defects* and *morphology*

wet processes

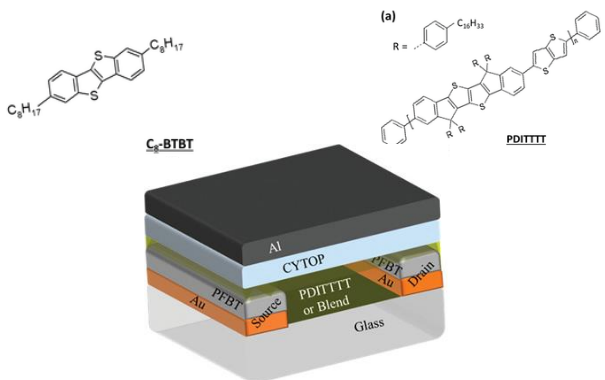
- large-scale and large-area (*i.e.* printing techniques)
- inexpensive manufacturing equipment
- easy tuning of properties through synthesis

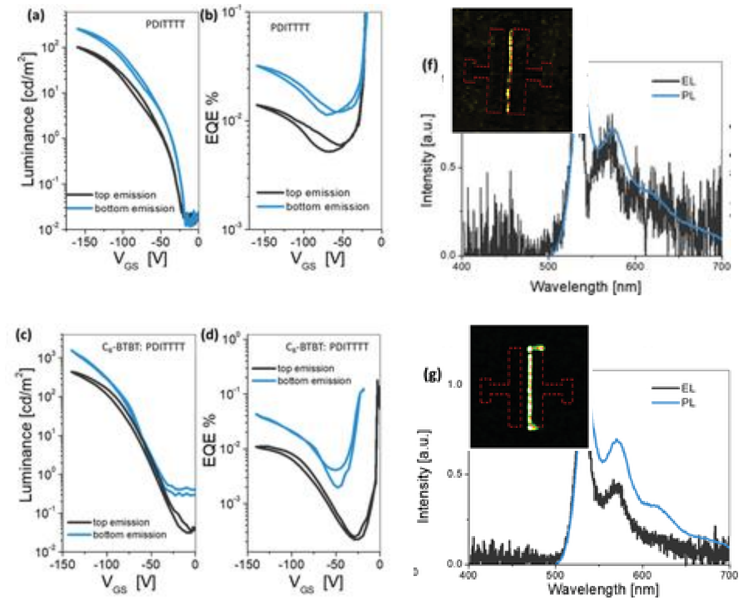
- *limited* control over interfaces
- *limited* control over crystallization/packing

Polymer LET: Blend to Enhance Mobility

Small-molecules/conjugated polymers blend can be used to enhance charge-carrier mobility, while preserving light emission characteristics

polymer/small molecule blend



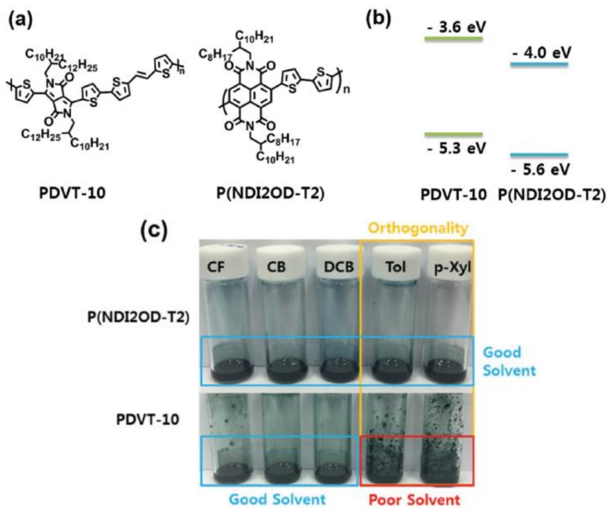


EL, EQE curves and corresponding emission spectra for PDITTTT and C8BTBT:PFITTTT blend-based OLET

Adv. Elec. Mat. **6**(1), 1901132 (2020)

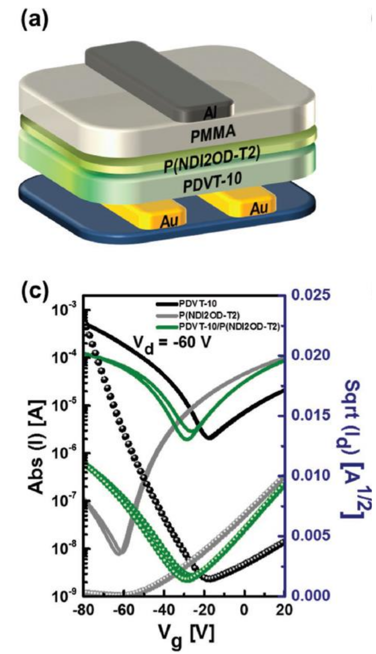
Polymer LET: Bi-layer

Multi-layer approach based on polymers requires high degree of materials compatibility



Adv. Optical Mater. 1700655 (2017)

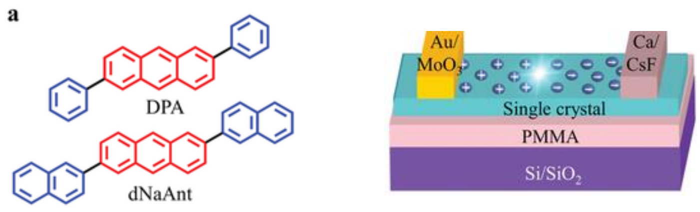
(a) Molecular structure of PVDT-10 (p-type) and P(NDI2OD-T2)(n-type) with corresponding energy diagram; (c) solubility studies to address bi-layer fabrication process compatibility.

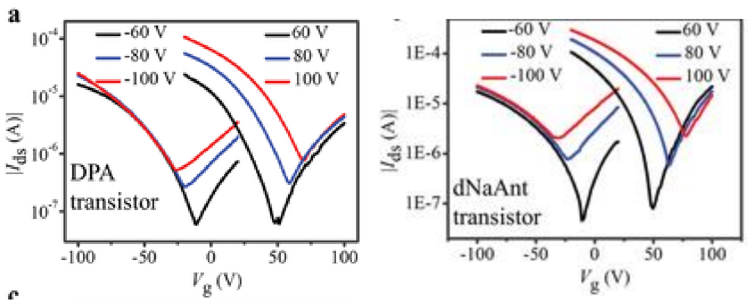


(top) Schematic diagram of solution-processed bi-layer *p-n* heterojunction (TG-BC). (bottom) mobility variation in single- and bi-layer device with corresponding *p*-channel

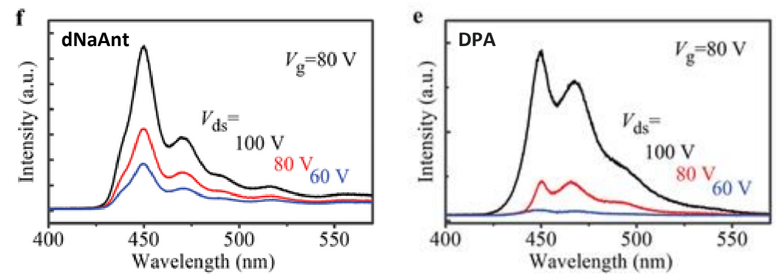
(Single Crystal) Organic Light Emitting Transistor

Chemical structures of single crystals DPA and dNaAnt OSCs and corresponding device.





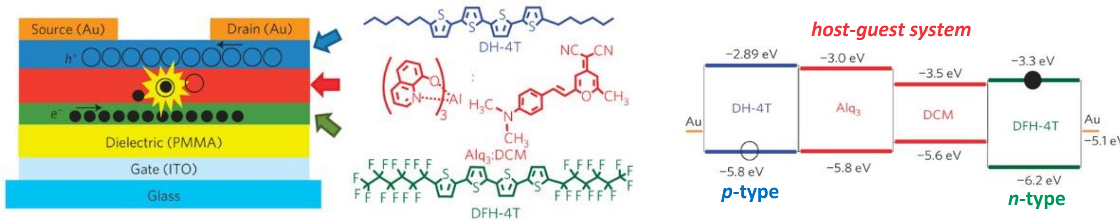
Transfer characteristics of DPA (a) and dNaAnt (c) single-crystal OLET at different negative and positive V_{DS}.



EL spectra for different applied voltage for dNaAnt- and DPA-based OLETs.

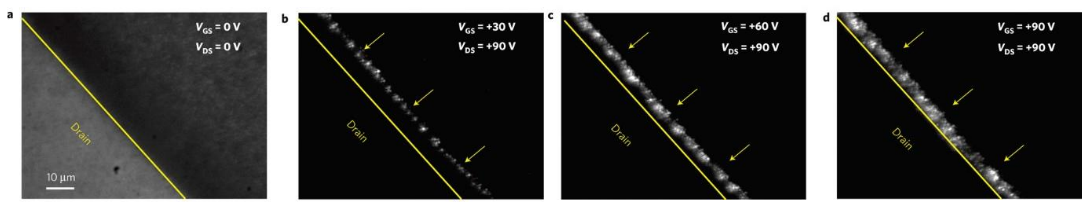
Adv. Mat. **31**(37), 1903175 (2019)

Multi-layer OLETs: Controlling Light

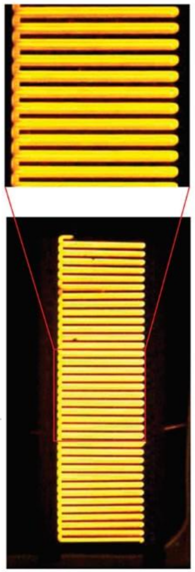


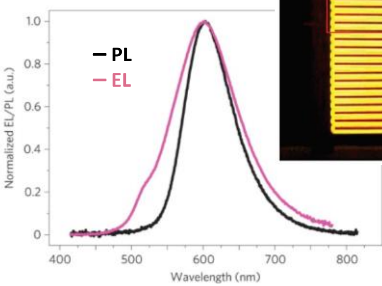
Multi-Layer (3L) active region consists of three different organic layers where the first, in direct contact with the dielectric, and the third layers are field-effect *h*- and *e*- transporting OSC, and the intermediate one in the emission layer (host-guest).

Controlling the light emission location (within the channel)



Optical micrograph of OLET channel (a) without bias, where solid yellow line indicate the drain electrode edge and (b-d) during a transfer curve (values as labelled).



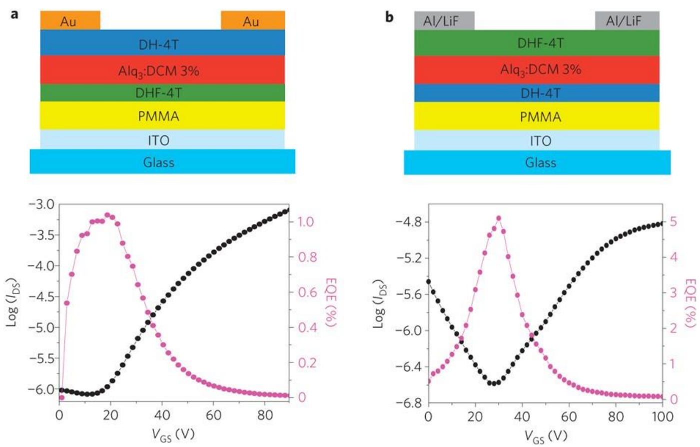


Optical image of the interdigitated 3L OLET structure in its ON state and relative EL and PL spectra.

Nat. Mat. **9**, 496 (2010)

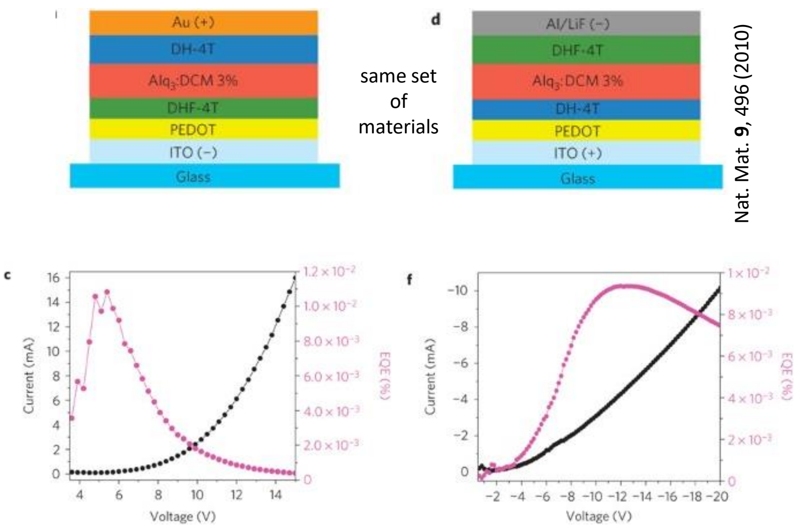
Multi-layer Approach: Role of Interface

transistor **configuration**



Transfer curves with corresponding efficiency measured with drain-source potential at 90 V, while sweeping the gate-source potential from 0 to 90 V, for direct/inverted configuration

vs. diode **counterpart**



same set of materials

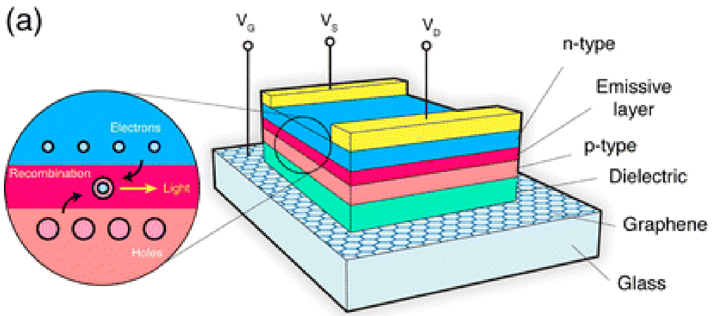
Nat. Mat. **9**, 496 (2010)

Schematic structure of 3L OLED with corresponding transfer characteristics and EQE for direct/inverted configuration

Summary

Today

- organic light emitting transistors: organic transistors capable of emitting light
- basic working principles and structures



Next Class

- **Application** of **Organic Light Emitting Transistors**