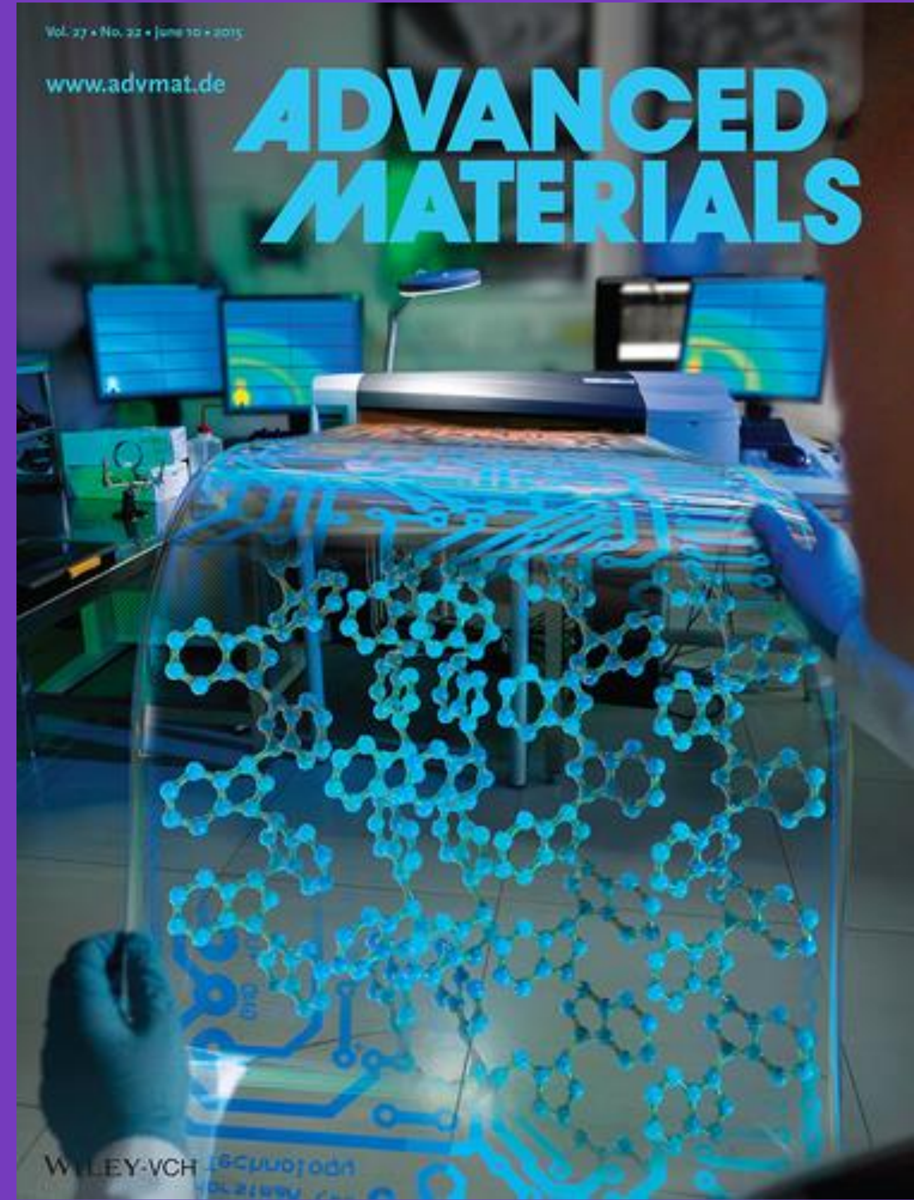
ELEC-E9210 Organic Electronics: Materials, Devices & Applications

Organic Field-Effect Transistors III



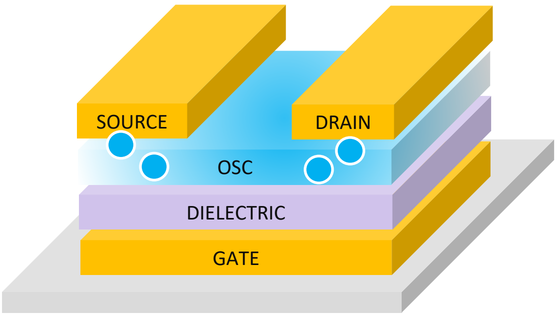
Aalto University
School of Electrical Engineering

organicelectronics.aalto.fi

Today´s Class

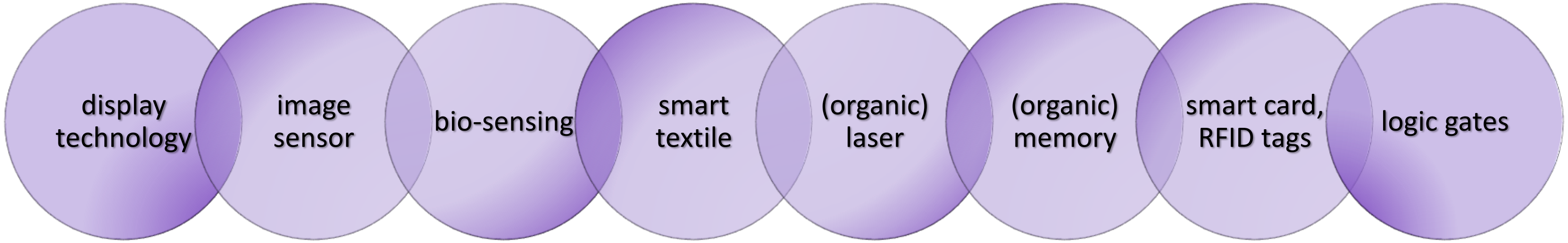
Previously:

- Basic ***working principle*** of OFET
- ***Building blocks*** of OFET (dielectrics, interfaces, …)



Today´s class:

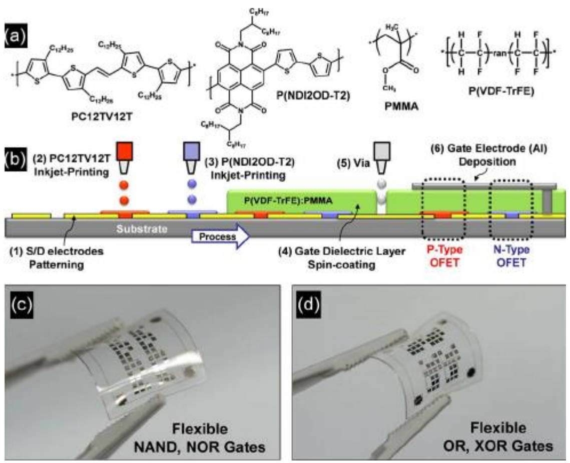
- OFET applications, mainly based on the switching mechanism



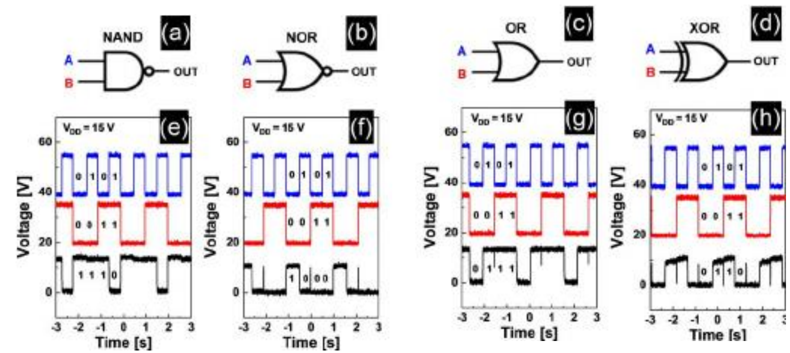
light weight, flexibility, low-cost (compared to Si)

OFETs for *Flexible* Logic Gates

Logic gate is an electronic device capable of implementing a Boolean function, where one or more binary input(s) (*i.e.* (0,1), (on/off)) produces a single binary output. They are often implemented using through diodes or transistors.



(a) Molecular structures of PC12TV12T, P(NDI2OD-T2), PMMA, and P(VDF-TrFE) polymers with (b) schematic for the fabrication of TG-BC OFET. Optical images of flexible printed logic gates (PEN).

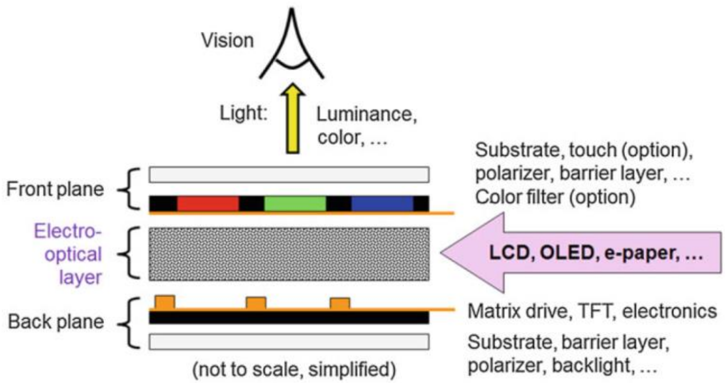


IEEE Elec. Dev. Lett. **34**(1), 126 (2013)

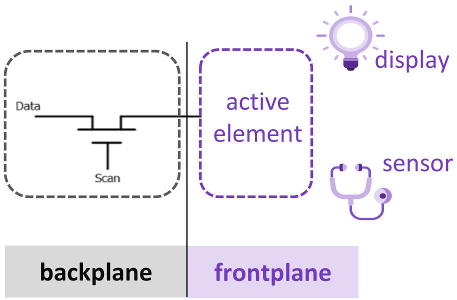
Electronic circuit symbols of the various printed logic gates: (a,e) NAND, (b,f) NOR, (c,g) OR and (d,h) XOR.

Organic materials enable fabrication of logic gates on **flexible/plastic substrates**

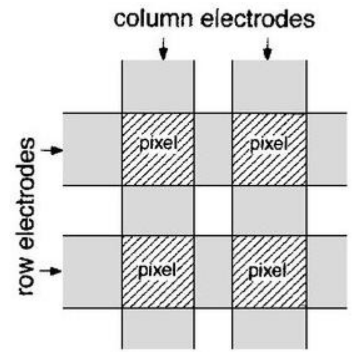
Display Technology (Backplane)



driving/switching transistor



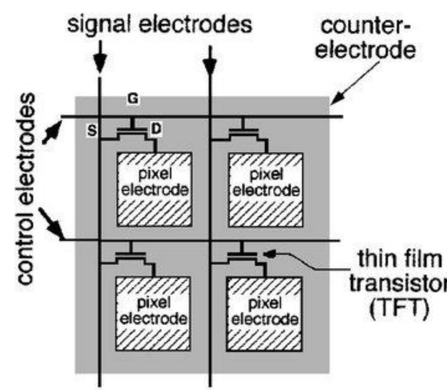
passive *vs.* active matrix



pixel keeps its state without active driving circuitry until refresh

The signal is divided into:

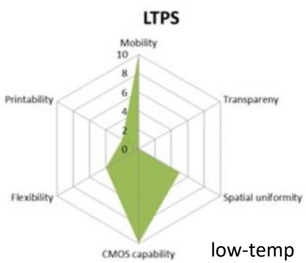
- **row: select voltage** determines the row in which all *n* pixels are addressed simultaneously, while all other rows are unselected (V_{unsel} potential).
- **column: video signal** is applied for each *m* columns individually (V_{on})



each element is **individually addressed**; it includes a **transistor** and a **capacitor**, which are ***actively maintaining its state*** while other pixels are being addressed

Ann. Rev. of Mat. Res. **27**(1), 555 (2003)

Available Backplane Technology



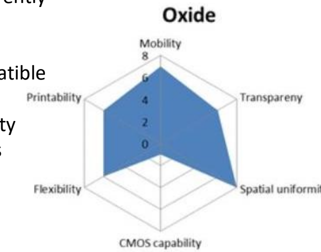
low-temp polycrystalline Si

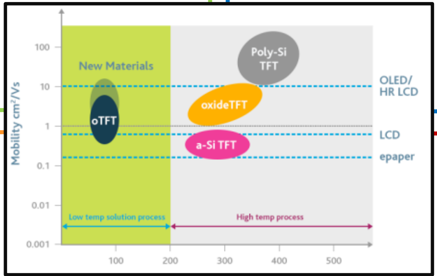
LTPS process used in AM-LCD and AM-OLED display runs at ***temperature around 450°C*** on polysilicon film.

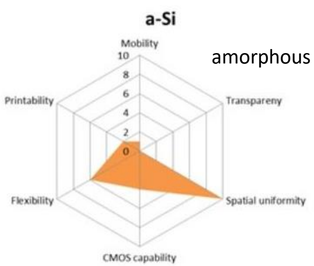
Low-temp LTPS (~200°C) on plastic substrate is yielding good results, however leakage current and threshold stability needs to be improved for high quality active matrix displays

Transparent oxide semiconductors (*i.e.* ZnO) are currently promising candidates for low-temp TFT applications.

- **ZnO** (wide bandgap, -3.3eV @RT) RT process, compatible with plastic substrates, highly transparent (VIS)
- **IGZO** (InGaZnO): large area uniformity and high mobility
- **CNT** high mobility/ compatible with plastics substrates



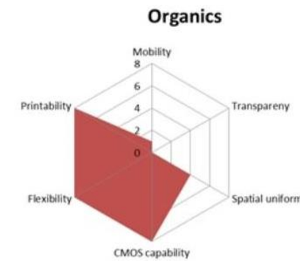




amorphous Si

a-Si routinely used in AM-LCD, however application in OLED display media are limited by:

- low mobility (μ~1cm²/Vs)→ active matrix addressing remains a challenge
- *n*-type TFTs ONLY
- transistor stability



OSC processes compatible with:

- **plastic substrates**
- ***low-cost***, ***large-scale*** fabrication process

Current limitations:

- low(er) mobility (compared to Si)

OTFT have been implemented in (LCD, EPD, OLED) flexible display

adapted from "*Metal Oxide TFT Backplanes for Displays 2014-2024: Technologies, Forecasts, Players*" IDTechEx

OTFT Backplanes: a Look into the Market

PLASTIC LOGIC
https://www.plasticlogic.com/

Plastic Logic (Dresden, Germany) develops and manufactures electrophoretic displays (EPD), based on OTFT. Founded in 2000 as spin-off company from U. of Cambridge and Cavendish Lab., specialized in polymer transistors/plastic electronics

many size up to 15.4´´, <200ppi (pixel/in)

PLASTIC LOGIC

- OTFT for active-matrix driving (EPD display)
- ultra-low power
- glass-free and thin
- bendable, robust and lightweight
- ultra-wide viewing angle
- COF/COP (chip-on-film/plastic) driver chips
- compatible with touch and front-light solutions
- different surface finish
- evaluation kits with reference hard- and software available

OTFT Backplanes: a Look into the Market (II)

FlexEnable Truly flexible electronics https://www.flexenable.com/

in Cambridge (UK), since 2015, from PlasticLogic split, FlexEnable became the *technology provider*, working to drive innovation across flexible video-rate displays and flexible sensors

ultra flexible
bending radius down to 250µm

ultra thin
down to 25µm

ultra light
6g/A4 sheet

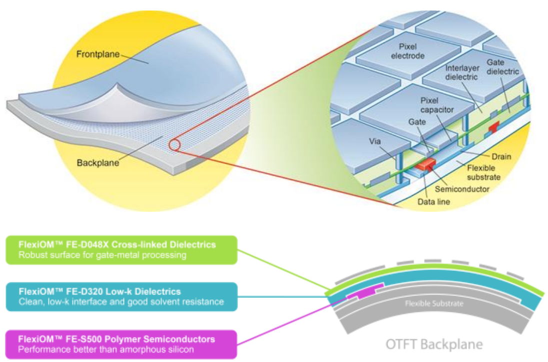
long lifetime
better than a-Si

low temperature
<100ºC

high mobility
better than a-Si

leakage current
lower than a-Si

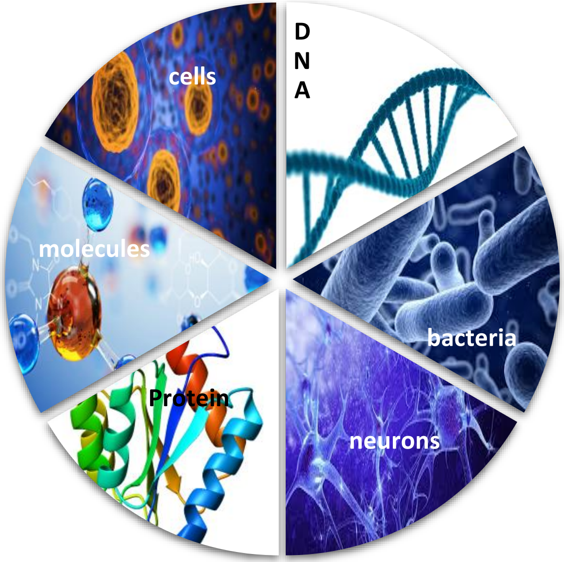
long lifetime
better than a-Si



Example of integrating flexible backplane (transistor array) with a front-plane (sensor or display technology)

FlexEnable announced the integration of curved, glass-free organic LCDs (OLCDs) into the Novares Nova Car, in collaboration with Novares.

OFET Bio-Sensors



Printed and flexible OTFT devices enable ***wearable smart sensors*** (*i.e.* nursing the elderly and infants not capable of performing self-care)

Flexibility | Thinness | Lightweight

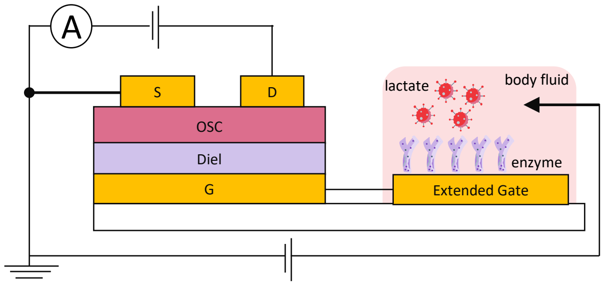
↓

can be attached to human skin or clothing with minimal physical discomfort

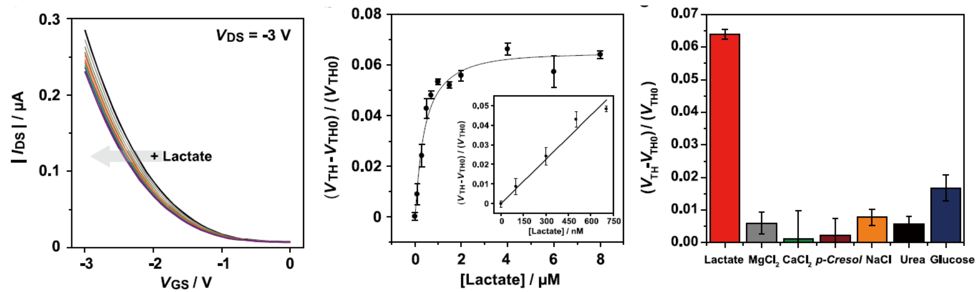
OFET as Electrochemical Sensors

Extended-Gate Field-Effect Transistor (EG-FET): external sensor electrode is connected to the OFET gate

detection on the sensor induces a change in the OFET gate bias → change in drain current



OFET sensitivity to different analytes



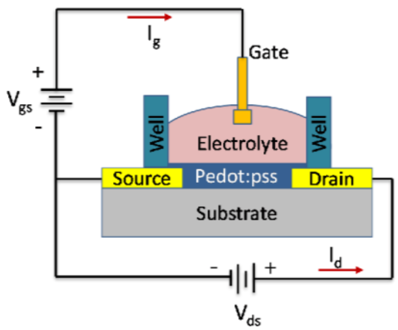
Biosensors & Bioelectronics **74**, 45 (2015)

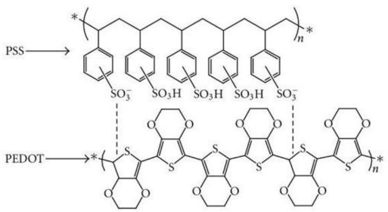
- circuit to detect small changes in current
- circuit to control the reference potential

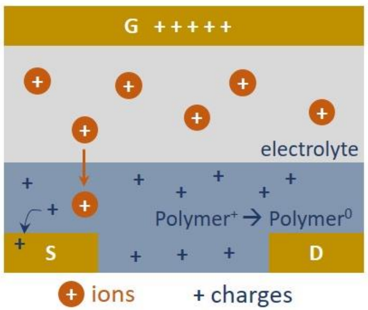
- easy fabrication
- high input impedance

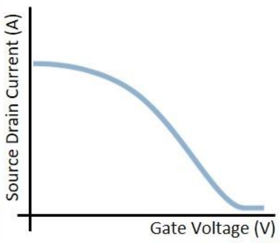
Organic Electrochemical Transistors (OECT)

Organic Electrochemical Transistor (OECT) consists of a ***conducting polymer channel*** and a ***gate electrode,*** connected to each other through an ***electrolyte*** (*ion migration*).







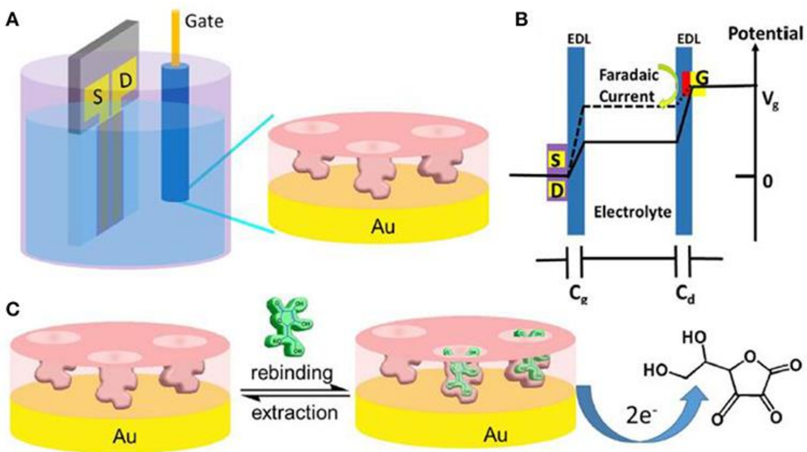


- if no gate voltage is applied, PEDOT:PSS is conducting (ON state)
- when a V_G is applied, the current is decreased due to the de-doping of the channel (OFF state).

using an *electrolyte as a gate* makes ***extremely flexible device design***
→ (gate) electrode can be placed on the side of the channel (lateral gating)

OECT as Multifunctional Sensing Platform

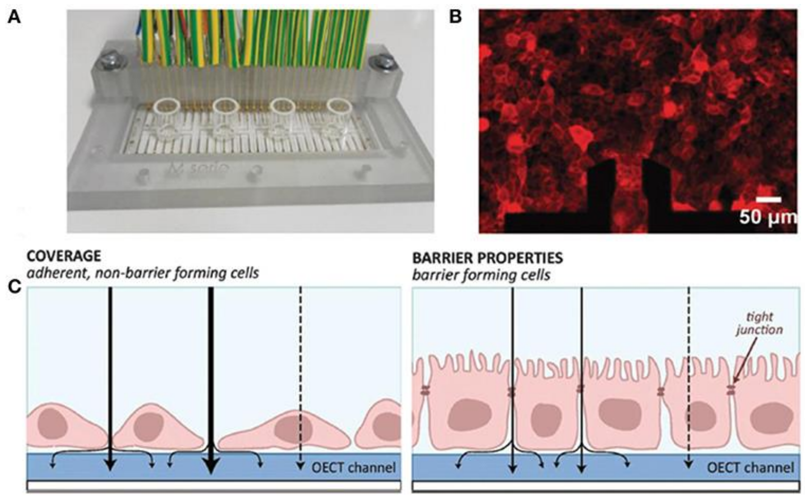
Receptor Sensors



Biosens. Bioelectron. **100**, 235 (2018)

OECT-based receptor sensor, where a *potential drop between OECT channel* and *gate* is measured (B) following the *receptor binding* (mechanism in (C)). Sensing mechanism is based on electrostatic actions on the interfaces of the cells and the OECT reactive layer.

Cell Monitoring

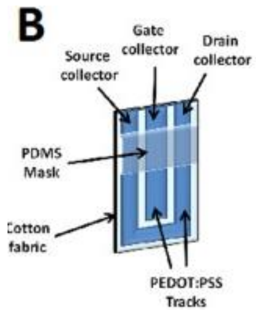


J. Mater. Chem. B **3**, 5971 (2015)

(A) Measurement platform consisting of 24 OECTs in 4 glass wells. (B) Fluorescence image of MDCK II epithelial cells transfected with RFP. (C) Schematics of cell coverage with (left) high-ion flow through non-barrier and (left) low-ion flow with barrier (left).

OECT on Textiles

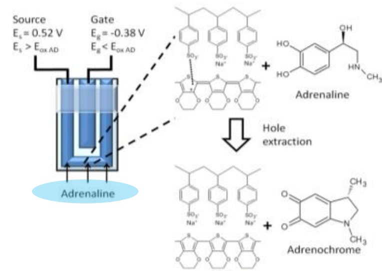
Development of wearable chemical sensors is needed in view of ***non-invasive*** and ***continuous*** monitoring of physiological parameters in healthcare applications

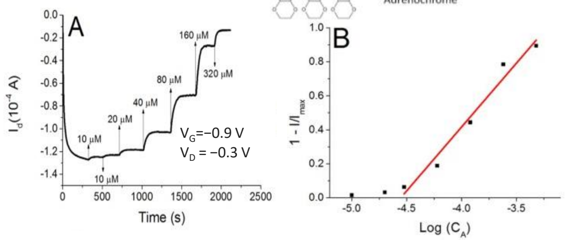


Sci. Rep. **6**, 33637 (2016)

Fully textile, wearable chemical sensor based on PEDOT:PSS, deposited by screen printing

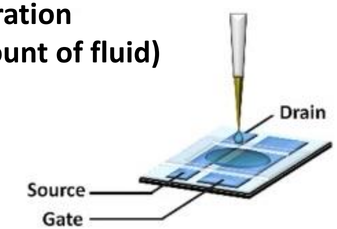
ideal operation: fully immersed

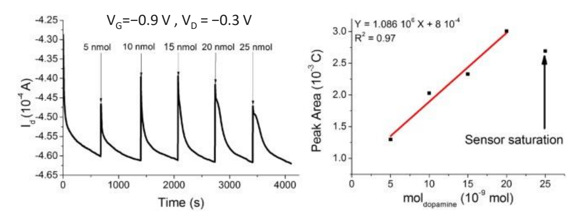




PEDOT:PSS can oxidize adrenaline, leading to hole extraction from the transistor channel (I_D ↓).
(A) I_d *vs.* time curve upon addition of different adrenaline amounts. (**B**) 1 – I/I_{max} *vs.* $LogC_{AA}$ plot

real-life operation (limited amount of fluid)





(left) I_D *vs.* time curves and (right) charge vs. mol_{dop} upon addition of different ***dopamine*** amounts

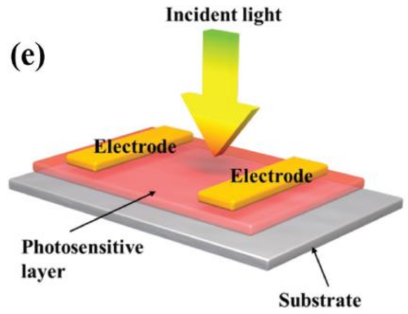
Organic Photodetectors

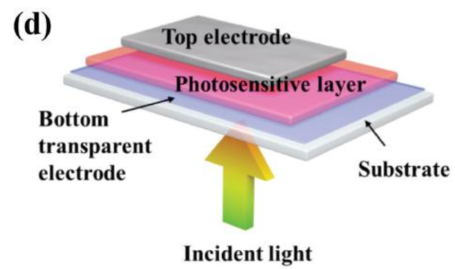
Photodetectors can be divided in 3 main categories

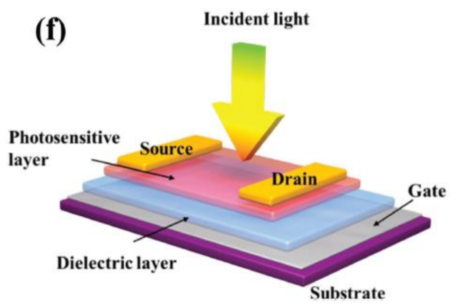
photo-<u>conductors</u>

photo-<u>diodes</u>

photo-<u>transistors</u>







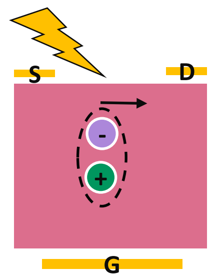
Organic molecules enable *lightweight*, *low-cost*, *large-scale* yields and *flexible* photodetectors applications

Adv. Sci. **5**, 1700256 (2015)

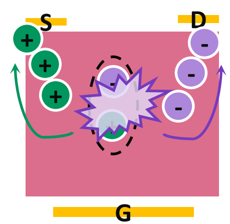
Organic PhotoTransistor (OPT)

Organic photo-transistors have the great advantage of ***current amplification*** in the process of light sensing (as compared to photodiode)

- light absorption (at specific λ)
- exciton formation
- exciton diffusion
- exciton dissociation
- carrier transport (towards electrodes)



light absorption & exciton dynamics



exciton dissociation & charge collection

External Quantum Efficiency

$$EQE = \frac{(I_{D,ph} - I_{D,dark})hc}{eP_{inc}A\,\lambda}$$

drain current in dark/illumination

incident power

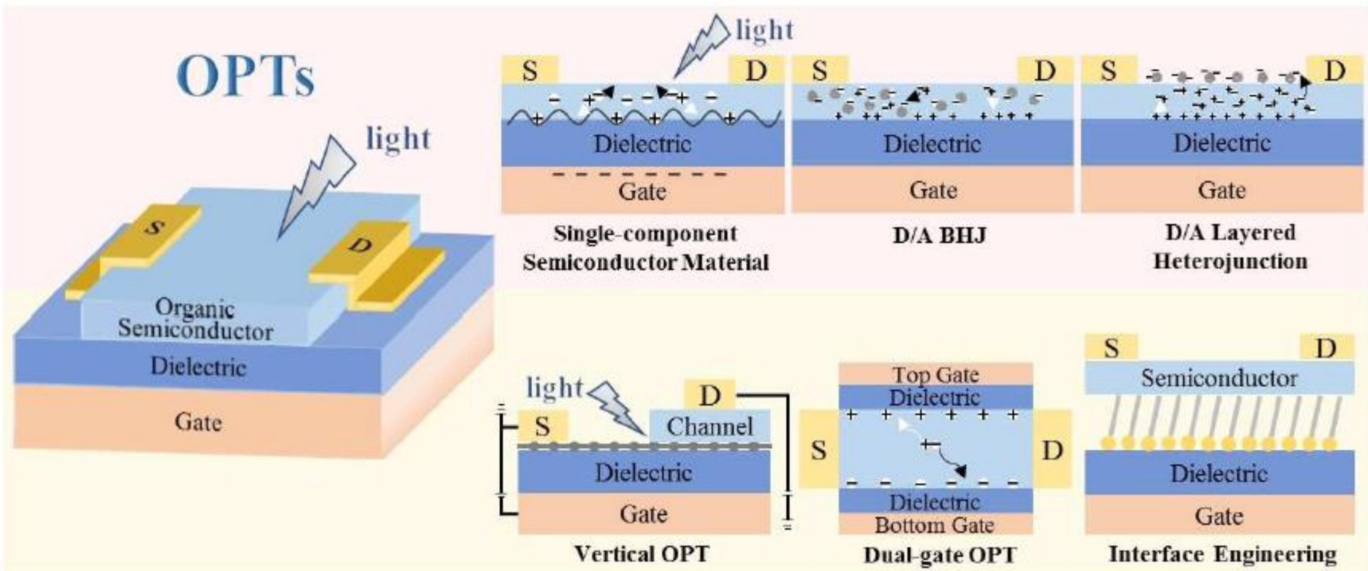
(photo)Responsivity, R

$$EQE\,\frac{\lambda q}{hc} = \frac{I_{ph}}{P_{inc}} = \frac{I_{D,ph} - I_{D,dark}}{P_{inc}}$$

OPT performances are mainly determined by (photoconductive) material properties

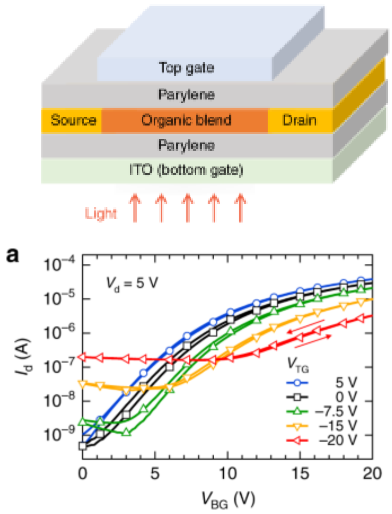
Organic Photo-Transistor & Light Sensing

Different photo-transistors configuration have been proposed to enhance sensitivity and photo-responsivity at specific wavelength



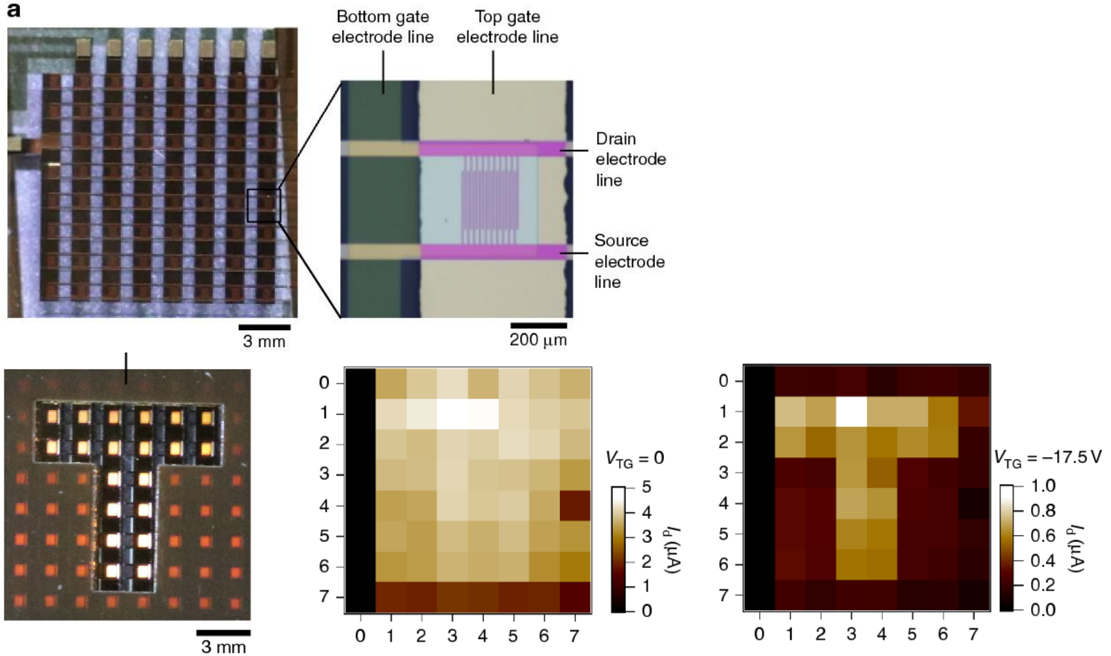
ChemPhotoChem **4**, 9 (2020)

(Dual Gate) OPT Array for Imaging



Nature Comm. **9**, 4546 (2018)

Schematics of the dual gate OPT and transfer curves measured in dark at various top gate biases (V_{TG}), with fixed source-drain bias (V_D = 5V).



(a) Array of double-gate OPT and (bottom) imaging response in condition of illumination with white light through a semi-transparent mask. Panel (e) demonstrates the possibility to resolve illuminated pattern.

Summary

Today´s Class: Organic Field-Effect Transistors

- Basic ***working principle*** of organic field-effect transistor and some characteristics
- ***Building blocks*** of organic field-effect transistor
- **Applications** of Organic Field-Effect Transistors (backplane, sensing, light sensing)

Next: Organic Light Emitting Diode

- Basic **working principle** of **organic light emitting diodes** (OLEDs)
- **Applications of OLED** device in several fields