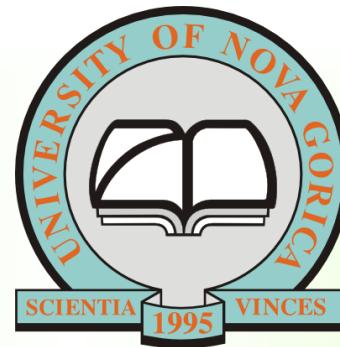


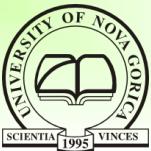
Resolving authentic time dependence of time-of-flight photocurrent in organic semiconductors

Egon Pavlica, Fei Tong, and Gvido Bratina

University of Nova Gorica

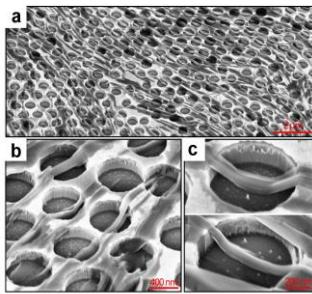
Slovenia





Motivation

- Semiconductivity of “amorphous” materials
- Molecules with intrinsic **functional properties**
- Van-der-Waals interactions
- Novel **optoelectronic** devices



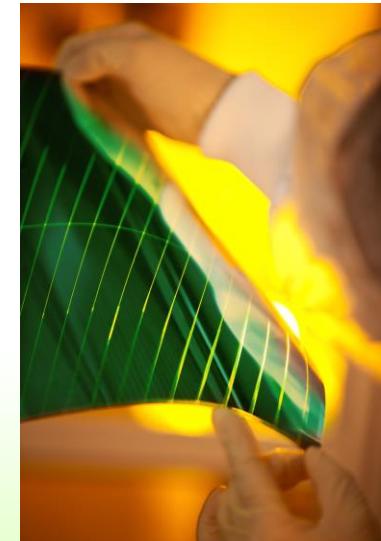
Fast vertical nanomesh photodetector



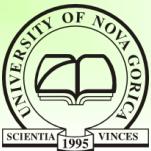
Skin electronics – Photo courtesy John Rogers (University of Illinois)



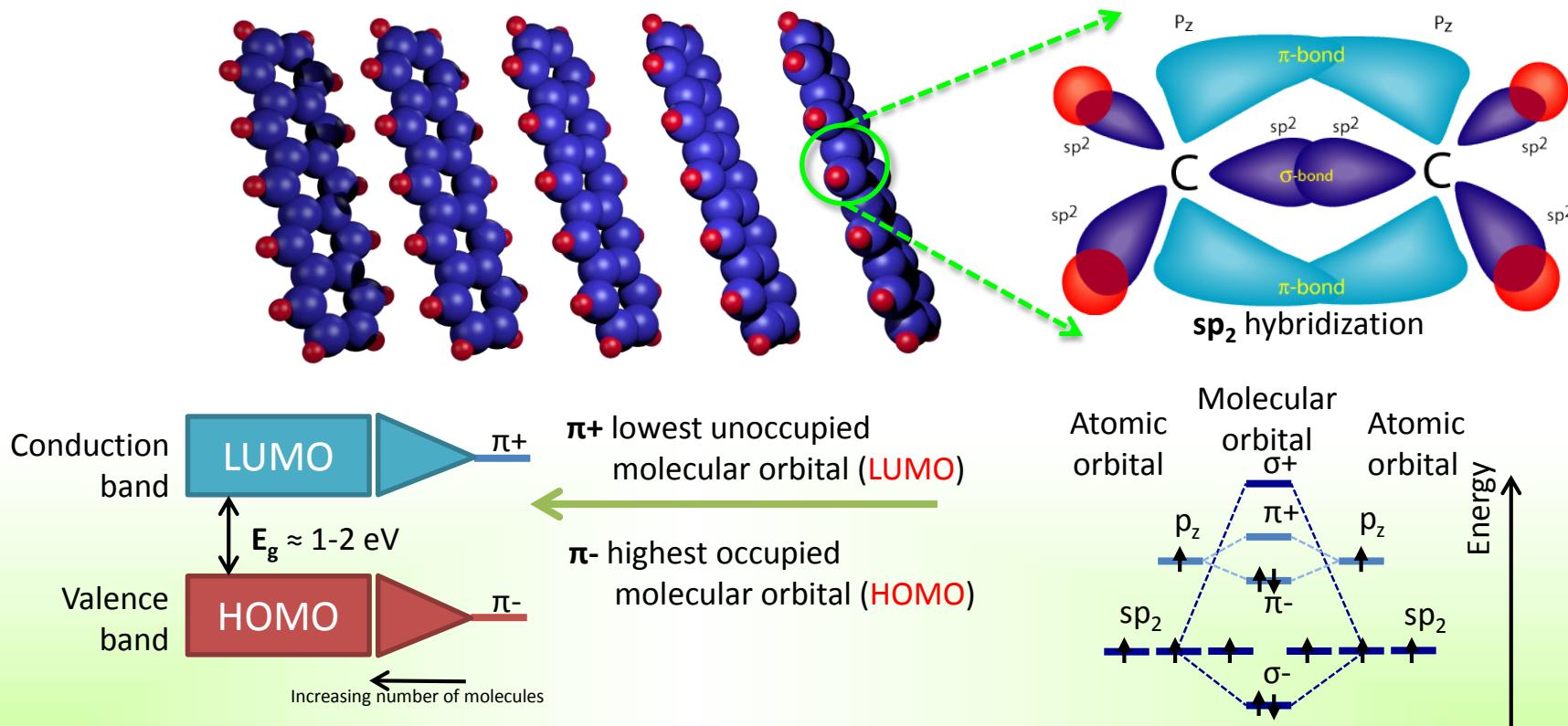
LG's and Samsung's OLED TVs
– diagonal 197cm (77") and 140 cm(55").



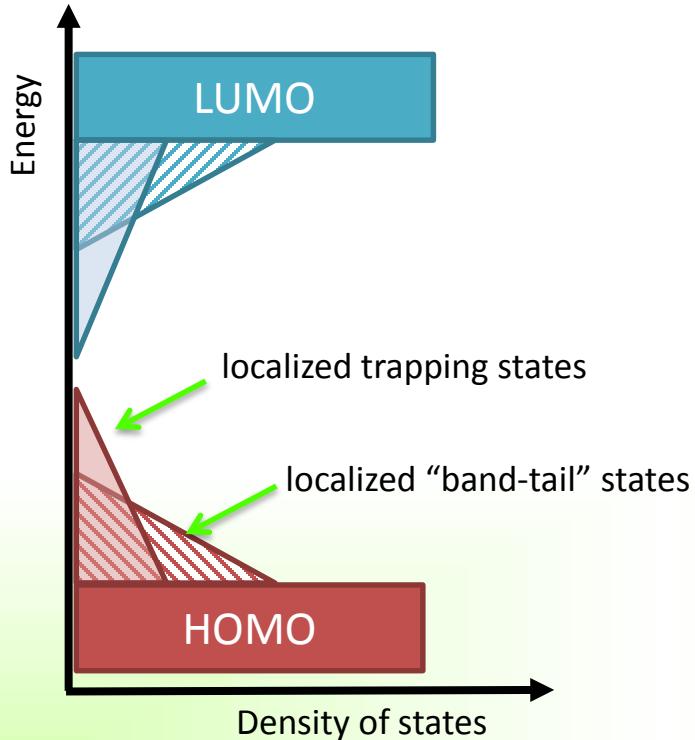
Flexible organic solar cells
(Solarfolie by Heliatek)



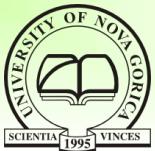
Organic Semiconductors



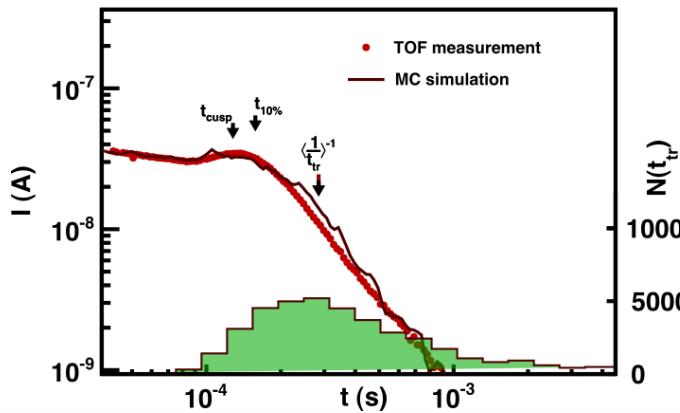
Disorder



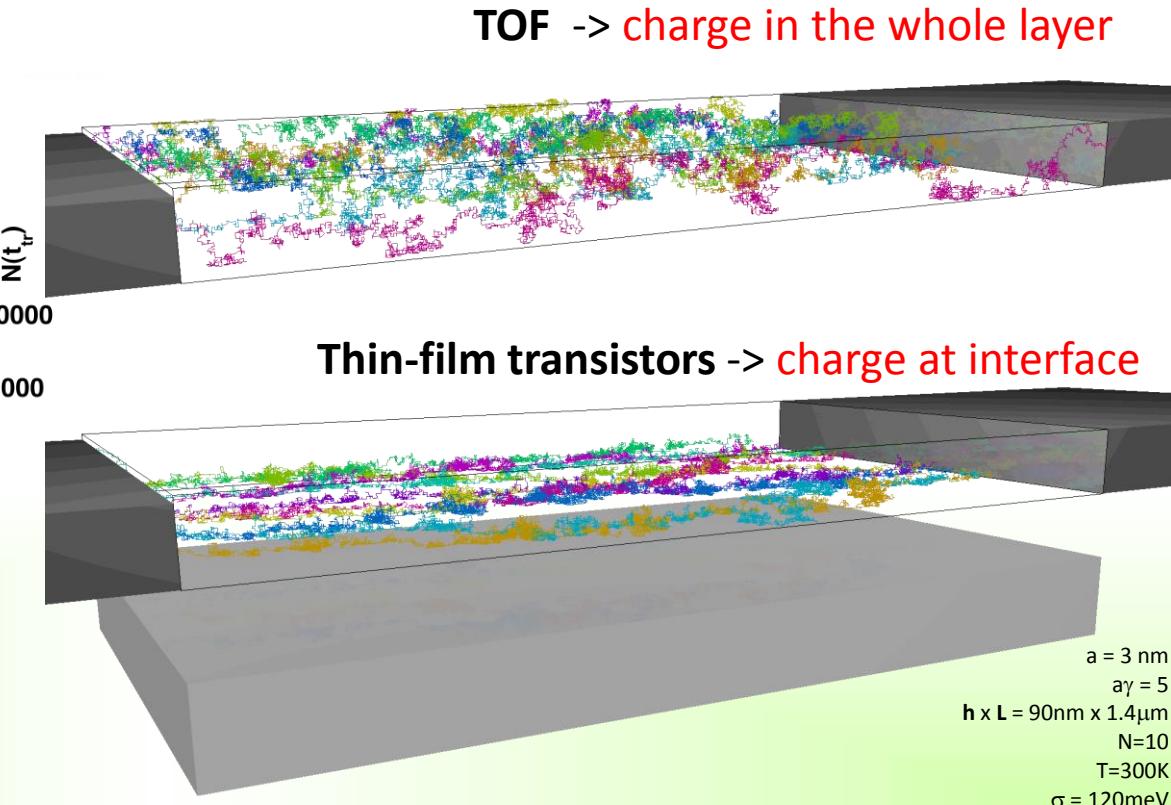
- Charge mobility: $10^{-6} - 10^2 \text{ cm}^2/\text{Vs}$
- Electric field and temperature dependent charge mobility (**Poole-Frenkel type**)
- Weak VdW interaction -> high level of structural imperfections
- Imperfections -> localized states
- Band theory + Multiple trap-and-release
- **Hopping theory / Percolation simplification**

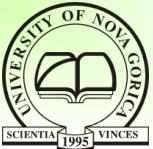


Kinetic Monte Carlo simulations



$a = 3 \text{ nm}$
 $h \times L = 90 \text{ nm} \times 130 \mu\text{m}$
 $N = 10240$
 $T = 300 \text{ K}$
 $\sigma = 150 \text{ meV}$
 $t_0 = 10^{-19} \text{ s}$
 $N_{ph} = 9.4 \times 10^7$

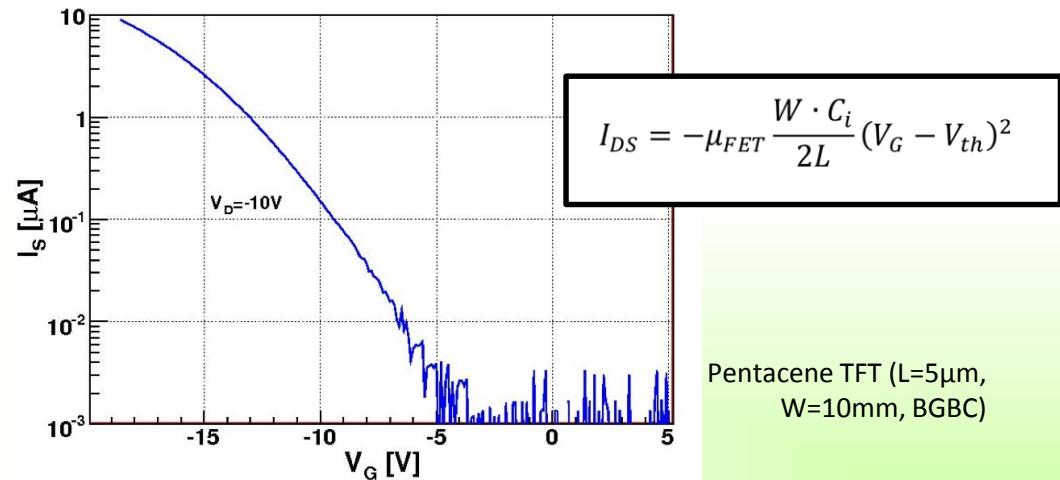
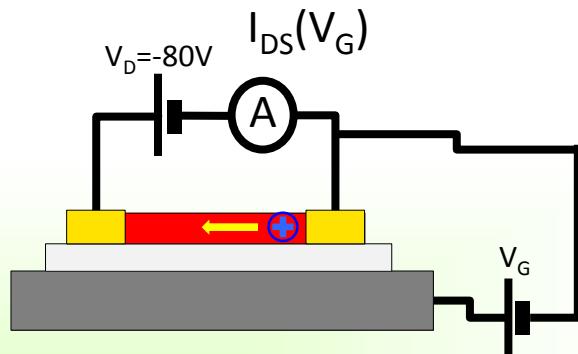


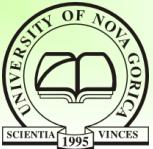


Experimental methods

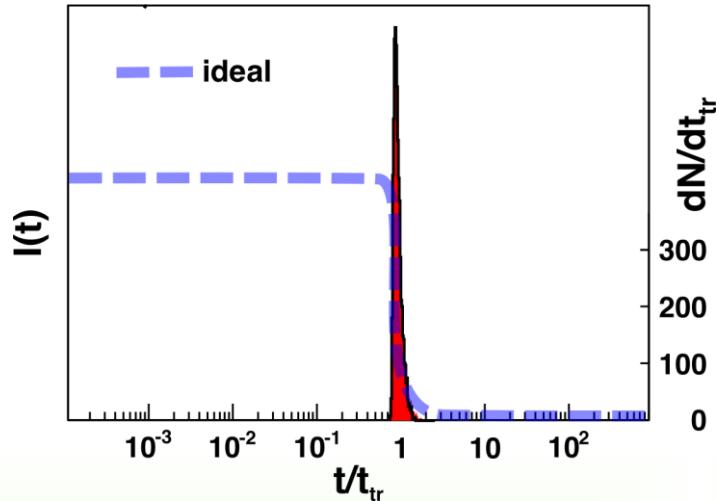
- FET mobility, SCLC, THz spectroscopy, Hall effect, Photoconductivity

Thin-film transistors -> field-effect mobility - μ_{FET}

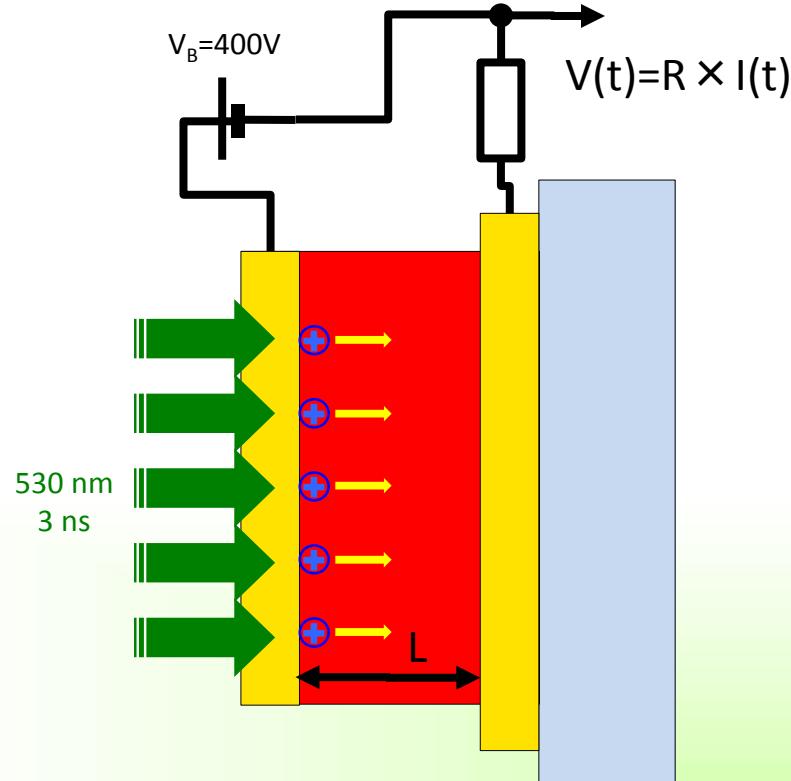


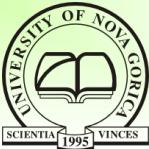


Parallel time-of-flight photoconductivity



$$\mu_{TOF} = v/E \quad E = V_B/L \quad v = L/t_{tr}$$

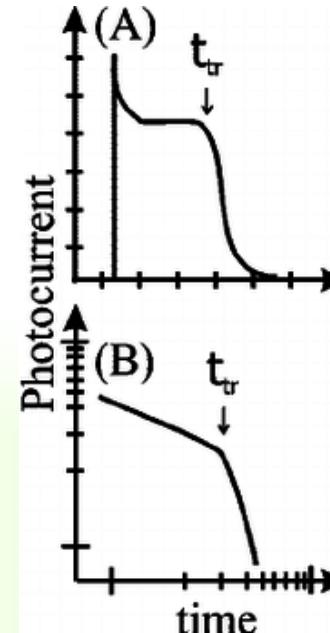


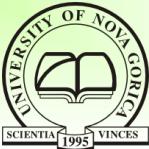


Scher-Montroll formalism

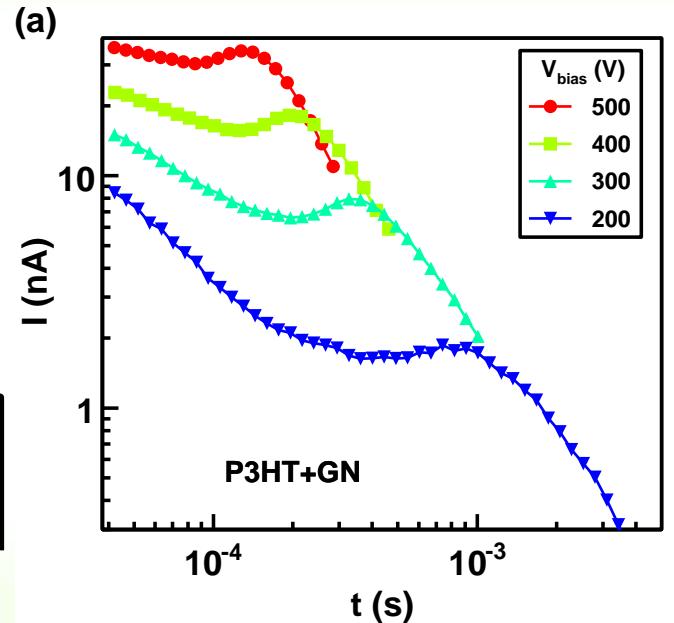
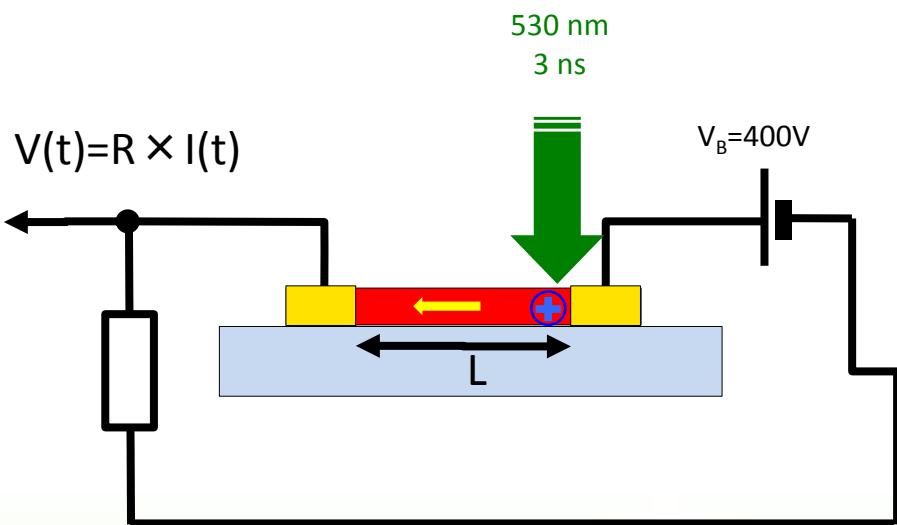
- Gaussian distribution of carriers velocity
- Uniform electric field
- Finite lifetime

$$I_M(t) = I_0 t^{\alpha-1} \left[1 + \left(t/t_{tr} \right)^a \right]^{-\frac{k}{a}}$$

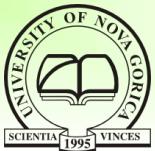




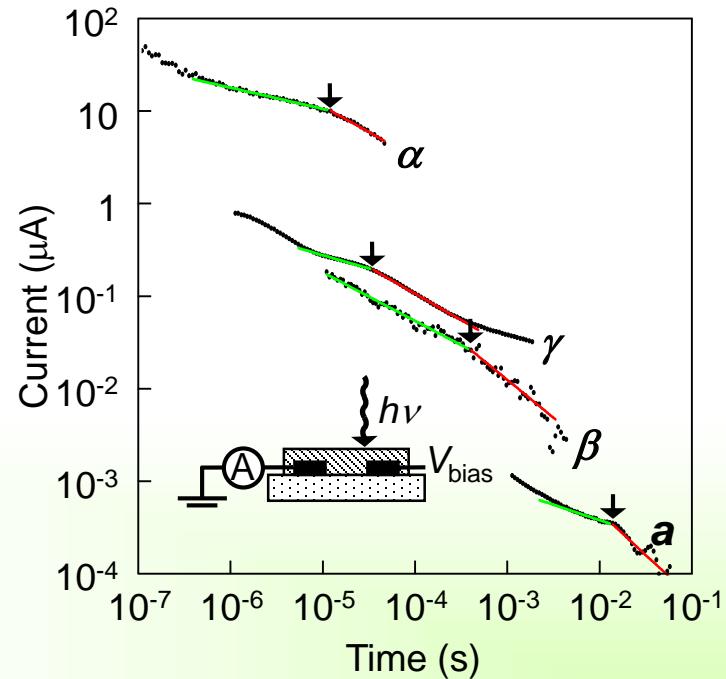
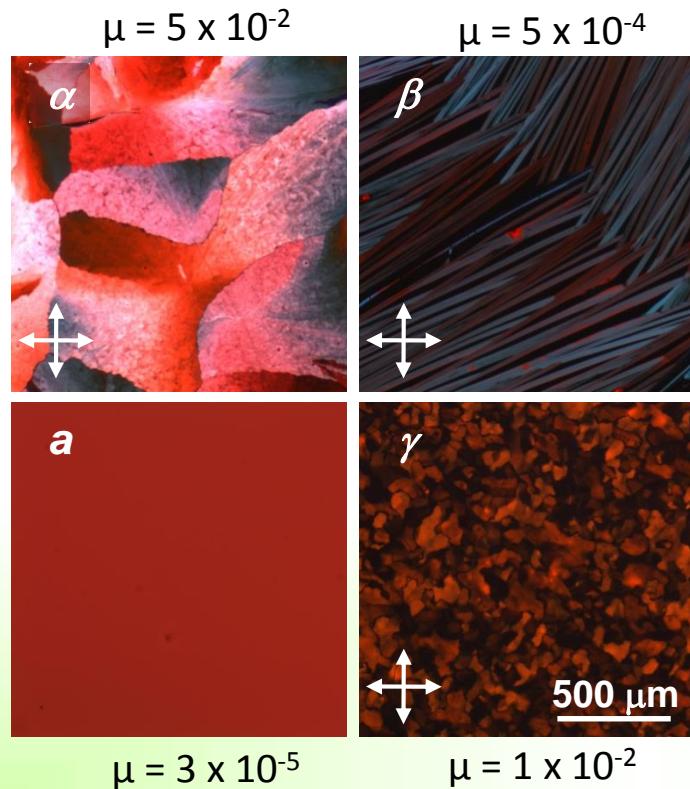
Coplanar time-of-flight photoconductivity



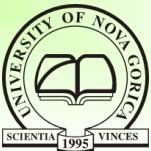
$$\mu_{TOF} = v/E \quad E = \cancel{V_B/L} \quad v = L/t_{tr}$$



TES-ADT polymorphs

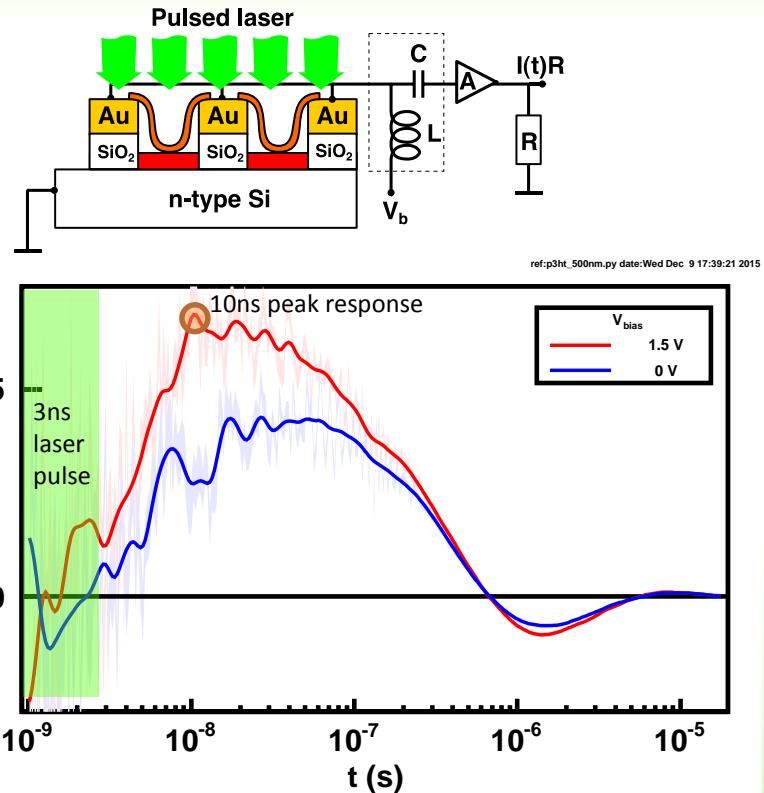
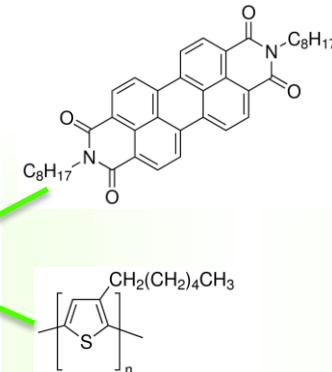
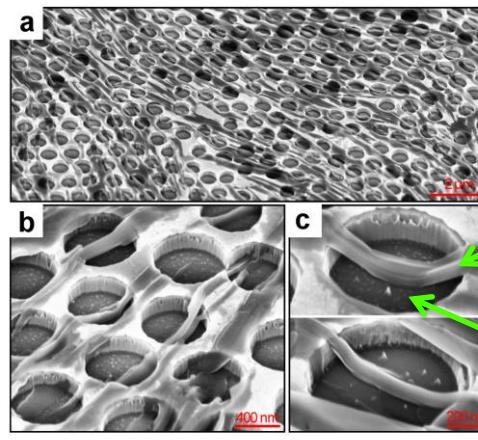


Liyang Yu et al, Chem. Mater. **25**, 1823 (2013)

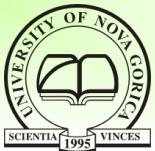


Single Crystal vertical channel p-n junctions

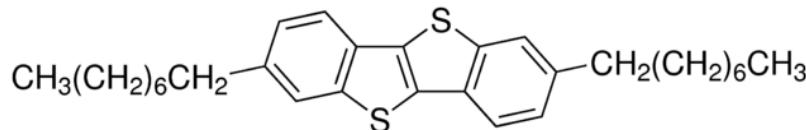
- Perylenedicarboximide (PTCDI-C8) single-crystal nanowires (n-type)
- Polythiophene (P3HT) (p-type)
- **10 ns response**
- S/N ratio 10^7 , EQE > 50%



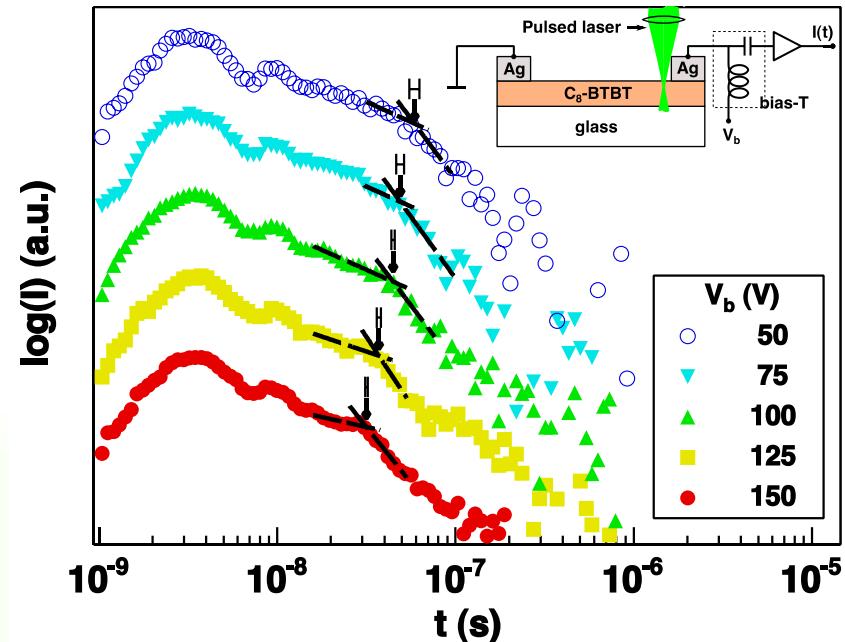
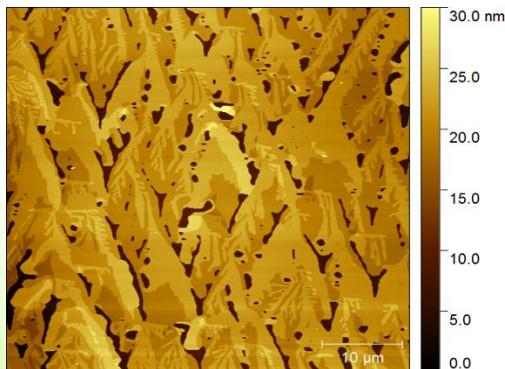
L. Zhang et al, Nat Nano (2016)



Photoresponse of single crystal thin-films

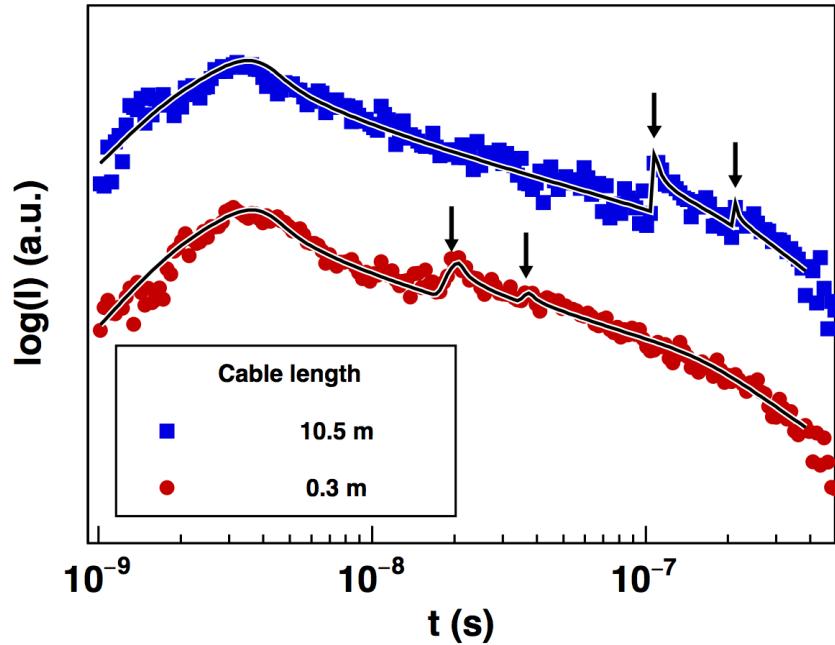


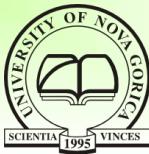
- Benzothieno-benzothiophene (C8-BTBT)
- millimeter-size single crystal
- Measured hole **mobility up to 100 cm²/Vs**



Different cable length

- Sample-amplifier distance
- Reflection peaks equidistant





Modeling of measured photocurrent

$$I_M(t) = I_0 t^{\alpha-1} \left[1 + \left(\frac{t}{t_{tr}} \right)^a \right]^{-\frac{k}{a}}$$

Authentic photocurrent model:

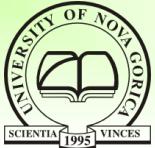
Laser pulse model:

Reflection:

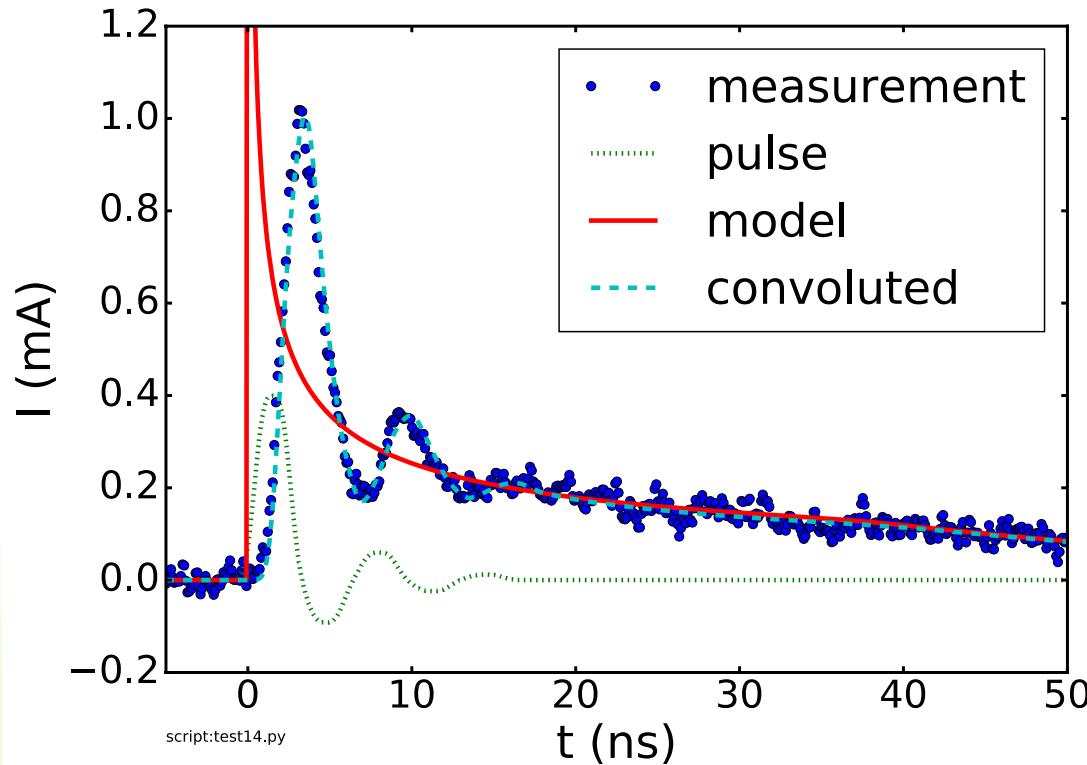
$$g(t, t_0) = \frac{1}{\sqrt{2\pi}\sigma} \exp \left[-\frac{1}{2} \left(\frac{|t - t_0|}{\sigma} \right)^\chi \right]$$

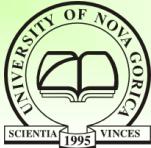
$$P(t) = g(t, t_0) + \sum_{i=1}^4 R_i \cdot g(t, t_0 + i \cdot \Delta t)$$

i	1	2	3	4
$i \cdot \Delta t$	3.25 ns	6.5 ns	9.75 ns	13.0 ns
R_i	-0.23	0.15	-0.06	0.03



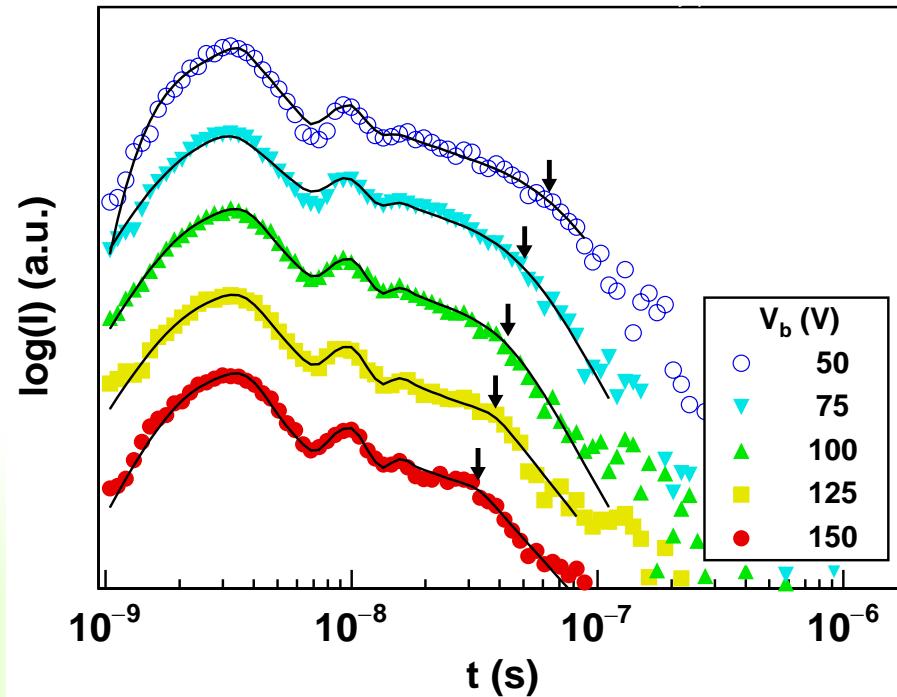
Modeling of measured photocurrent

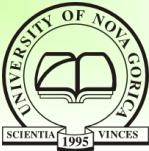




Modeling of measured photocurrent

- Model reproduces measurements





Summary

- Transient Current Setup was used to measure charge mobility in organic single-crystal semiconductors
- TOF photocurrent reflects **distribution** of charge carrier transit times
- Authentic photocurrent was "deconvoluted" using a series of laser pulse and its reflections



Acknowledgments

- **LFOS**
- **ISIS & icFRC, University of Strasbourg & CNRS:** Paolo Samori, Emanuele Orgiu, Tim Leydecker, Lei Zhang, Arthur Ciesielski, Mirella El Gemayel, Andrea Schlierf
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- *others*

