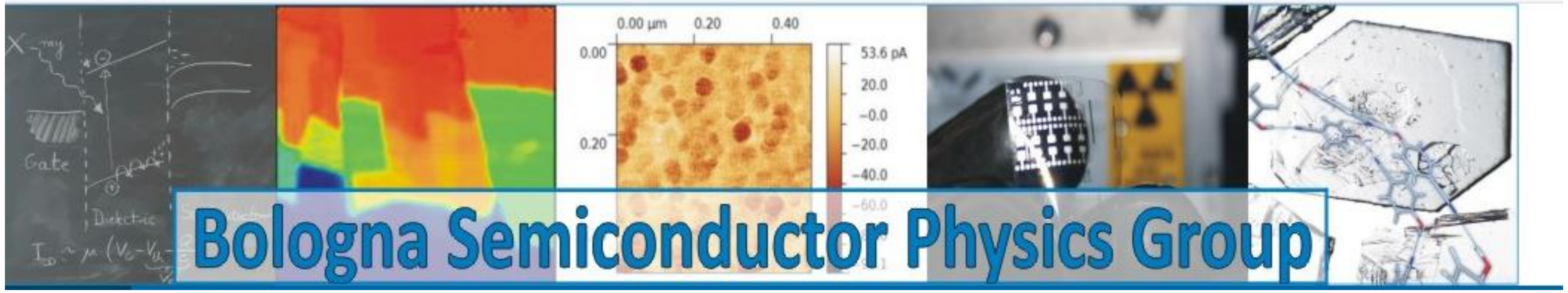
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

X-ray detectors with ultrahigh sensitivity based on high performance printed Organic Field Effect Transistors

Laura Basiricò [1,2], Ilaria Fratelli [1,2] Andrea Ciavatti [1,2], Adrian Tamayo [3], Carme Martínez-Domingo [3], Paolo Branchini [4], Elisabetta Colantoni [4], Stefania De Rosa [4], Luca Tortora [4], Adriano Contillo [5], Raul Santiago [6], Stefan T. Bromley [6,7], John E. Anthony [8], Marta Mas-Torrent [3], Ioannis Kymissis [9], and Beatrice Fraboni[1,2]

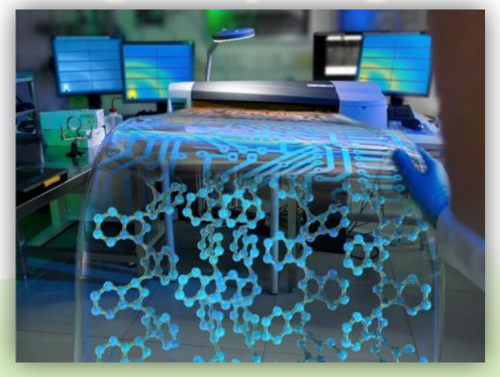
1. Physics and Astronomy Department of the University of Bologna, Viale Berti Pichat 6/2, 40127, Bologna (BO), Italy
2. Institute of Nuclear Physics, INFN-BO, Viale Berti Pichat 6/2, 40127, Bologna (BO), Italy
3. Institut de Ciència de Materials de Barcelona and Networking Research Center on Bioengineering, Biomaterials and Nanomedicine, Campus de la Universitat Autònoma de Barcelona, Cerdanyola, E-08193 Barcelona, Spain
4. Surface Analysis Laboratory INFN Roma Tre, Via della Vasca Navale 84, 00146 Rome, Italy
5. Elettra-Sincrotrone Trieste, Trieste, Italy
6. Departament de Ciència de Materials i Química Física & Institut de Química Teòrica i Computacional, Universitat de Barcelona, Barcelona, Spain
7. Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain
8. Center for Applied Energy Research, University of Kentucky, United States
9. Department of Electrical Engineering, Columbia University, New York, NY 10027, United States

SEMICONDUCTOR PHYSICS GROUP @
DEPARTMENT OF PHYSICS AND ASTRONOMY-UNIVERSITY OF BOLOGNA



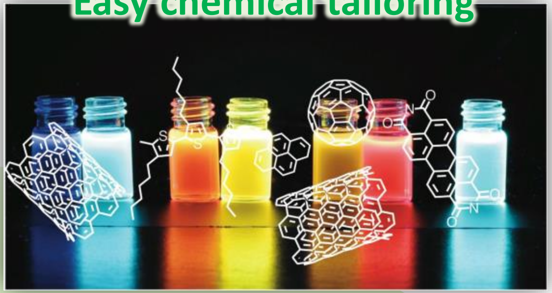
ORGANIC-HYBRID SEMICONDUCTORS FOR IONIZING RADIATION DETECTION - ADVANTAGES

Low-cost large-area printing techniques

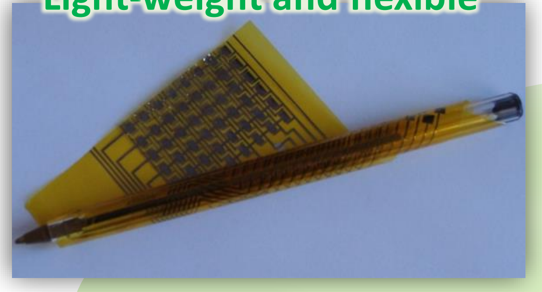


Wearable

Easy chemical tailoring



Light-weight and flexible

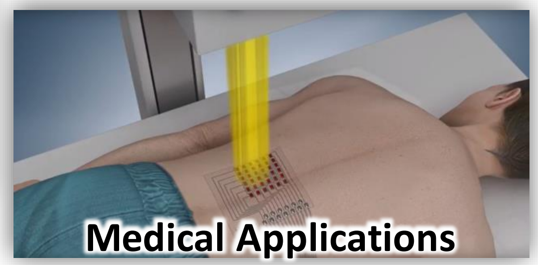


New generation of
low cost, **low power supply** and **mechanical flexible**
Thin and **comformable** sensor panels and patches

Cultural Heritage

Space Missions

Airport Security



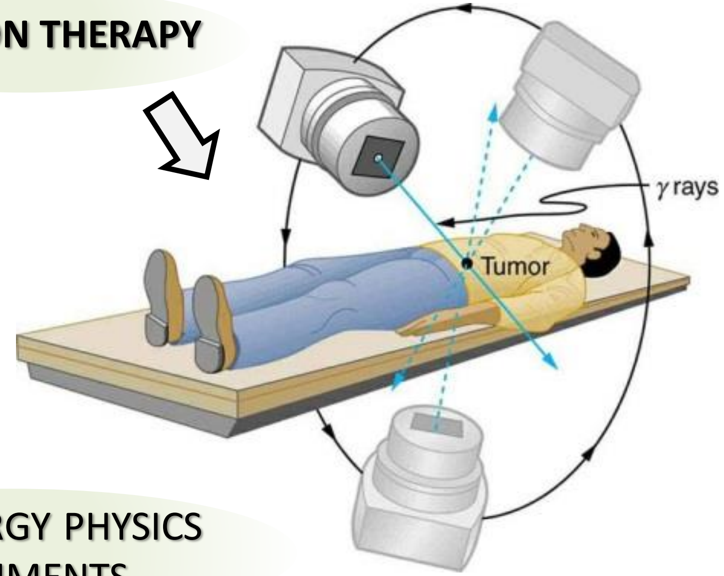
Medical Applications

Nuclear wastes management

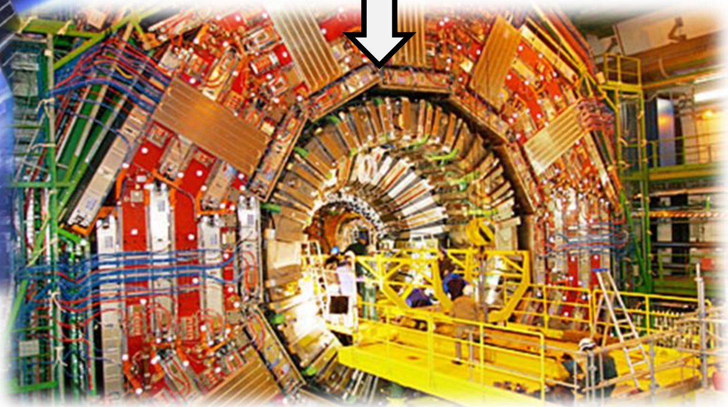
THIN FILM AND LARGE AREA: WHERE?

SPACE MISSIONS

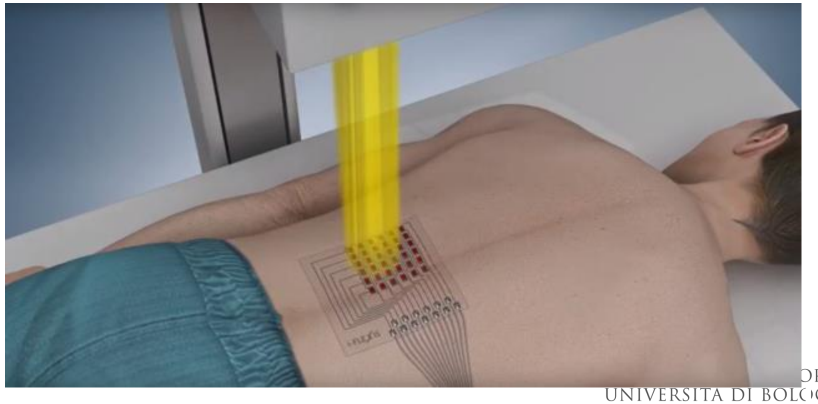
RADIATION THERAPY



HIGH ENERGY PHYSICS EXPERIMENTS



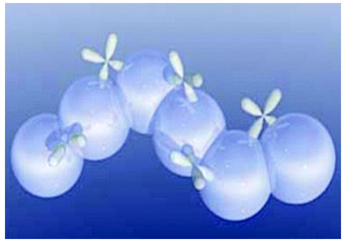
- **Light-weight** for limited amount of materials
- Possibility to **cover large surfaces** at low cost
- **Real-time** beam monitoring
- **Radiation hard** to strong fluxes due to weak radiation abortion
- **In-situ** dose evaluation thank to conformability to human tissues



FLEXIBLE LARGE AREA ELECTRONICS: MATERIAL PLATFORMS

High Mobility Oxide Semiconductors

e.g. $Ga_xIn_yZn_zO$

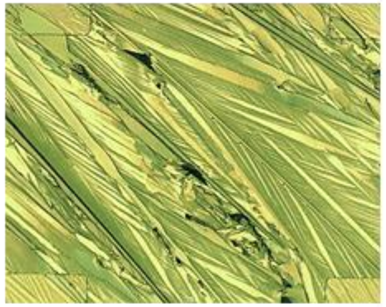


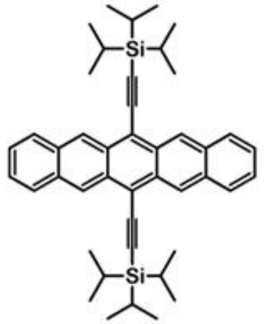
Physical/solution deposizion
μ = 10 – 50 cm^2/Vs

T. Cramer et al., Sc.Adv., ***4****, 63 (2018)*

Organic Semiconductors

e. g. TIPS pentacene



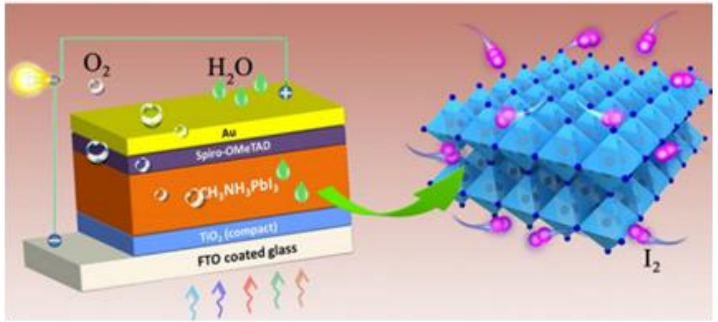


solution deposition
μ = 1 cm^2/Vs

L. Basiricò et al. Nature Comm ***7****, 13063 (****2016****)*
I.Temino et al., Nature Comm. ***11****, 235 (****2020****)*

Perovskites

e. g. $MAPbI_3$



solution deposition
μ = 1-600 cm^2/Vs

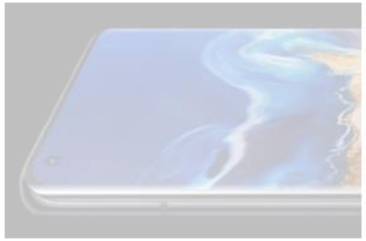
A.Ciavatti et al., Adv. Funct. Mater. ***29****, 1902346 (****2019****)*

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

FLEXIBLE LARGE AREA ELECTRONICS: MATERIAL PLATFORMS

High Mobility Oxide Semiconductors

e.g. $Ga_xIn_yZn_zO$

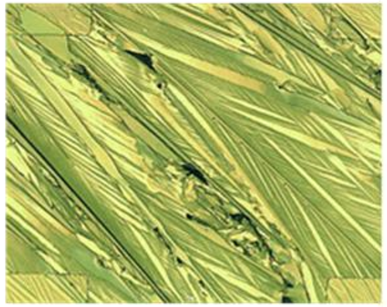


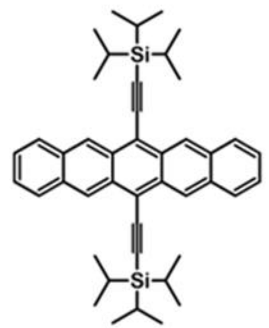
Physical/solution deposizion
μ = 10 – 50 cm²/Vs

*T. Cramer et al., Sc.Adv., **4**, 63 (2018)*

Organic Semiconductors

e. g. TIPS pentacene





solution deposition
μ = 1 cm²/Vs

*L. Basiricò et al. Nature Comm **7**, 13063 (**2016**)*
*I.Temino et al., Nature Comm. **11**, 235 (**2020**)*

Perovskites

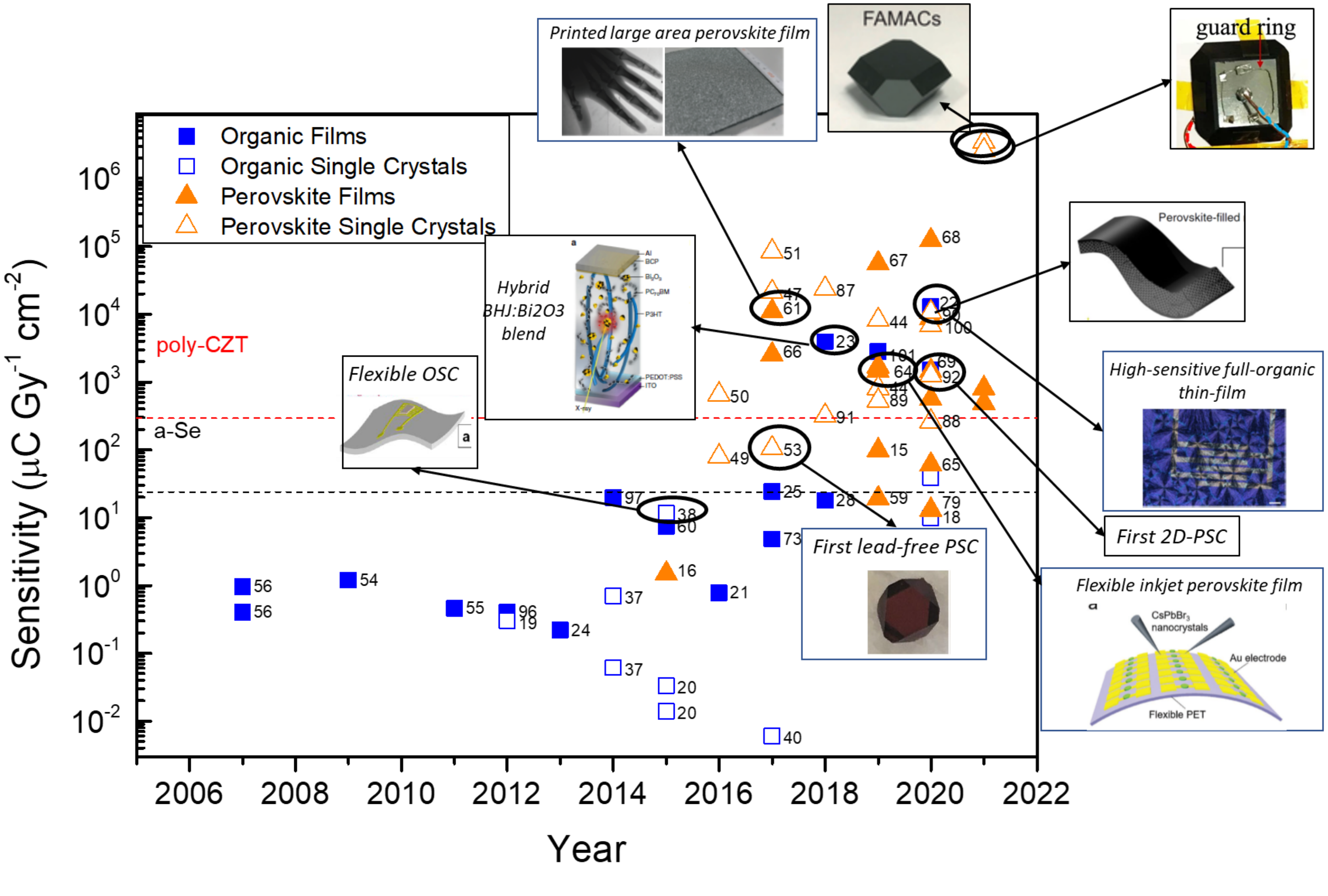
e. g. $MAPbI_3$

solution deposition
μ = 1-600 cm²/Vs

*A.Ciavatti et al., Adv. Funct. Mater. **29**, 1902346 (2019)*

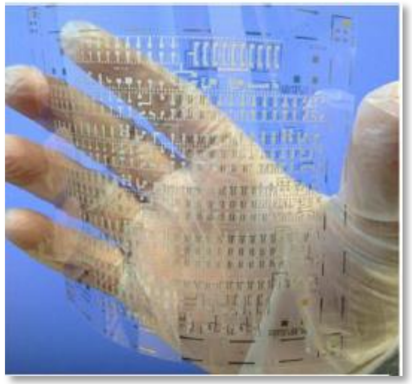
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

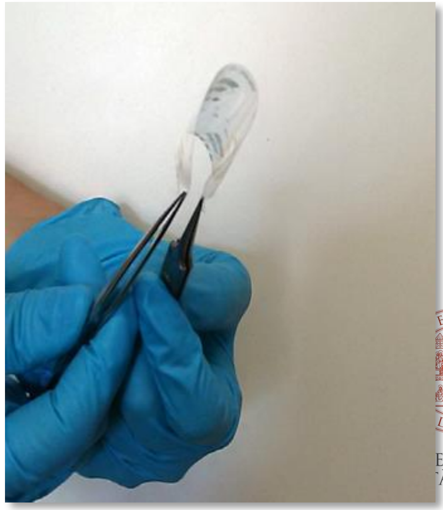
ORGANIC/HYBRID MATERIALS FOR X-RAY RADIATION DETECTION



Sensitivity: 10^6 μC/Gy cm^2 @ 0.2V @ RT

>> than polyCZT or a-Se

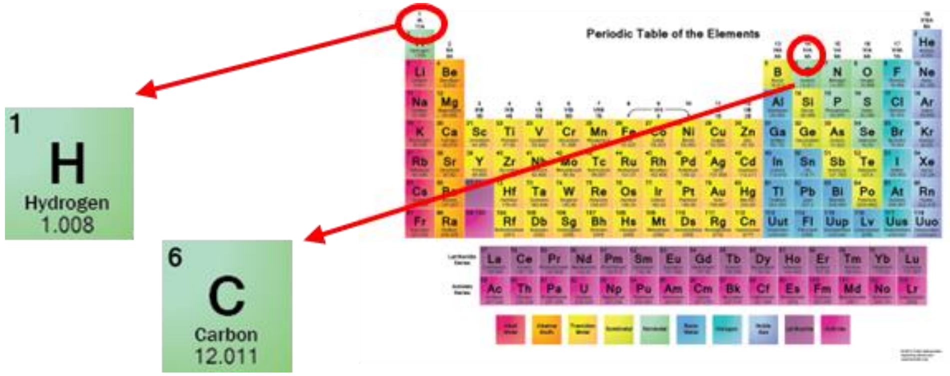


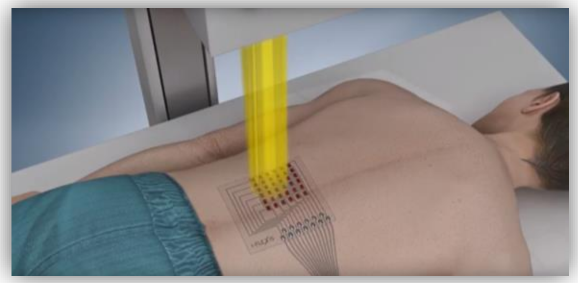


L. Basiricò et al., Adv. Mater. Technol. ***2020,*** *2000475*

WHY HIGH SENSITIVITY?

Chemical composition formed
by
LOW-Z ELEMENTS

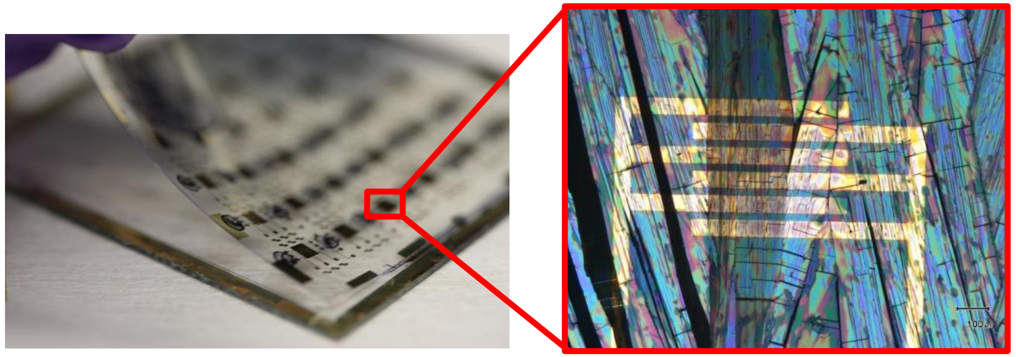




✓ **HUMAN TISSUE EQUIVALENCE** → ✓ Medical Dosimetry Applications

X **POOR ABSORPTION** → ✓ High Radiation Hardness

✓ **But still high Sensitivity!** Why?

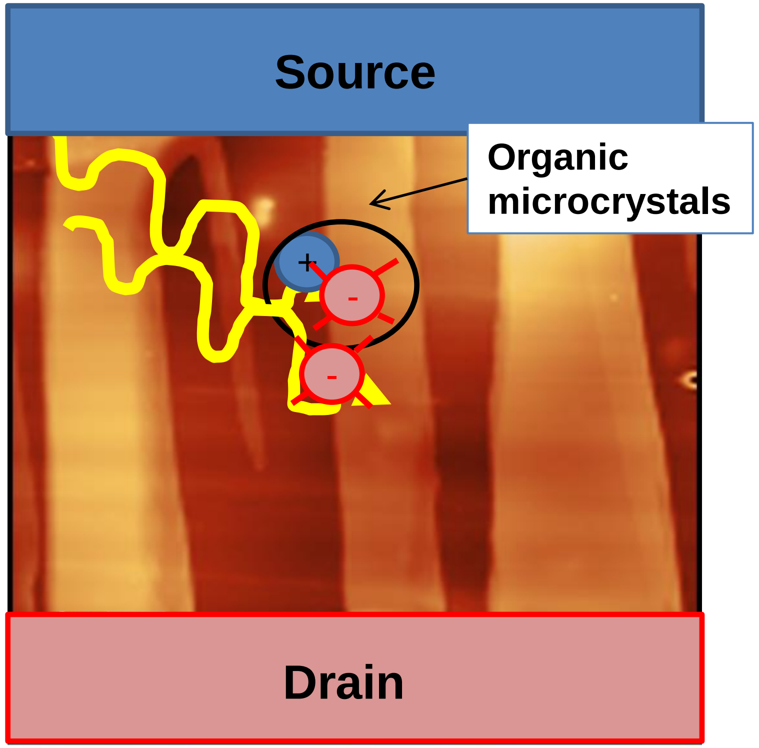


1 mm

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

WHY HIGH SENSITIVITY?
CHARGE TRAPS AND PHOTOCONDUCTIVE GAIN

V_{DS}=0.2V



- trapping of n-type carriers
- injecting contacts

L. Basiricò et al., *Nature Commun.* 7, **2016**.

under X-ray irradiation:

1) Additional electrons and holes are generated.
2) Holes drift along the electric field and reach the collecting electrode while **electrons remain trapped** in deep trap states and act as "doping centers".
3) To guarantee charge neutrality, **holes are continuously emitted** from the injecting electrode.
4) Recombination process takes place

→ $\Delta I_{PG} = G\, I_{CC}$

G = photoconductive gain ≈ 10^6

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

PHOTOCONDUCTIVE GAIN MECHANISM

$$\boldsymbol{Photocurrent} = \boldsymbol{G} \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot ln\left(\frac{\boldsymbol{\rho_0}}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \boldsymbol{\mu}}{L^2} \cdot \boldsymbol{I_{CC}}$$

PHOTOCONDUCTIVE GAIN EFFECT

Study of the electron trap states

→ MORPHOLOGY

→ INTERFACES

TRANSPORT PROPERTIES

Boosting the electrical mobility

I. Temiño, L. Basiricò et al., Nat. Commun., vol. 11, 2136, 2020
Tamayo, A., Fratelli, I., et al, Adv. Electron. Mater., 2200293 (2022).

IONIZING RADIATION ABSORPTION

Small molecules CHEMICAL TAILORING

A. Ciavatti et al., Adv. Funct. Mater. ***29****, 1–8 (2019).*

DEVICE ARCHITECTURE

OFET structure

S.Lai et al, Adv.Electr.Mat. ***8****, 1600409 (2017)*

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

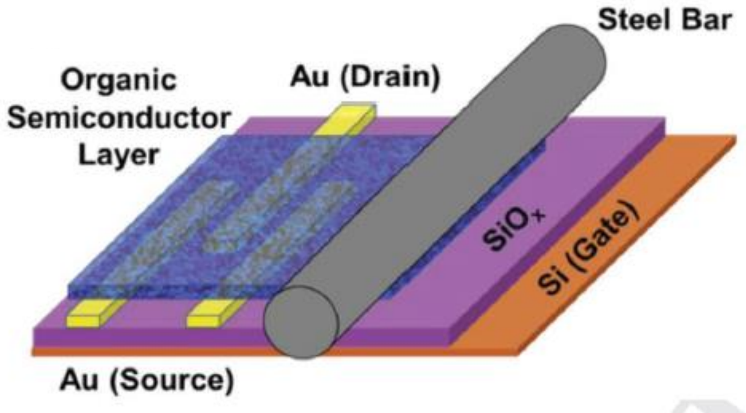
DEVICE ARCHITECTURE/TRANSPORT PROPERTIES

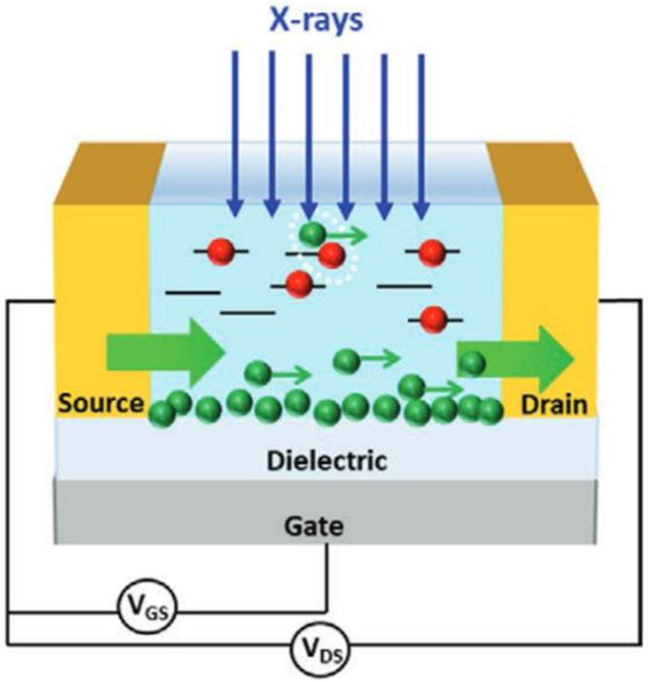
Organic Field Effect Transistors as X-Rays detectors

$$\boldsymbol{Photocurrent} = \boldsymbol{G} \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \boldsymbol{\mu}}{L^2} \cdot \boldsymbol{I_{CC}}$$

BAMS: Bar Assisted Meniscous Shearing Technique

BOTTOM GATE – BOTTOM CONTACTS OFETs





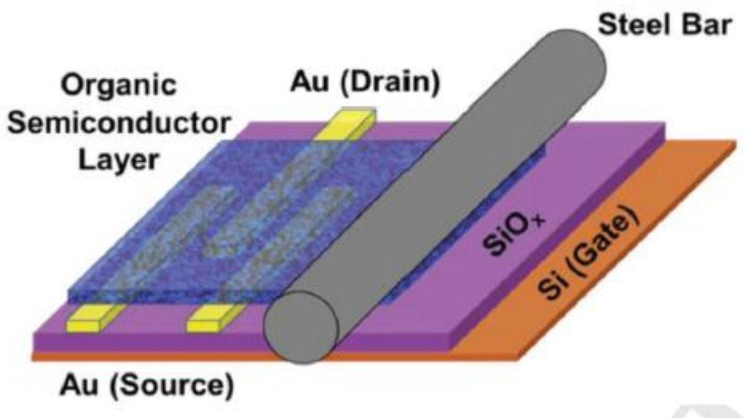
$\rho_0 \nearrow$ $\quad$ $G \nearrow$

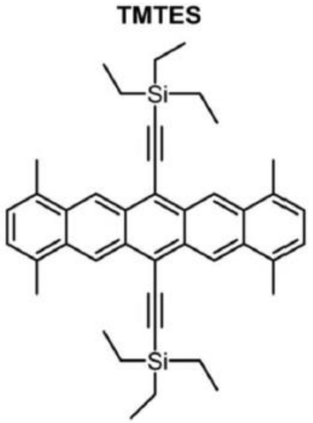
DEVICE ARCHITECTURE/TRANSPORT PROPERTIES
Organic Field Effect Transistors as X-Rays detectors

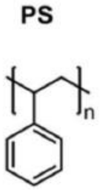
$$\boldsymbol{Photocurrent} = \boldsymbol{G} \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot \ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \boldsymbol{\mu}}{L^2} \cdot \boldsymbol{I_{CC}}$$

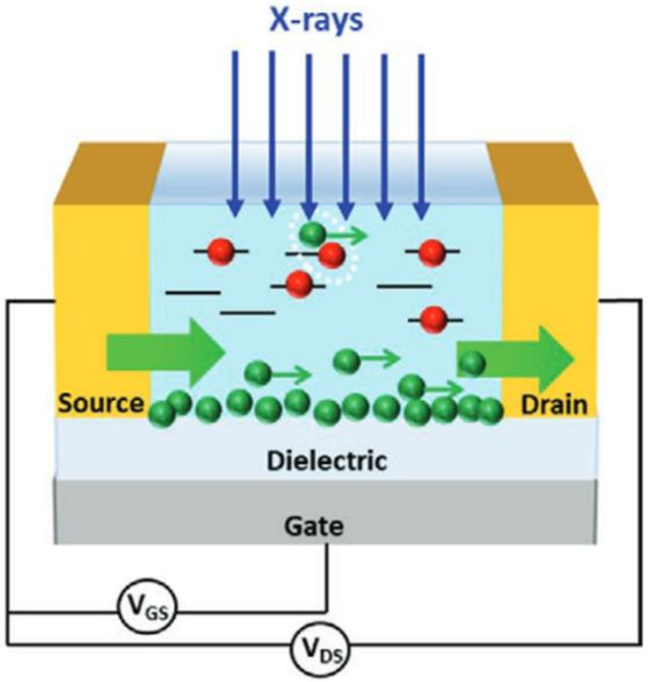
BAMS: Bar Assisted Meniscous Shearing Technique

BOTTOM GATE – BOTTOM CONTACTS OFETs

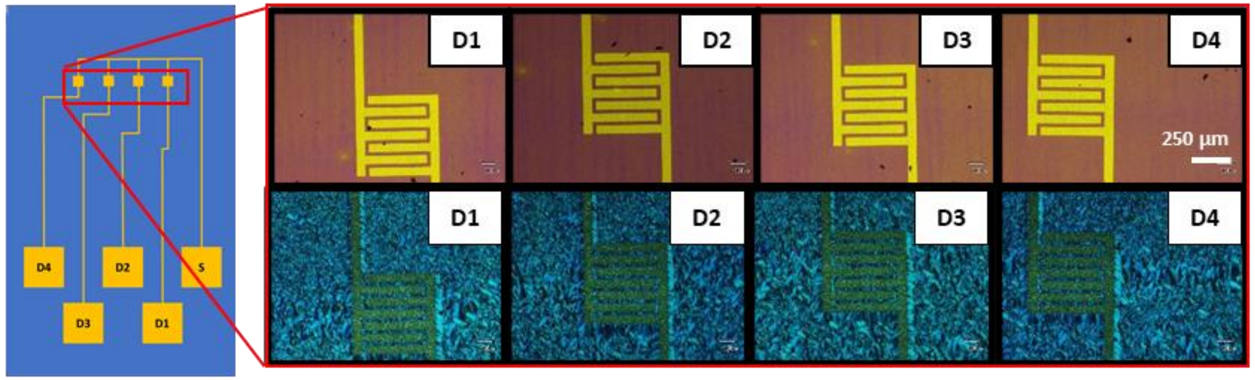




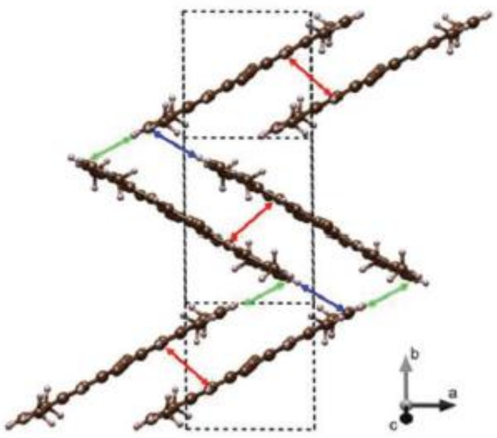




$\rho_0 \nearrow$ $G \nearrow$



TMTES - PII



Crystallization in herringbone motif

→ 2D electronic isotropy, more desirable for charge transport

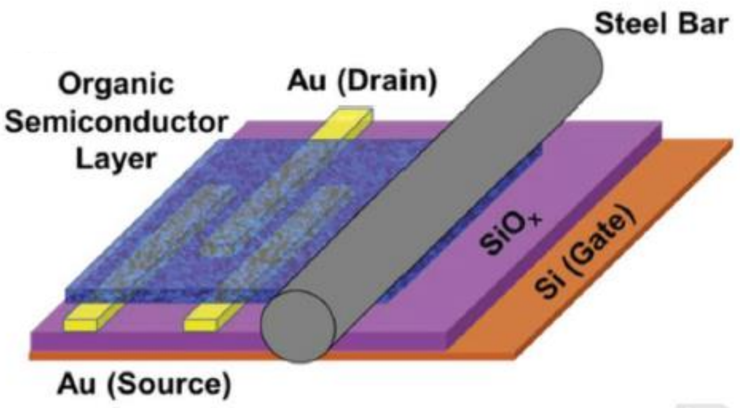
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

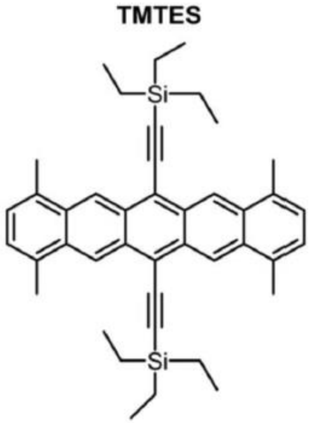
DEVICE ARCHITECTURE/TRANSPORT PROPERTIES
Organic Field Effect Transistors as X-Rays detectors

ToF-SIMS: Time-of-Flight Secondary Ion Mass Spectrometry

BAMS: Bar Assisted Meniscous Shearing Technique

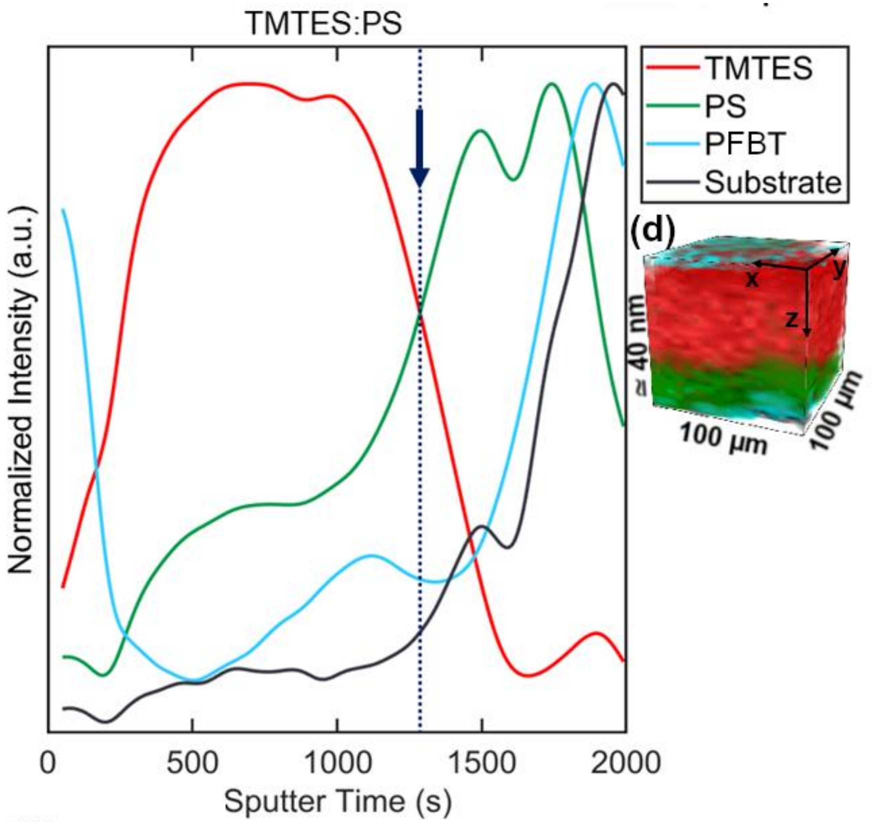
BOTTOM GATE – BOTTOM CONTACTS OFETs

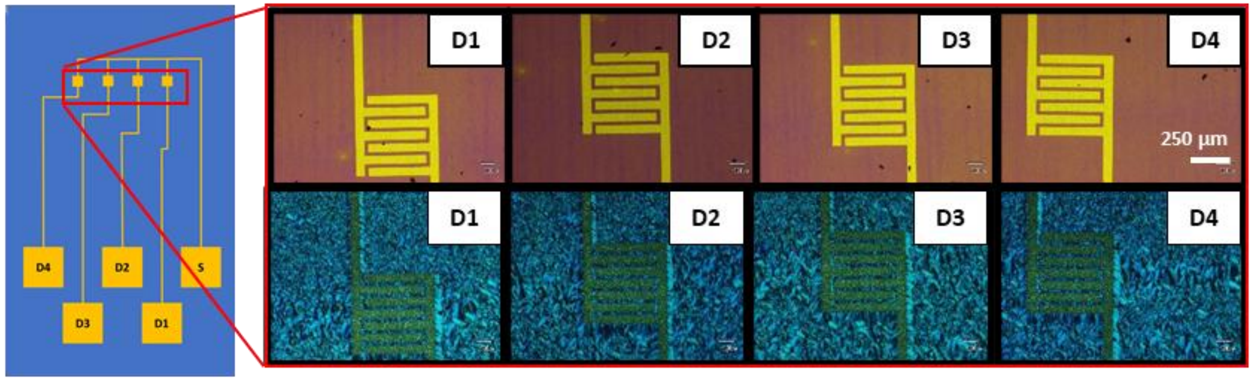




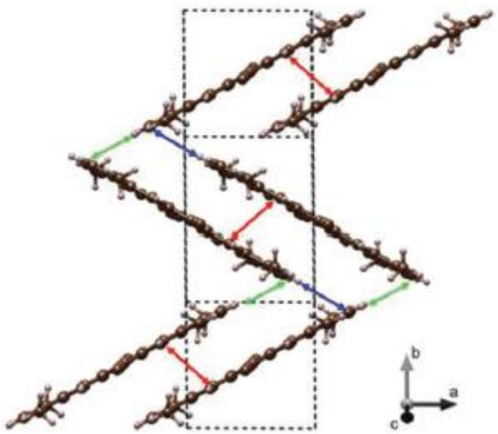
Majority Trap passivation at SiOx/OSC interface

TMTES:PS 2:1





TMTES - PII



Crystallization in herringbone motif

→ 2D electronic isotropy, more desirable for charge transport

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

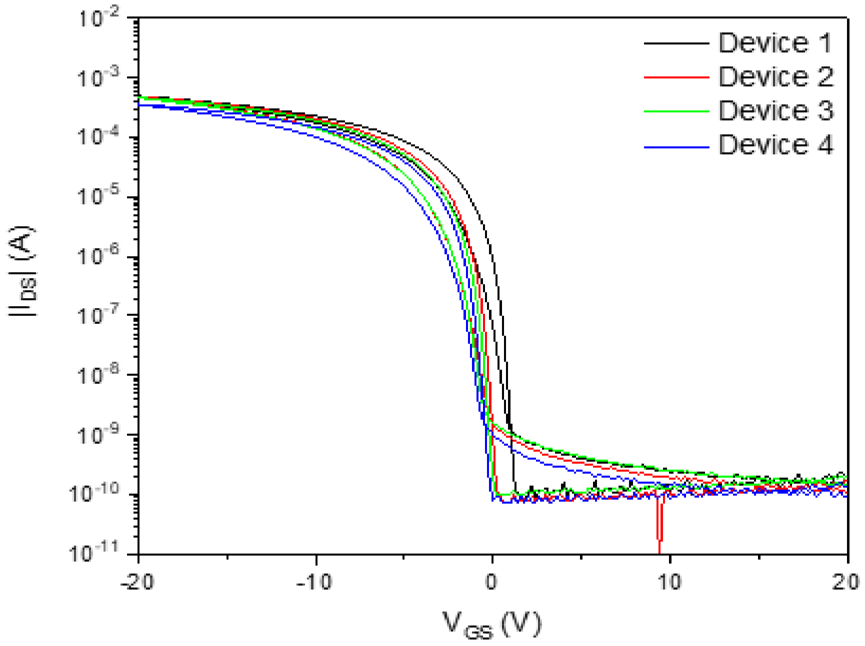
DEVICE ARCHITECTURE/TRANSPORT PROPERTIES
ROLE OF TRAP STATES: Dielectric/SC interface

High electronic performance and reproducibility

Lower trap density for holes

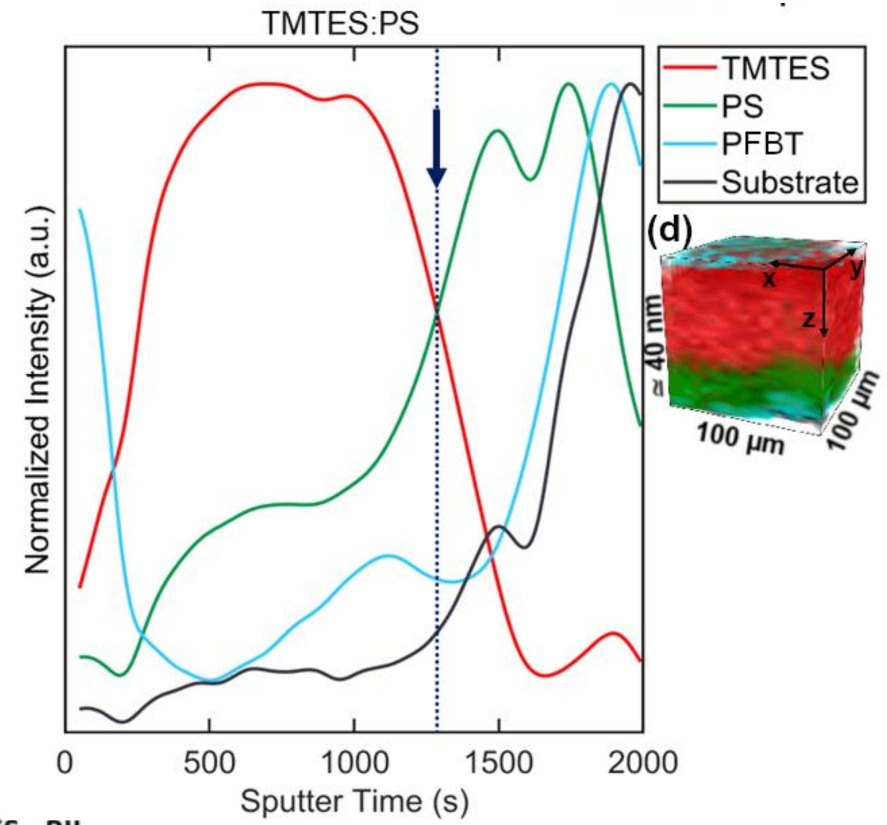
$(3.9 \pm 0.9)\times10^{11}$ eV^{-1} cm^{-2} with PS
$(6.2 \pm 1.1)\times10^{12}$ eV^{-1} cm^{-2} w/o PS

$\mu_{holes\text{-}FET} \approx 2.6 \pm 0.6$ cm^2 V^{-1} s^{-1}

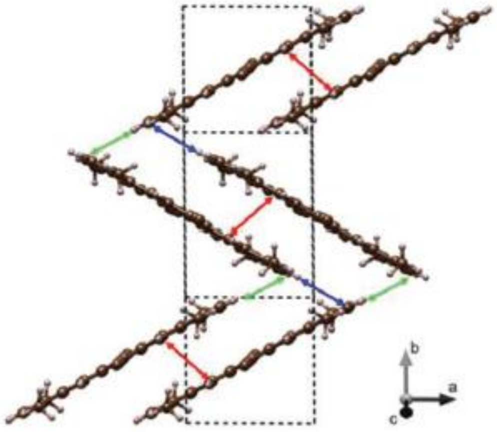


ToF-SIMS

Majority Trap passivation at SiOx/OSC interface



TMTES - PII



Crystallization in herringbone motif
→ 2D electronic isotropy, more desirable for charge transport

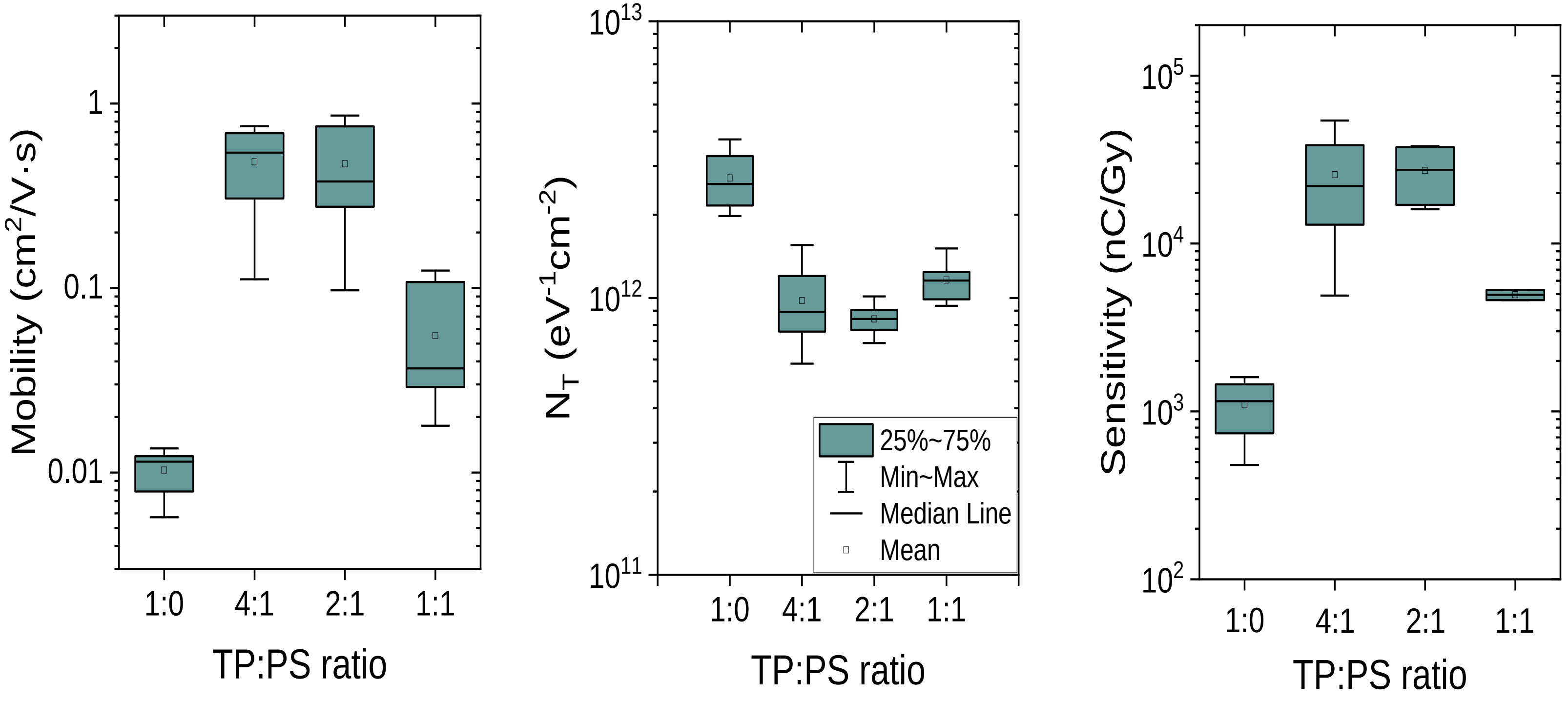
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DEVICE ARCHITECTURE/TRANSPORT PROPERTIES
ROLE OF TRAP STATES: Dielectric/SC interface

$$\mathbf{Photocurrent} = \boldsymbol{G} \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \boldsymbol{\mu}}{L^2} \cdot \boldsymbol{I_{CC}}$$

Mo-target X-ray tube 35 kV
dose rates in the range 5–55 mGy s^{-1}

BLENDS OSC:Polystyrene passivates the interface state with the dielectric → >> ***hole mobility***



$$S = \frac{\Delta I}{dr}$$

$$S \propto G$$

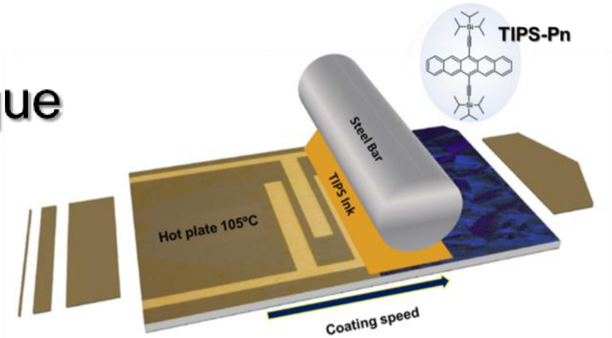
μ ↗ **S** ↗

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

FILM MORPHOLOGY: ROLE of GRAIN BOUNDARIES

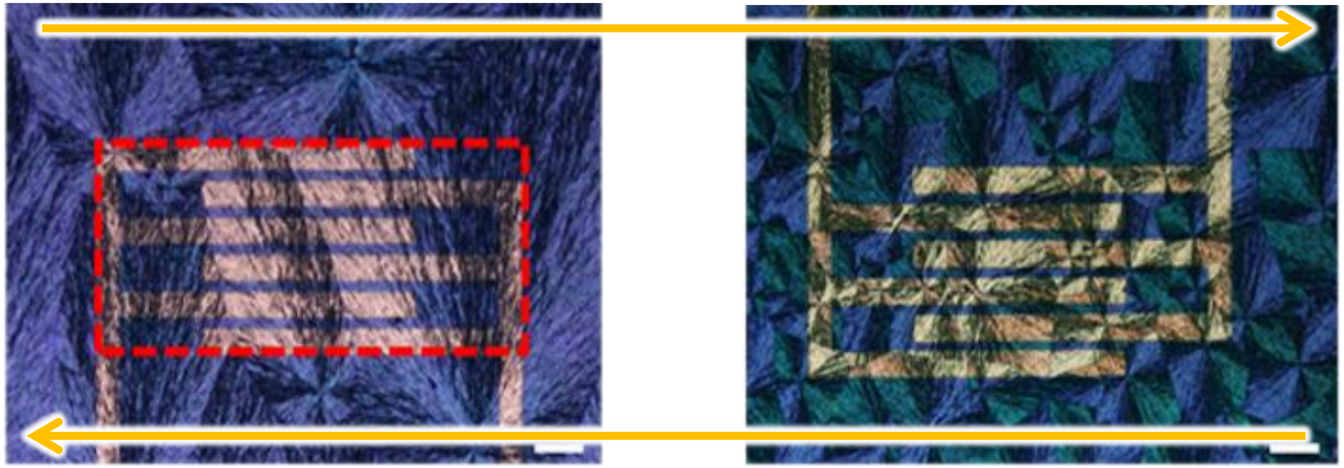
$$\textbf{Photocurrent} = G \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \mu}{L^2} \cdot I_{CC}$$

BAMS: Bar Assisted Meniscus Shearing deposition technique



Tuning **deposition parameters** ⇨ Tuning **morphology**

INCREASING THE **DEPOSITION SPEED**



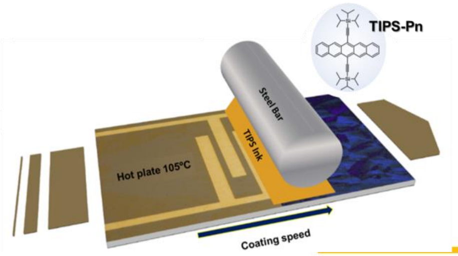
INCREASING THE **GRAIN DIMENSIONS**

I. Temiño, et al *Nat. Commun.* **11**, 1–10 (2020).

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

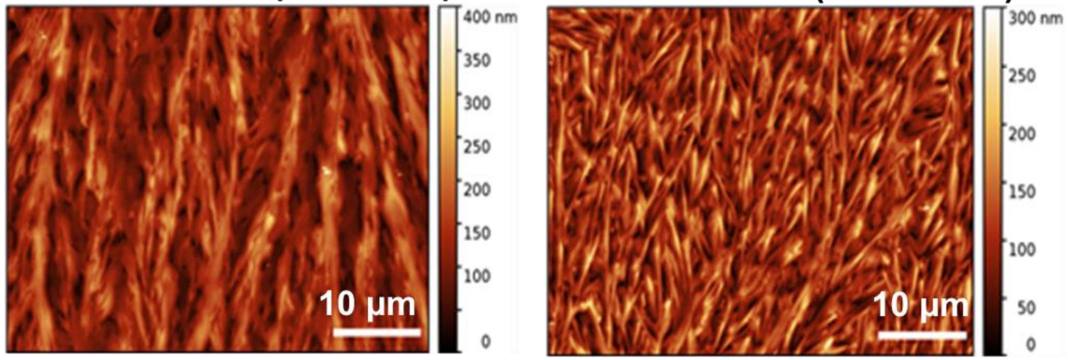
FILM MORPHOLOGY: ROLE of GRAIN BOUNDARIES

$$\textit{Photocurrent} = G \cdot I_{CC} = \frac{\tau_r}{\tau_t} \cdot I_{CC} = \frac{\alpha}{\gamma} \cdot \left[\alpha \cdot \ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} \cdot \frac{V \cdot \mu}{L^2} \cdot I_{CC}$$

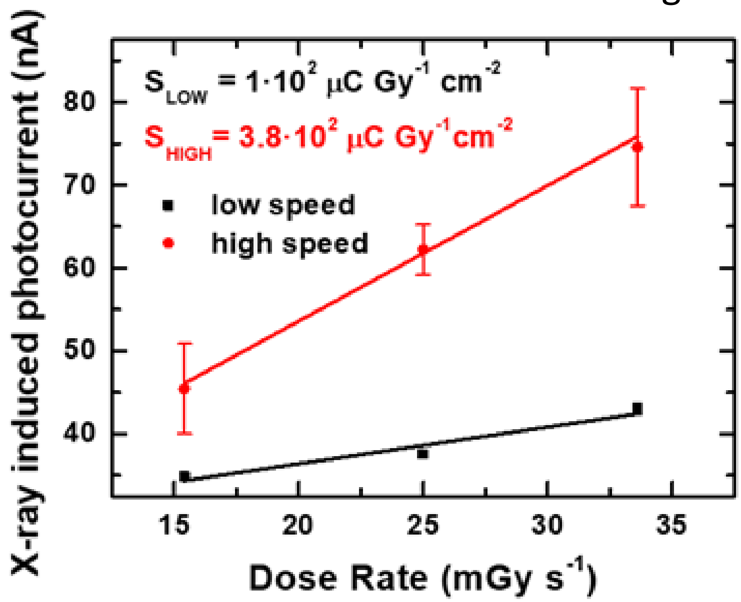


INCREASING THE **DEPOSITION SPEED**

LOW SPEED (4 mm s^{-1}) | HIGH SPEED (28 mm s^{-1})



Mo-target X-ray tube 35 kV
dose rates in the range 5–55 mGy s^{-1}



$$S = \frac{\Delta I}{dr}$$

Deposition Speed (mm s^{-1})	Grain Size (μm^2)	Thickness (nm)	Mobility ($cm^2\ V^{-1}\ s^{-1}$)	N_T ($10^{12}\ eV^{-1}\ cm^{-2}$)	Sensitivity ($\mu C\ Gy^{-1}\ cm^{-2}$)
Low (4)	17 ± 3	70 ± 20	(2.5 ± 0.7) $\cdot 10^{-2}$	1.7 ± 0.4	(1.0 ± 0.2) $\cdot 10^{2}$
Standard (10)	6 ± 2	80 ± 20	(1.7 ± 0.5) $\cdot 10^{-2}$	1.8 ± 0.5	(3.8 ± 0.1) $\cdot 10^{2}$
High (28)	6 ± 2	120 ± 50	(2.4 ± 0.6) $\cdot 10^{-2}$	1.6 ± 0.4	(3.8 ± 1.2) $\cdot 10^{2}$

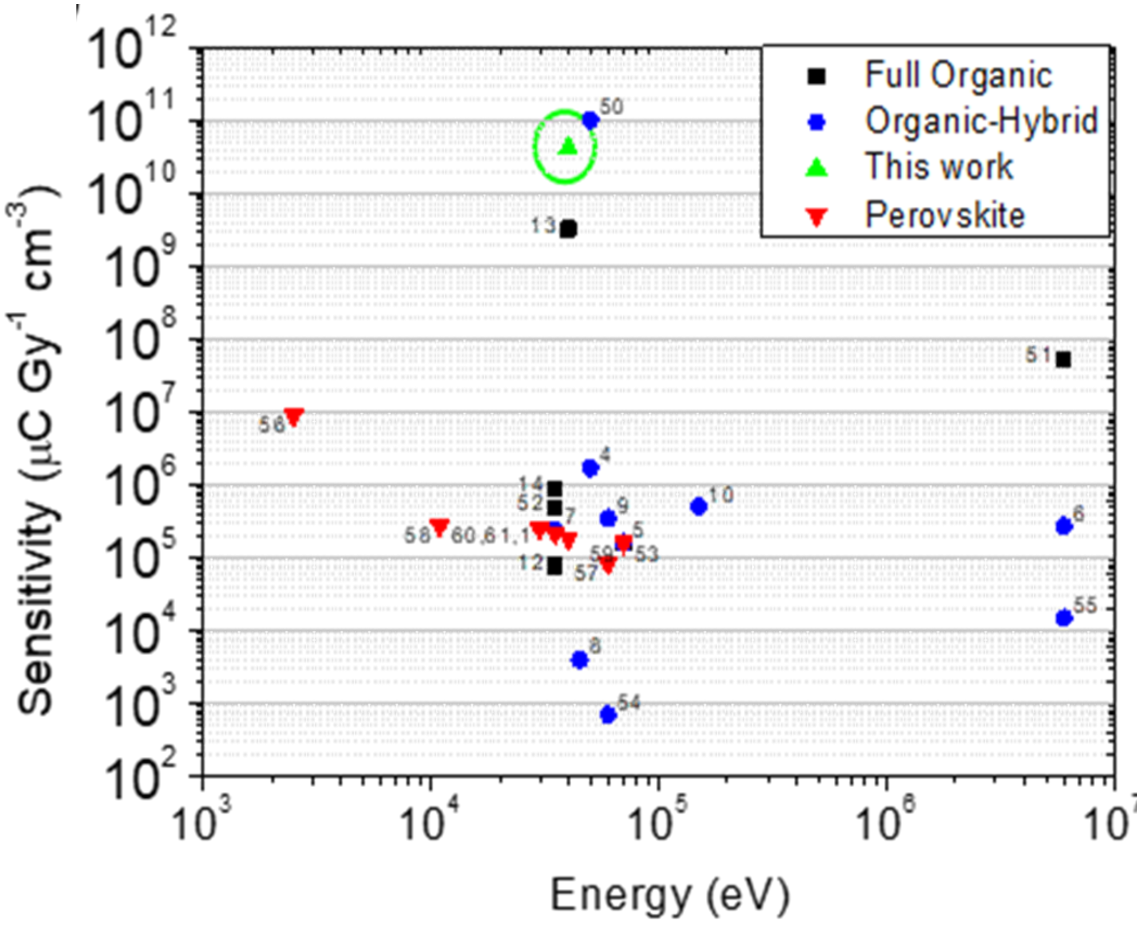
Grain size ↓ **S** ↑

I. Temiño, et al *Nat. Commun.* **11**, 1–10 (2020).

CHEMICAL TAILORING/TUNING TRANSPORT PROPERTIES

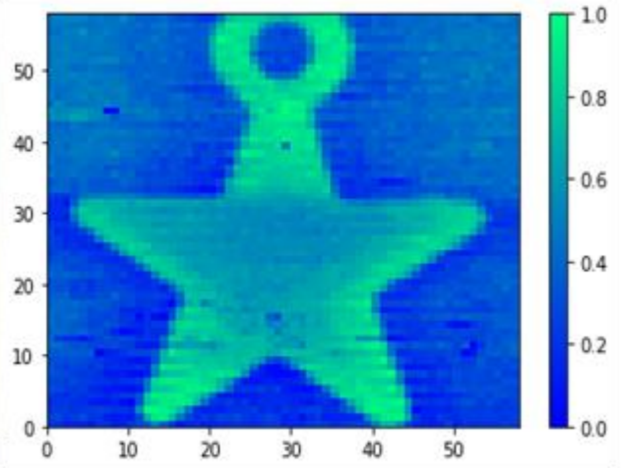
Tamayo, et al, Adv. Electron. Mater., 2200293 (2022).

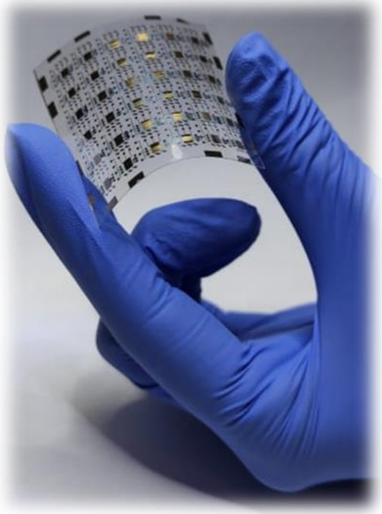
Sensitivity = 4 x 10^{10} μC Gy^{-1} cm^{-3}



SYRMEP beamline @ ELETTRA synchrotron

Elettra Sincrotrone Trieste





Transfer on flexible large area substrates

Fratelli et al., Adv. Mater. Technol. ***2023****, 2200769*

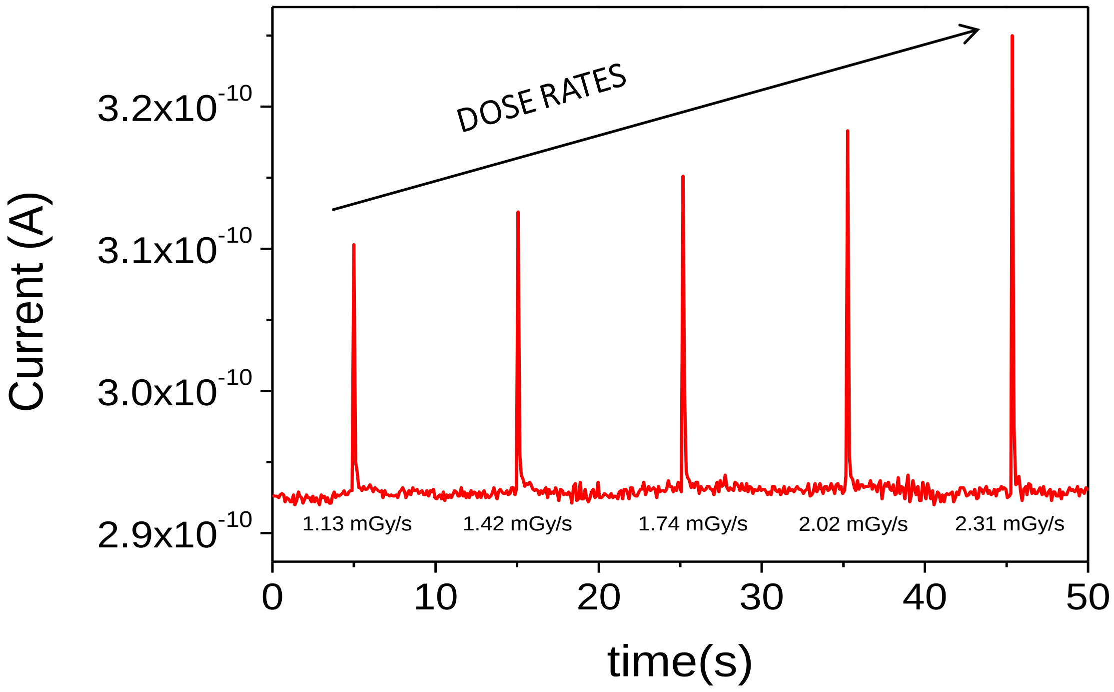
Beam monitoring for medical application

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DIRECT RADIATION DETECTION BY ORGANIC THIN FILMS:
VALIDATION IN REAL–LIFE MEDICAL APPLICATION

DENTAL RADIOGRAPHY

Intraskan DC (dental radiography system, Skaneray Europe srl.)



Limit Of Detection = 8 μGy

typical **dose delivered** during dental diagnostic

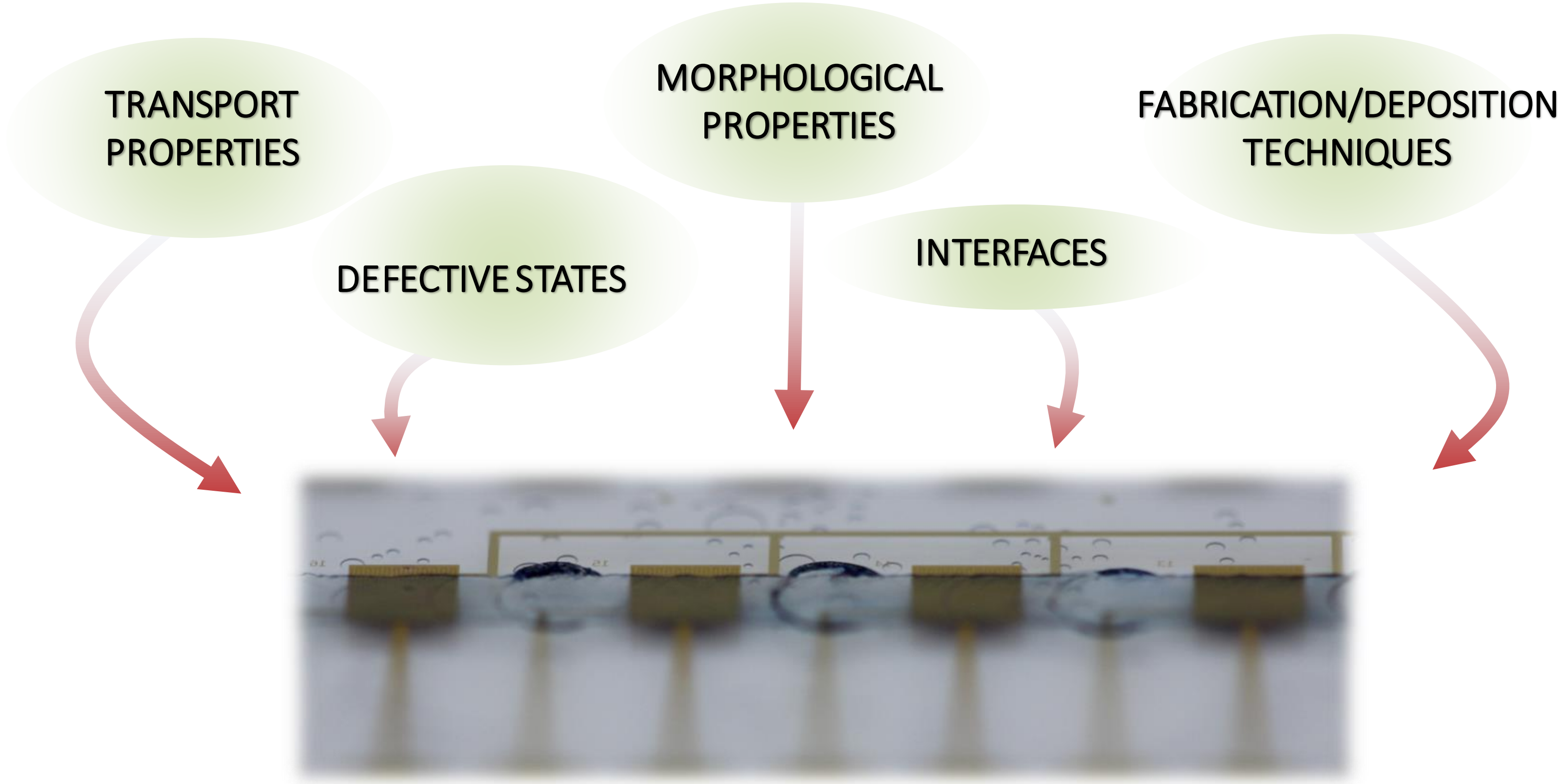
100 ms

Typical **frame rates** of a commercial dental radiographic apparatus

L. Basiricò, et. al. Frontiers in Physics. ***8****, 11 (2020).*

CONCLUSIONS

Fully organic, lightweight, printed radiation detectors based on **high performance printed Organic Field Effect Transistors,** can effectively and **directly detect ionizing radiation with ultrahigh sensitivity**



ACKNOWLEDGMENTS

https://site.unibo.it/semiconductor-physics/en

People of Fraboni's Group working on this research @ Department of Physics and Astronomy – DIFA UNIBO

Prof. Beatrice Fraboni
Dr. Andrea Ciavatti
Dr. Ilaria Fratelli



COLUMBIA UNIVERSITY

Columbia University
CLUE LAB and Prof. Ioannis Kymissis

University of Kentucky
Prof. John Anthony

Elettra Sincrotrone Trieste

ELETTRA Sincrothron, Trieste
Dr. Giuliana Tromba
Dr. Diego Dreossi

ROMA TRE UNIVERSITÀ DEGLI STUDI

ICMAB INSTITUT DE CIÈNCIA DE MATERIALS DE BARCELONA — EXCELENCIA SEVERO OCHOA

ICMAB-CSIC
Dr. Marta Mas-Torrent

FIRE

Flexible organic Ionizing Radiation dEtectors
INFN (Italian Insitute for Nuclear Physics)
(2019-2022)

INFN

RELOAD

RivELatOri innovativi per cure ADroterapiche

cdp — Fondazione CARIPLO — TUTE SERVARE MUNIFICE DONARE • 1816

(2024-2025)

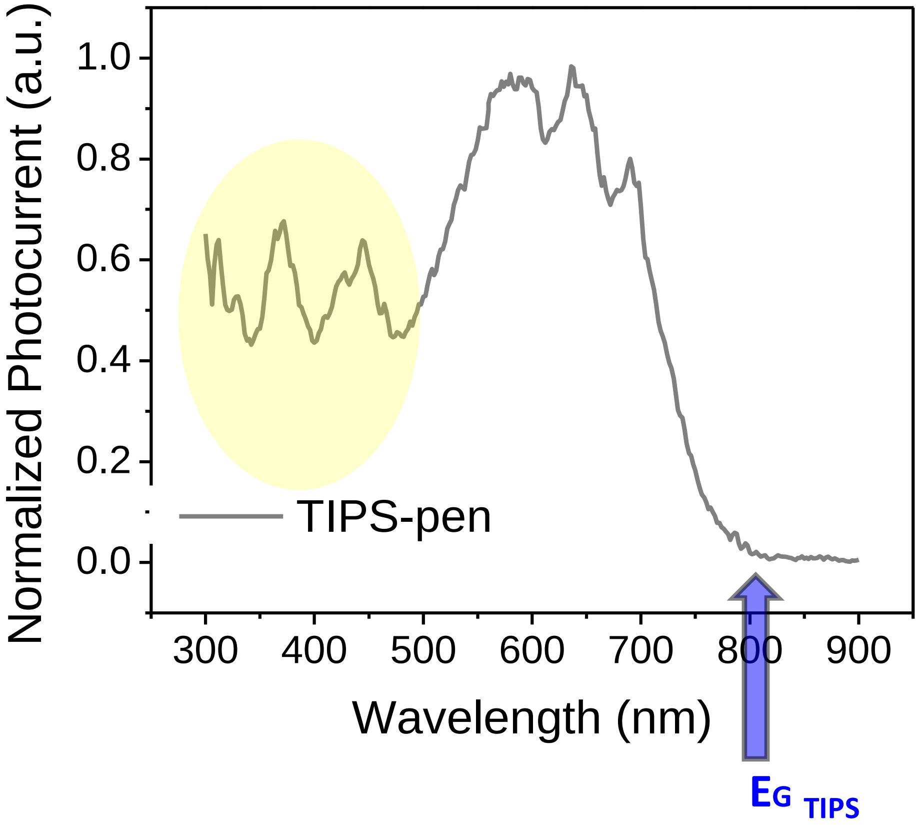
BACKUP SLIDES

ROLE OF PHOTOACTIVE TRAPS STATES:
Photocurrent Spectroscopy Optical Quenching

→ **experimentally assess and identify the trap states** which activate the photoconductive gain effect in organic thin film based devices

Fratelli et al., Adv. Mater. Technol. ***2023****, 2200769*

→ Simultanous irradiation with **X-rays** (W-target X-150 kVp) and **visible photons**



I. Kymissis et al., *IEEE Trans. Electron Devices* **57**, 380–384 (2010).

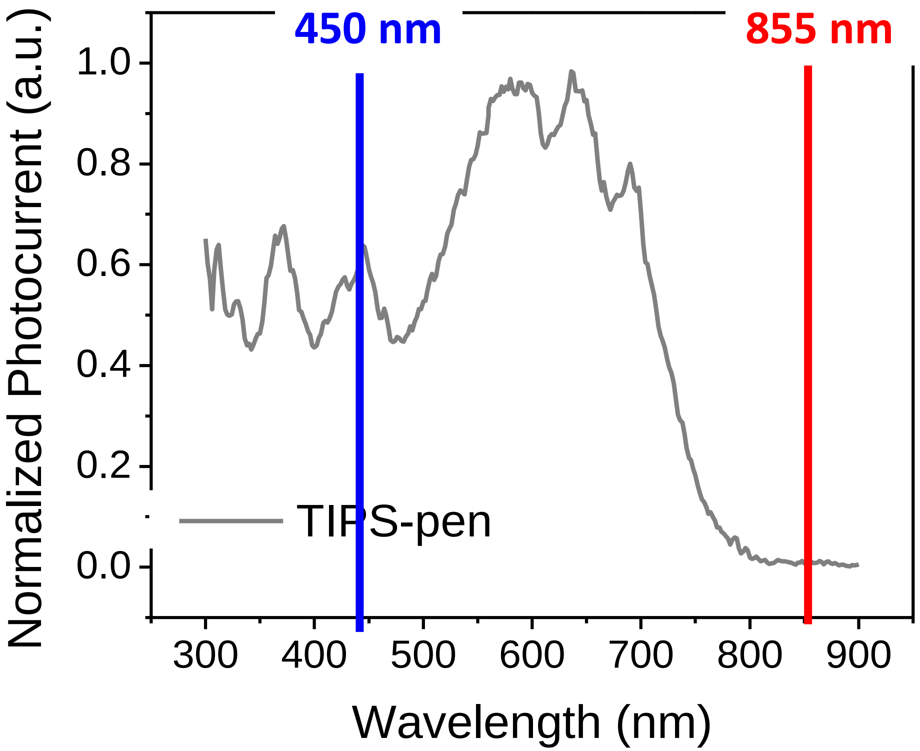
→ **electron traps** in organic transistors, enhance the photoconductivity for photons in the range [350 – 480] nm

ROLE OF PHOTOACTIVE TRAPS STATES:
Photocurrent Spectroscopy Optical Quenching

→ **experimentally assess and identify the trap states** which activate the photoconductive gain effect in organic thin film based devices

Fratelli et al., Adv. Mater. Technol. ***2023****, 2200769*

→ Simultanous irradiation with **X-rays** (W-target X-150 kVp) and **visible photons**

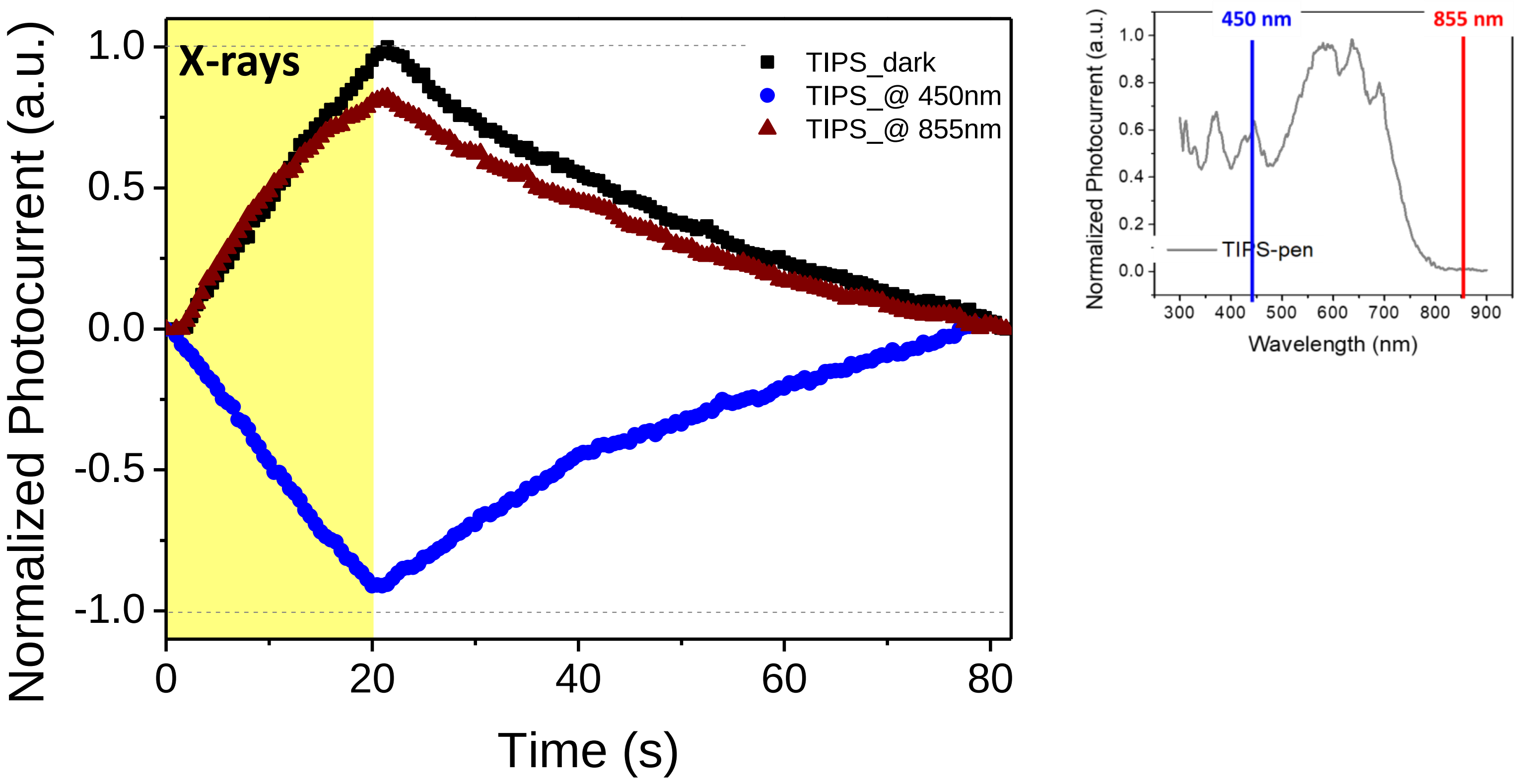


I. Kymissis et al., *IEEE Trans. Electron Devices* **57**, 380–384 (2010).

→ **electron traps** in organic transistors, enhance the photoconductivity for photons in the range [350 – 480] nm

LED (450 nm and 855 nm) have been selected because they correspond to two different and crucial position in the Photocurrent spectrum.

ROLE OF PHOTOACTIVE TRAPS STATES:
Photocurrent Spectroscopy Optical Quenching

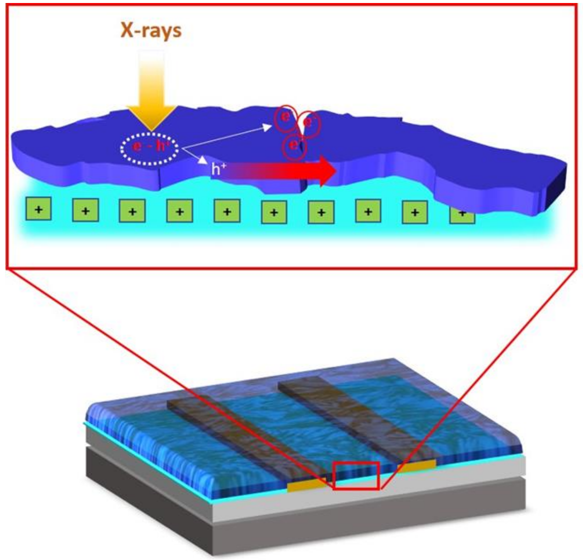


855 nm light (below bandgap) have no effect on X-ray response.

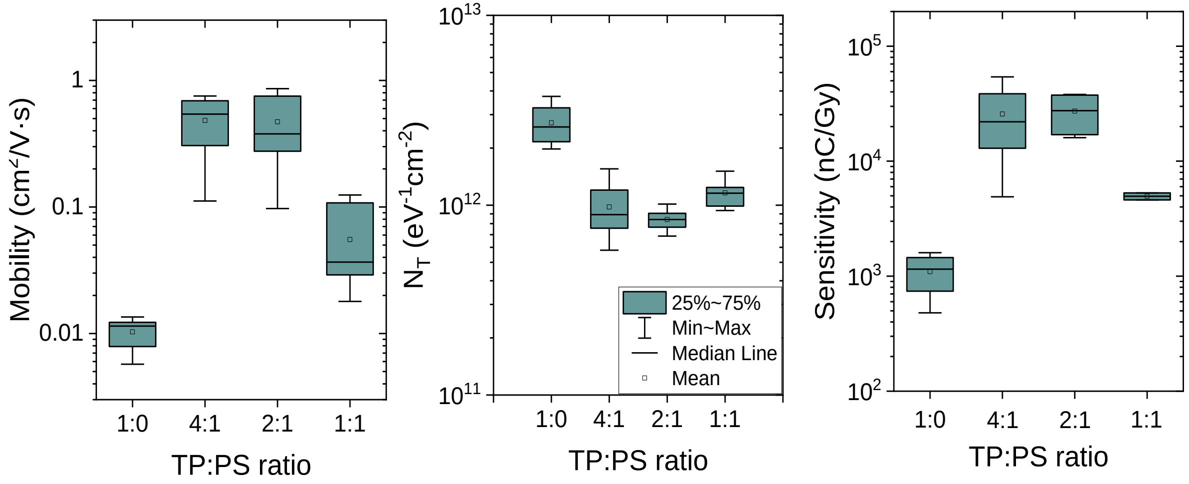
450 nm light fills and saturates e- traps that become inactive→ completely **quench the PC gain** X-ray induced signal→ decrease of current → X-rays facilitate a recombination between the electron already trapped and the hole already present/generated.

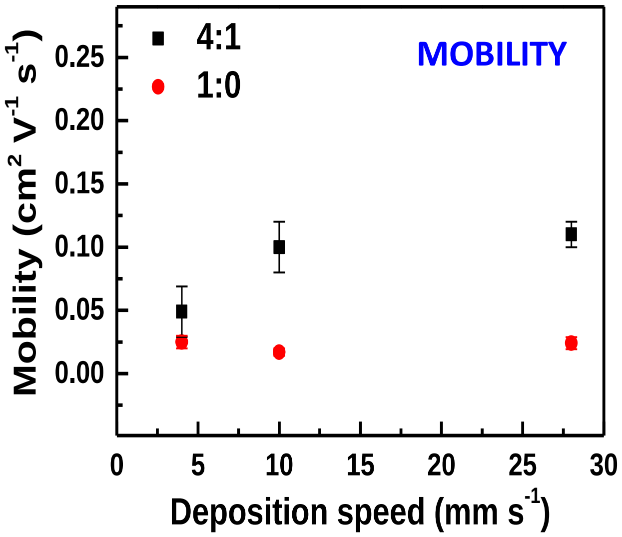
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

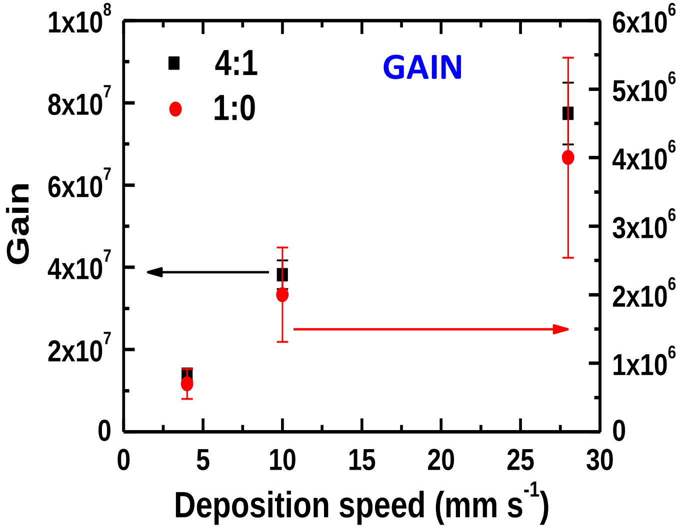
CONTROL OF ELECTRICALLY ACTIVE DEFECTS: INTERFACE STATES



BLENDS TIPS:Polystyrene passivates the interface state with the dielectric → >> ***hole mobility***

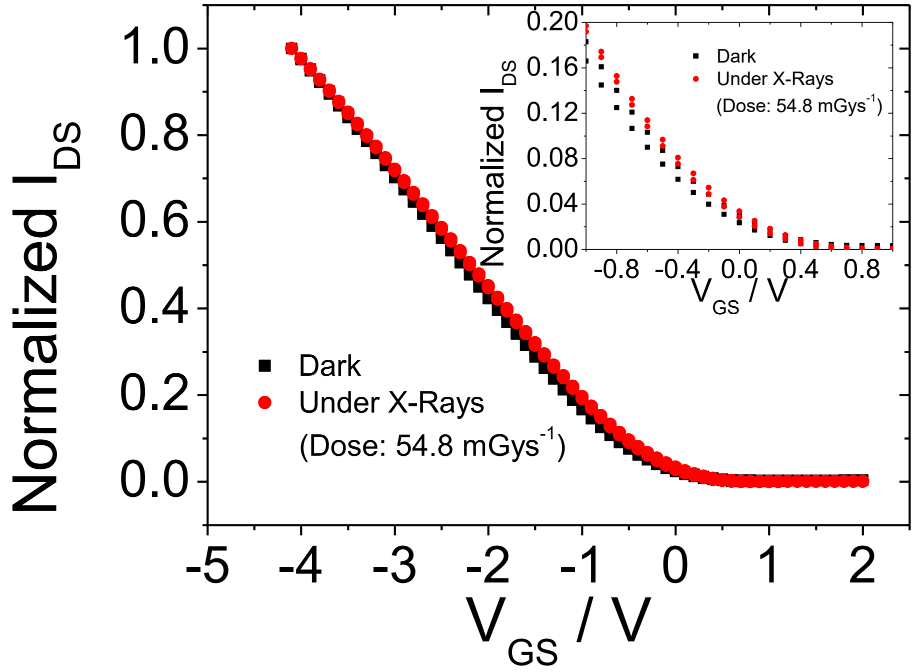


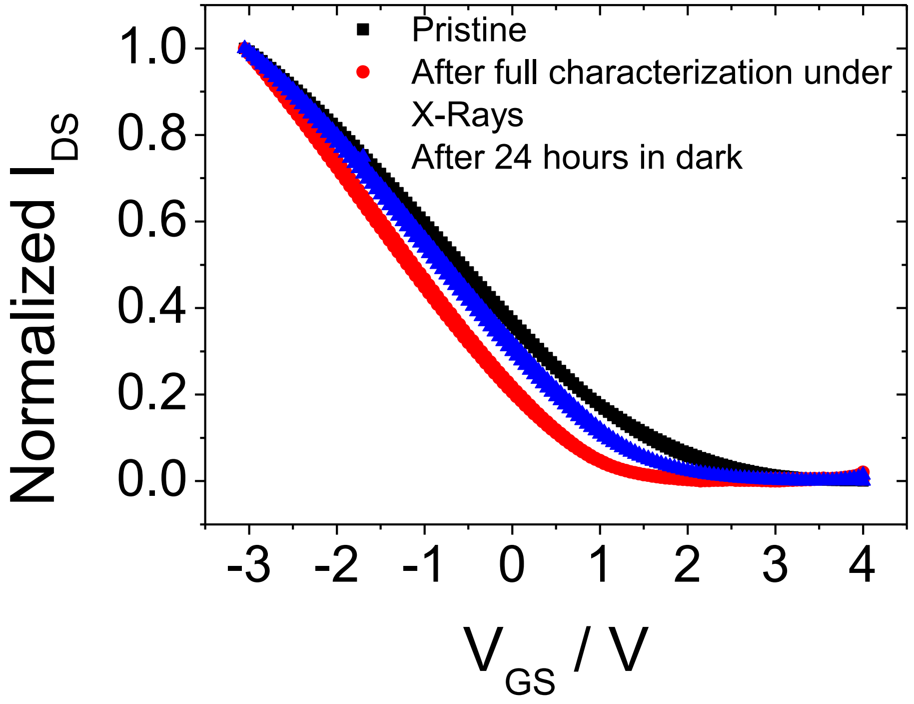




similar mobility values, BUT the photocurrent gain follows the grain size variation with deposition speed (e.g. ***electron/interface traps***).

Radiation Hardness (TIPS-pentacene)



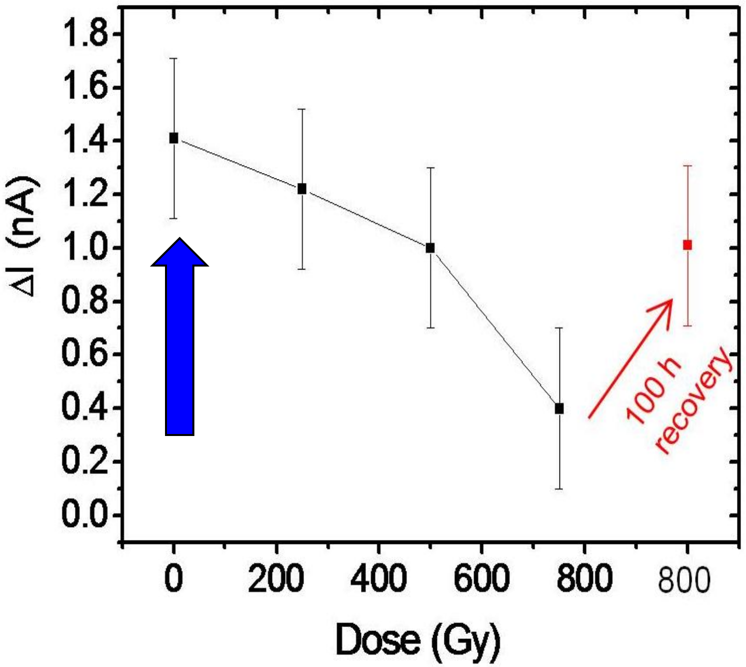


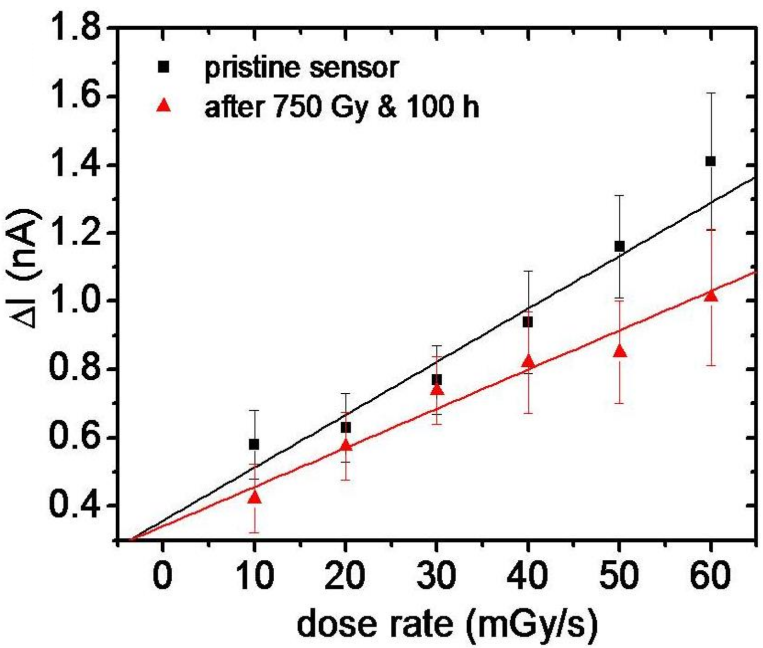
transfer characteristic curves :
before (black squares) and during (red circles) X-ray exposure at a dose rate of 54.8 mGy s-1

transfer characteristic **in pristine state (black squares), after X-ray exposure with a total dose of 160 Gy (red dots)** and **after 24 h kept in dark (blue stars).**

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Radiation hardness under X-rays:
organic thin film (TIPS- pentacene) - II





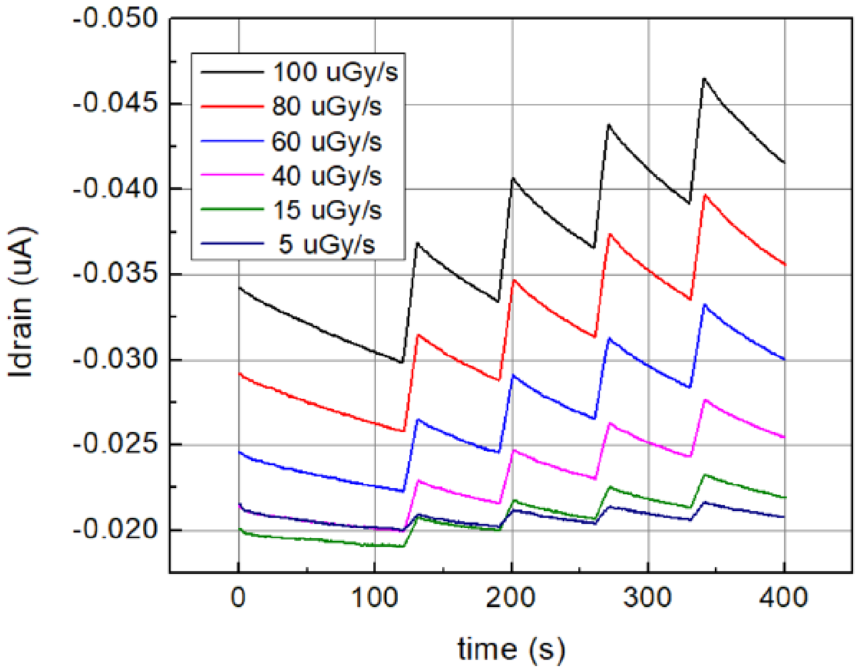
Four steps of 200Gy X-ray irradiation (35KV Mo tube). **Total dose 800Gy**

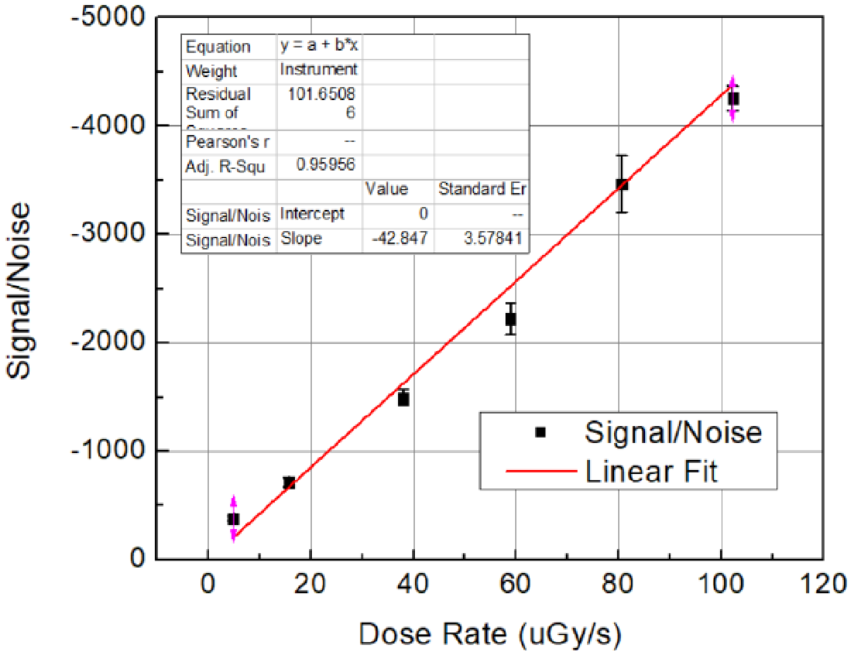
Total irradiation dose for medical diagnostic detectors: 5-10 Gy/year

Recovery allowed only after the last step (100h in the dark)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Limit of Detection



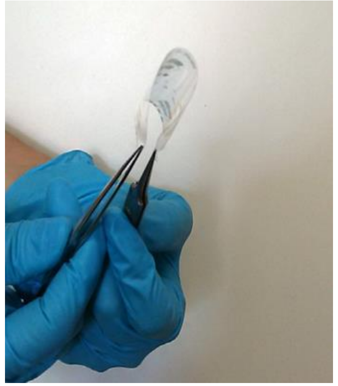


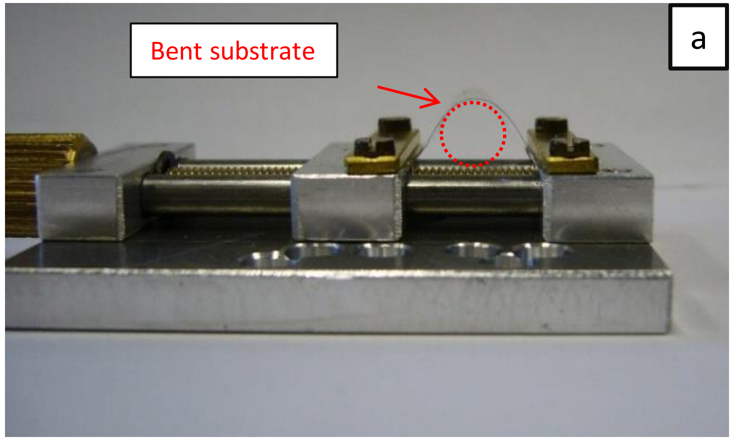
Measured LoD: 5 µGy s^{-1}
Extracted: 0.8 µGy s^{-1}

Typical dose rate values presently used in medical diagnostics: 5.5 µGy s^{-1}

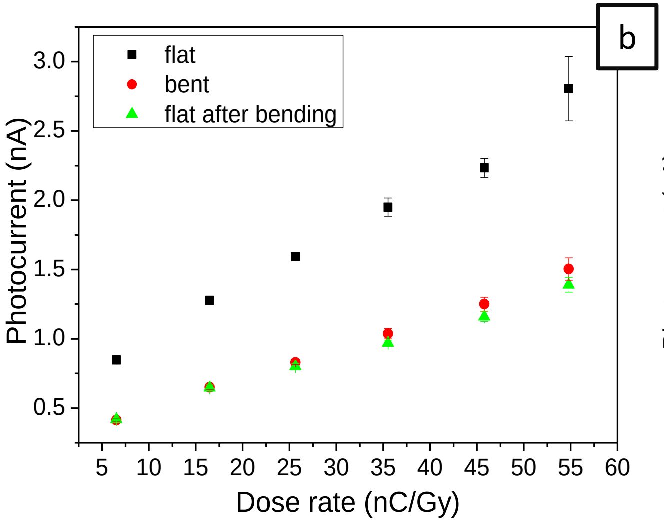
standard radiographic examinations have average effective total doses in the range: 0.005–10 mGy

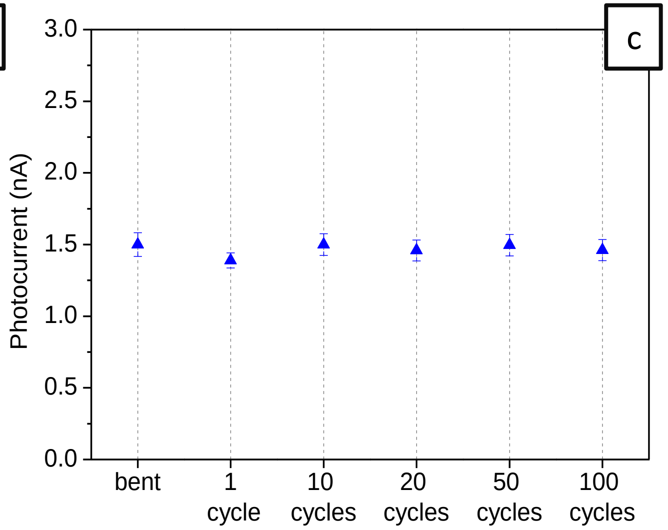
Mechanical flexibility





bending radius of 0.3 cm
→ Conformable to human body

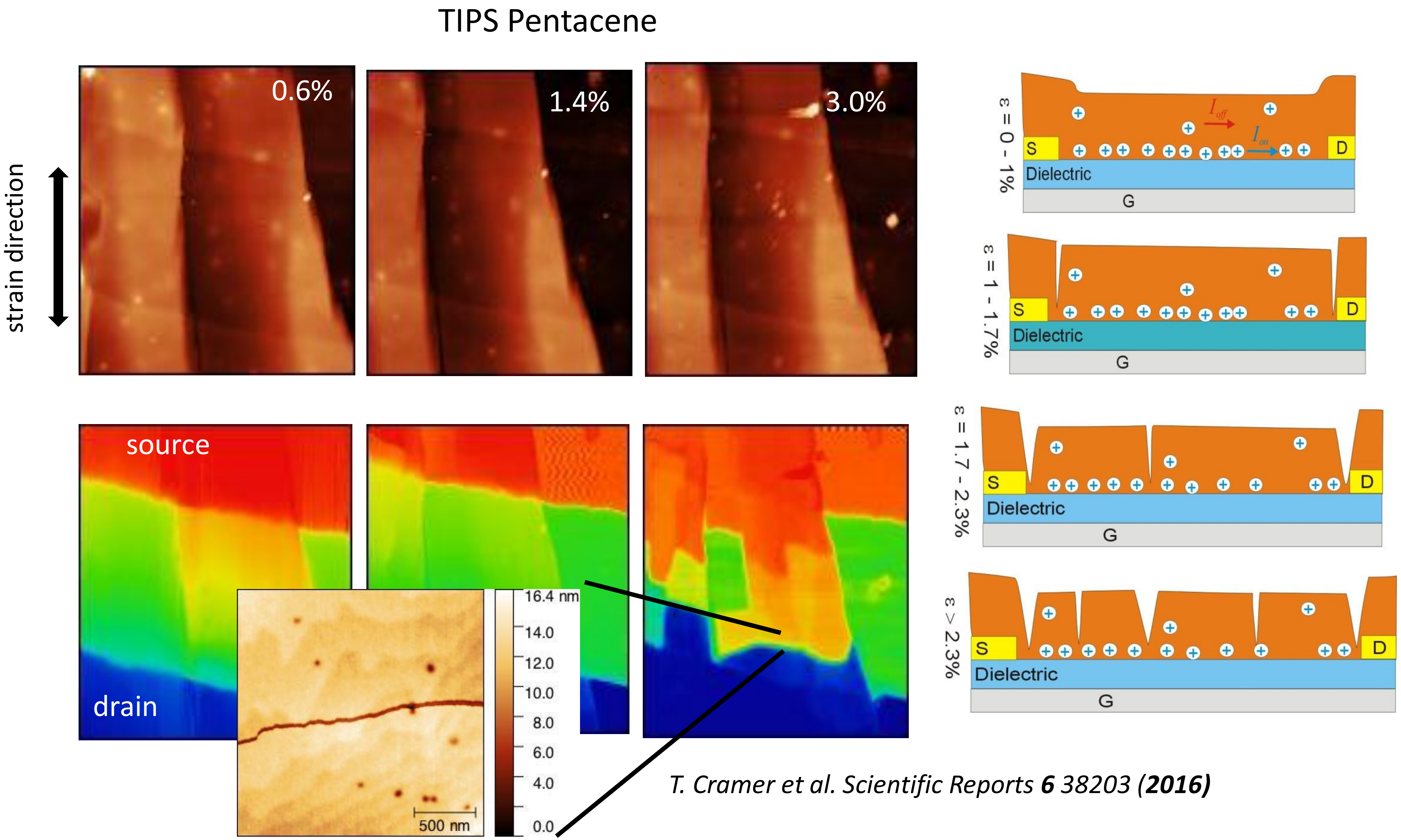




- Decrease of about 50% after first bending
- Stability over 100 bending cycles.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

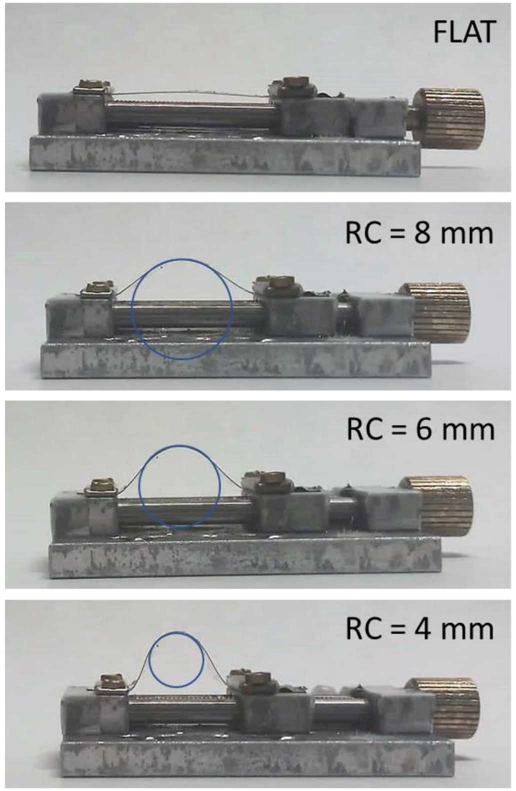
KPFM on strained transistors: nanocrak formation

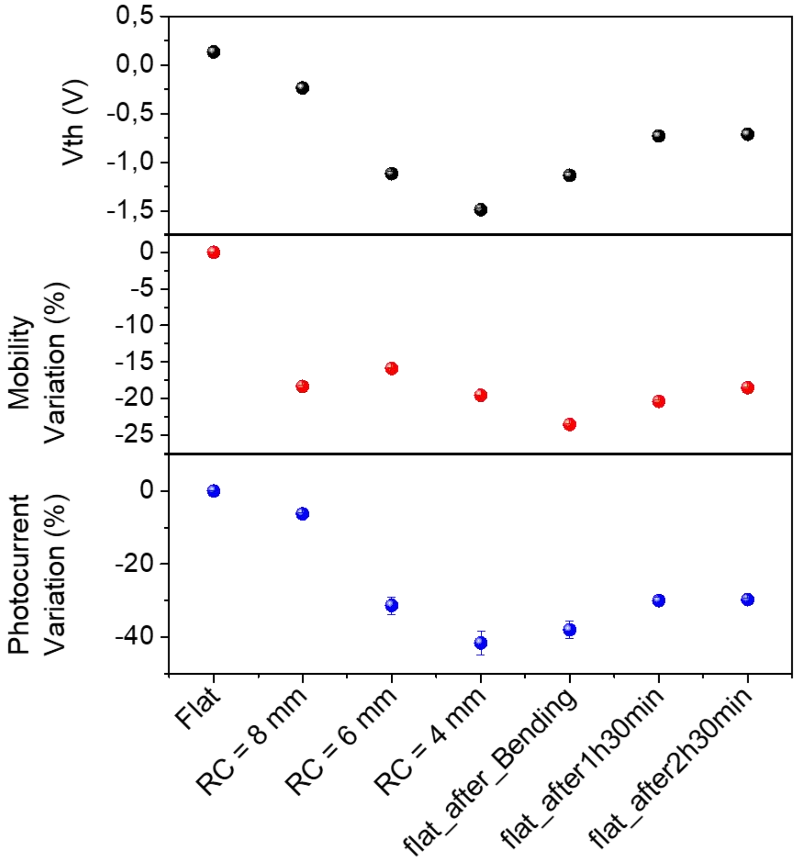


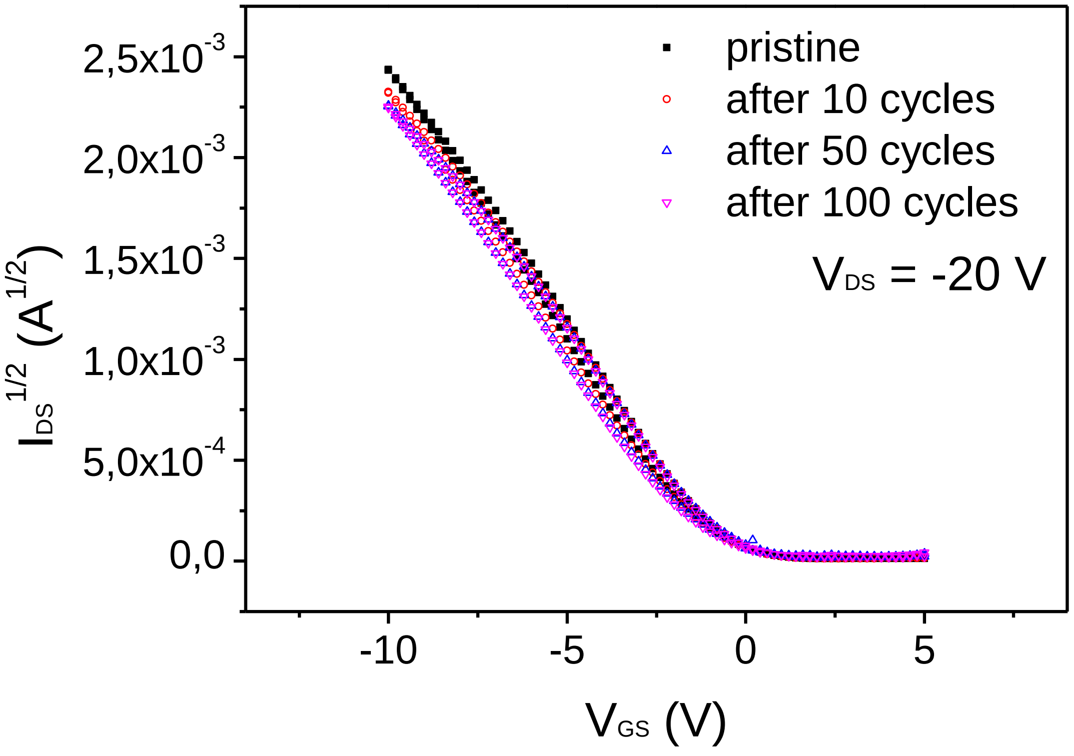
*T. Cramer et al. Scientific Reports **6** 38203 (**2016**)*

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Mechanical flexibility





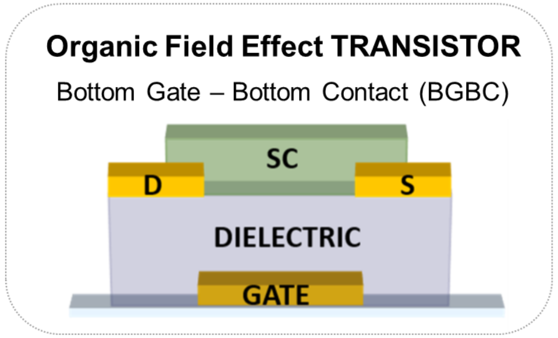


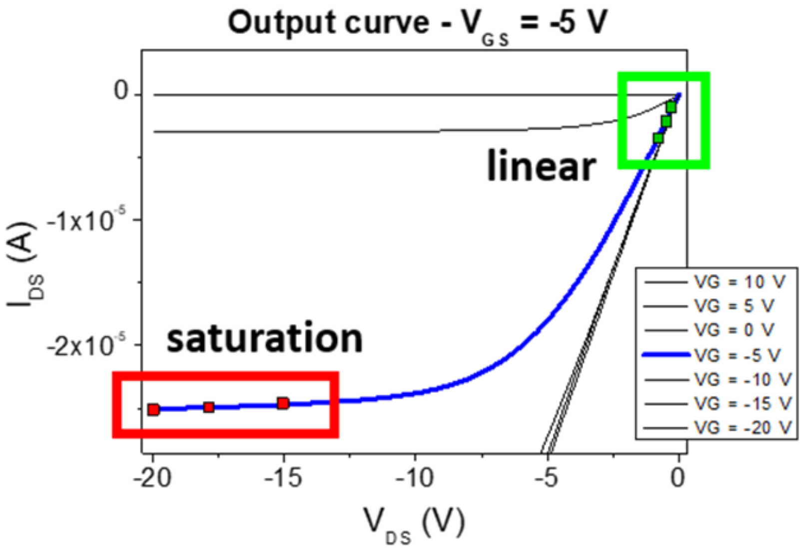
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

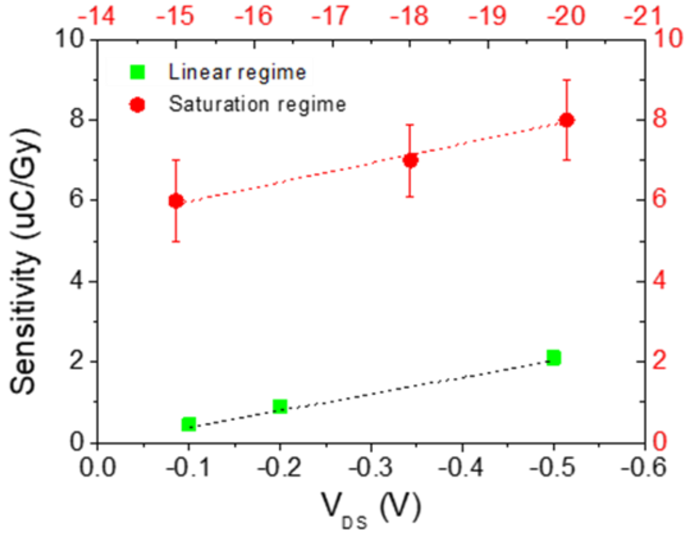
Printed organic detector architectures

OFETs advantages

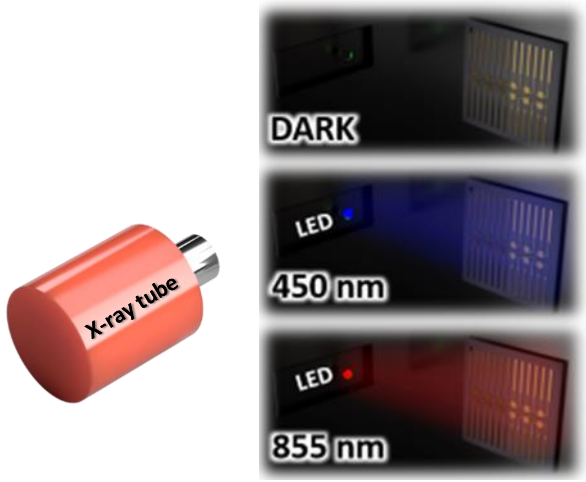
- ✓ Multiparametric device
- ✓ V_{GS} → switch ON/OFF, allow to address the pixel
- ✓ V_{DS} → tuning of the sensitivity

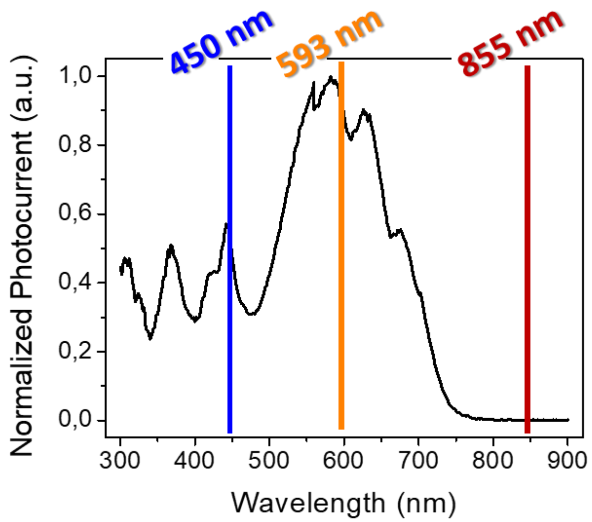






Role of photoactive traps states





<u>Quenching of photoconductive gain by visible light</u>

LED (450, 593 and 855 nm) have been selected because they correspond to three different and crucial position in the Photocurrent spectrum.

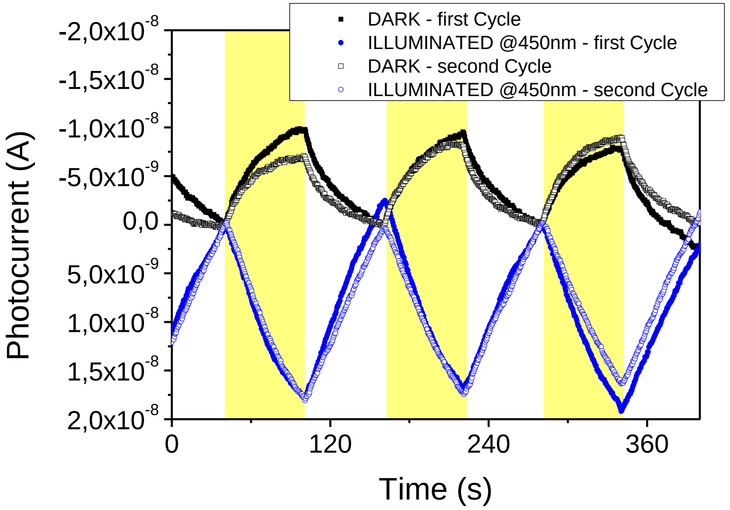
855 nm light (below bandgap) have no effect on X-ray response.

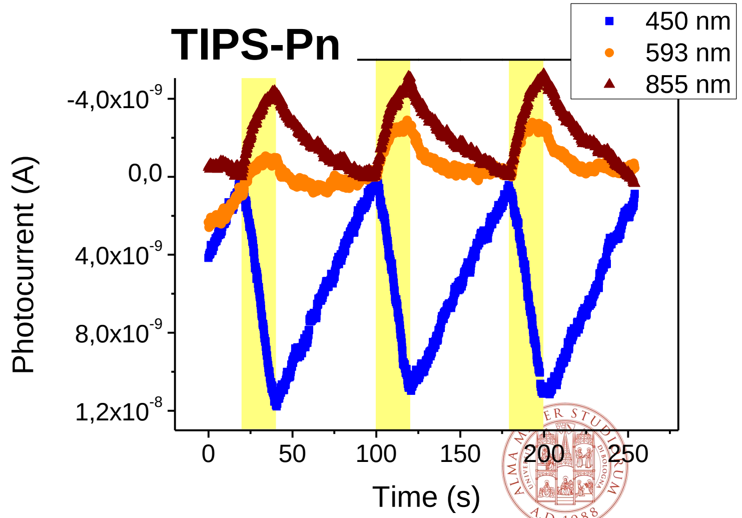
590 nm light only partially reduce the X-ray response (absorption of visible photons above band gap, correlated to a large conductivity increase and a decrease in the X-ray signal.to-noise ratio)

450 nm light completely quench the X-ray induced signal→ decrease of current → X-rays facilitate a recombination between the electron already trapped and the hole already present/generated.

<u>I. Kymissis et al., *IEEE Trans. Electron Devices* **57**, 380–384 (2010).</u>

→ electron traps in organic transistors, enhance the photoconductivity for photons in the range [350 – 480] nm





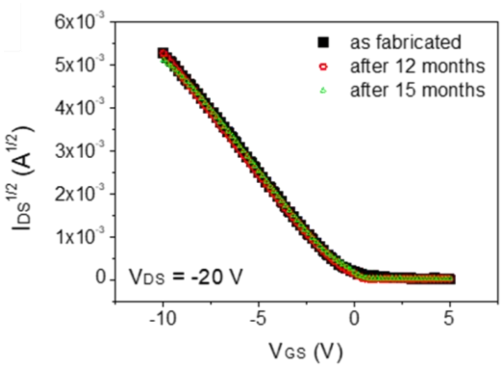
I. Fratelli et al., in press AdvMatTech (2022)

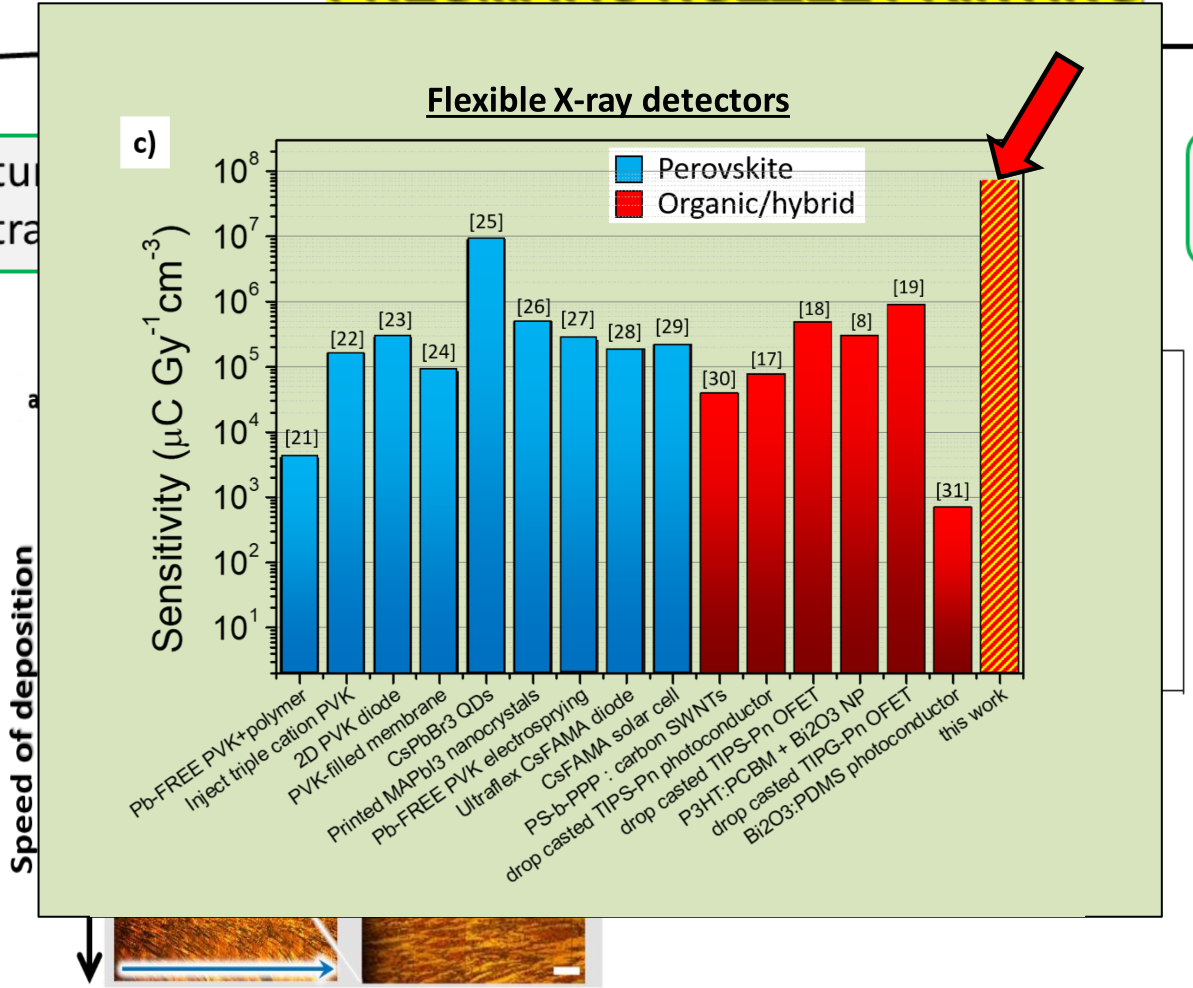
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

CONTROL STRATEGIES OF DEVICE PARAMETERS

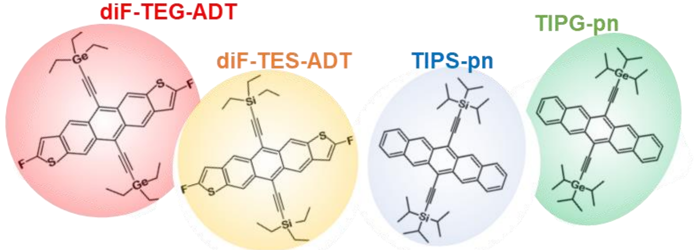
PNEUMATIC NOZZLE PRINTING

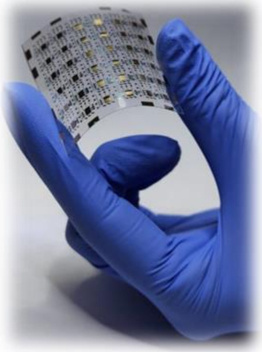
Transistor architectur
onto **FLEXIBLE** substra





Enhancing the absorption rate by **Chemical tailoring**

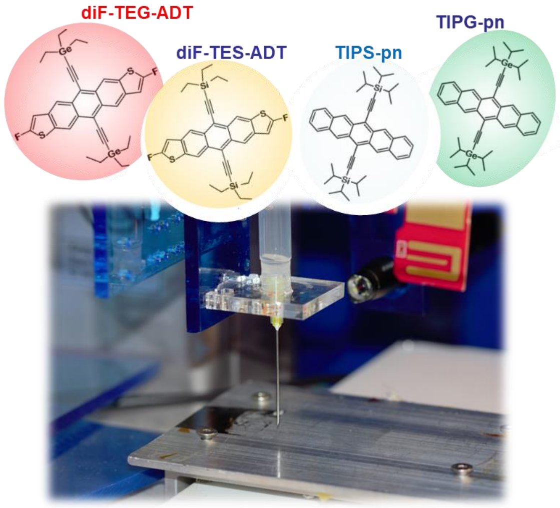




ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

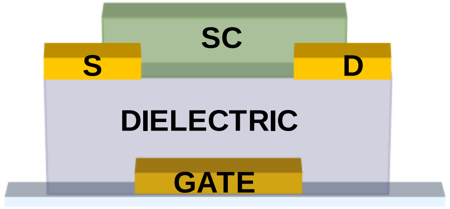
I. Fratelli et al., in press AdvMatTech (2022)

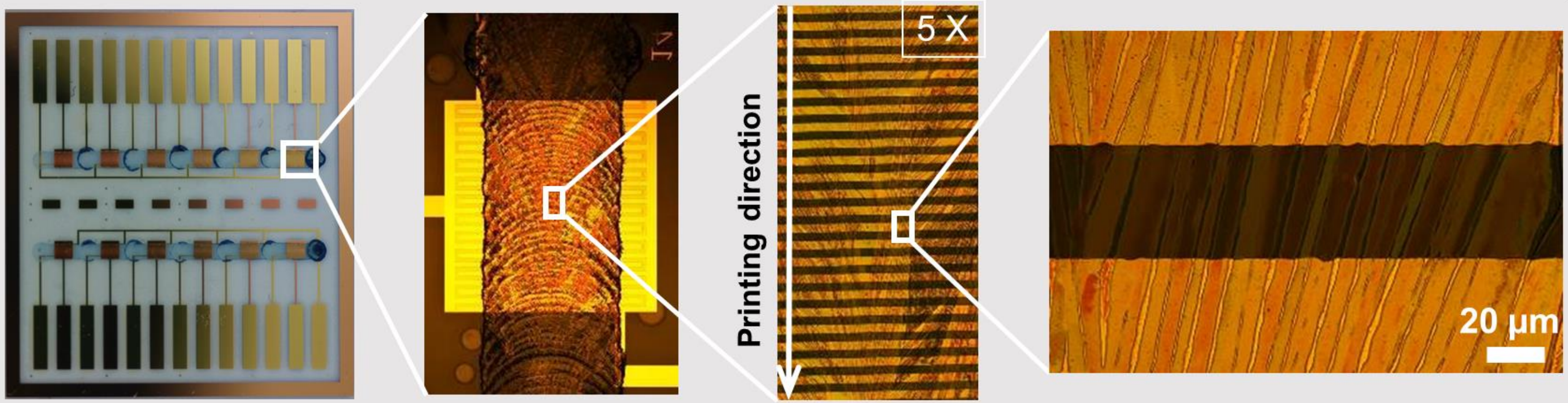
DEPOSITION TECHNIQUE: PNEUMATIC NOZZLE PRINTING



Microcrystalline structure
Very packed films
Thickness = [100-200] nm
Width = varies depending on the deposition parameters

Bottom Gate – Bottom Contacts OFETs



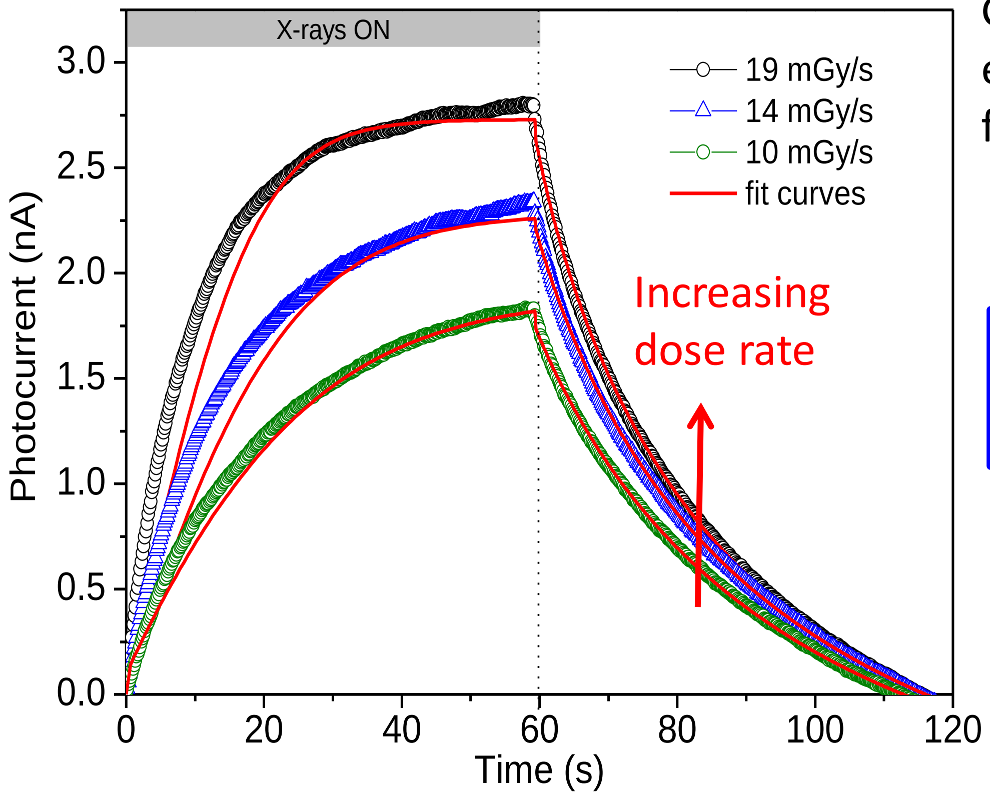


PNEUMATIC NOZZLE PRINTING

- **Transistor** architecture onto **FLEXIBLE** substrate
- Full control of the **MORPHOLOGY**
- Improvement of the **Transport properties**
- Enhancing the absorption rate by **Chemical tailoring**

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Photoconductive Gain effect



Dynamics of X-ray response

Device: W = 48 mm, L = 30 µm, bias 0.2 V Synchrotron 17 keV X-ray beam

Good agreement with the saw-tooth shape experimental data, using a single set of fitting parameters

G = photoconductive gain

$$G = \frac{\tau_r}{\tau_t} = \frac{29.4}{1.1 \times 10^{-3}} = 2.6 \times 10^4$$

Transit time

$$\tau_t = \frac{L^2}{V\mu} = 1.1 \text{ ms}$$

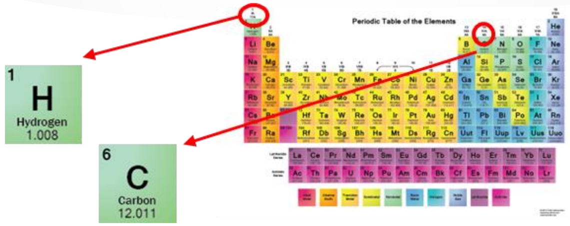
Carrier lifetime

$$\tau_r = \frac{\alpha}{\gamma}\left[\alpha \ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}} = 29.4 \text{ s}$$

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ORGANIC SEMICONDUCTORS FOR IONIZING RADIATION DETECTION - ADVANTAGES

Chemical composition formed by
LOW-Z ELEMENTS



✓ **HUMAN TISSUE EQUIVALENCE**

✓ Medical Applications

X **POOR ABSORPTION**

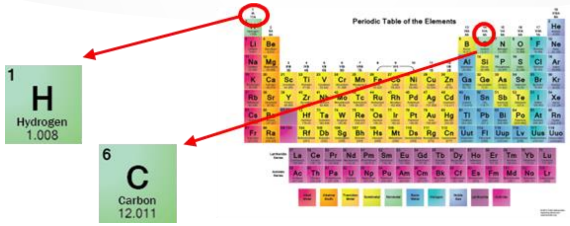
EXTERNAL QUANTUM EFFICIENCY ≈ [0.01 – 0.001] %

✓ High Radiation Hardness

✓ **But still high Sensitivity!** Why?

ORGANIC SEMICONDUCTORS FOR IONIZING RADIATION DETECTION - ADVANTAGES

Chemical composition formed by **LOW-Z ELEMENTS**



✓ **HUMAN TISSUE EQUIVALENCE**

✓ Medical Applications

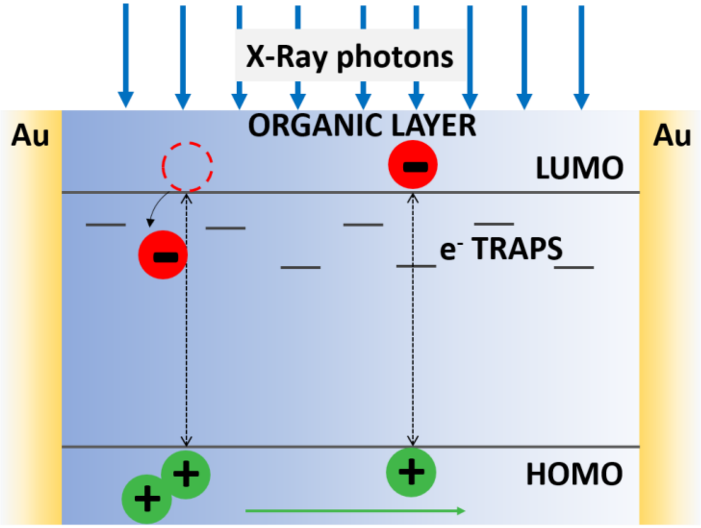
X **POOR ABSORPTION**

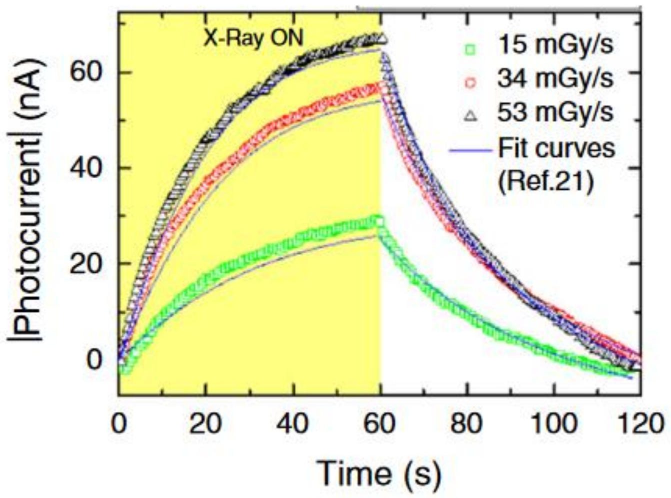
EXTERNAL QUANTUM EFFICIENCY ≈ [0.01 – 0.001] %

✓ High Radiation Hardness

✓ **But still high Sensitivity!** Why?

PHOTOCONDUCTIVE GAIN EFFECT





$$G = \frac{\tau_r}{\tau_t}$$

Carriers lifetime

$$\tau_r = \frac{\alpha}{\gamma}\left[\alpha \ln\left(\frac{\rho_0}{\rho_X}\right)\right]^{\frac{1-\gamma}{\gamma}}$$

Transit time

$$\tau_t = \frac{L^2}{V\mu}$$

VERY HIGH
INTERNAL QUANTUM EFFICIENCY

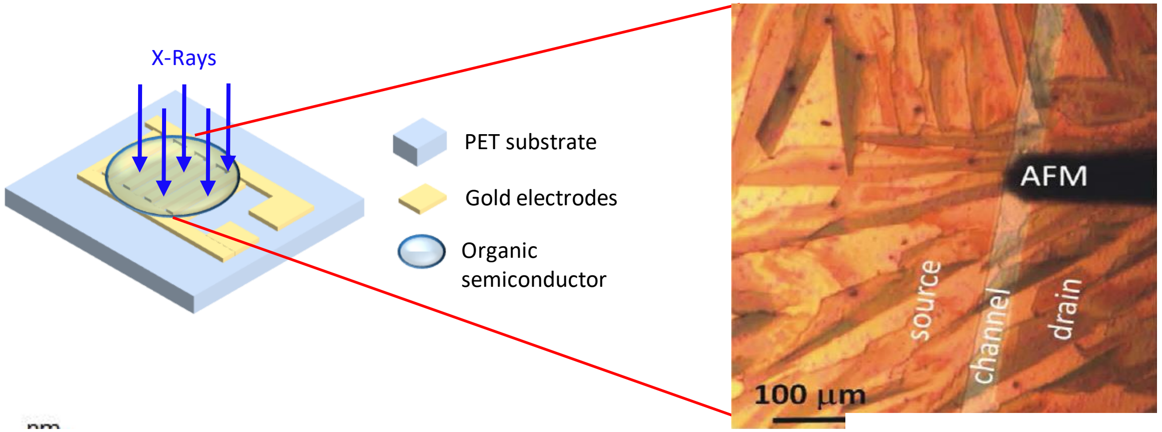
→ COLLECTION EFFICIENCY

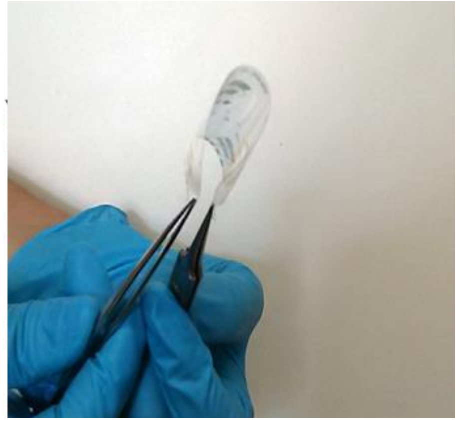
→ GAIN up to 10^7

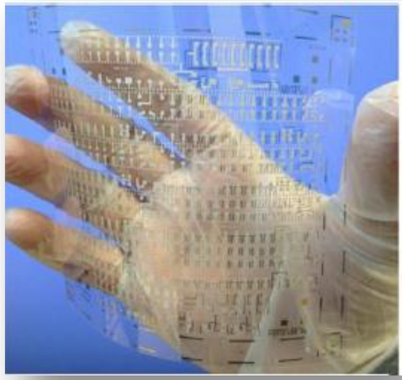
L. Basiricò et al., Nat. Commun., vol. 7, 13063, 2016

I. Temiño, L. Basiricò et al., Nat. Commun., vol. 11, 2136, 2020

FLEXIBLE ORGANIC RADIATION SENSORS



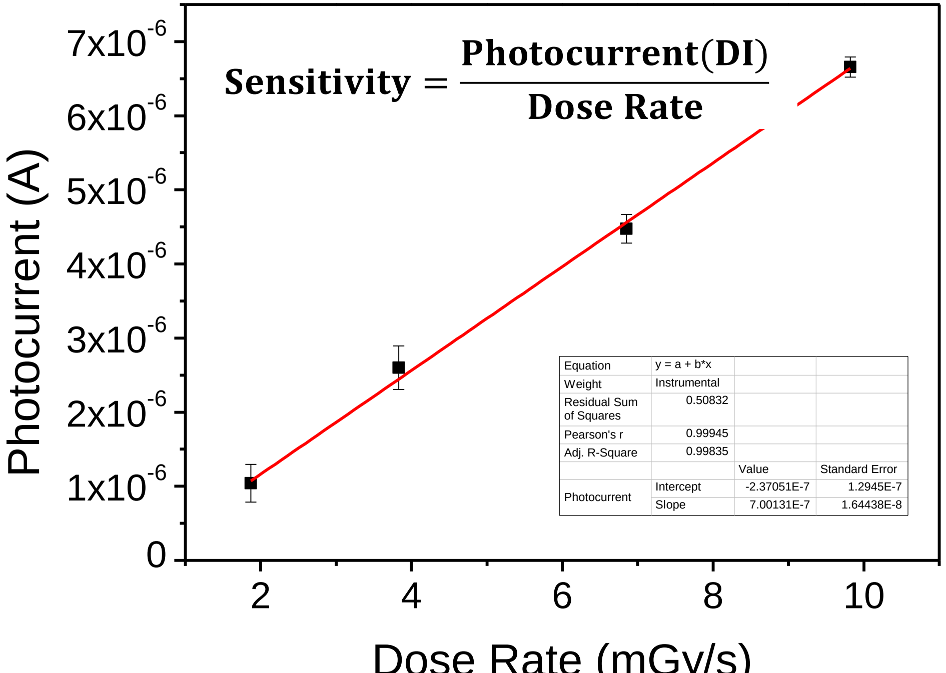




Sensitivity: $7x10^6$ μC/Gy cm^2 @ 0.2V
>> than polyCZT or a-Se

Room temperature

Linear response **(dosimetry)**



I.Temino et al. Nature Comm. ***11****, 2136 (2020)*

MATER STUDIORUM
ERSITÀ DI BOLOGNA