Recent progress in organic semiconductor polymer blend films for OFETs

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Phose2023 - Workshop on "Photodetectors and sensors for particle identification and new physics searches"

Istituto Nazionale di Fisica Nucleare
SEZIONE DI ROMA TRE

ROMA TRE UNIVERSITÀ DEGLI STUDI

OUTLINE

- Organic Field-Effect Transistors (OFETs)
- State of Art
- Materials and methods
- Optical Microscopy
- ToF-SIMS Study
- Electrical Characterization
- X-Ray Characterization

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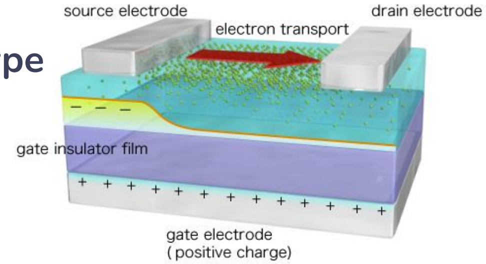
Organic Field-Effect Transistors

n-type



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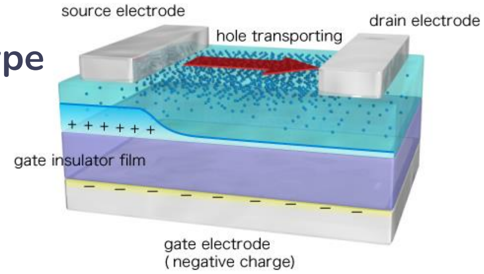

Schematic representation of organic field-effect transistors.

Organic Semiconductor

- ★ Cheapness
- ★ Eco-sustainability
- ★ Bio-compatibility
- ★ Flexibility

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Organic Field-Effect Transistors

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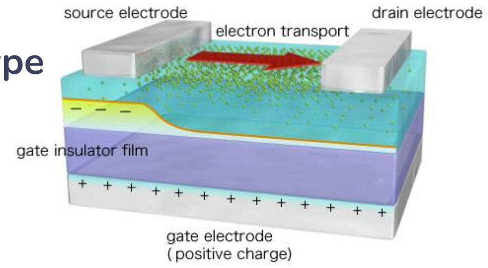

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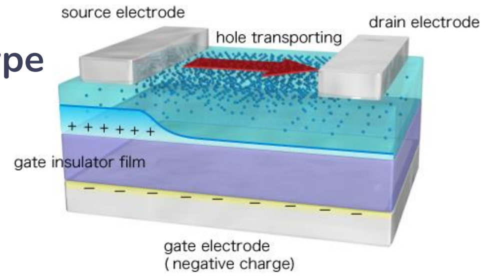

Schematic representation of organic field-effect transistors.

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- ★ Eco-sustainability
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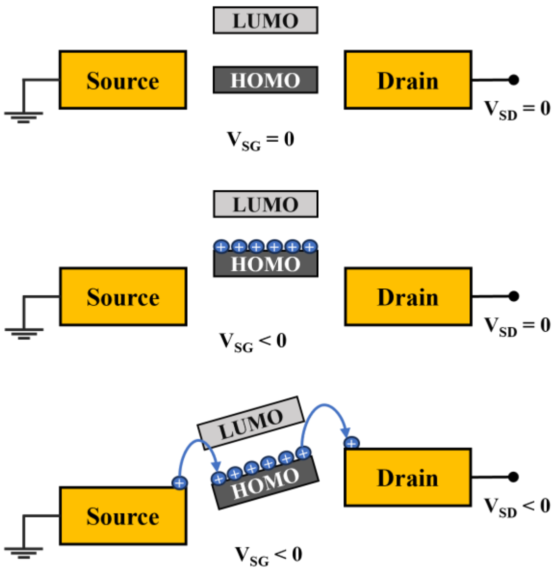
Working Principle



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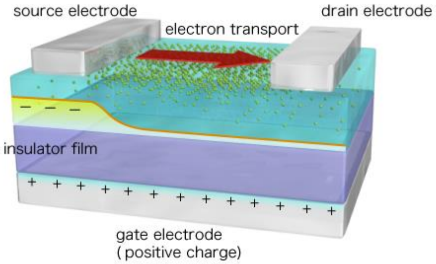
Organic Field-Effect Transistors

n-type



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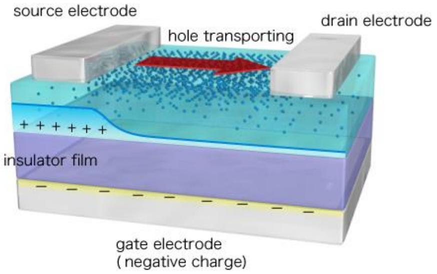

Schematic representation of organic field-effect transistors.

Organic Semiconductor

- ★ Cheapness
- ★ Eco-sustainability
- ★ Bio-compatibility
- ★ Flexibility

Open issues

- ★ Low mobility
- ★ Shorter lifetime

GOAL

The study focuses on developing organic semiconductor/polymer blend films aimed at enhancing stability, mobility, and X-ray sensitivity.

A new generation of biocompatible devices (e.g., X-Ray Imaging system).

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State of Art

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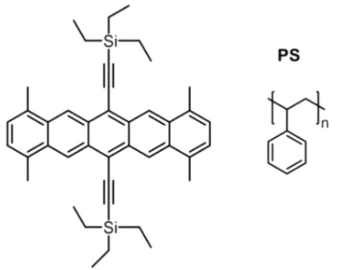
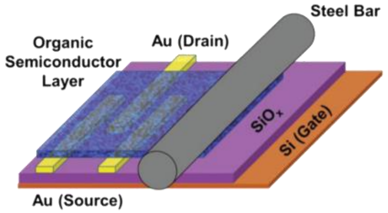
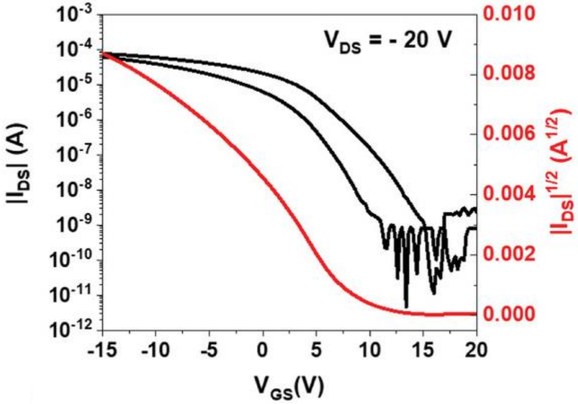
Device Fabrication



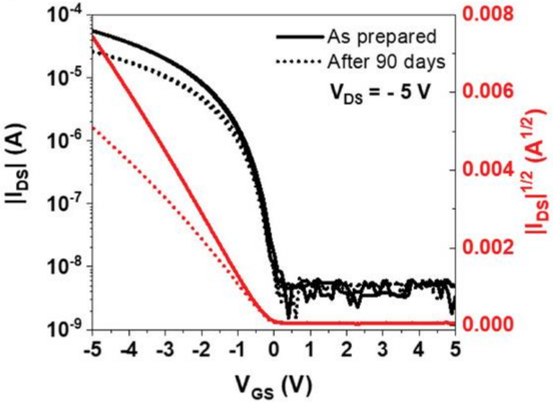


Electrical Characterization

TMTES



TMTES:PS



Sample	Mobility ($cm^2V^{-1}s^{-1}$)	Vth (V)
TMTES	$(1.0 \pm 0.3) \cdot 10^{-1}$	27 ± 9
TMTES:PS	2.6 ± 0.6	$-(1.1 \pm 0.2)$

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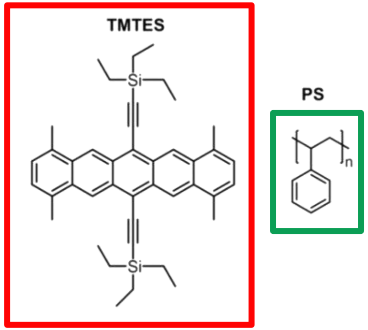
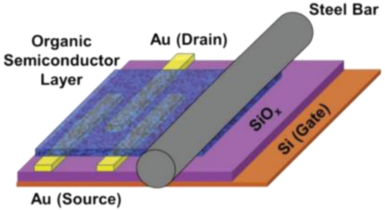
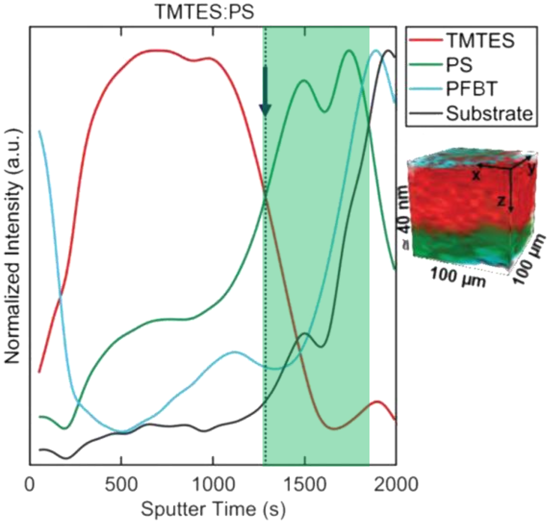
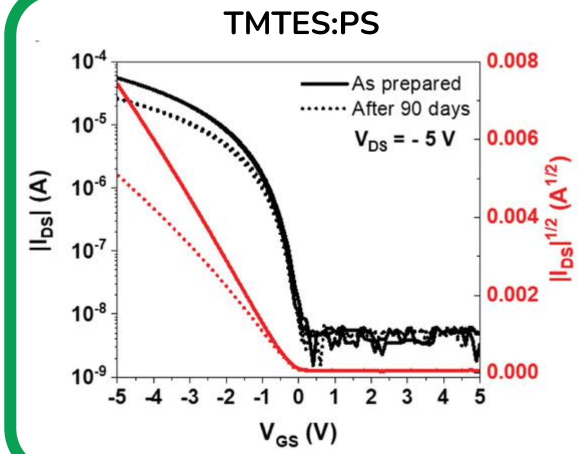




Electrical Characterization



PS Segregation



Highest stability over time and OFET performance thanks to the bottom PS layer that passivates the interfacial charge traps.

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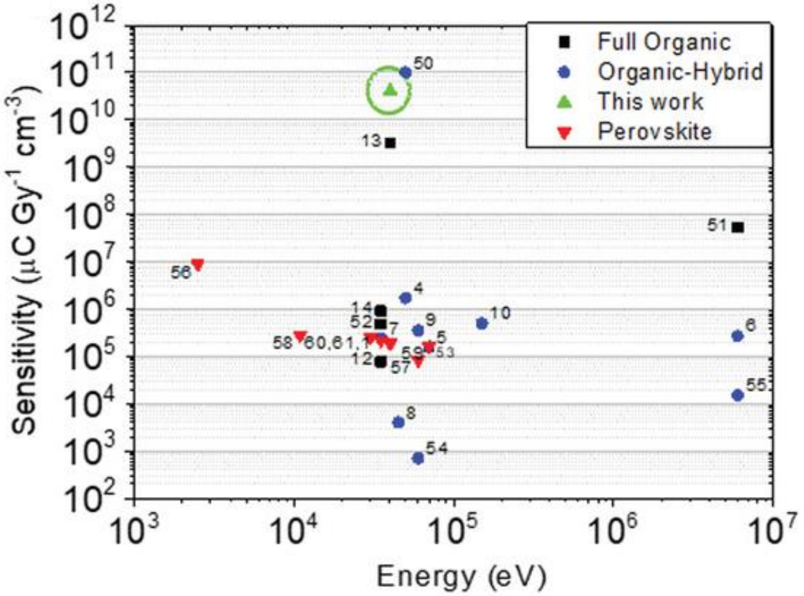
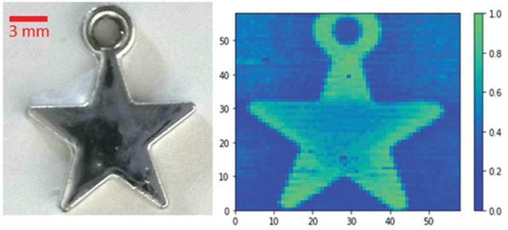
X-Ray Characterization



incident dose rate on the samples between 318 and 1665 μ Gy s^{-1}

High average mobility of 2.6 ± 0.6 cm^2 V^{-1} s^{-1}

Sensitivity to X-rays up to (4.10 ± 0.05) 10^{10} μC Gy^{-1} cm^{-3}, highest value reported so far for a fully-organic tissue equivalent active layer



ELETTRA light source (Trieste, Italy).

X-ray energy range (8.5–35 keV) and dose rates (0.05–35 mGy s^{-1}), well suited for diagnostic mammography

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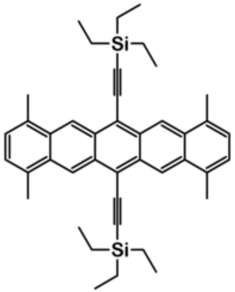
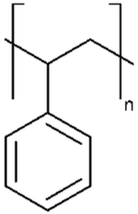
Materials and Methods

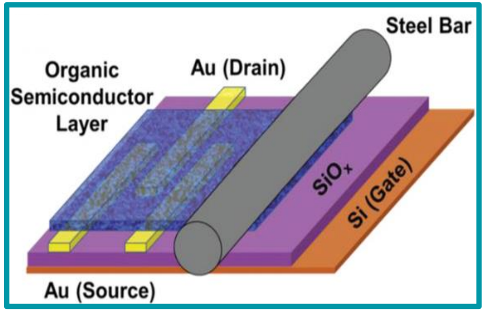
TMTES-Pentacene



Polystyrene (PS)



TMTES:PS volume ratio			
1:0	4:1	2:1	1:2



FABRICATION STEPS:

- ★ **Layout: Photolithography**
- ★ **Electrodes: Thermal Evaporation** (5 nm **Cr** + 40 nm **Au**) and **Lift-Off**
- ★ **Gold activation: UV Ozone** 25 min + **SAM** of PFBT (10^{-3} M)
- ★ **Deposition of active layer by BAMS:** 10 mm/s, 105

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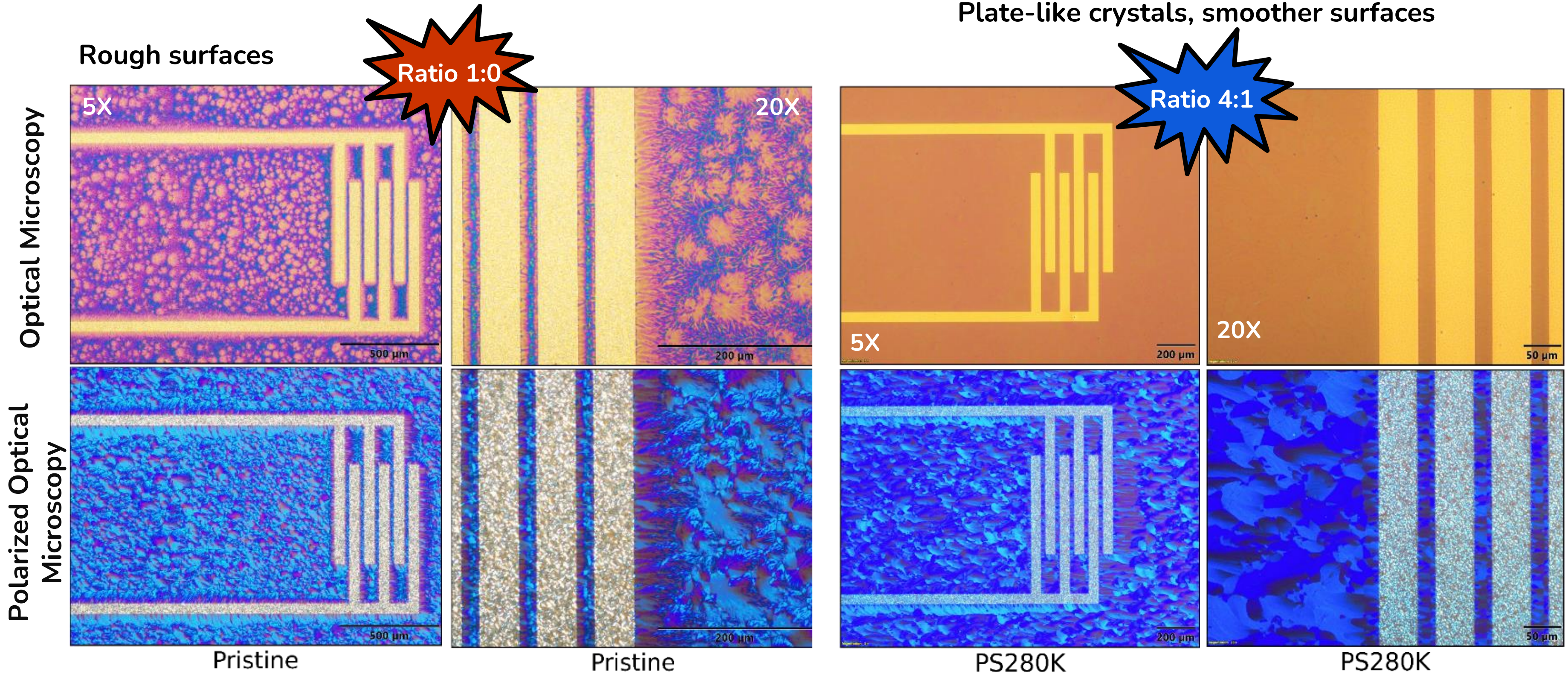
Optical Microscopy



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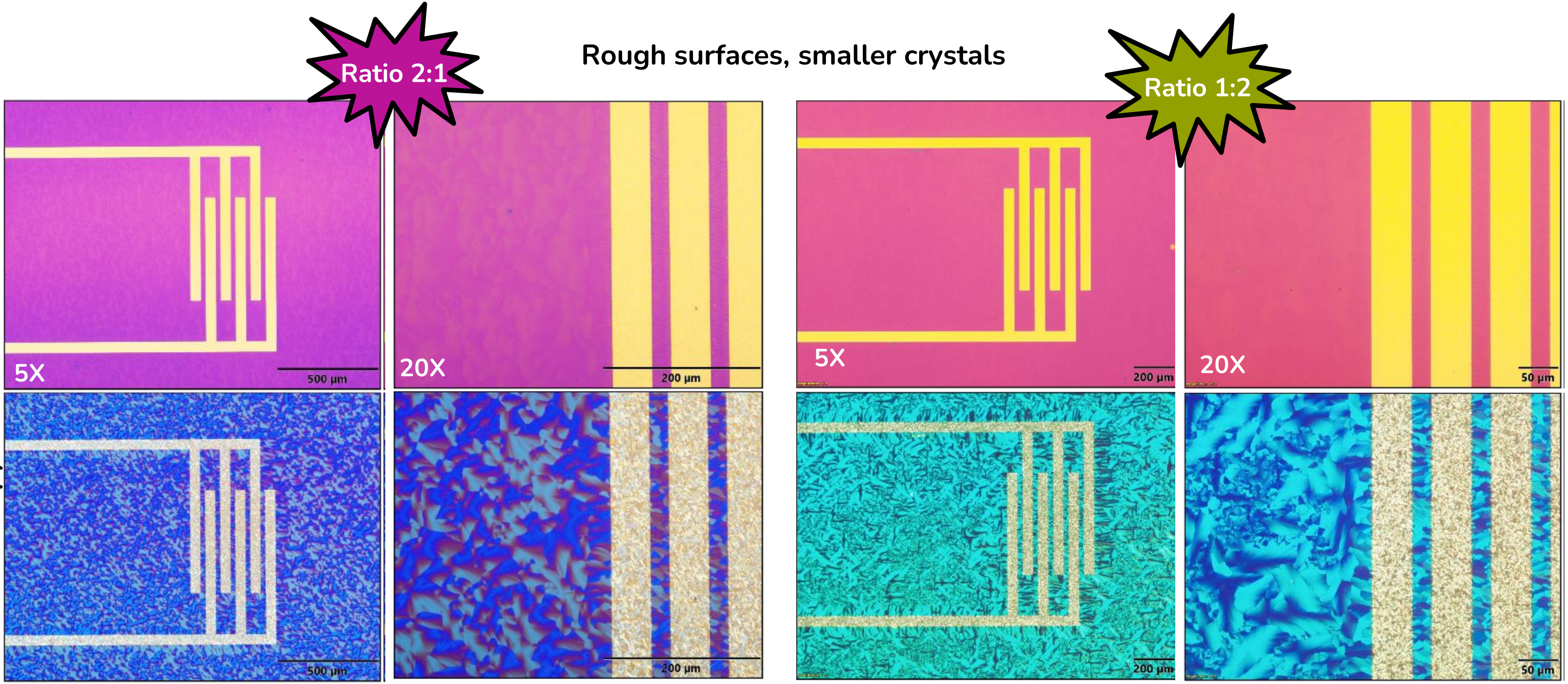
Optical Microscopy

Rough surfaces, smaller crystals



PS280K PS280K PS280K PS280K

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ToF-SIMS: Surface Analysis

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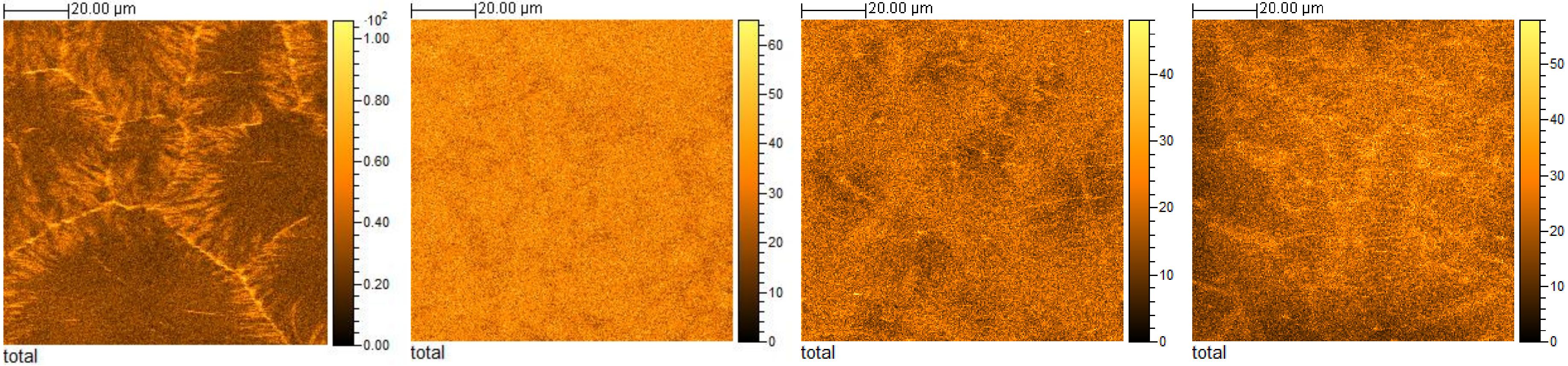
Ratio 1:0 | Ratio 4:1 | Ratio 2:1 | Ratio 1:2



The superficial image of the total ion counts obtained from ToF-SIMS represents the spatial distribution of all detected ions, providing a comprehensive surface composition map of the sample at a microscopic level.

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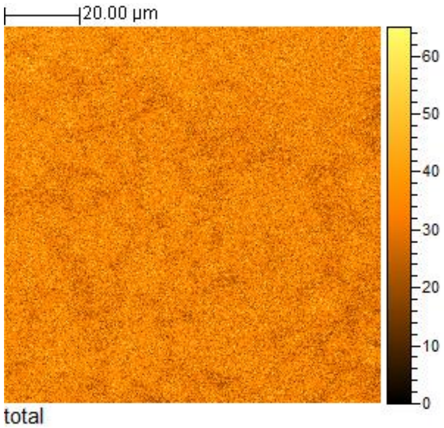
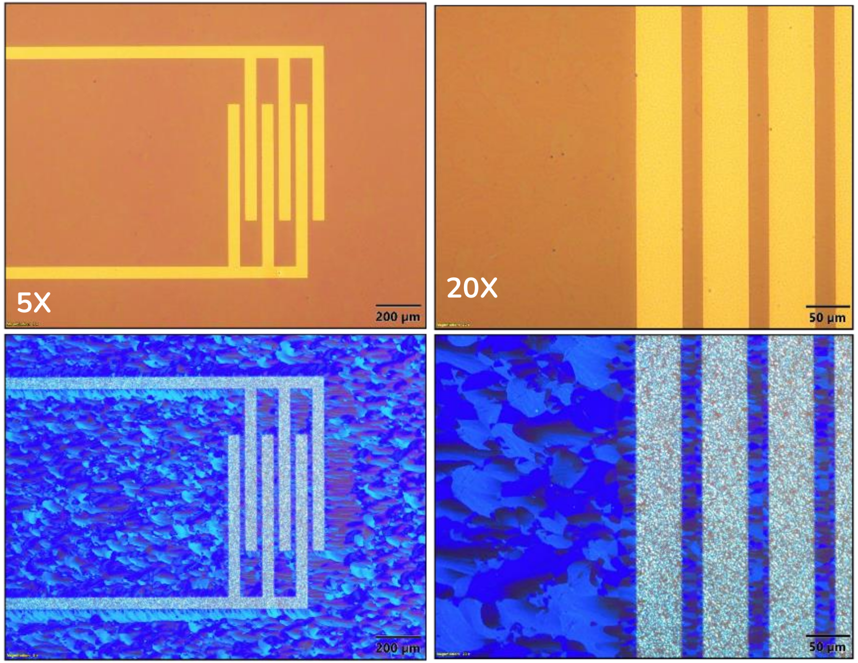
ToF-SIMS: Surface Analysis

Ratio 4:1

The most homogenous surface, corresponding to plate-like crystals in optical microscopy





PS280K PS280K

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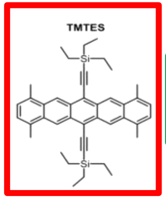
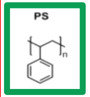
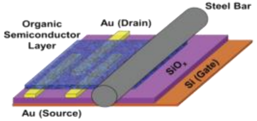
ToF-SIMS: Depth Profiling

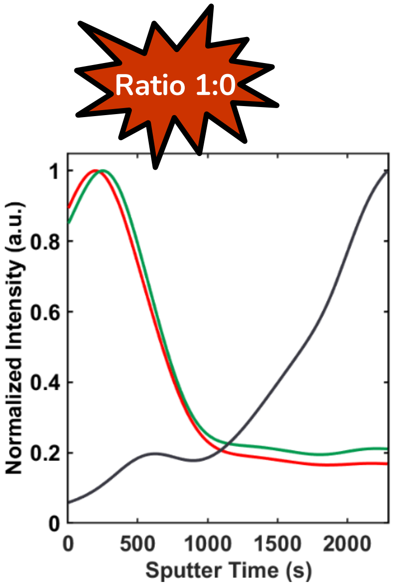
TMTES
$\sum_{i=3}^{7} C_iH_3$
Substrate

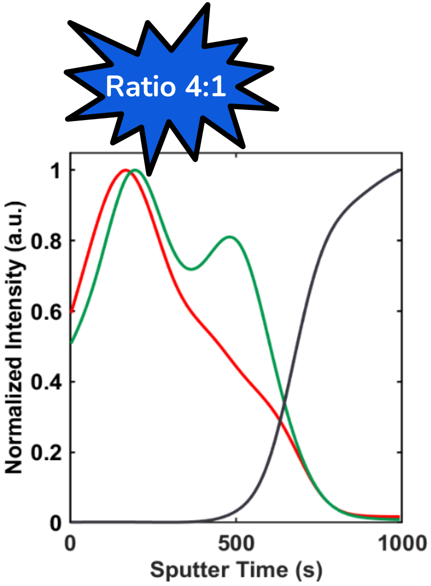


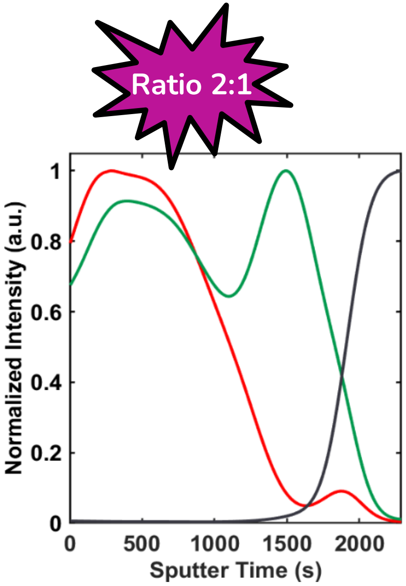


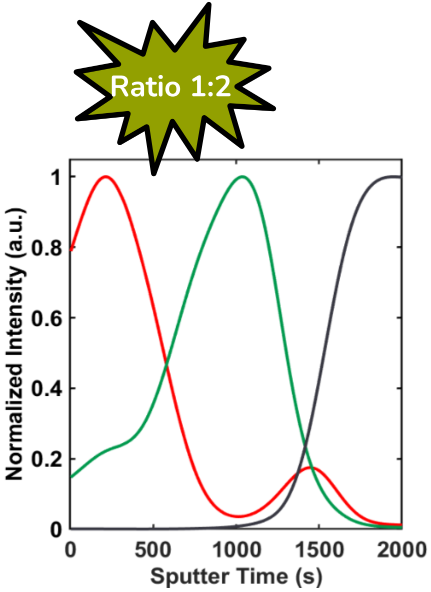


The depth profiling reveals the distribution of specific ions as a function of depth, offering insights into the layered structure and compositional variations within the sample









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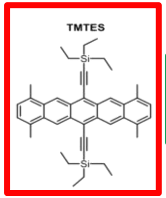
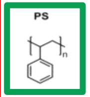
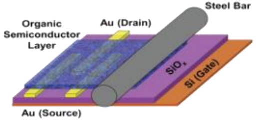
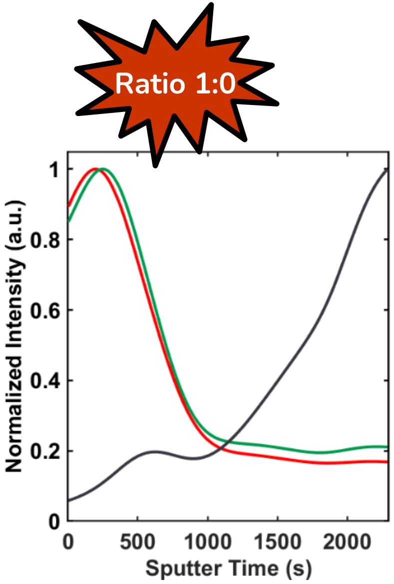
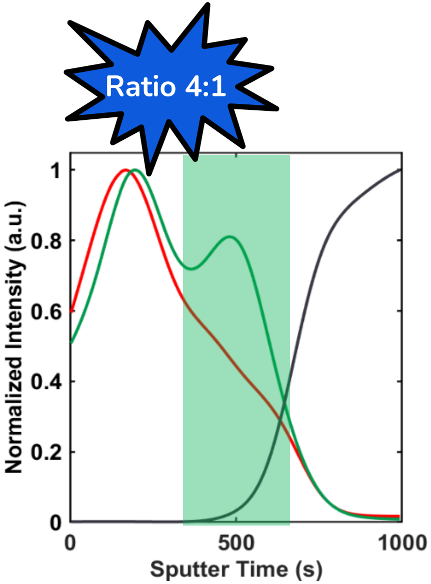


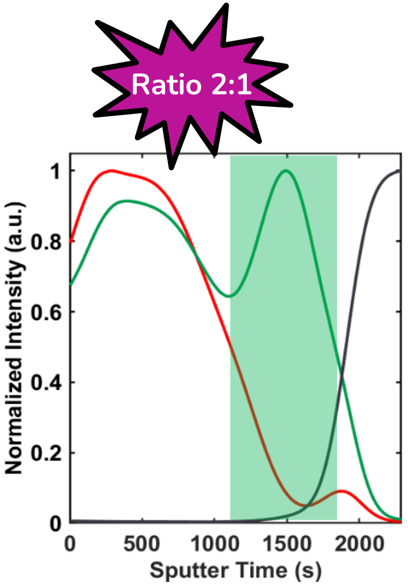


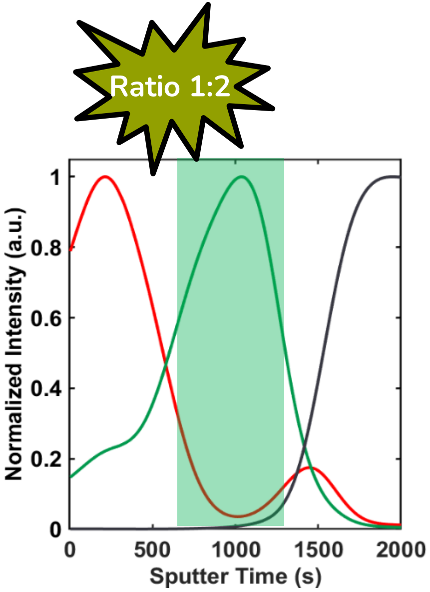


In all TMTES:PS devices there is a clear phase segregation









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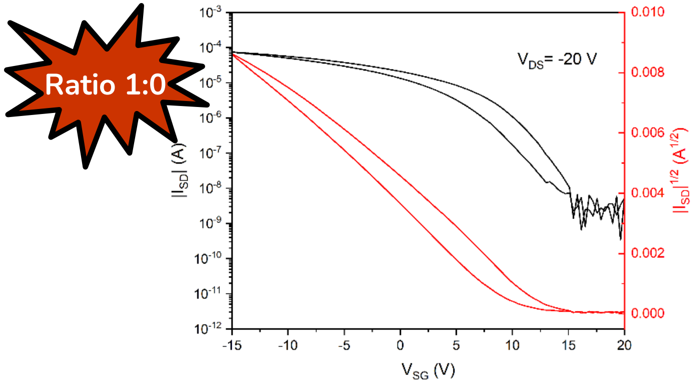
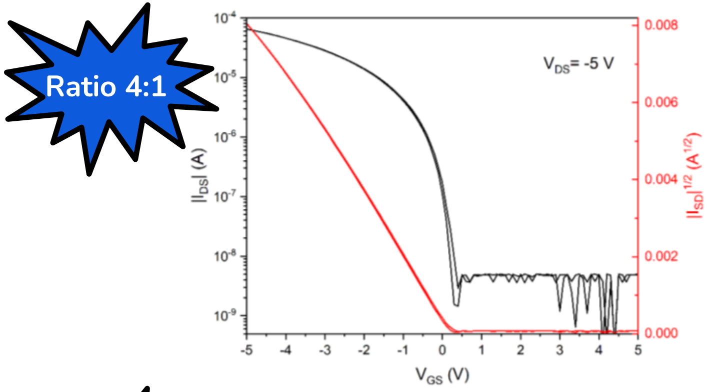
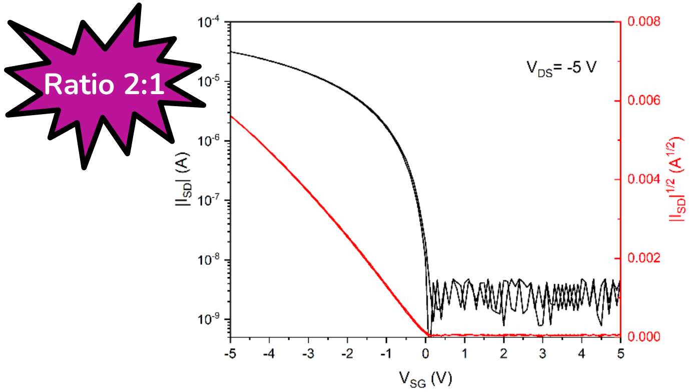
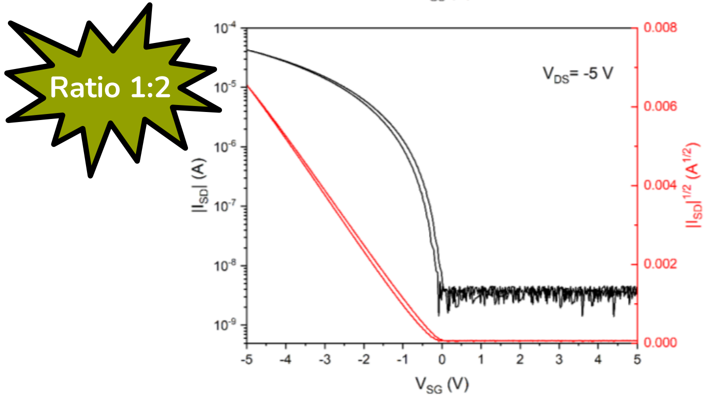
Electrical Characterization









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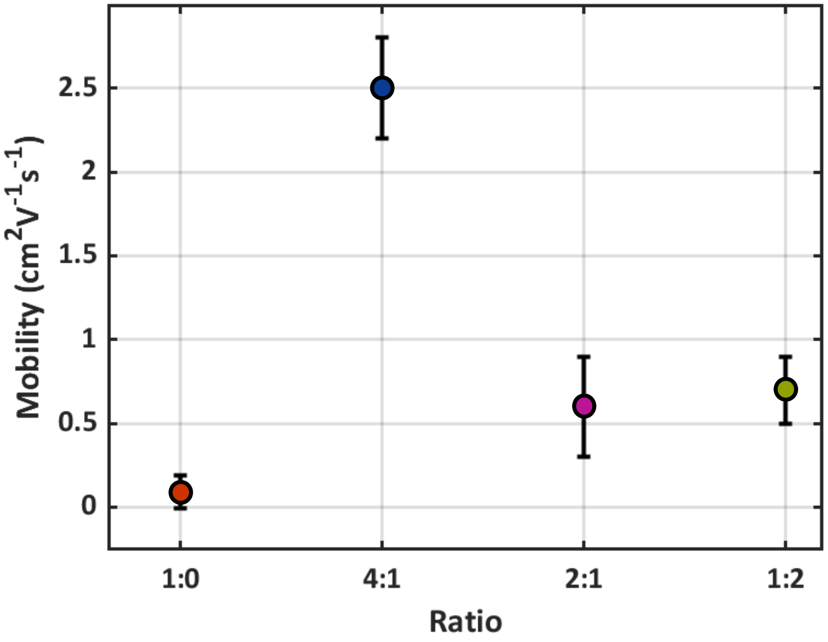
Electrical Characterization

Ratio	Mobility $(cm^2V^{-1}s^{-1})$	Vth (V)
1:0	$(0.90 \pm 0.05) \cdot 10^{-1}$	15 ± 3
4:1	2.5 ± 0.3	0.4 ± 0.1
2:1	0.6 ± 0.3	0.1 ± 0.06
1:2	0.7 ± 0.2	0.2 ± 0.06

4:1 → Devices with the **highest mobility** correspond to:

- ★ The **plate-like crystals** in optical microscopy
- ★ Best **homogeneity** in Surface Analysis by ToF-SIMS

Ratio 4:1



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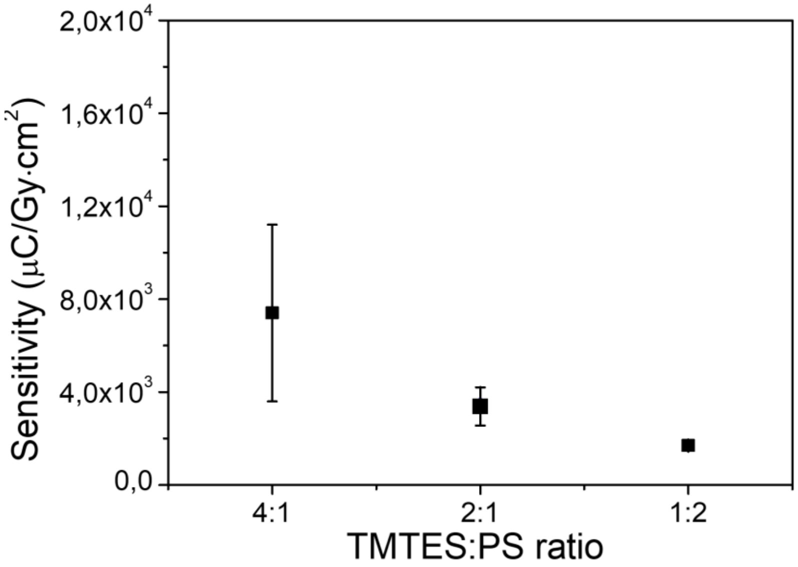
X-Ray Characterization

X-ray tube with tungsten target was used at a fixed 40 kV operating voltage the filament current was changed between 100 and 500 μA leading to an incident dose rate on the samples between 318 and 1665 $\mu\,Gy\,s^{-1}$

4:1 → Devices with the **highest sensitivity** correspond to:

- ★ The **plate-like crystals** in optical microscopy
- ★ Best **homogeneity** in Surface Analysis by ToF-SIMS
- ★ **Highest mobility**

Ratio 4:1



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Summary

The study focuses on developing organic semiconductor/polymer blend films aimed at enhancing stability, mobility, and X-ray sensitivity, targeting applications in flexible and bio-electronic devices.

Goals:

- ★ Improved OFET performance with TMTES-Pentacene:Polystyrene blends.
- ★ Investigation of phase segregation and its impact on device efficiency.
- ★ Determination of the optimal TMTES:PS ratio (**4:1**) for highest device performance.
- ★ Achievement of high sensitivity in X-ray characterization.

To-Do list:

- ★ Evaluate devices with a lower amount of PS (e.g., ratio 8:1).
- ★ Assess long-term stability.
- ★ Perform AFM measurements to determine the roughness of the samples.

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Dr. Beatrice Fraboni
Dr. Laura Basiricò
Dr. Ilaria Fratelli

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Thanks to Semiconductor Physics Group

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Dr. Luca Tortora
Dr. Andrea Fabbri

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Backup slides

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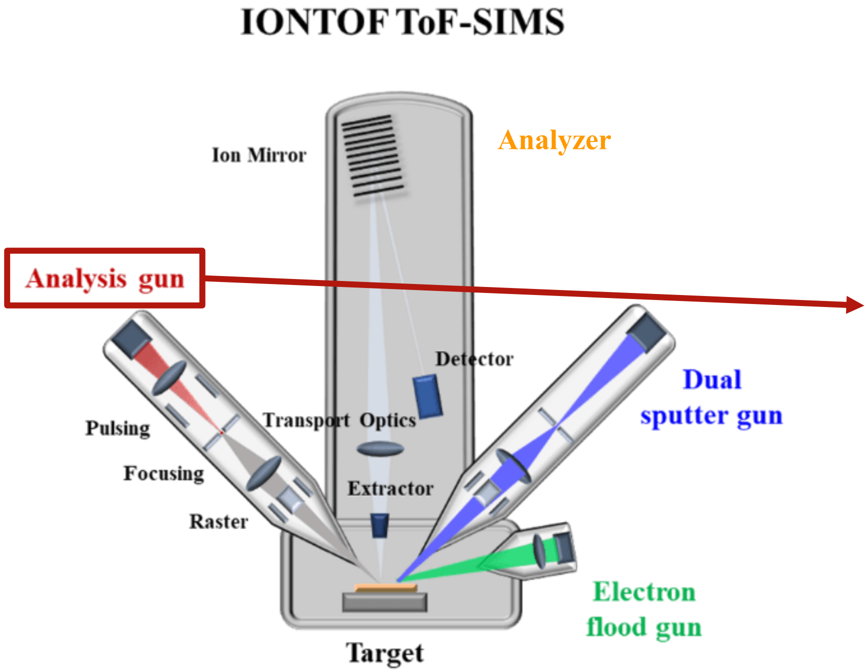
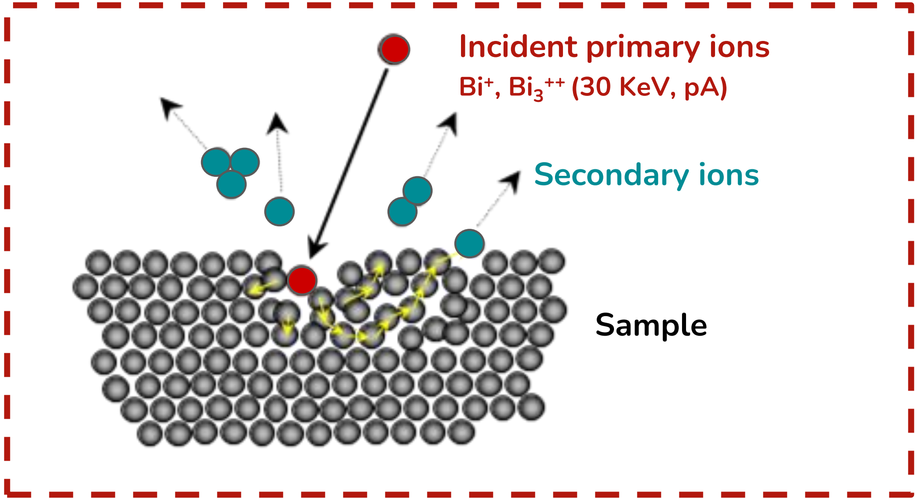
ToF-SIMS principle





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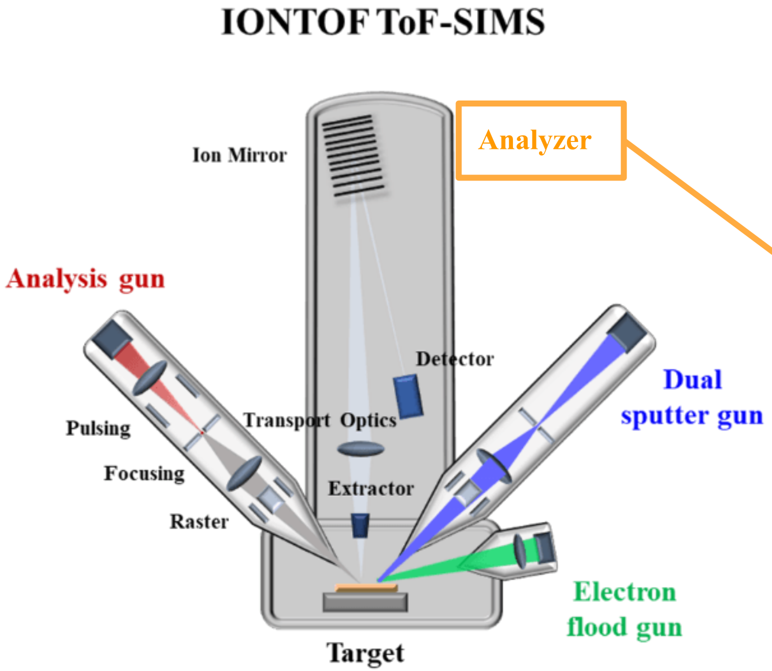
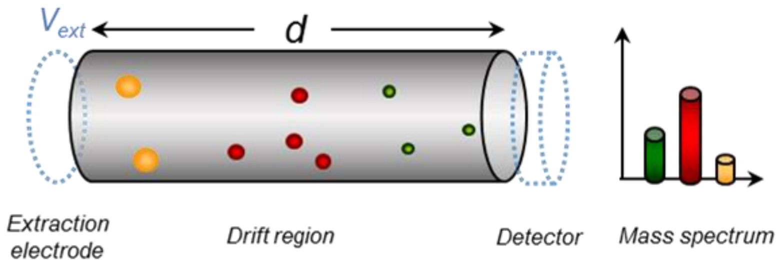


Time-of-Flight detector



$$E = qV = \frac{1}{2}mv^2 \rightarrow t = d\left(\frac{m}{2qV}\right)^{1/2} \propto m^{1/2}$$

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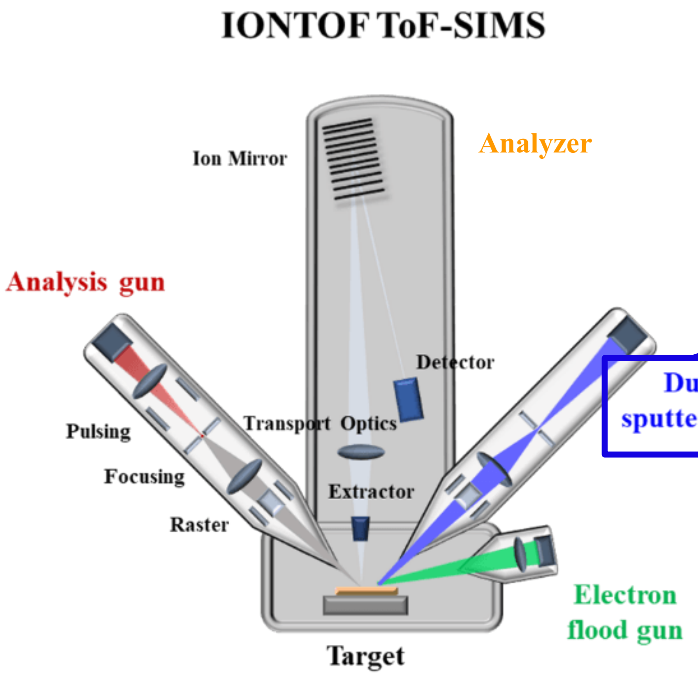
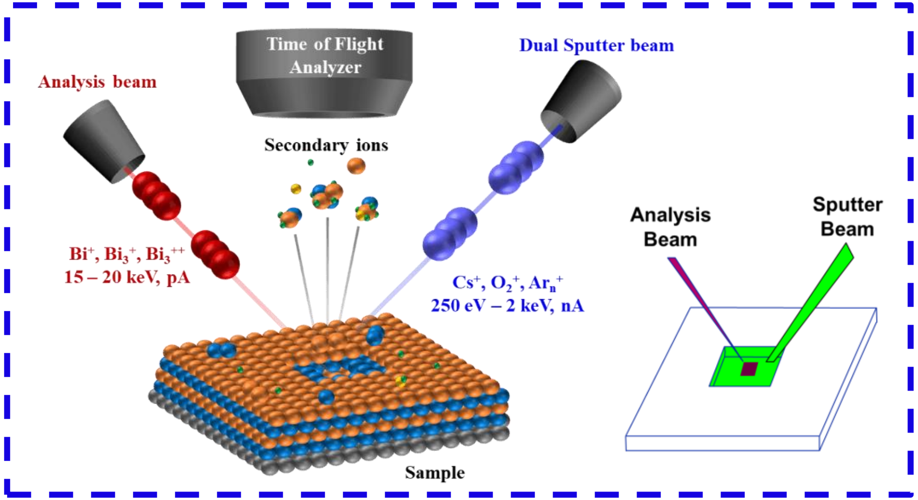
ToF-SIMS principle



Dual-beam mode



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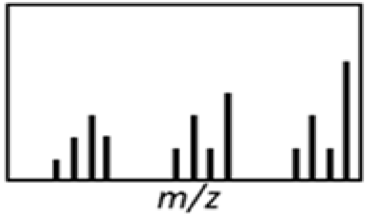
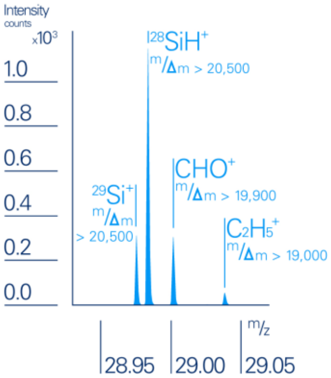
ToF-SIMS data

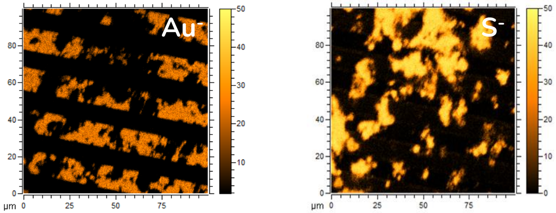
Spectrometry



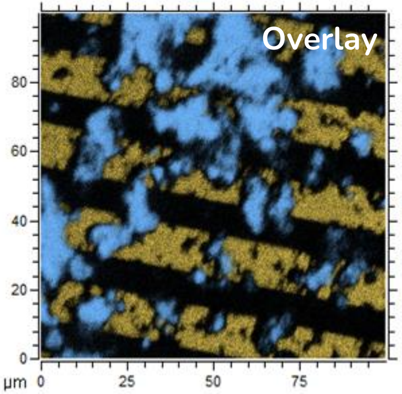
⚠ High mass resolution (~20000 m/Δm)



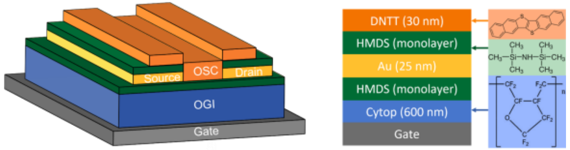
Imaging



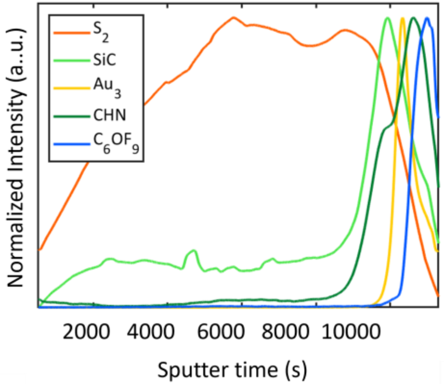
⚠ High lateral resolution (~100 nm)



Depth-Profiling



⚠ Monolayer sensitivity (~5 nm)



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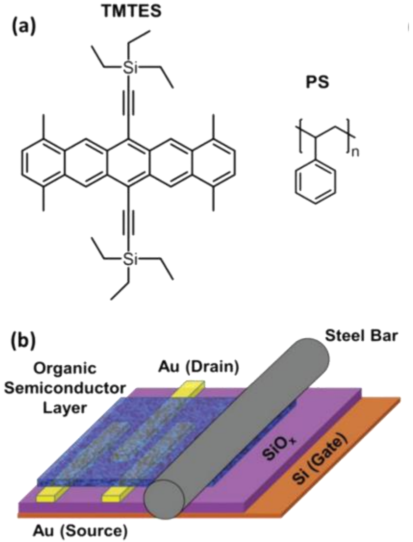
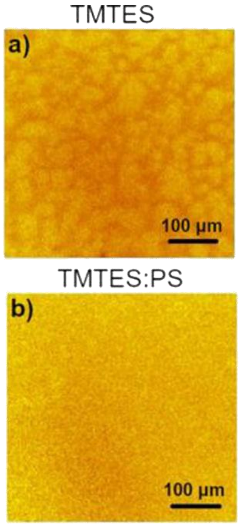
State of Art

Device Fabrication



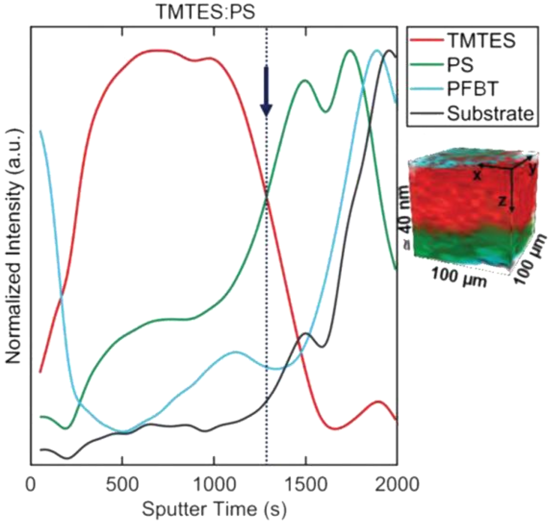
a) Chemical structures of TMTES and PS, and b) scheme of the OFET layout.

Surface Analysis



ToF-SIMS 2D chemical maps: a) TMTES, and b) TMTES:PS sample.

In-Depth Analysis



Normalized ToF-SIMS depth profiles and 3-D rendering of the characteristic ions.

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XRD

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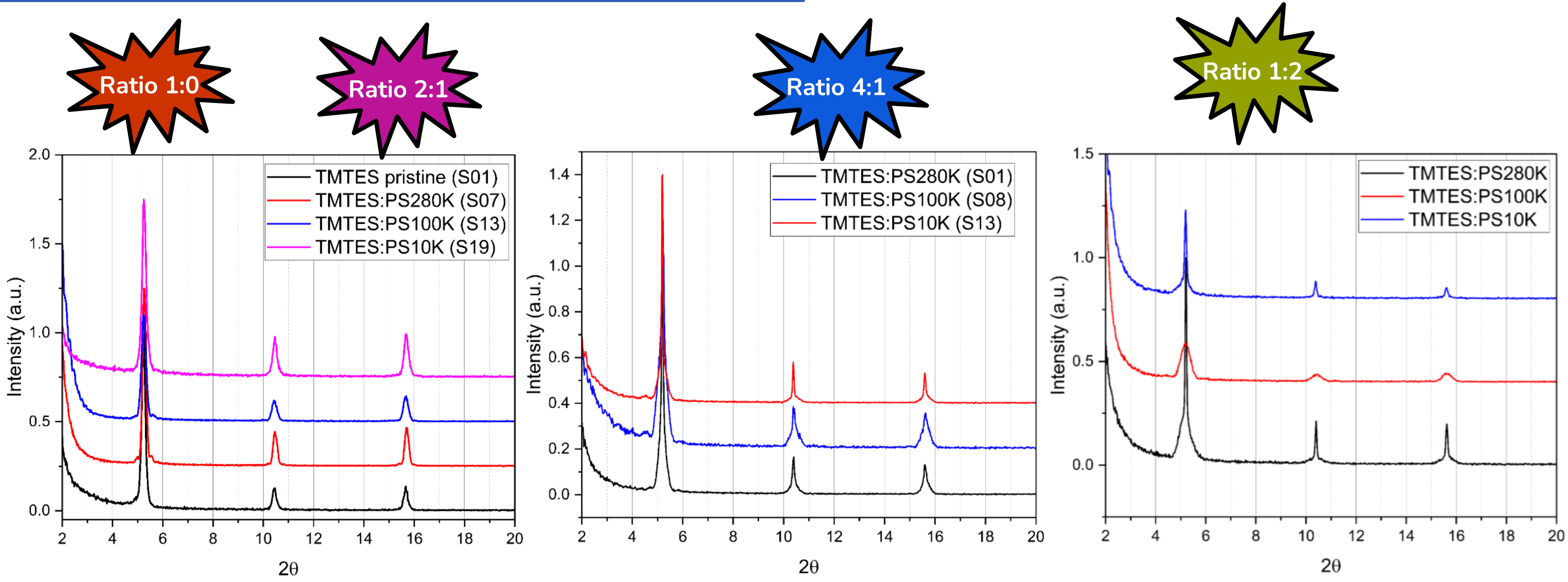

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