



Direct imaging of defect formation in strained organic flexible electronics by Scanning Kelvin Probe Microscopy

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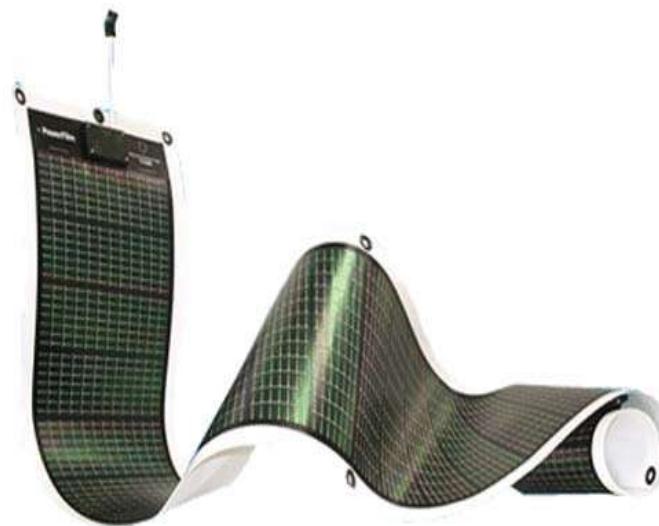


Flexible Large Area Electronics

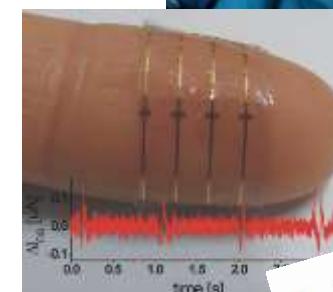
- non-planar surfaces
- deformable systems (robotics, humans)



Displays



Photovoltaics



i-FLEX
Integrated flexible photonic sensor system

Sensors / Detectors

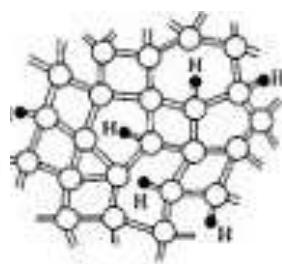
A. Campana et al., Adv. Mat. 2014
L. Basicirò et al. Nat. Commun. 2016, accepted



Flexible Large Area Electronics: The Material Platforms

Amorphous Silicon

Si

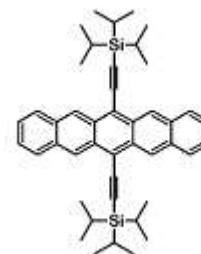


physical deposition

$$\mu = 1 \text{ cm}^2/\text{Vs}$$

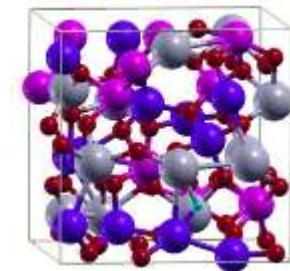
Organic Electronics

e. g. TIPS pentacene



Oxide Based Electronics

$\text{Ga}_x\text{In}_y\text{Zn}_z\text{O}$



solution based deposition

$$\mu = 1 \text{ cm}^2/\text{Vs}$$

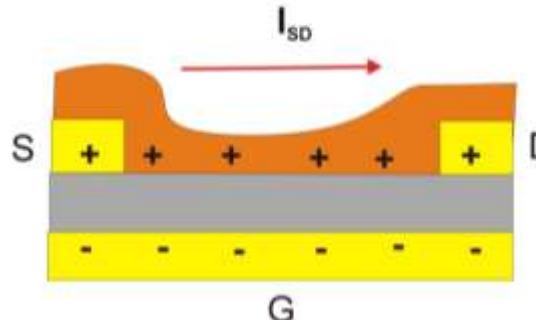
physical deposition

$$\mu = 10 - 50 \text{ cm}^2/\text{Vs}$$

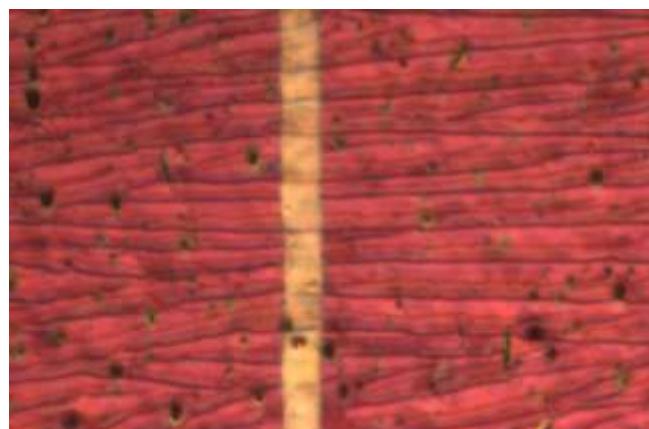
- K. Asadi et al. Nat. Commun. 2013
T. Cramer et al. Phys. Rev. B 2015
T. Cramer et al. Adv. Elec. Mat. 2016



Low-voltage Organic Thin Film Transistor

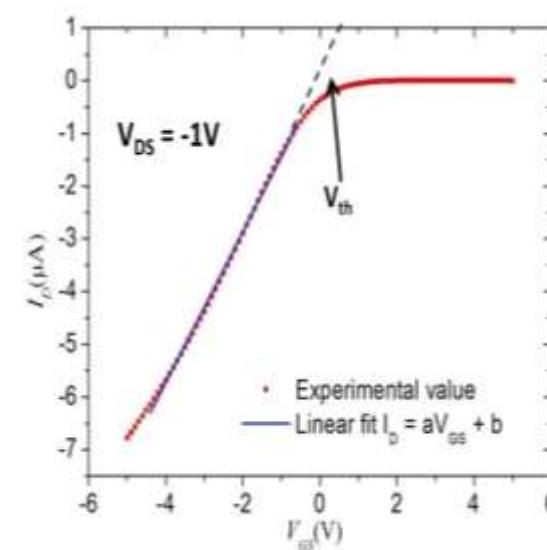


TIPS Pentacene
Au
Parylene
 Al_2O_3
Al
PEN



nm
100
-100

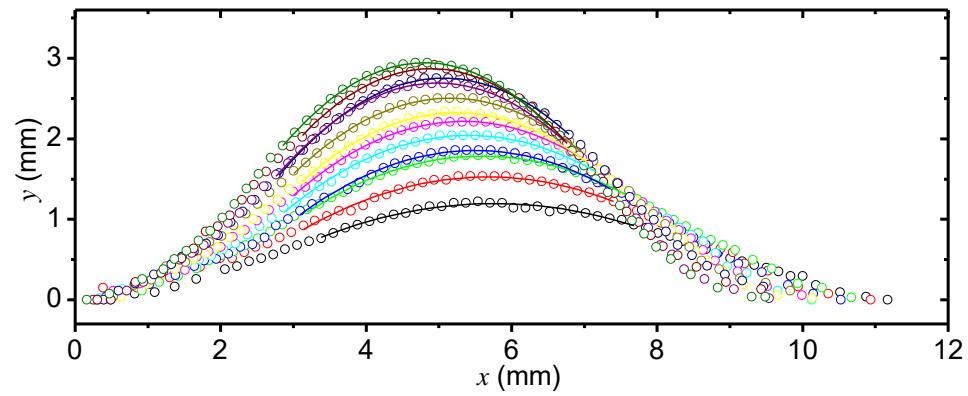
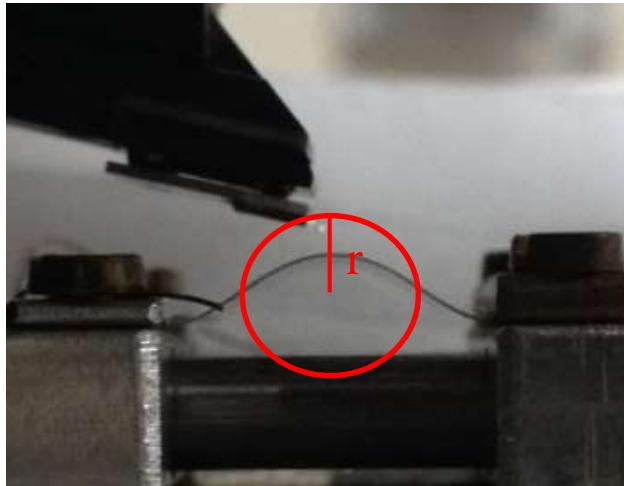
source drain



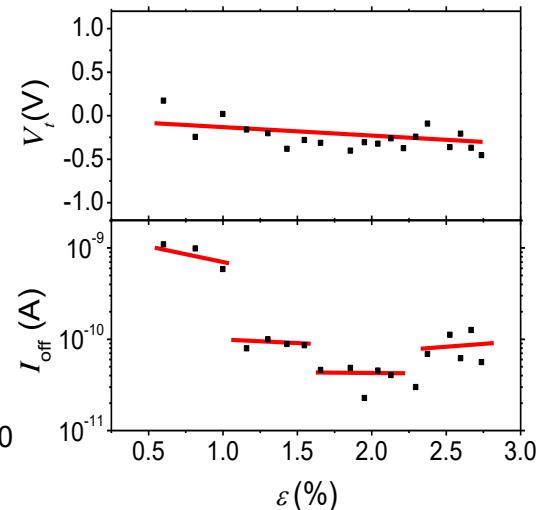
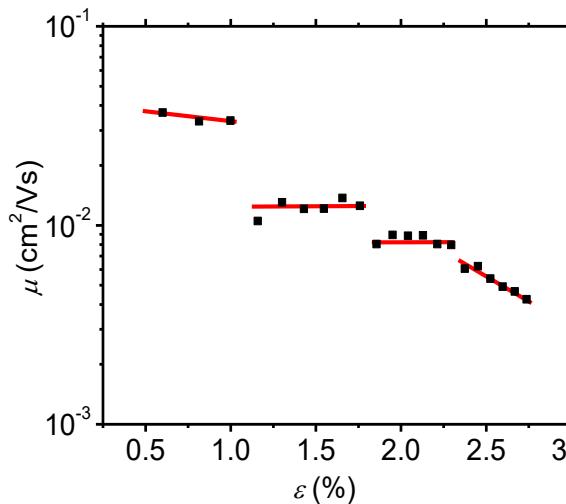
ALMA MATER STUDIORUM - UNIVERSITÀ DI BOLOGNA



Transistor characterization under strain

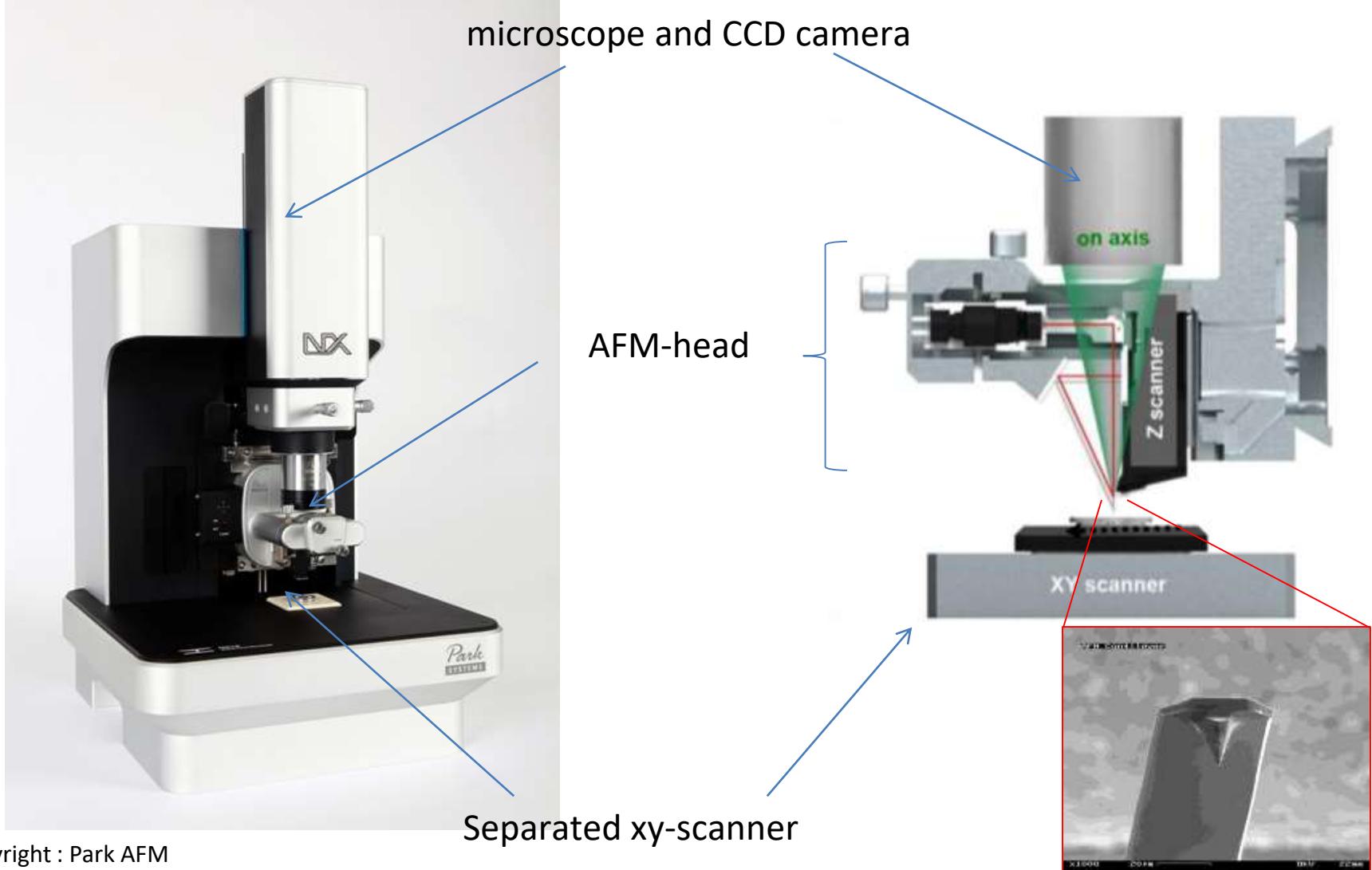


$$\text{surface strain: } \varepsilon = \frac{t}{2r}$$





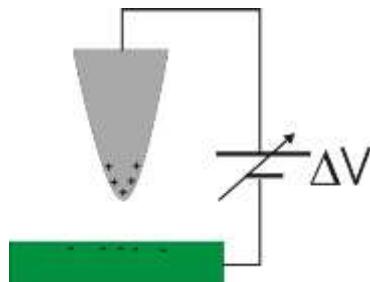
Atomic Force Microscopy





Scanning Kelvin Probe Microscopy

– Probing electrostatic surface potentials –

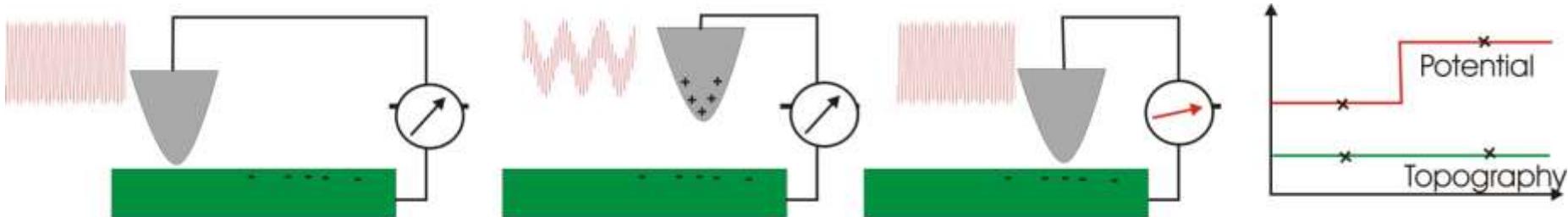


capacitor containing tip and sample surface

$$\text{Energy: } E = \frac{1}{2} C \Delta V^2$$

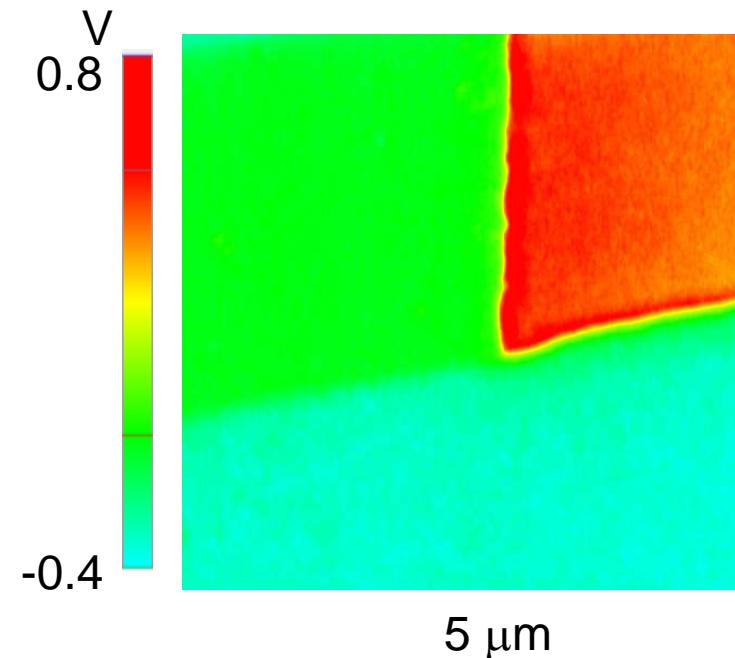
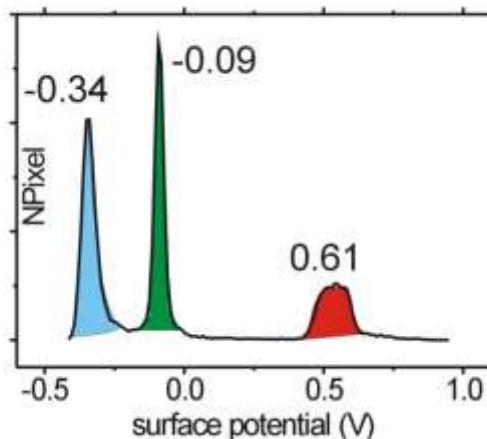
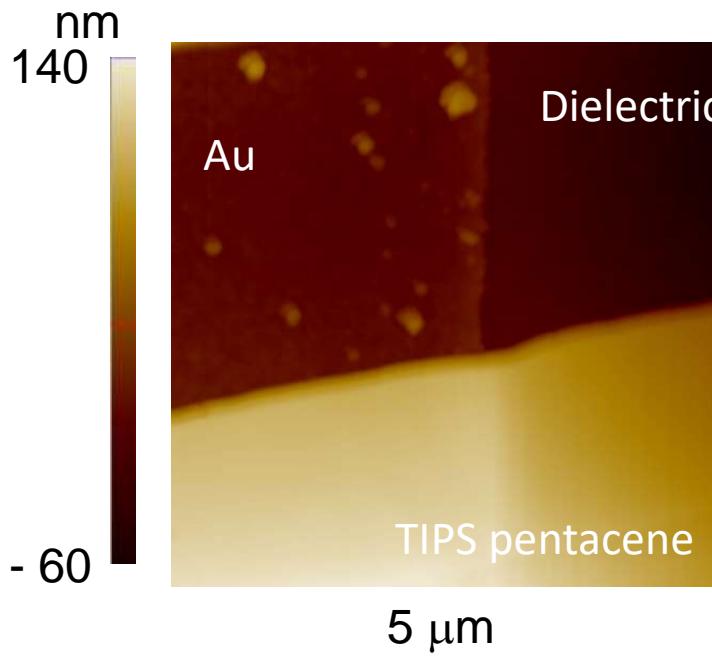
$$\text{Force: } F_{el} = \frac{\partial E}{\partial D} = \frac{1}{2} \frac{\partial C}{\partial D} \Delta V^2 \sim \frac{1}{2} \frac{C}{D^2} \Delta V^2$$

Distinguish in frequency domain: mechanics: 270 kHz
electrostatics: 17 kHz





SKPM contact potentials ($V_G = 0V$; $V_D = 0V$)

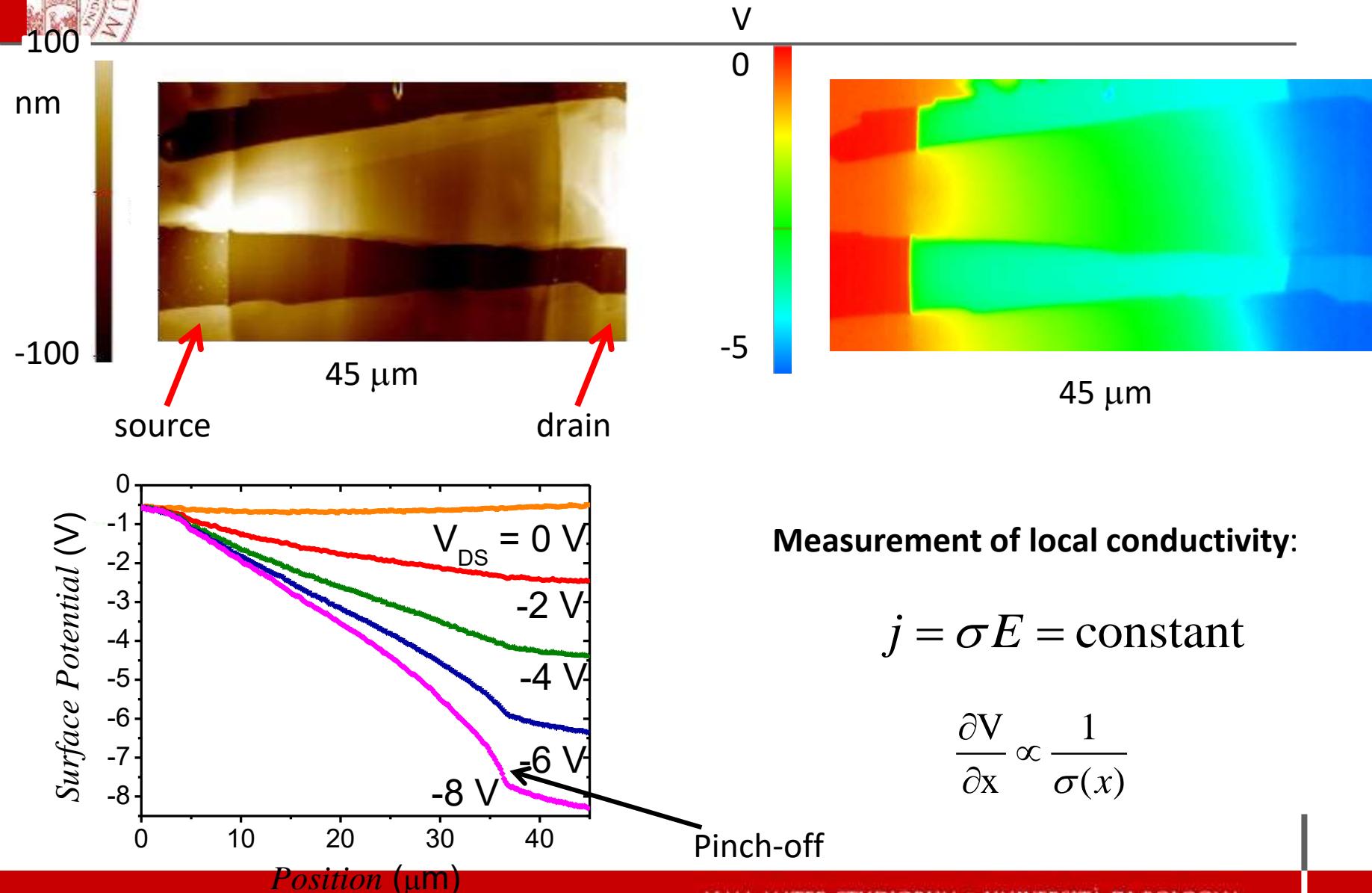


Workfunction Au: 5.1 eV
Al: 4.25 eV

The surface potential on the dielectric corresponds to the underlying Aluminum gate electrode

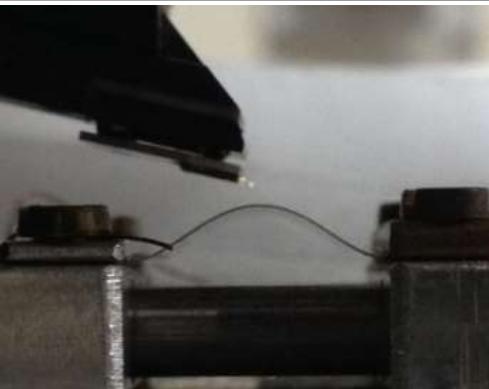


SKPFM on biased transistor ($V_G = -5V$)

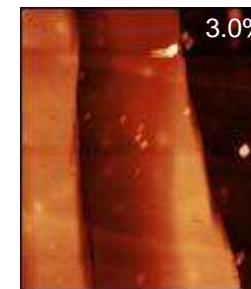
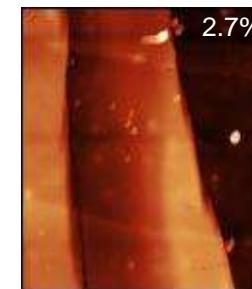
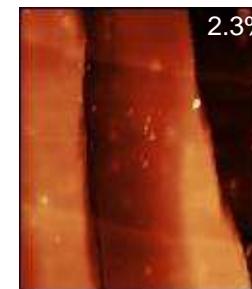
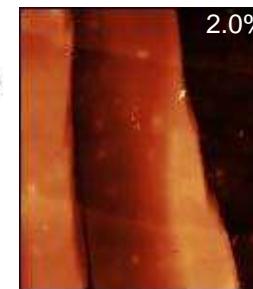
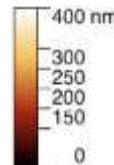
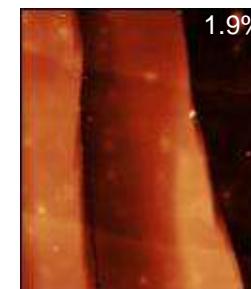
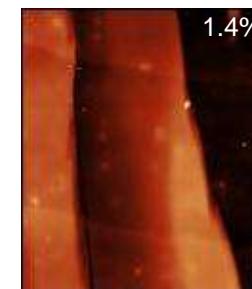
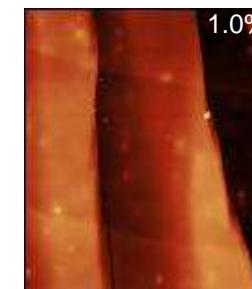
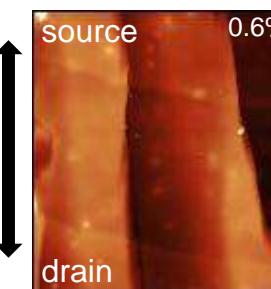




AFM on strained transistor

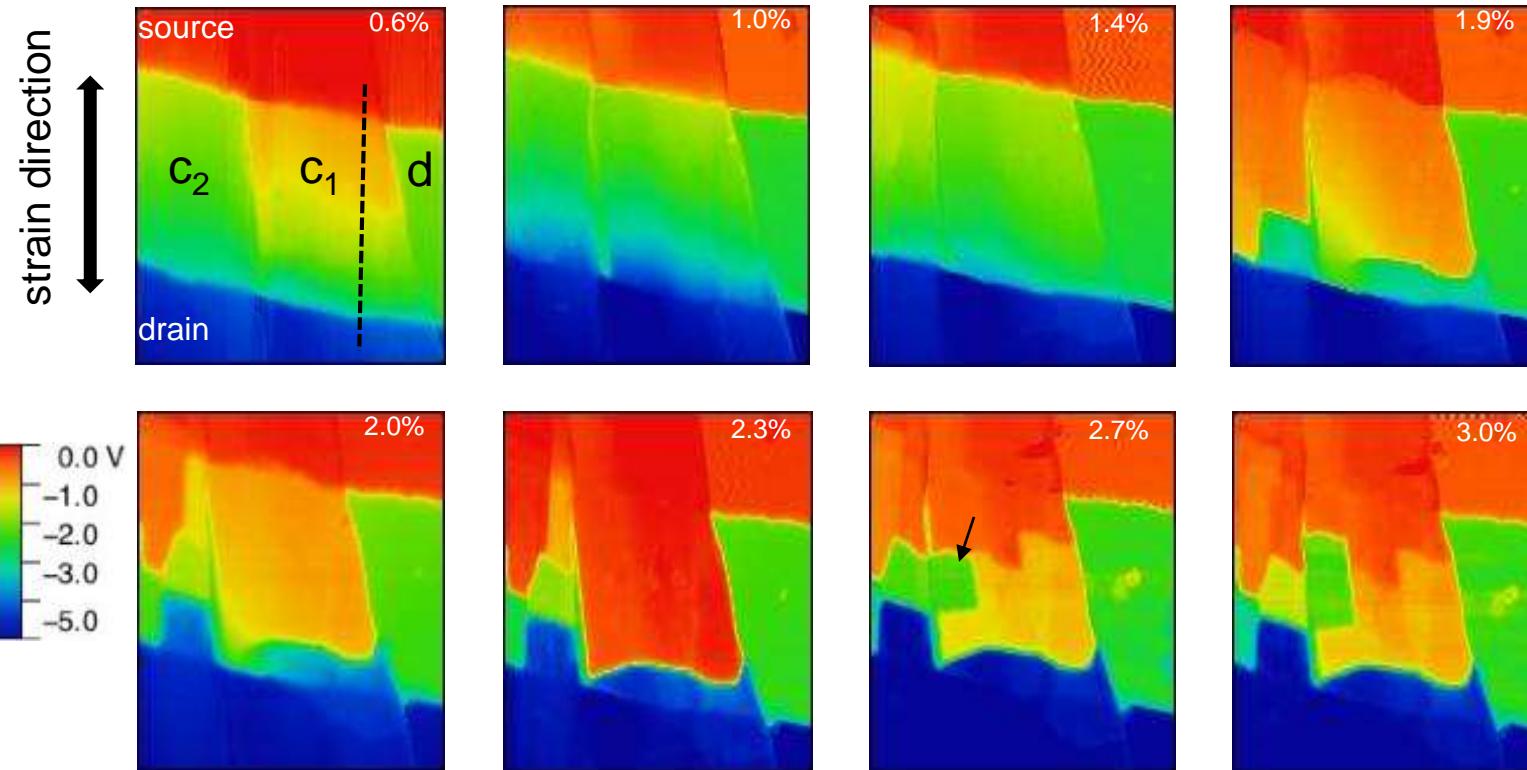


strain direction
↑ ↓





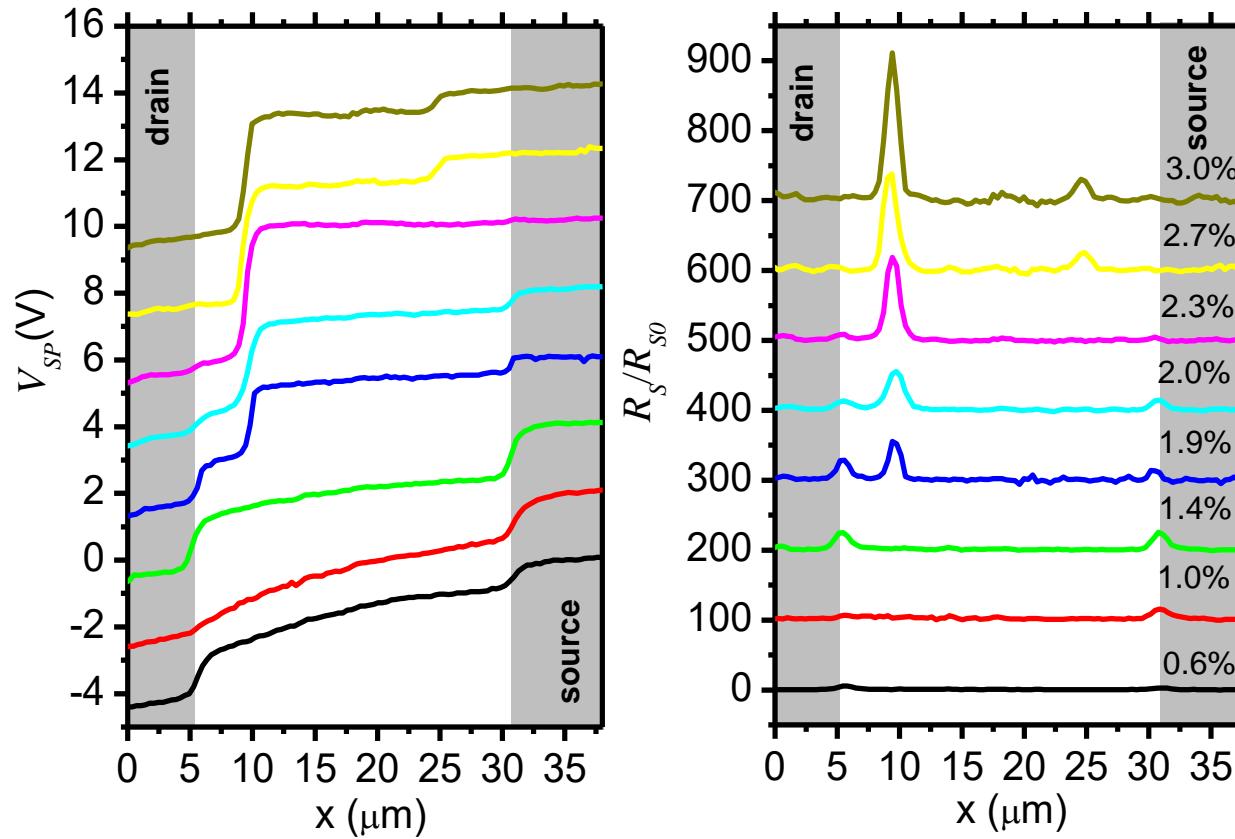
SKPM on strained transistor



T.Cramer et al. Scientific Reports, 6, 38203, 2016



SKPM on strained transistor

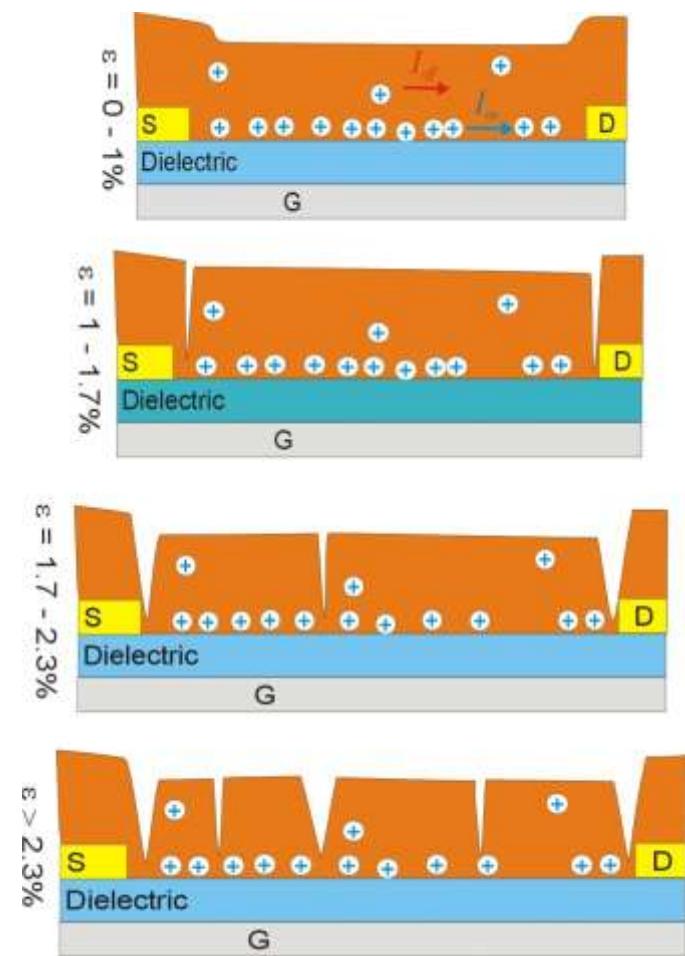
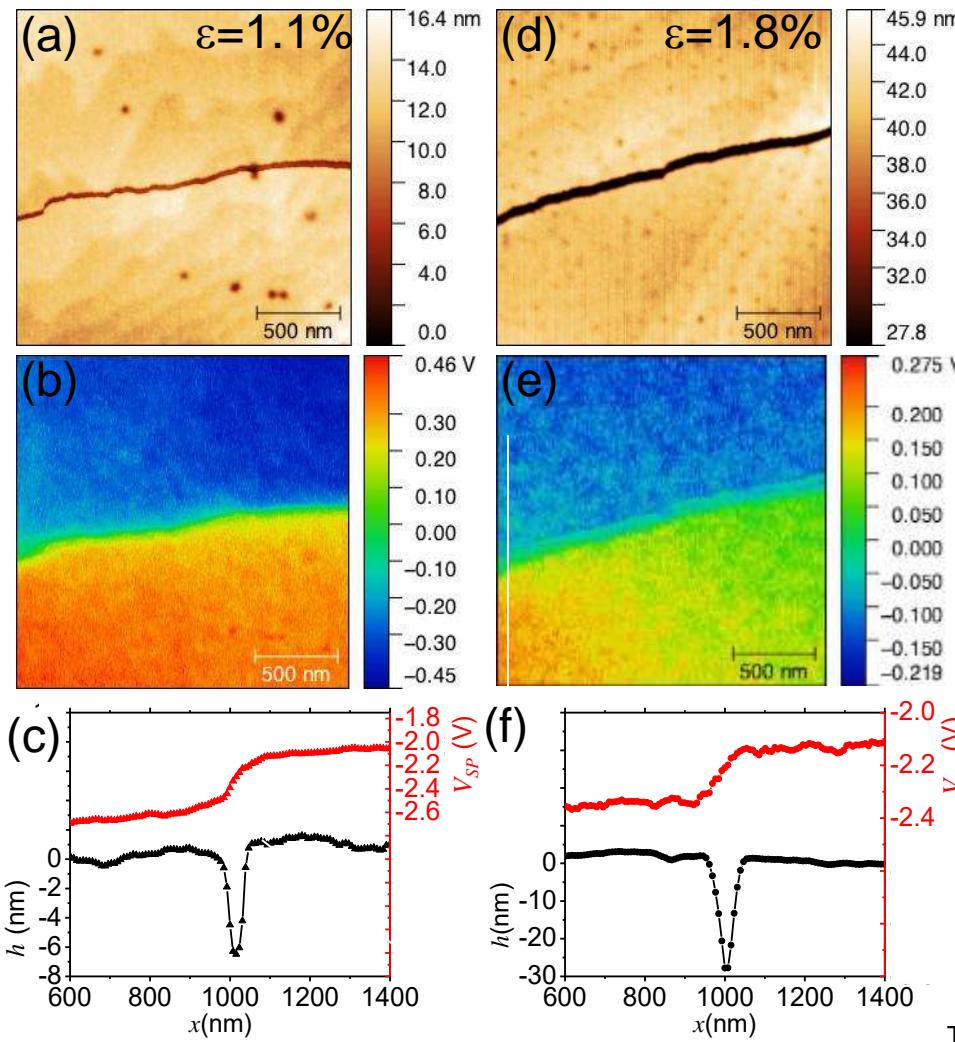


$$\frac{I_D}{W} = \int_{z=0}^t J_x dz = \int_{z=0}^t \sigma(x, z) E(x) dz = \frac{1}{R_S(x)} \frac{\partial V(x)}{\partial x}$$

T.Cramer et al. Scientific Reports, 6, 38203, 2016



Nano-crack formation



T.Cramer et al. Scientific Reports, 6, 38203, 2016



Conclusions

- AFM in Non-Contact mode on mechanically strained substrates is possible
- SKPM to investigate failure and defect formation in thin film devices
- In microcrystalline organic semiconductors failure is caused by nano-crack formation starting at $\varepsilon > 1\%$
- Strong adhesion of micro-crystals to the dielectric surface reduces crack propagation and maintains charge transport up to $\varepsilon < 3\%$
- Searching for semiconductors which combine good elastic properties (polymers) and large + long-range electronic overlap



Acknowledgements



i-FLEXIS
Integrated flexible photonic sensor system



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DI CAGLIARI



BIOAGE



implantable organic nano-electronics

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Organ Models for the Investigation
of Age Related Diseases