2011/6/2 20:00-22:00
Lake Buena Vista, Florida USA

CPMT Seminar

Printed Devices and Large Area Interconnect Technologies for New Electronics

Printed Organic Transistors for Ultraflexible and Stretchable Electronics

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The University of Tokyo

Outline

- Background & Motivation
    - ✓Organic integrated circuits on plastics
- All printed organic transistors
- Ultraflexible organic CMOS circuits

  T. Sekitani et al., Nature Materials, 9, 1015 (2010).
- Stretchable integrated circuits

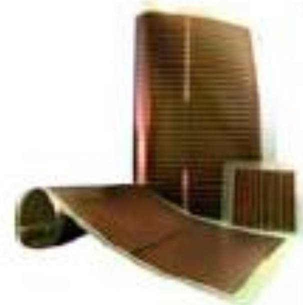
  T. Sekitani et al., Science 321, 1468 (2008).

  T. Sekitani et al., Nature Materials 8, 494 (2009).
- Future Prospects & Summary

Flexible & Printed electronics

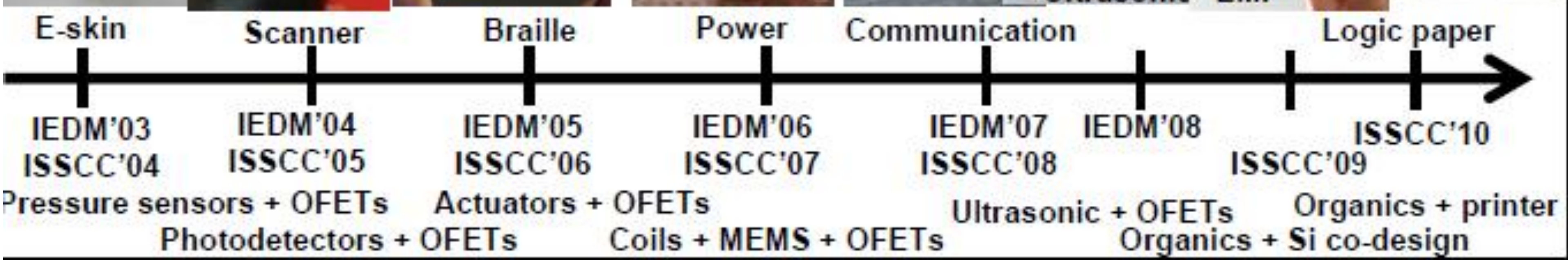
Flexible displays

PV

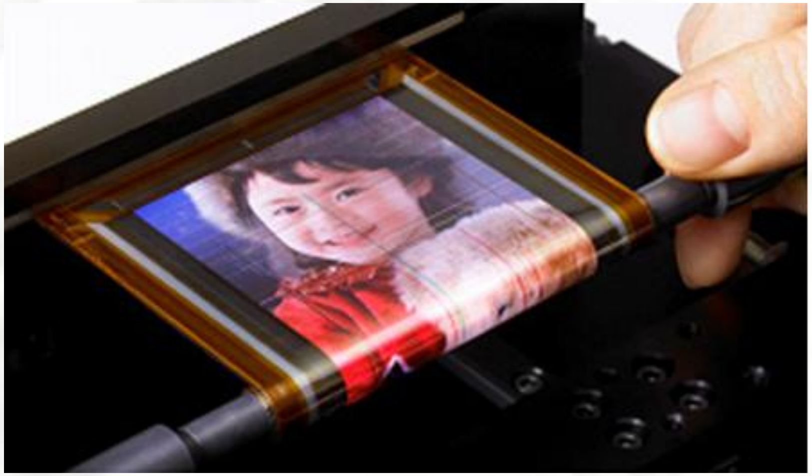


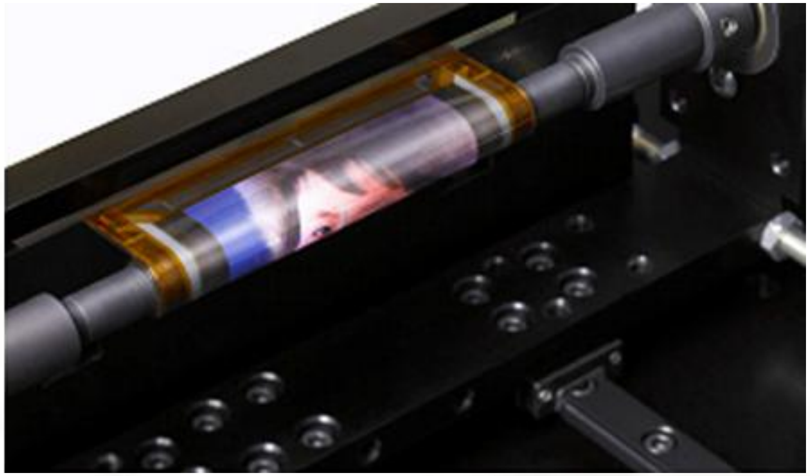
RFID

Large-area sensors and actuators



Flexible displays





SONY, SID 2010
From http://www.sony.co.jp/SonyInfo/News/Press/201005/10-070

- ✓Peri-Xanthenoxanthene (PXX)derivative
  ➔ Mobility: 0.4 cm^2/Vs
- ✓Organic driving cells with 2T-1C structure
- ✓Resolutions：121ppi (432×240×RGB pixels)
- ✓Critical bending R = 4 mm

Flexible TFTs on *plastic*

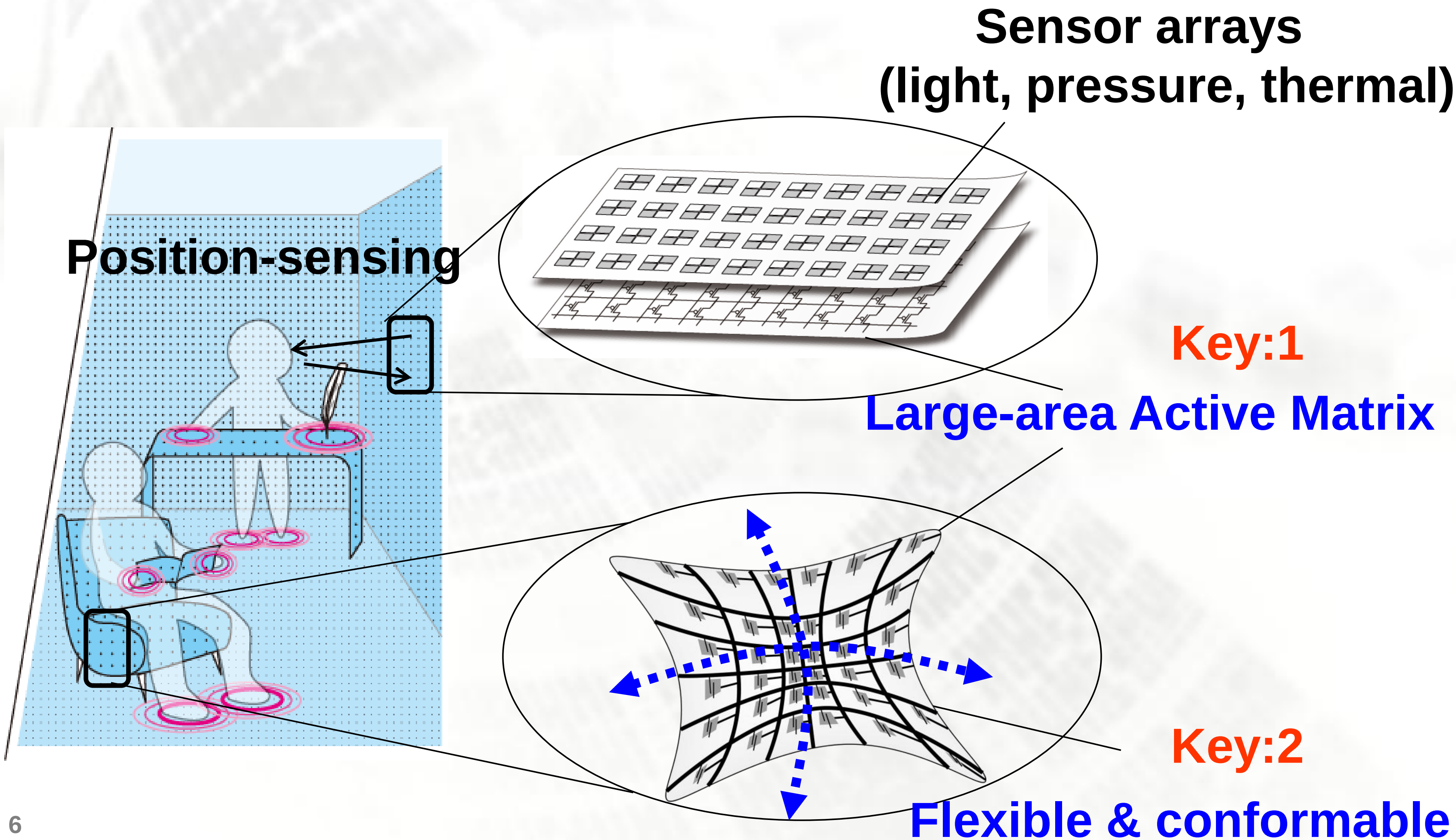
	Poly-Si TFTs (ref. 1) EPSON	Oxide TFTs (ref. 2) TIT	CNT TFTs (ref. 3) Illinois U.	Organic TFTs (ref. 4) UT	a-Si TFTs (ref. 5) Princeton U.	Organic TFTs (ref. 6) Erlangen
Mobility	>10 cm^2/Vs	>7 cm^2/Vs	15 cm^2/vs	0.5 cm^2/Vs	0.5 cm^2/Vs	0.1 cm^2/Vs
Operation voltage	4 V	10 V	20 V	40 V	15 V	2.5 V
Bending radius	10 mm	30 mm	10 mm	0.5 mm	0.5 mm	2.5 mm

1. *Journal Soc. Inf. Displays* 16, 107(2008).
2. *Nature* 432, 488-492 (2004).
3. *Appl. Phys. Lett.* 86, 243502 (2005).
4. *Appl. Phys. Lett.* 87, 173502 (2005).
5. *Appl. Phys. Lett.* 96, 042111 (2010).
6. *Appl. Phys. Lett.* 95, 103309 (2009).

Organic TFTs can easily construct complementary circuits on plastics.
➔ Low-process temperatures & stable p-type, n-type semiconductors

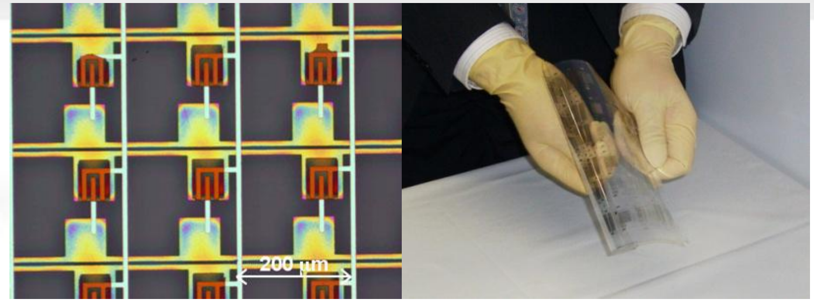
Technical challenges for skin-like interfaces

➔ Large-area & flexible active matrix

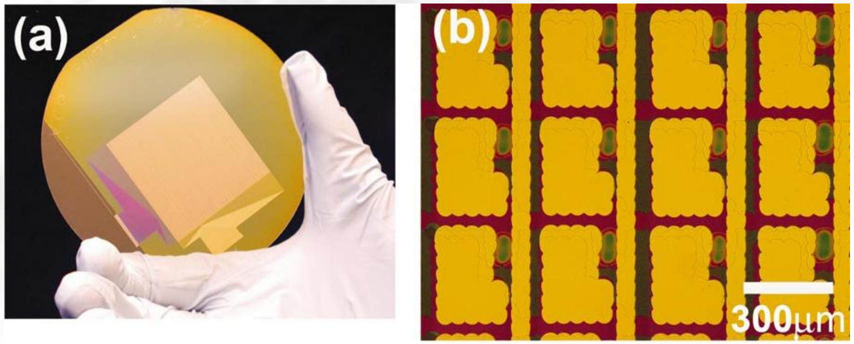


Printed TFT active matrices for displays

K. Yase, et al., (2008) AIST

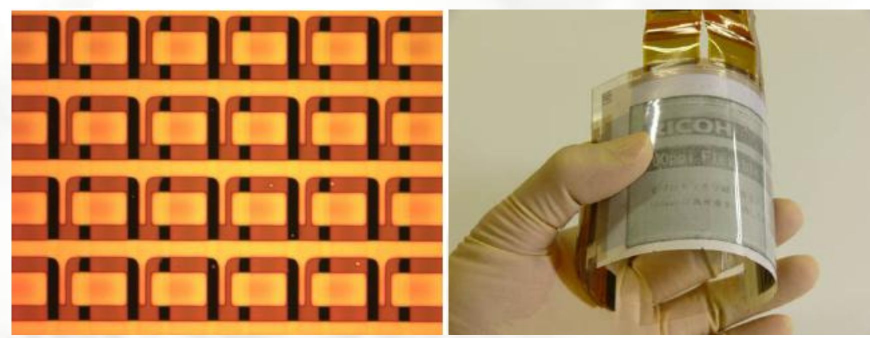


Micro-contact printing
Semiconductor: P3HT
Mobility: ~0.01 cm^2/Vs
127 μm pixel pitch (200ppi)



Inkjet printing
Semiconductor: PQT
Mobility: ~0.08 cm^2/Vs
340 μm pixel pitch

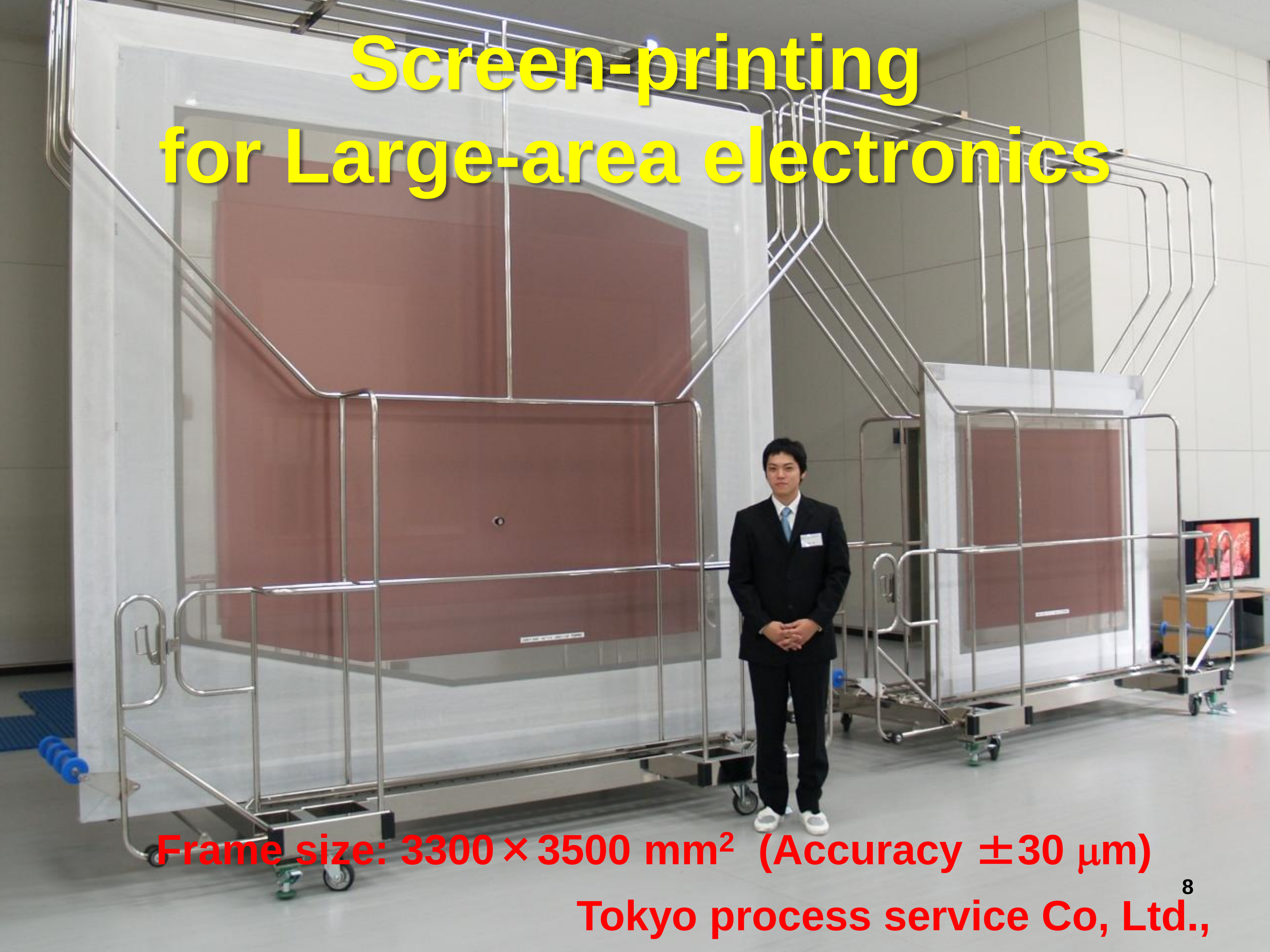
A. C. Arias, et al., (PARC)
Appl. Phys. Lett. 85, 3304 (2004)



Inkjet printing + UV
Semiconductor: Small molecule
Mobility: ~0.1 cm^2/Vs
127 μm pixel pitch (200ppi)
3.2 inch-diagonal

K. Suzuki et a., IDW'09 (2009) RICOH

Screen-printing for Large-area electronics



Frame size: 3300×3500 mm^2 (Accuracy ±30 μm)

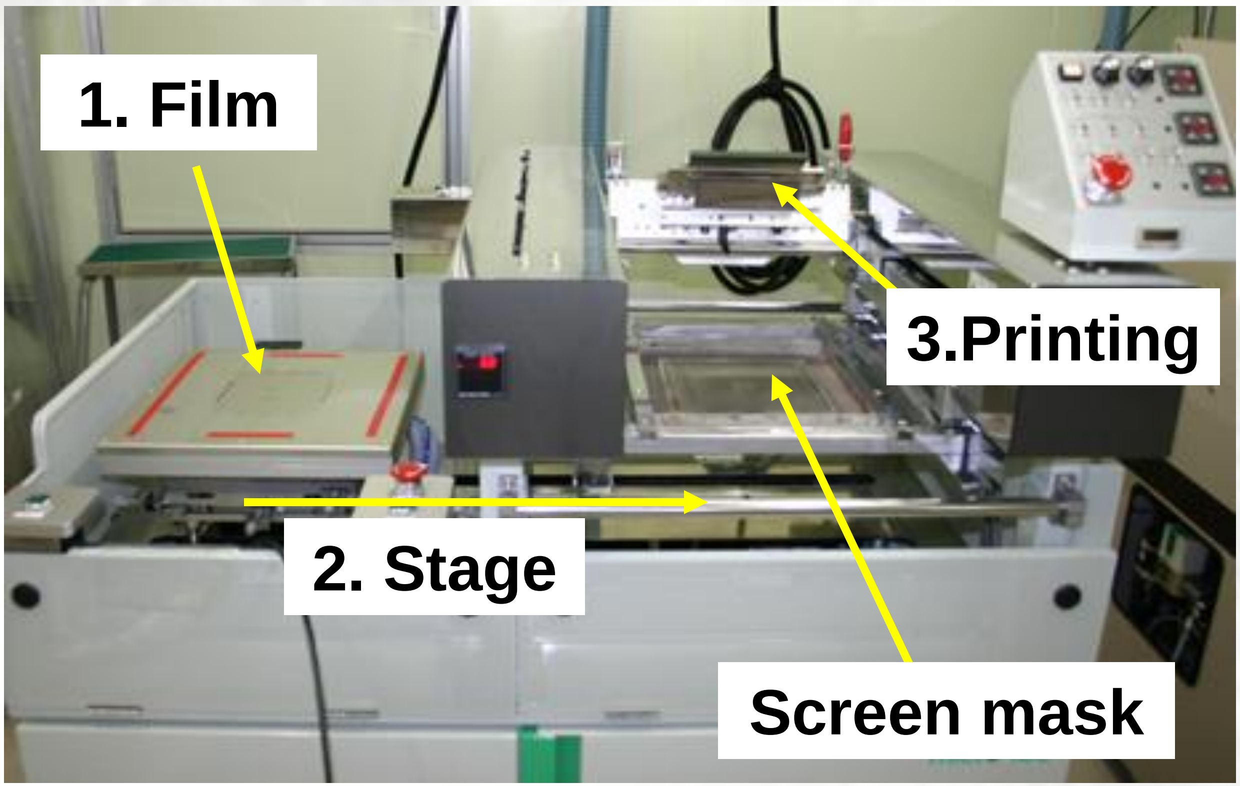
Tokyo process service Co, Ltd.,

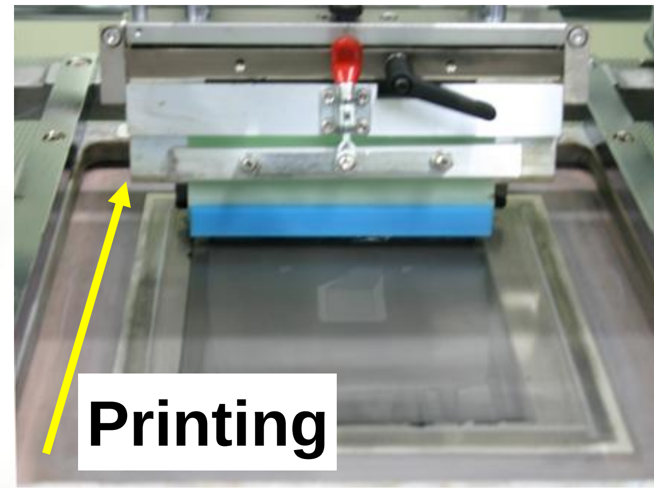
Screen-printing system

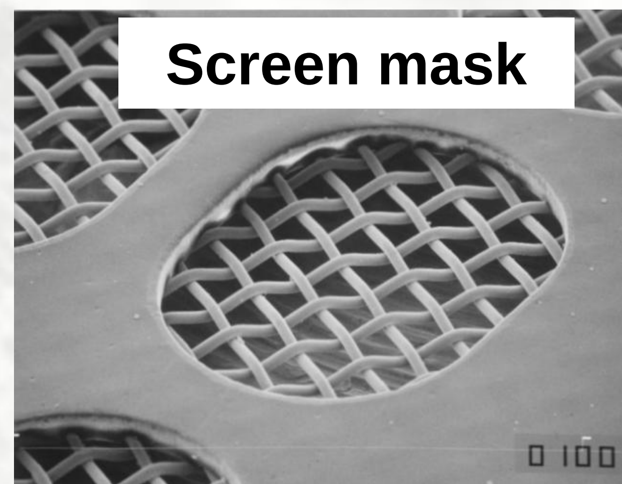
Printing area : 300 × 300 mm²

Repeat accuracy : 5 μm

Microtec Co. Ltd.



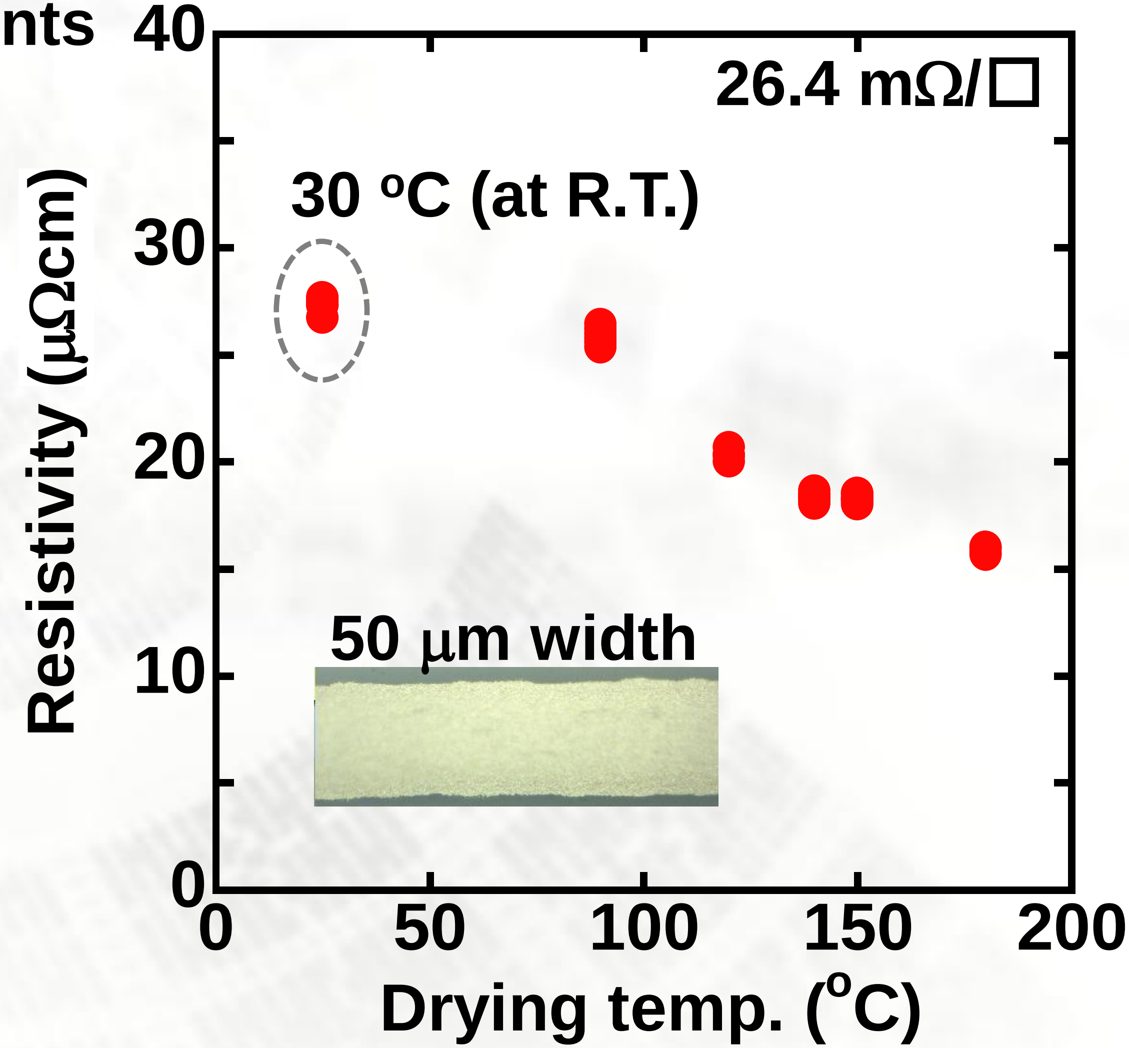




500μm

Ag paste with low-drying temperature

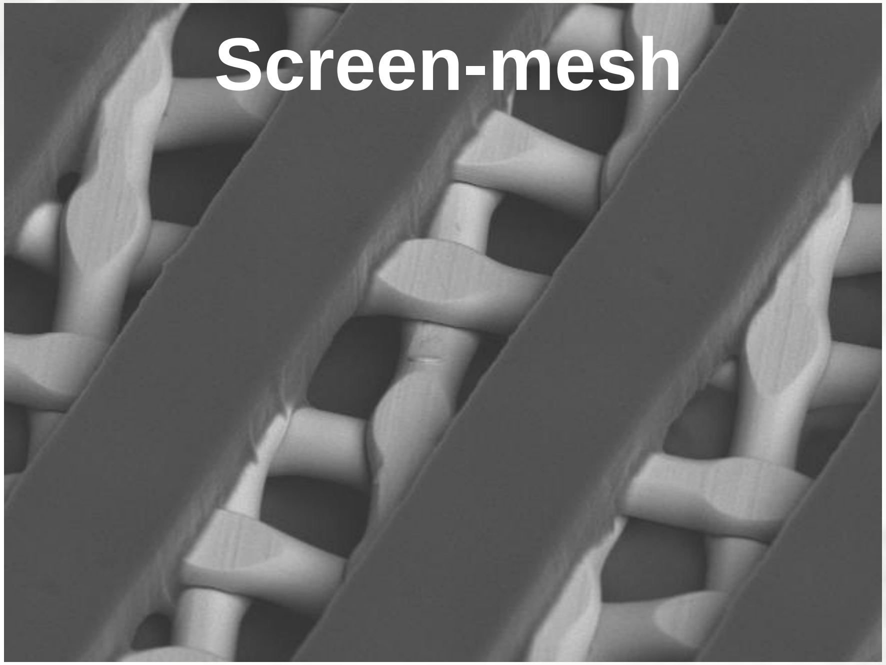
Viscosity: 360 Pa·s
➔very few organic solvents

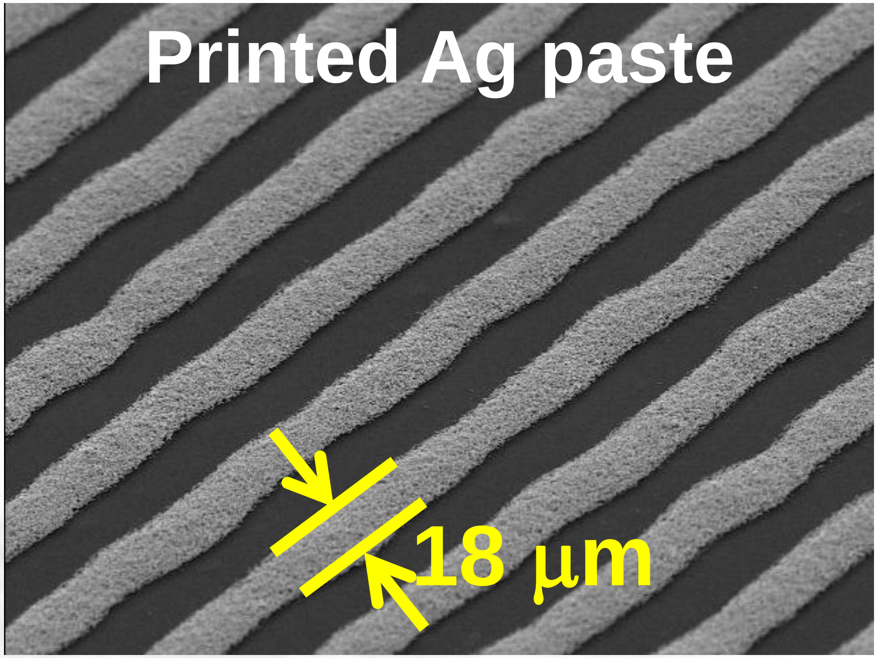


High-definition screen-printing

High-viscosity ink { ✓ High-squeezing pressure; ✓ Large-clearance between screen-mask and substrate

This work





✓ Twill-weaven mesh for high tensile force (3000 N/mm)

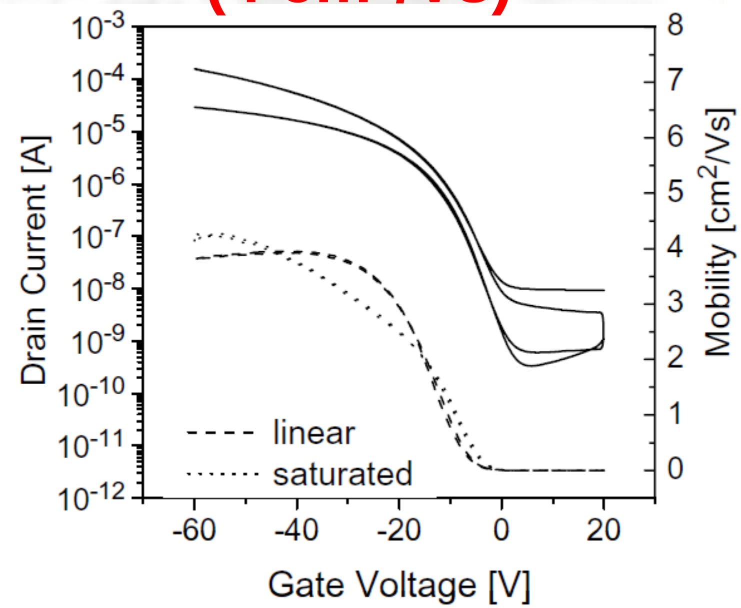
✓ Finely patterned without ink bleed

Organic semiconductor ink

Solution –processable polycrystalline organic semiconductor

- **High-mobility (4 cm^2/Vs)**
- **Annealing is not required**
- **Air-stable**

Iisicon OSC (Merck Ltd.)



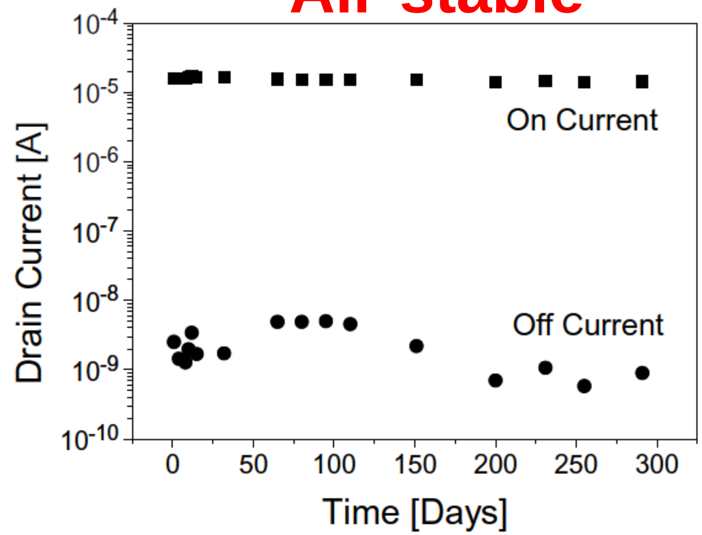


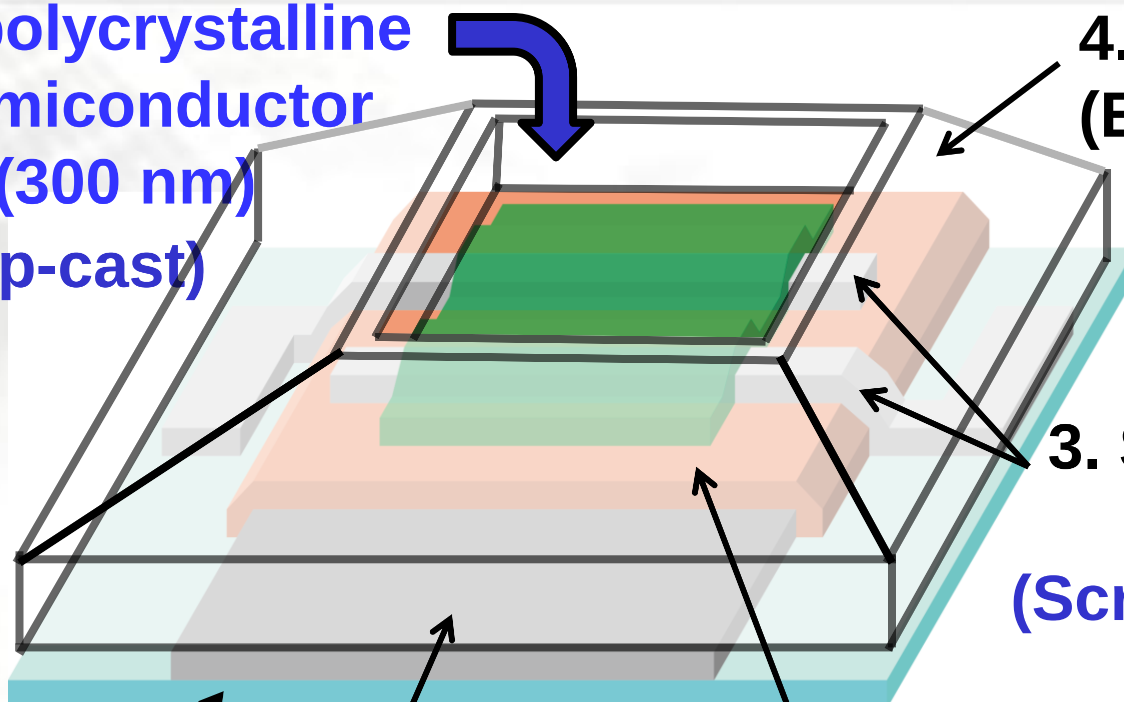
Fig. 3 Example lifetime data for a spin coated top gate device stored in normal laboratory conditions.

Iisicon OSC (Merck Ltd.)

- G. Lloyd et al., *Tech Dig* of IDW '08
- M. Carrasco-Orozco et al., *Tech Dig* of IDW '09
- G. Lloyd et al., *Tech Dig* of IDW '10

Transistor fabrication by printing

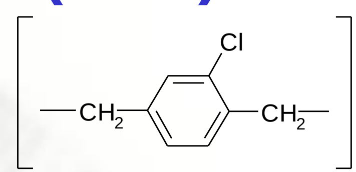
5. Solution-polycrystalline Organic semiconductor lisicon (300 nm) (IJP, Drop-cast)



4. Bank (Epoxy: 5 μm) (Screen printing)

3. S/D electrode (Ag: 5 μm) (Screen printing)

2. Gate dielectric layer (CVD) (parylene：400 nm)



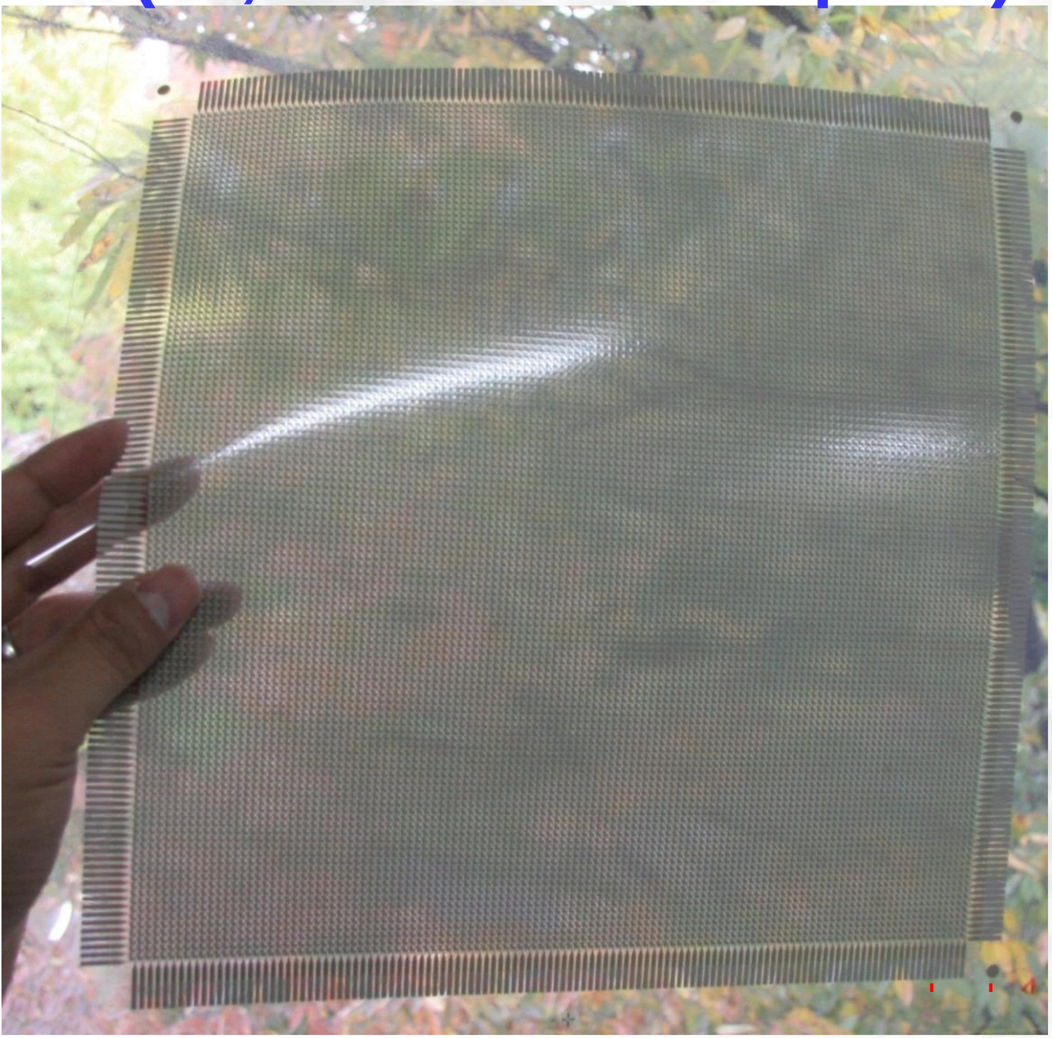
1.Gate electrode (Ag: 3 μm) (Screen printing)

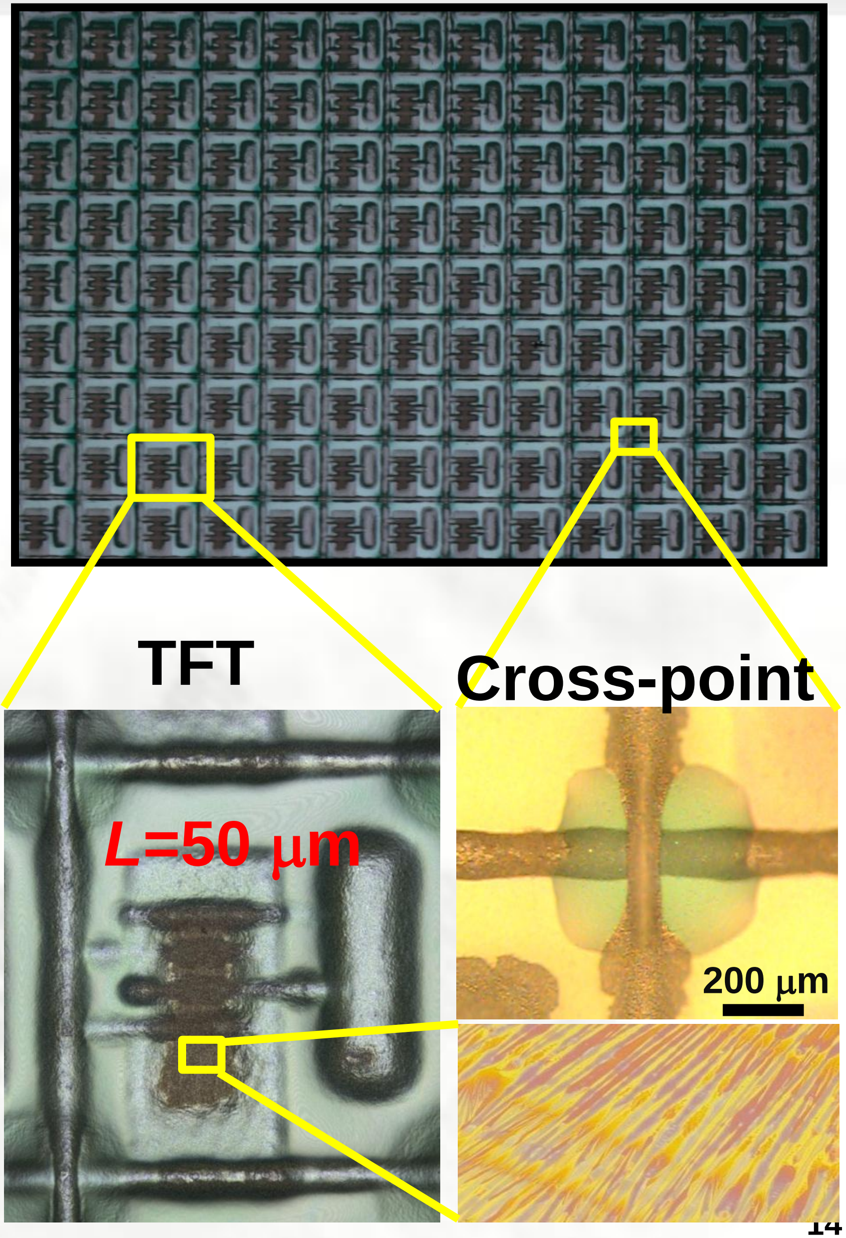
Substrate (PEN: 125 μm)

Dry at 3 hours in ambient air ＋ Parylene encapsulation

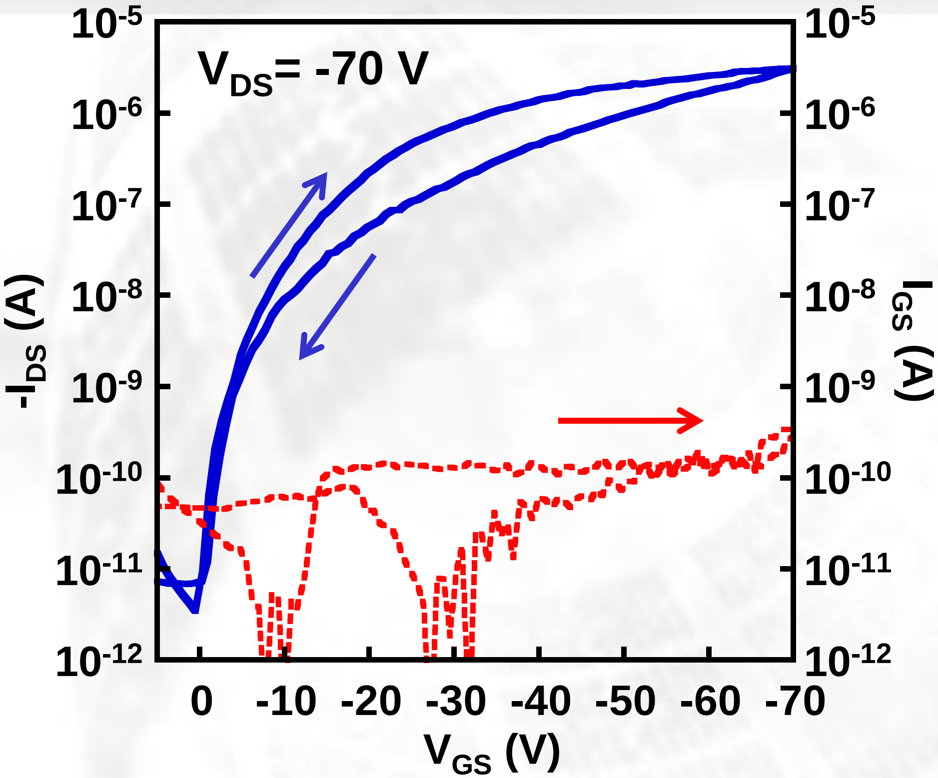
Printed transistor active matrix

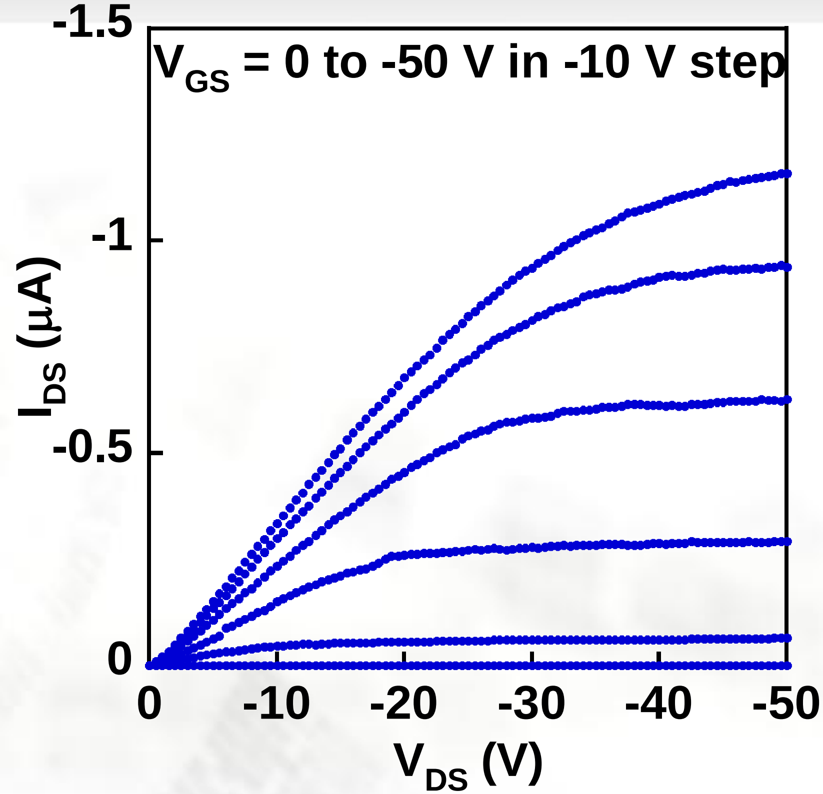
300 x 300 mm^2
(14,400 cells: 1mm pitch)





Polycrystalline organic TFT





Mobility : ~0.18 cm^2/Vs

On/off ratio : 10^3~10^6

In air

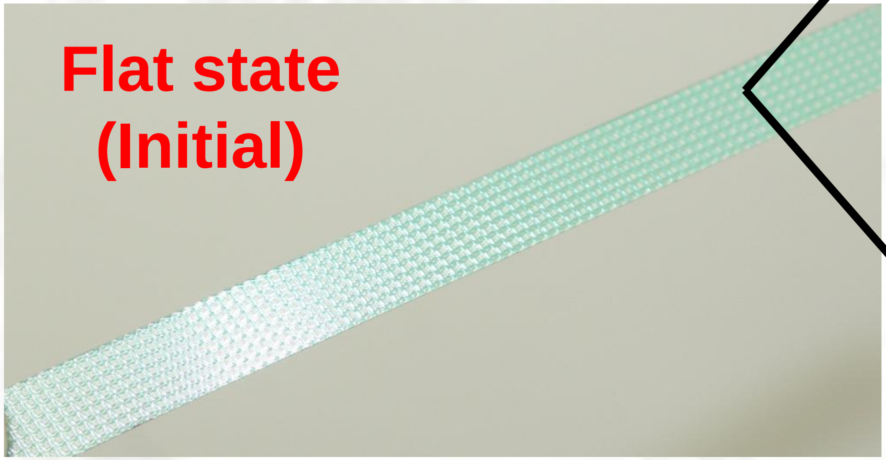
5 days

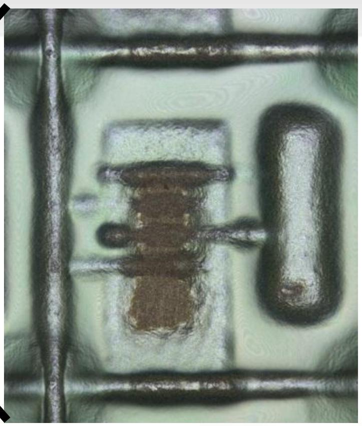
μ: 0.13 cm^2/Vs

V_{TH}: -3.2 V

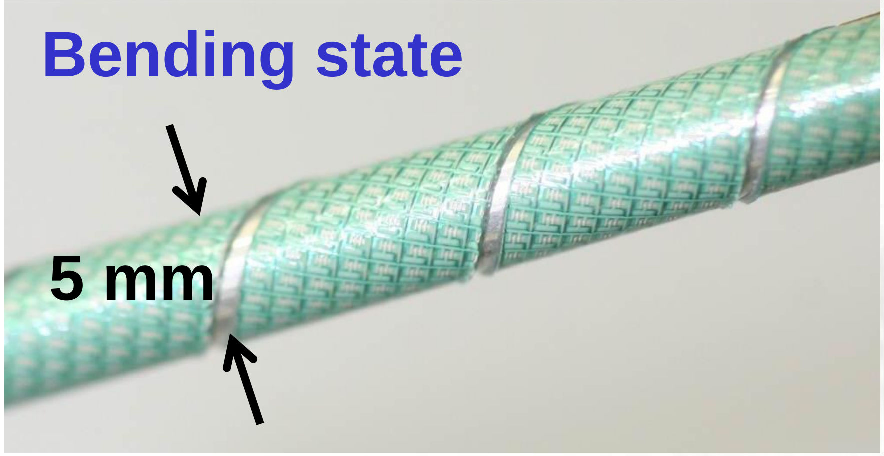
On/Off: >10^3

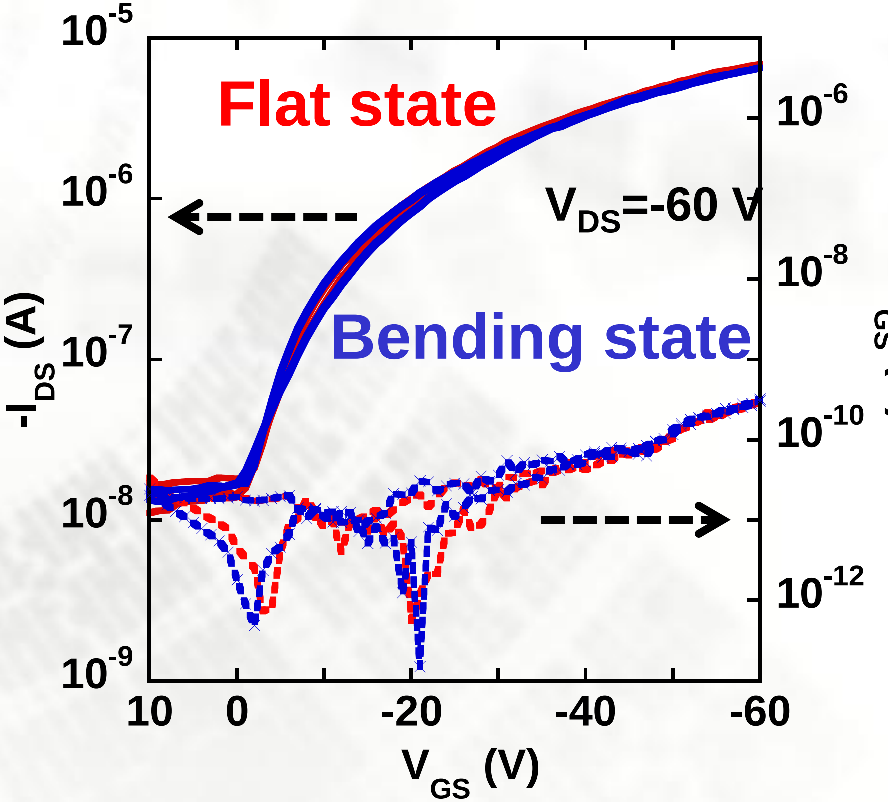
Bending Test



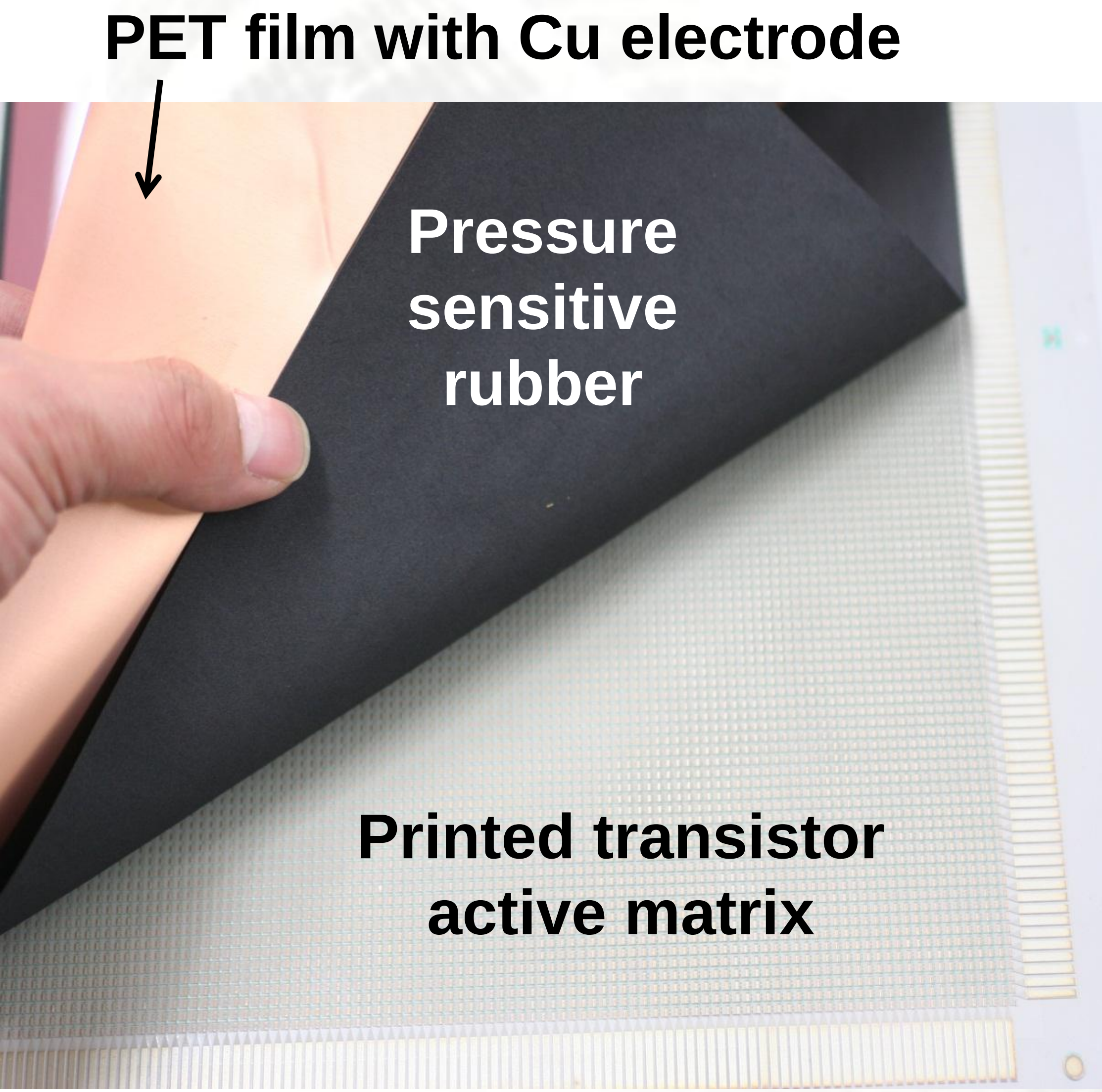


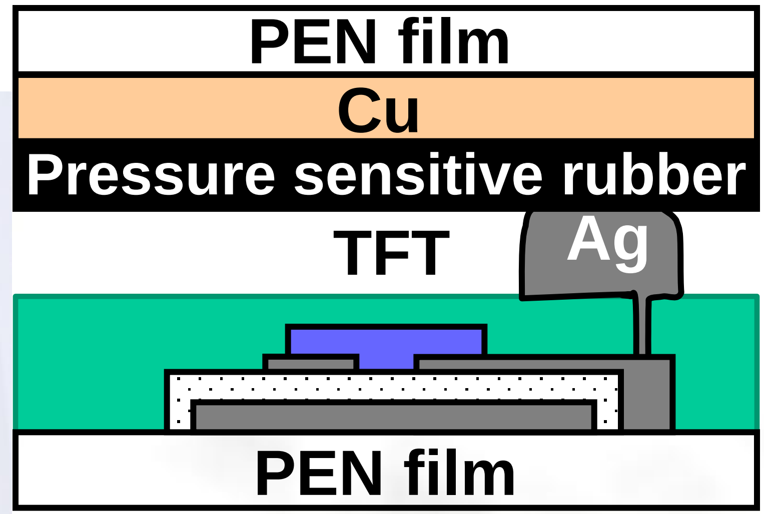
L=50 μm

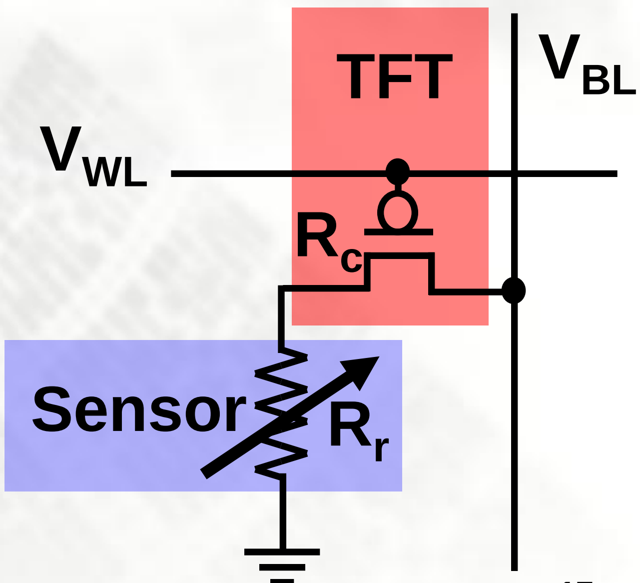


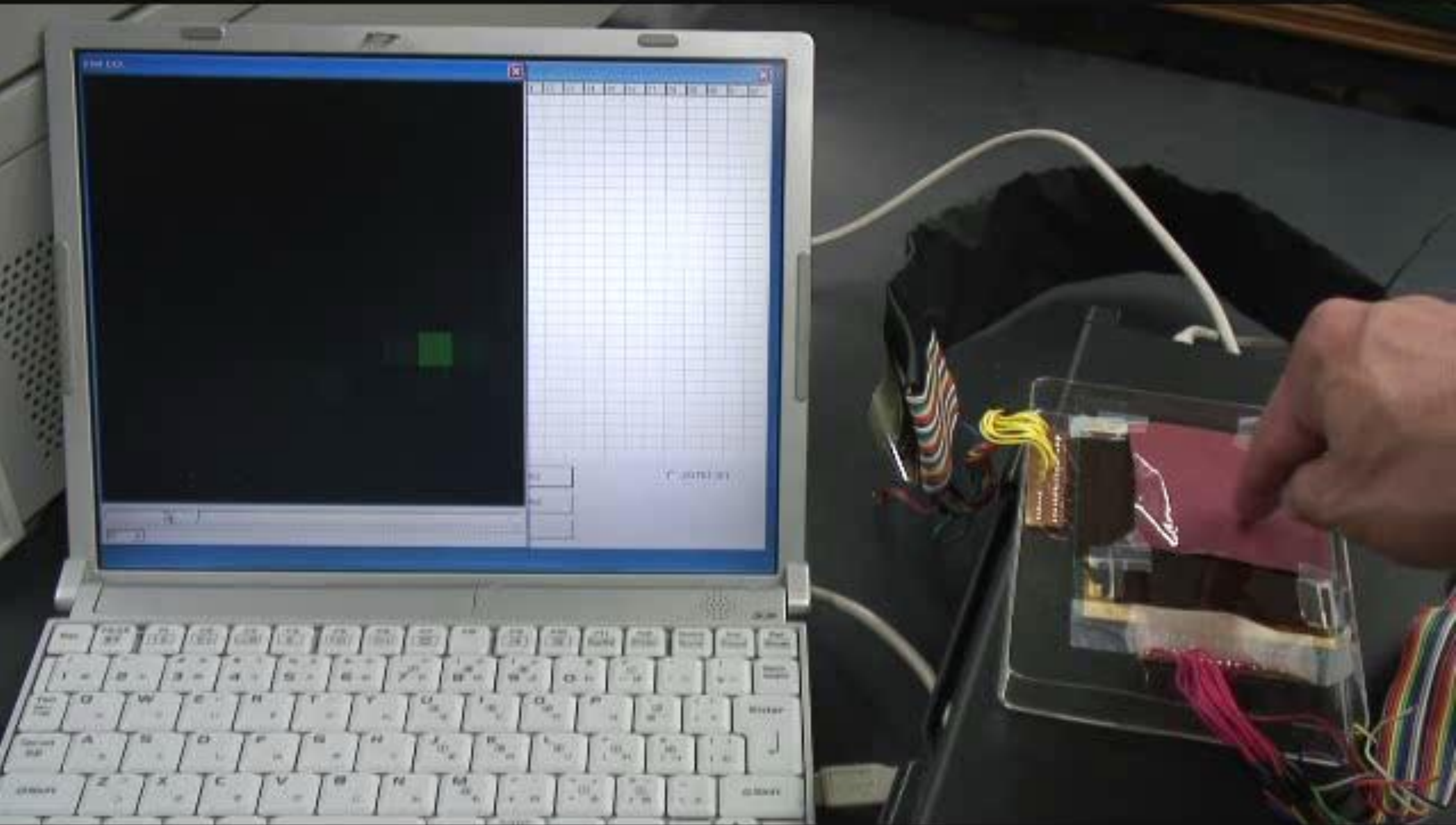


Flexible touch-sensor sheet

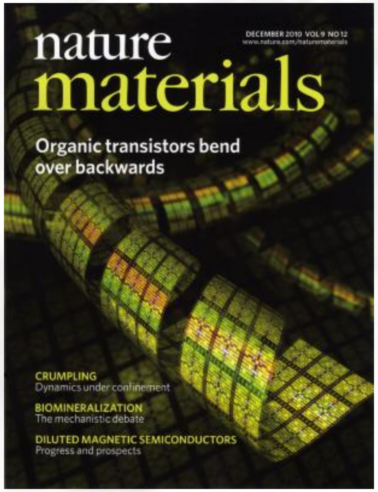


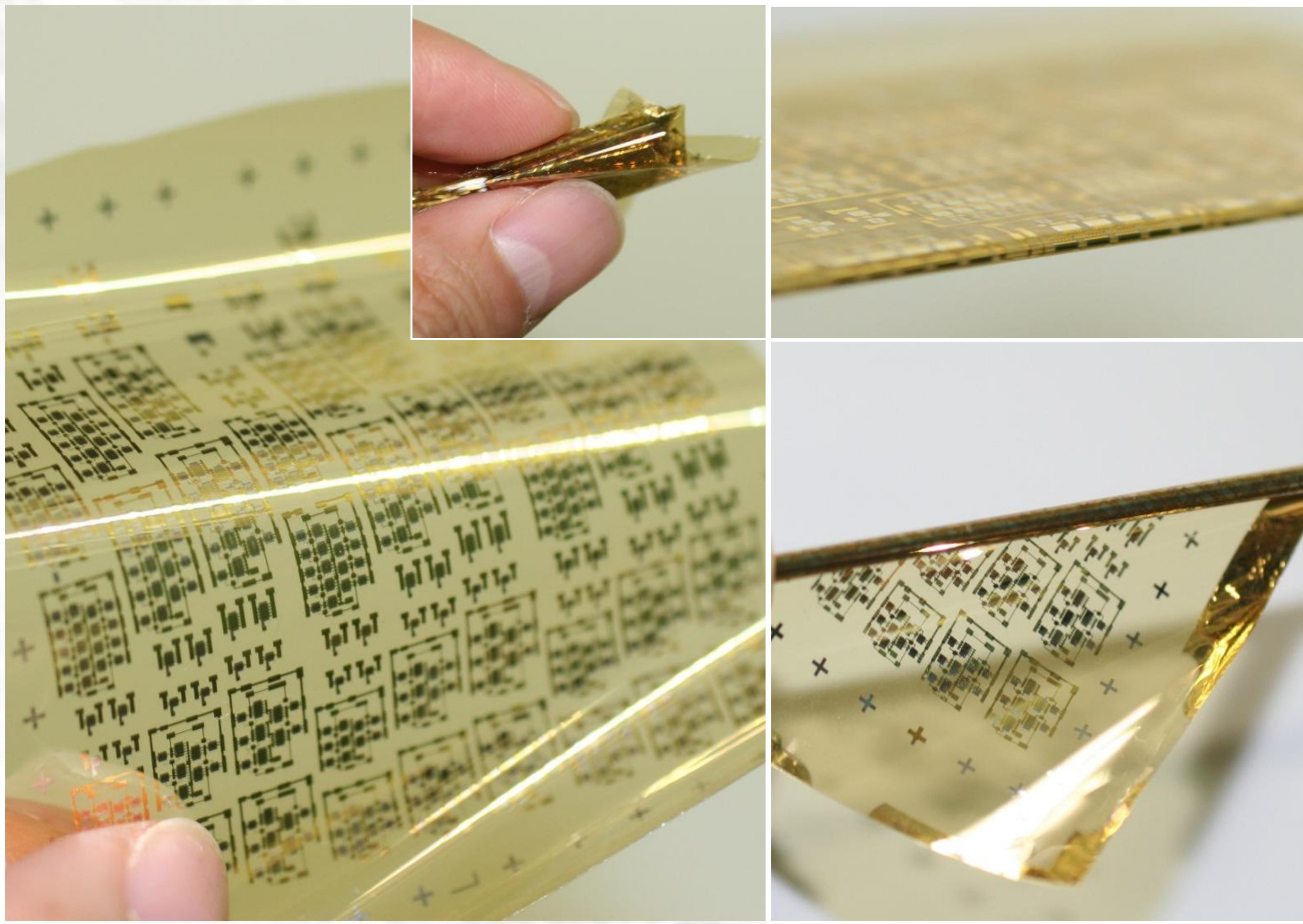






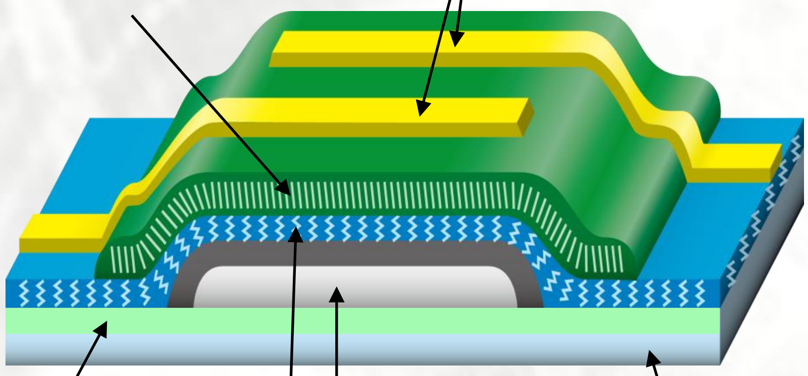
Low-voltage operational ultraflexible organic CMOS circuits





T. Sekitani, et al., Nature Materials, 9, 1015 (2010)

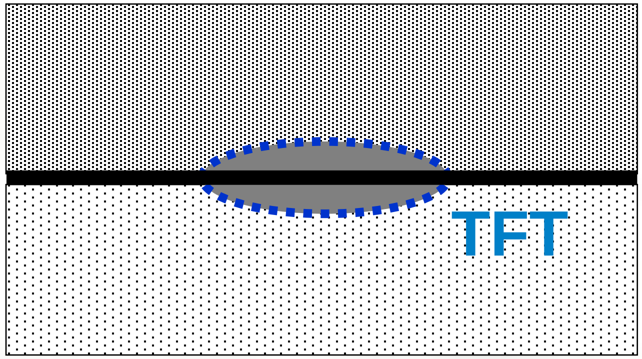
TFT structure



AlO_x (4 nm)+SAMs (2 nm)

Klauk, et al., Nature 445 745 (2007)

Encapsulation (13 μm)

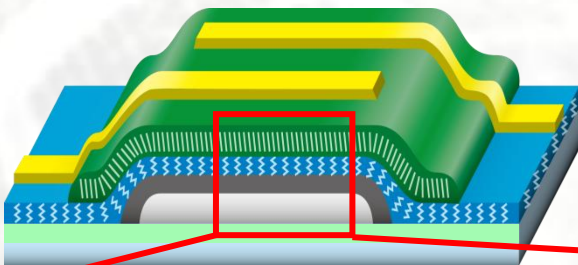


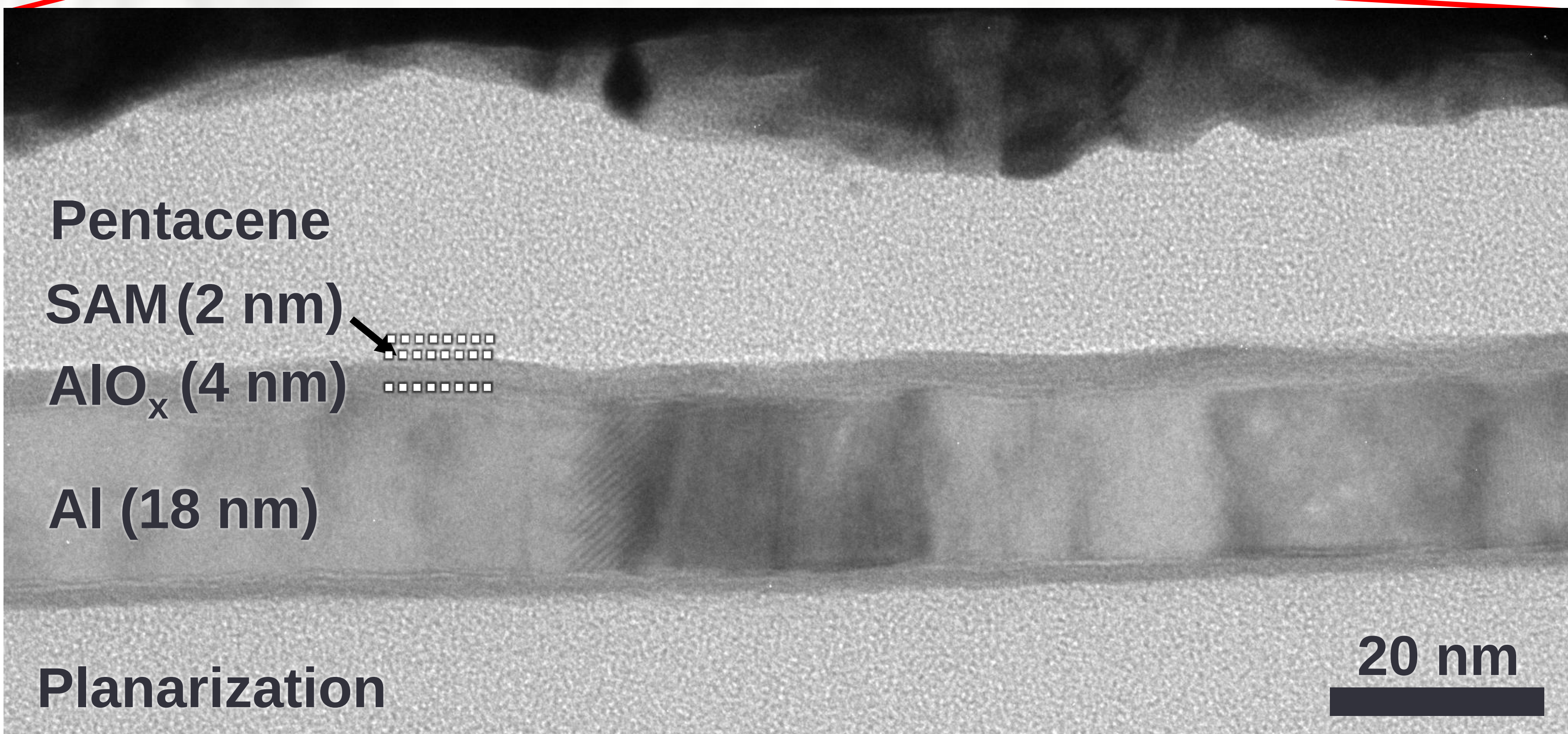
Substrate +Planarization(13 μm)

TFT: Neutral strain

Cross-sectional picture

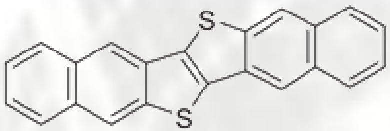
(FIB/TEM)





Organic TFTs on plastic

P-type DNTT TFT

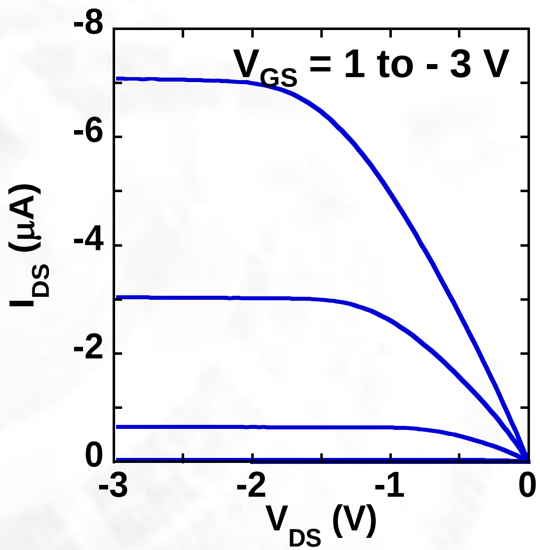


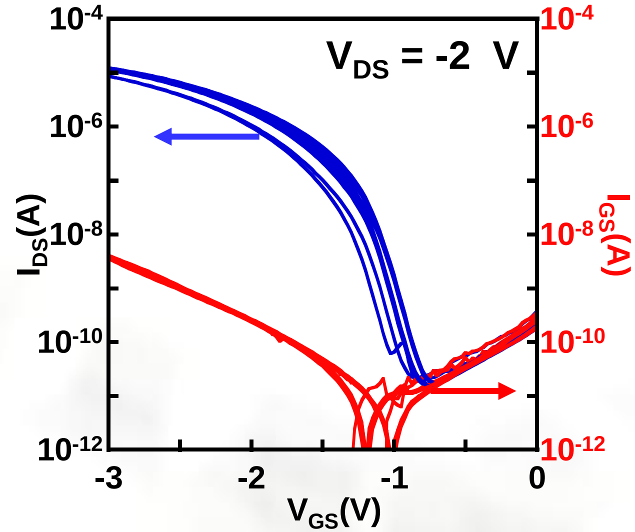
JACS 129, 2224 (2007).

3.0 cm²/Vs

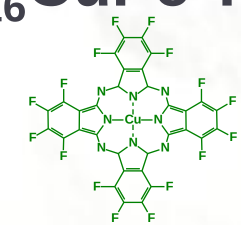
On/off: > 10^5

80 mV/dec





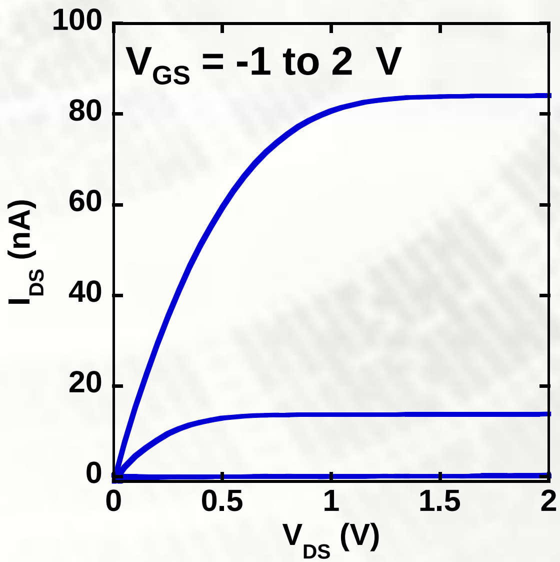
N-type $F_{16}CuPc$ TFT

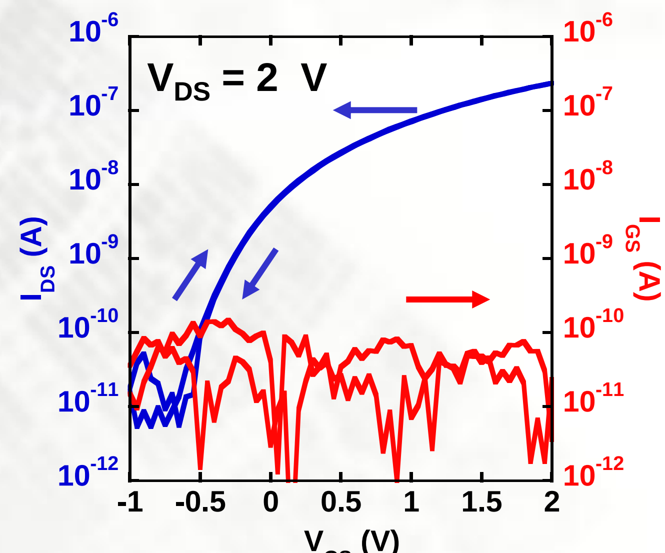


0.02 cm²/Vs

On/off: > 10^4

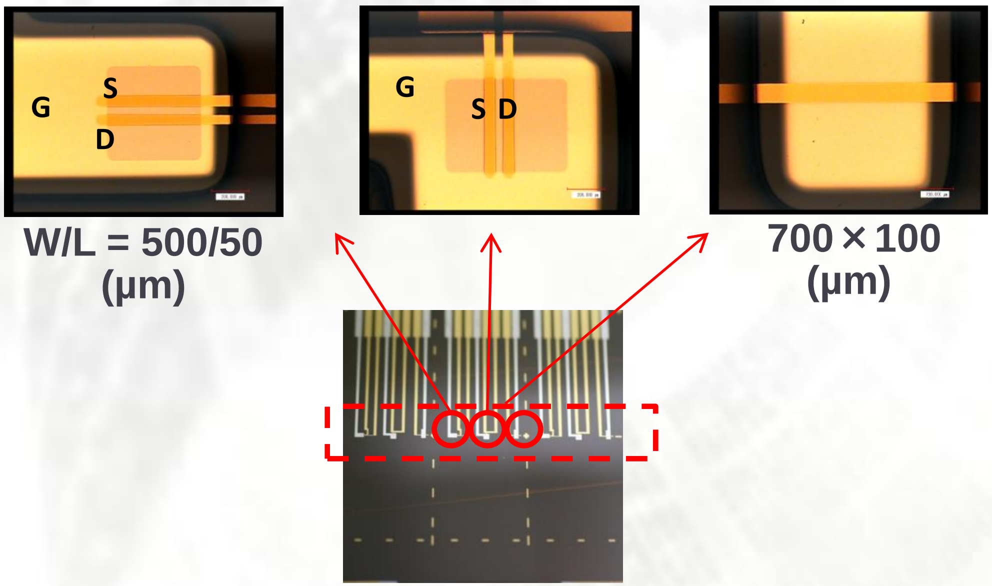
150 mV/dec

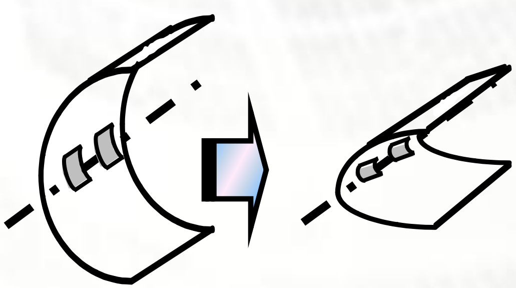




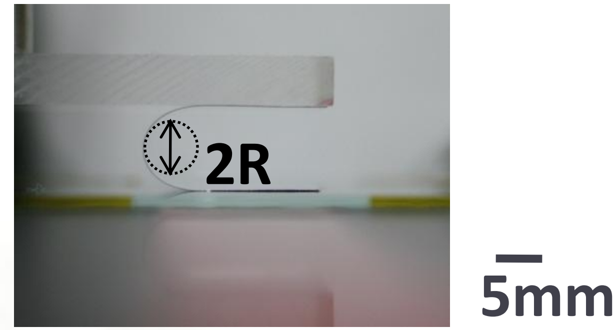
Bending test

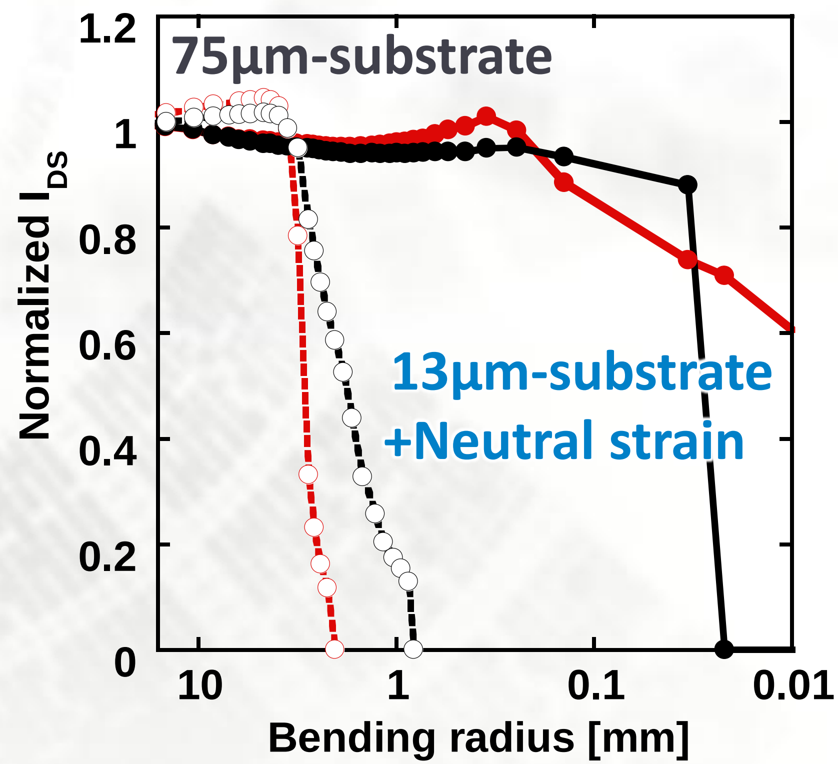
Current // Strain (Parallel)	Current ⊥ Strain (Perpendicular)	Capacitor





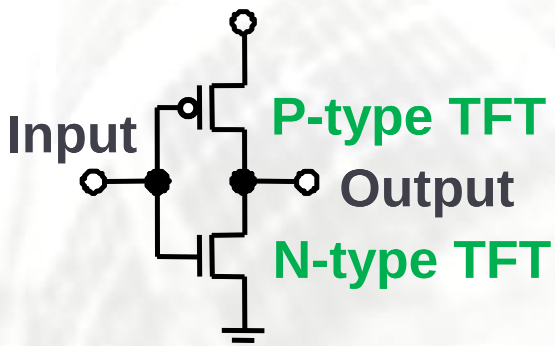
Cross-section

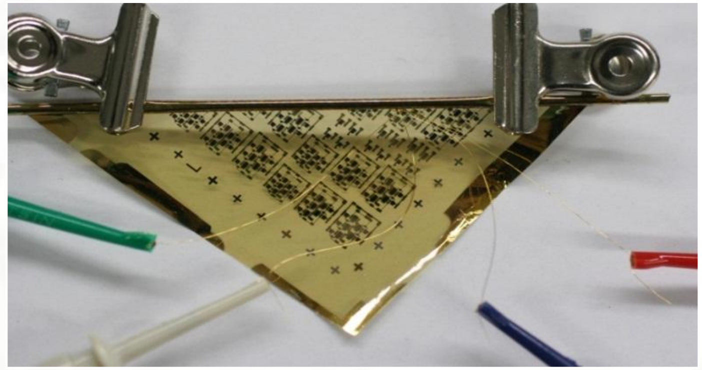




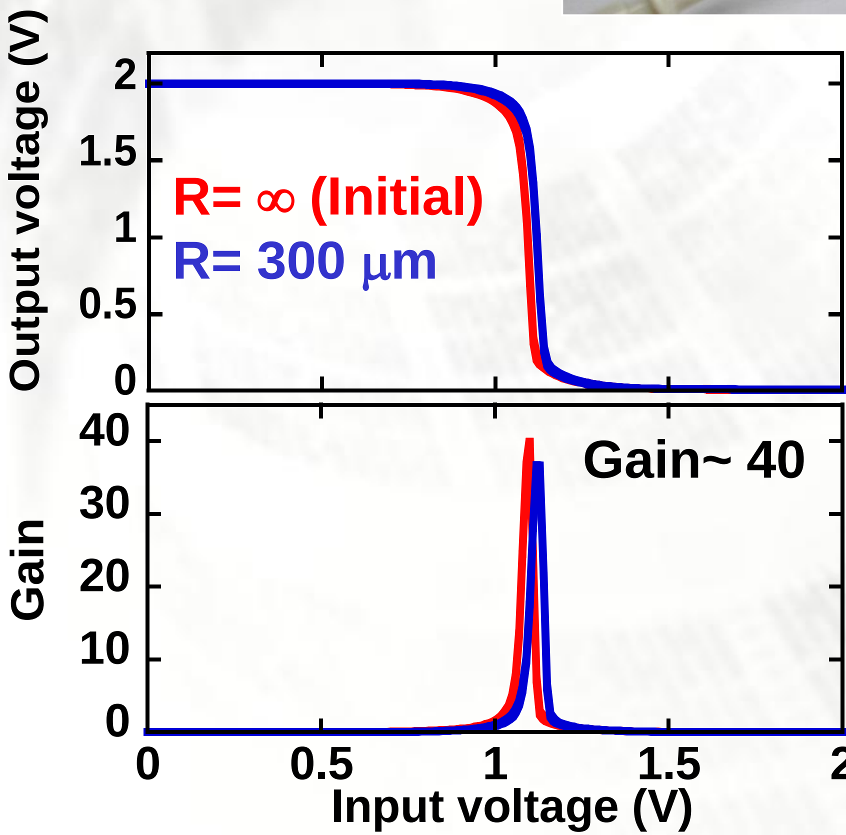
R < 0.5 mm (13 μm-thick substrate)
R ~ 4.0 mm (75 μm-thick substrate)

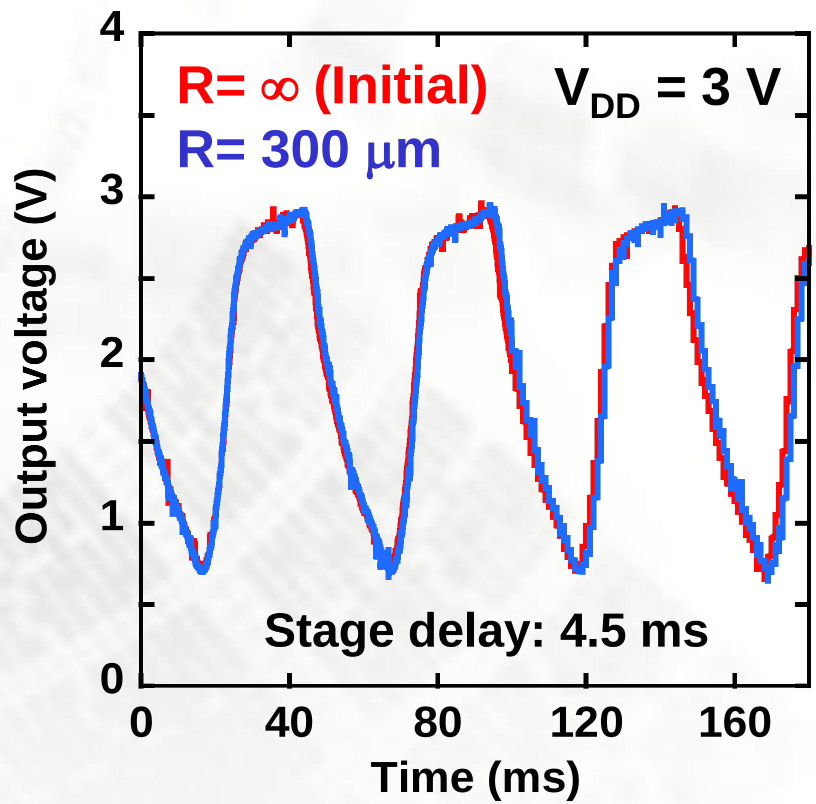
Organic CMOS circuits



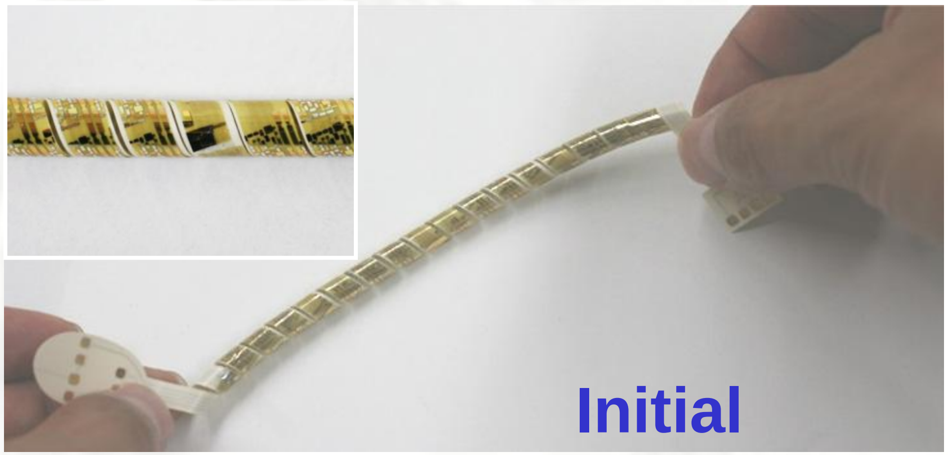


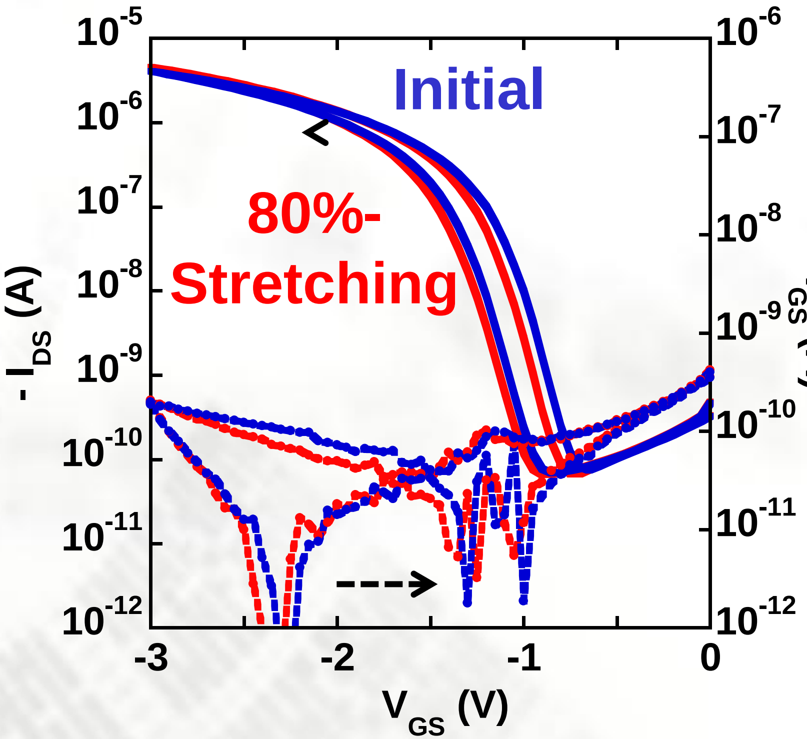
- ✓ Inverter
- ✓ Ring oscillator





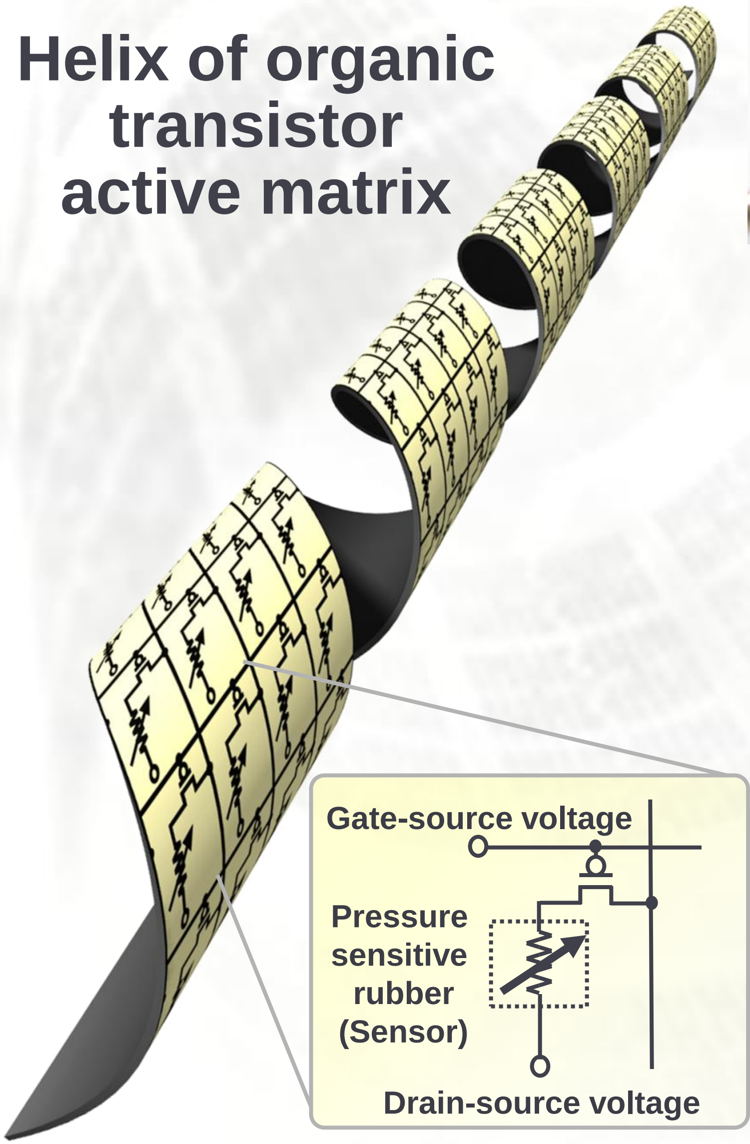
Stretchable integrated circuits on shape-memory polymer

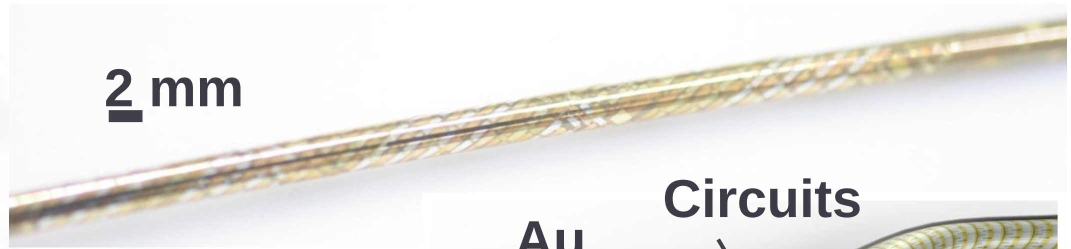


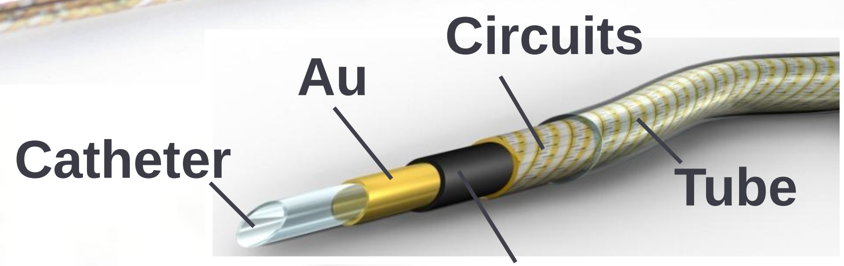


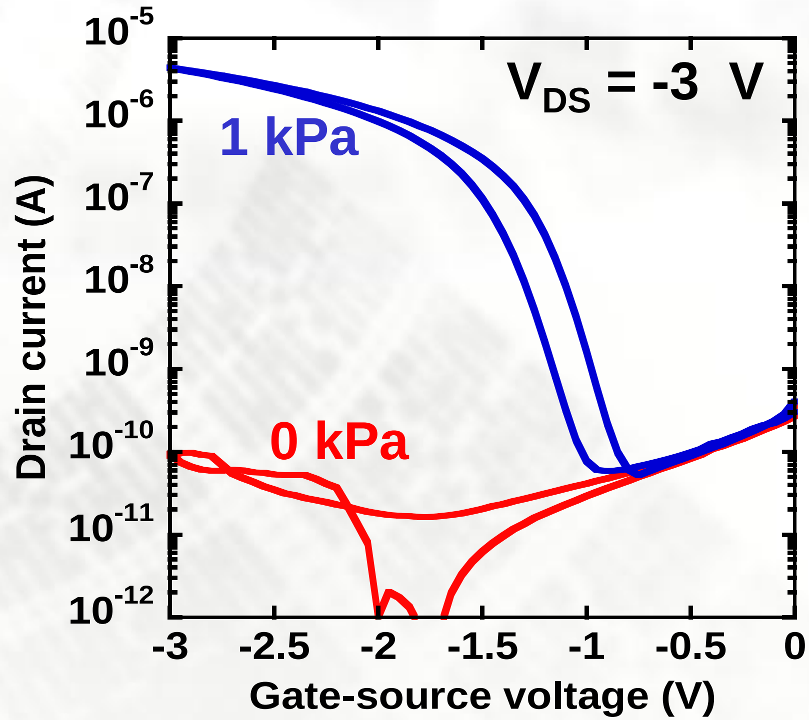
Fine-tube electronics for medical

Helix of organic transistor active matrix







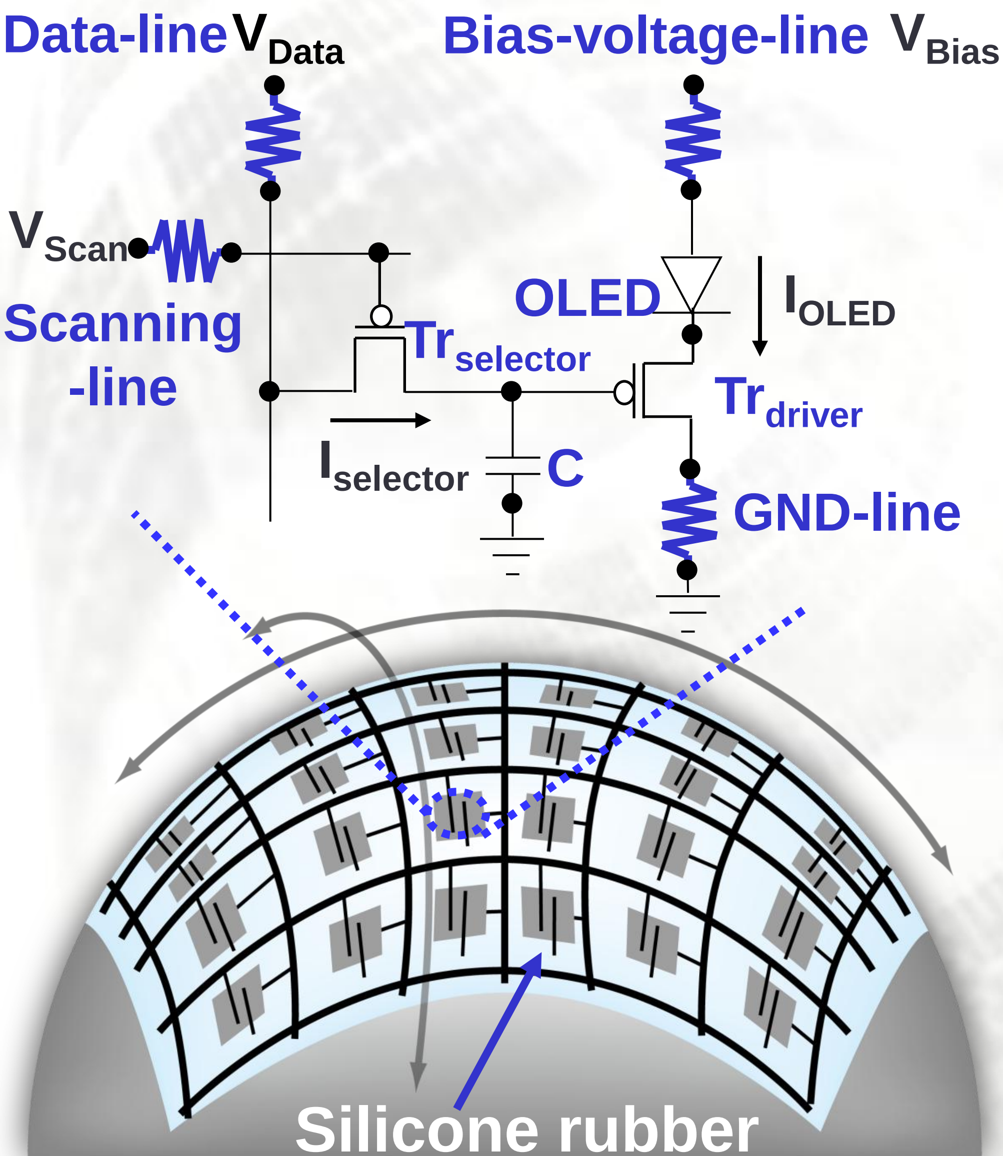


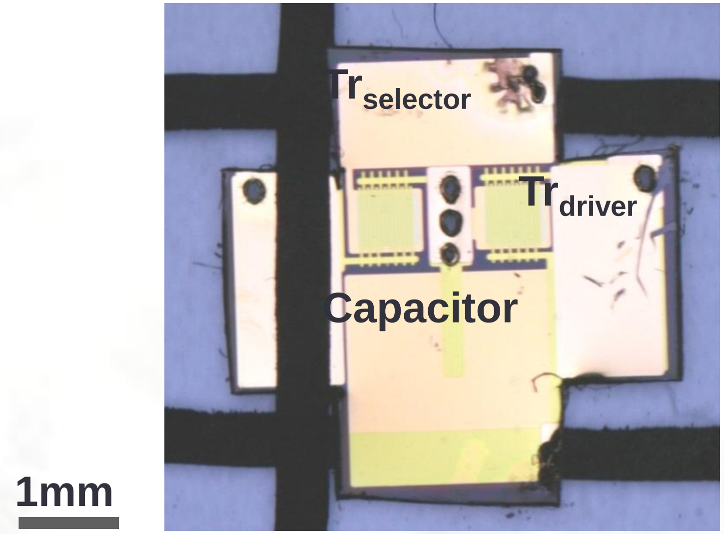
Printed elastic conductor

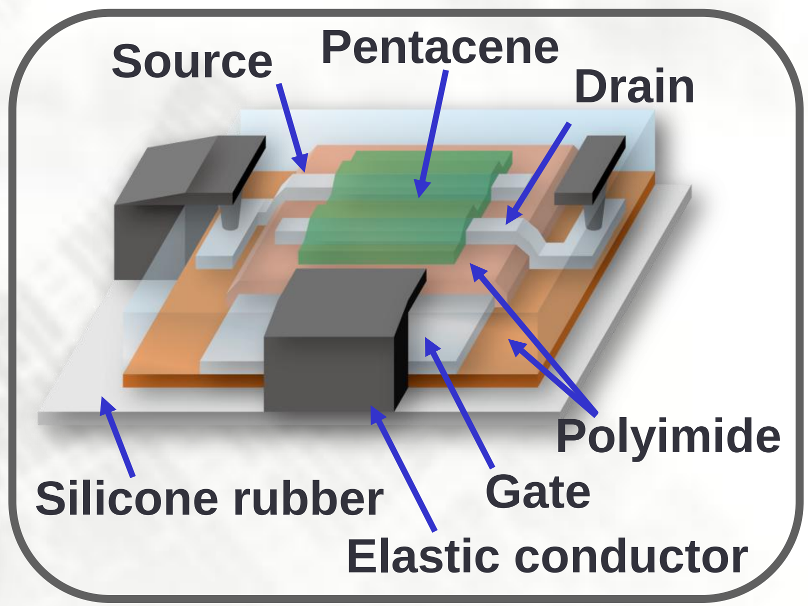
Science 321, 1468 (2008).

Resolution : 100 μm
Conductivity : ~100 S/cm
Stretchability : ~140%

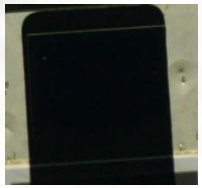
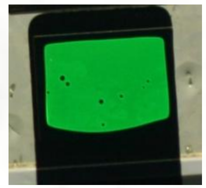
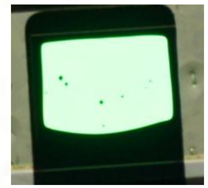
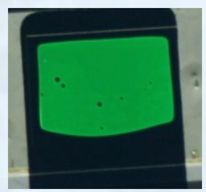
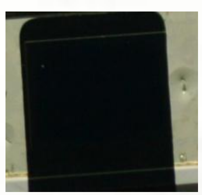
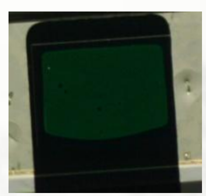
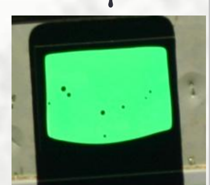
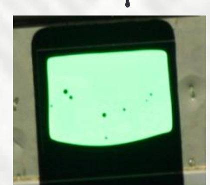
Structure for stretchable displays







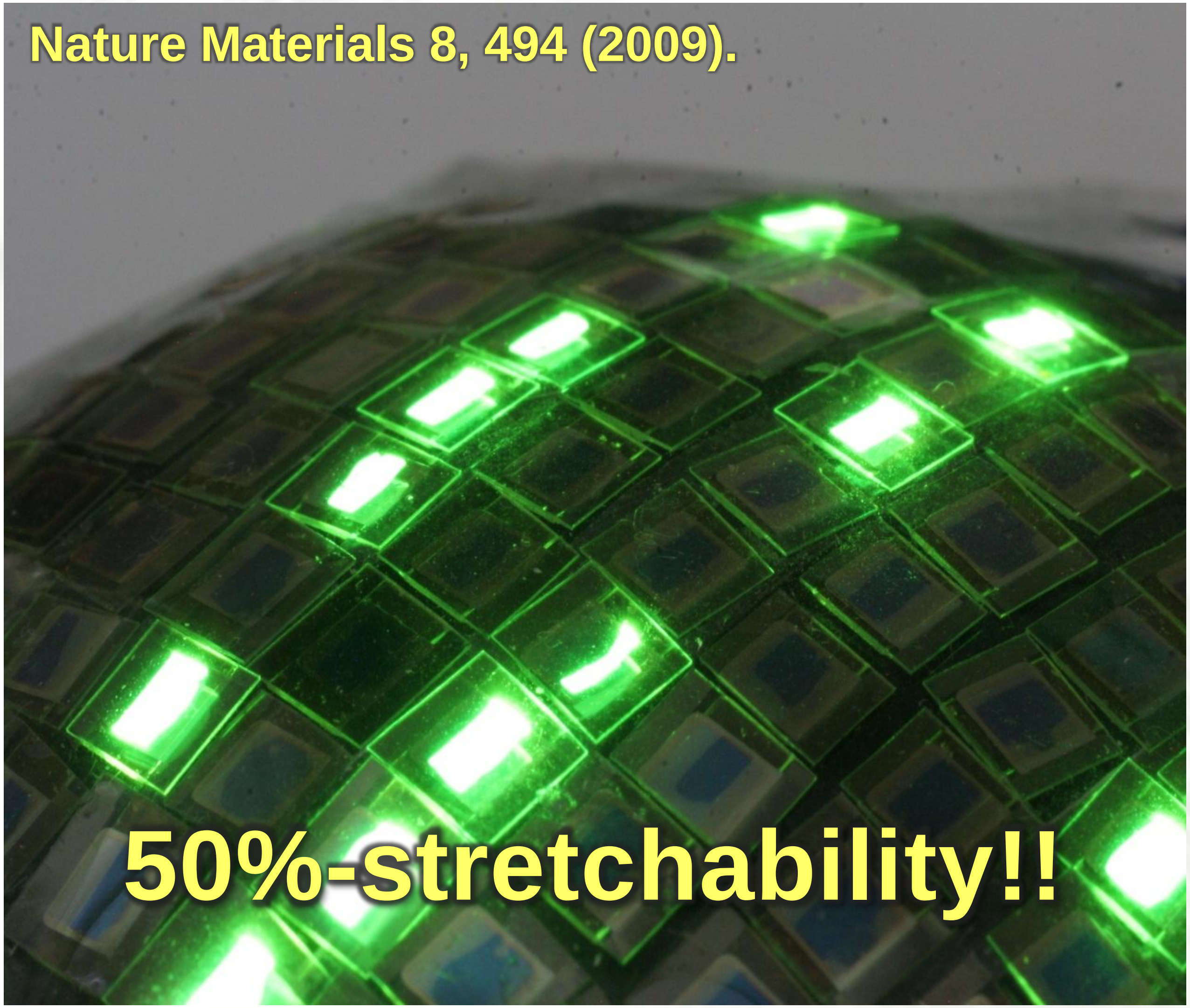
Luminance of organic LEDs with organic driving cell

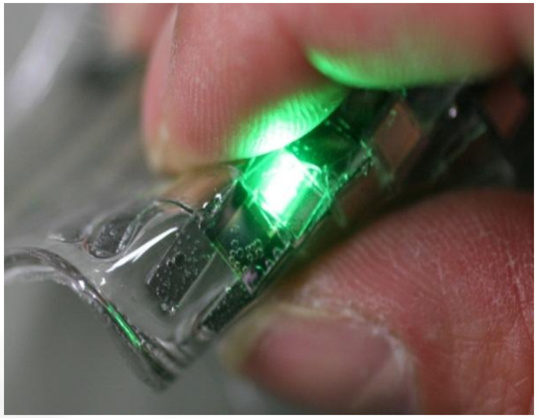
V_{Scan}	+40 V	–5 V	–10 V	–30 V	–40 V
Cu wiring (Control sample)	6.7 nA  0.0 cd/m^2	1.7 μA  0.3 cd/m^2	35 μA  6.1 cd/m^2	381 μA  88.3 cd/m^2	1.3 mA  408 cd/m^2
Elastic conductor	7.0 nA  0.0 cd/m^2	1.6 μA  0.28 cd/m^2	31.6 μA  5.5 cd/m^2	343 μA  77.2 cd/m^2	1.2 mA  364 cd/m^2
Conventional conducting rubber	2.6 nA  0.0 cd/m^2	280 nA  0.0 cd/m^2	6.6 μA  1.2 cd/m^2	19.4 μA  3.4 cd/m^2	40μA  7.1 cd/m^2

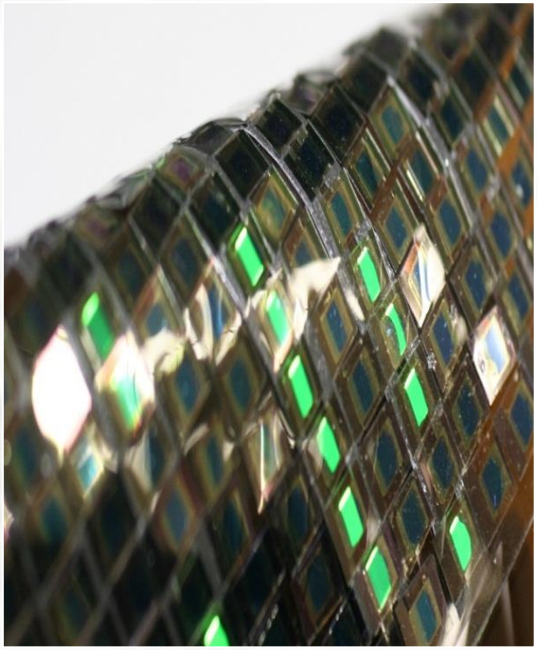
Δ8%

Δ97%

Stretchable active matrix OLED display

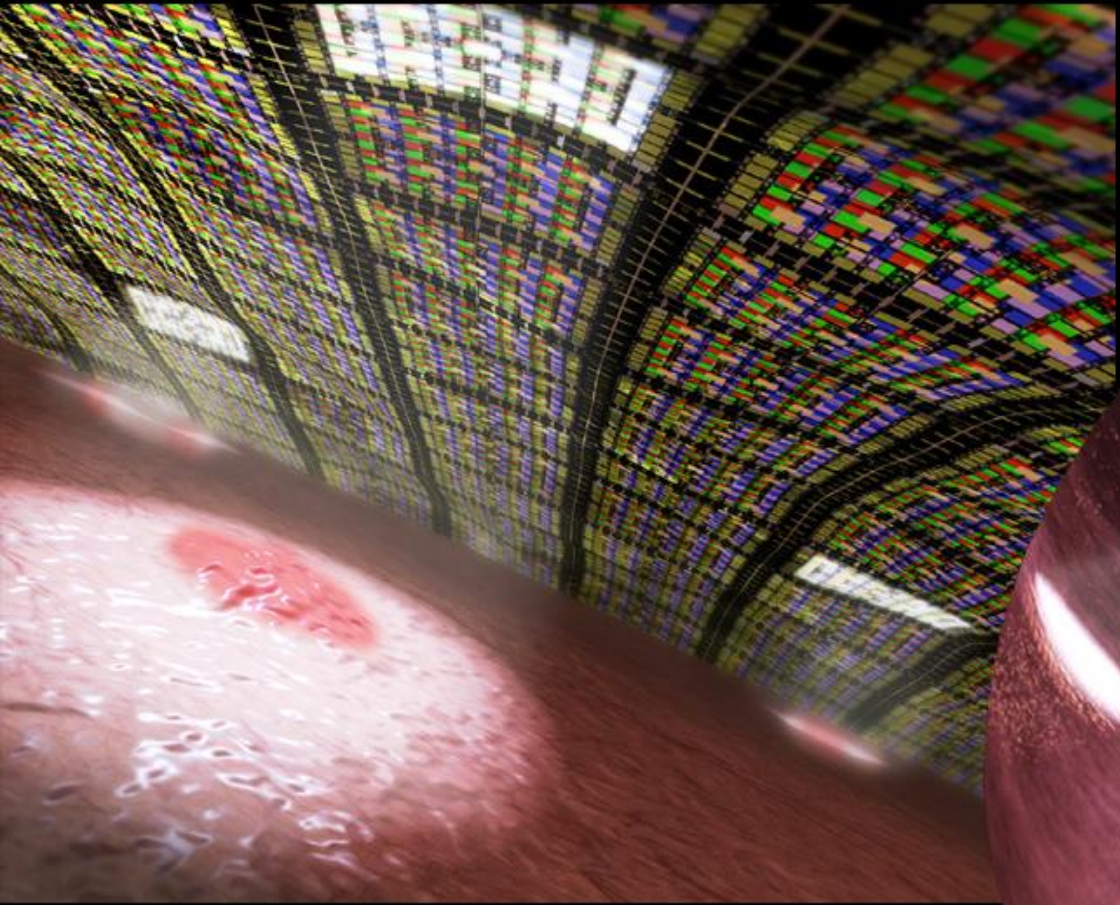


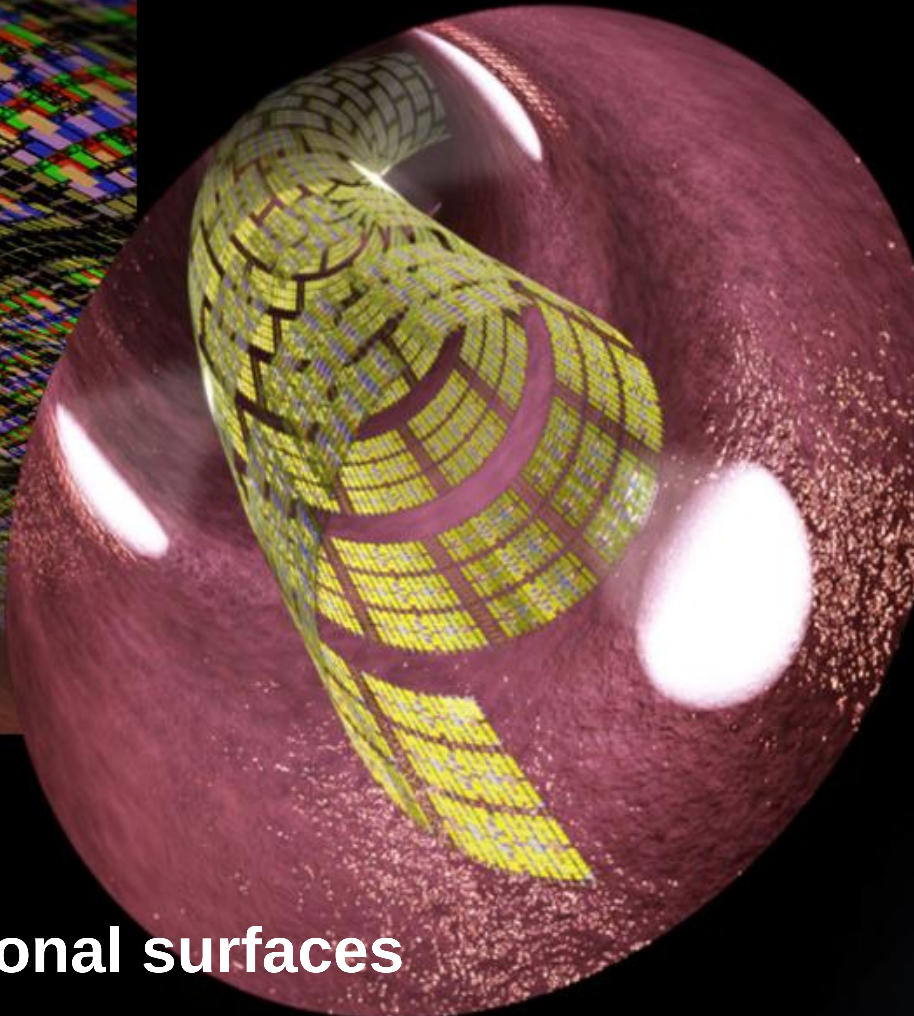




Displays on an egg.

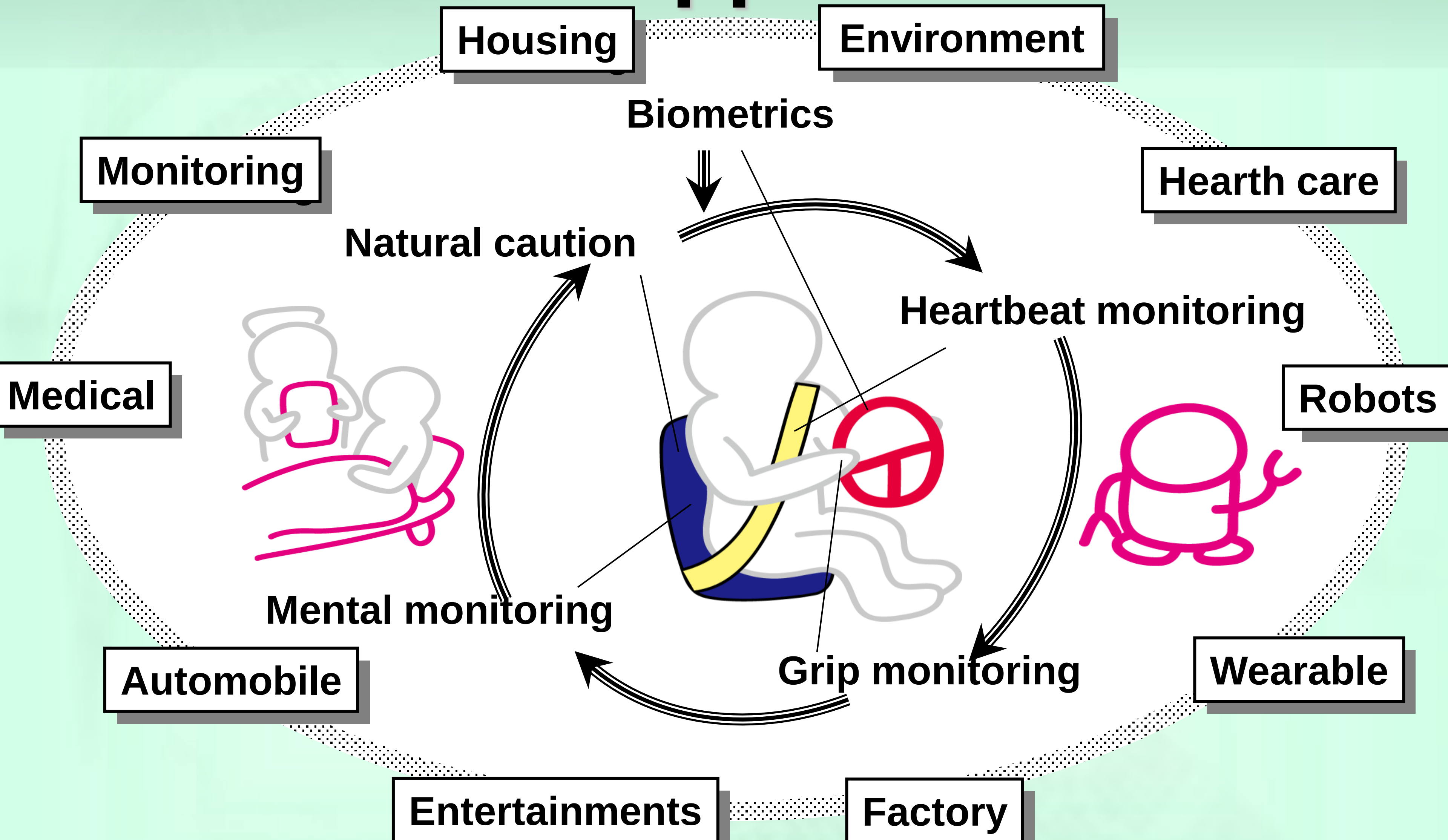
Ultraflexible sensor & lighting for bio/medical applications





Sensing and medical treatment
in blood vessel and unconventional surfaces

New applications



Stretchable, large-area electronics using organics can cover arbitrary curved surfaces and movable parts, and thus would significantly expand where electronics can be used.

Acknowledgements

Max Planck Institute for Solid State Research

Dr. H. Klauk
Dr. U. Zschieschang

University of Tokyo

Prof. T. Sakurai
Prof. M. Takamiya
(Circuit design)

Dai nippon printing

Dr. H. Maeda
(Organic LEDs)

Kyosera Chemical

Daisan-Kasei Chemical

Funding: JST/CREST. KAKENHI (Wakate S), Special Coordination Funds for Promoting Science and Technology, & NEDO

Summary

- ✓ **All-printed organic transistors**

  Solution-semiconductor: 0.18 cm^2/Vs, on/off ~ 10^6

- ✓ **Printed transistor active matrix**

  300 x 300 mm^2 (14,400 cells: 1mm pitch)

  Large-area flexible touch-sensor system

- ✓ **Organic TFTs with SAM gate dielectric on thin films**

  P-type DNTT TFT : 3.0 cm^2/Vs, On/off: > 10^5, 80 mV/dec

  N-type $F_{16}CuPc$ TFT : 0.02 cm^2/Vs, On/off: > 10^4, 150 mV/dec

- ✓ **Ultraflexible Organic CMOS circuits**

  Inverter : Gain~40, Ring Oscillator : 4.5 ms (stage delay)

  Medical sensors and display applications

- ✓ **Stretchable electronics**

  Stretchable active matrix OLED display on curved surface