EP2DS.20 & MSS.16
July 1, 2013

Ultraflexible and stretchable organic devices

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The University of Tokyo

Outline

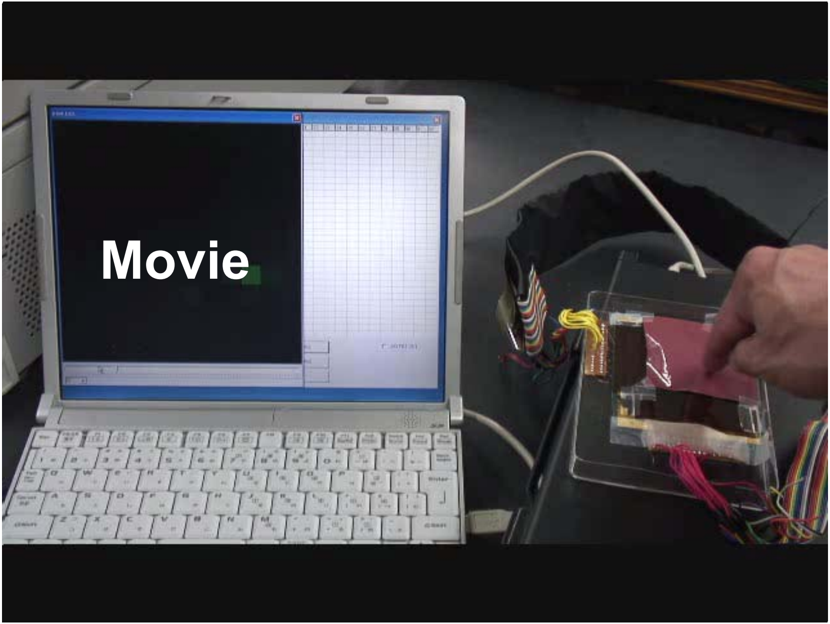
- Introduction
- Ultrathin OPV, OLED & OTFT
- Emerging applications
- Summary

Robotic E-skin

T. Someya, et al., IEDM #8.4, 203 (2003).
T. Someya, et al., PNAS 101, 9966 (2004).
T. Someya, et al., PNAS 102, 12321 (2005).
T. Sekitani, et al., Nature Mat. 6, 413 (2007).
T. Sekitani, et al., PNAS 105, 4976 (2008).
T. Sekitani, et al., Science 321, 1468 (2008).

In 2003

2^{nd} Generation E-skin in 2006



Touch panel

Intuitive

From Apple Homepege

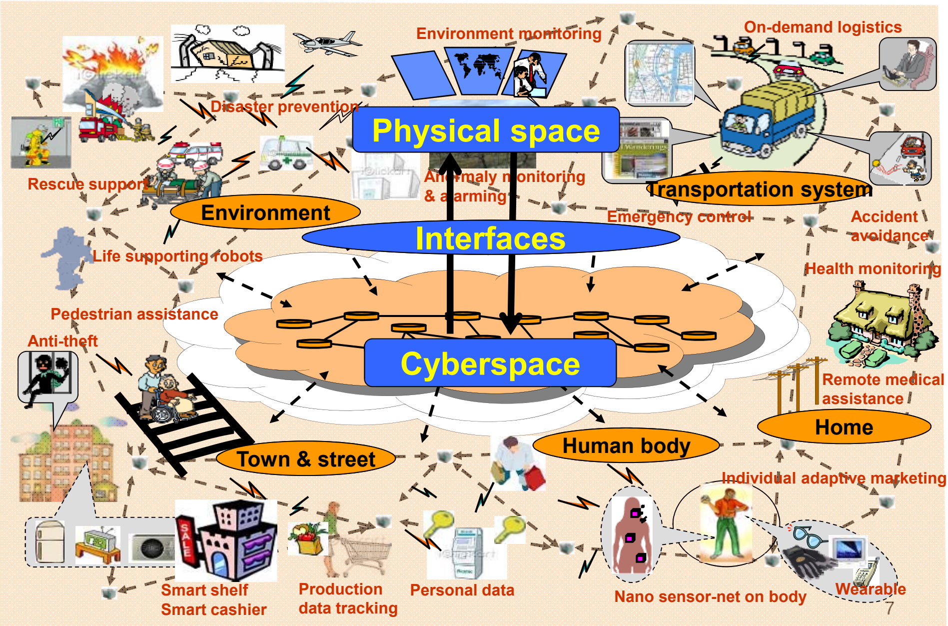
Impact of iPad

All the cyberspace applications have been covered.

All the required platforms are almost the same.

➔ Network connection, IT processing, and IT services

New electronics targets physical space



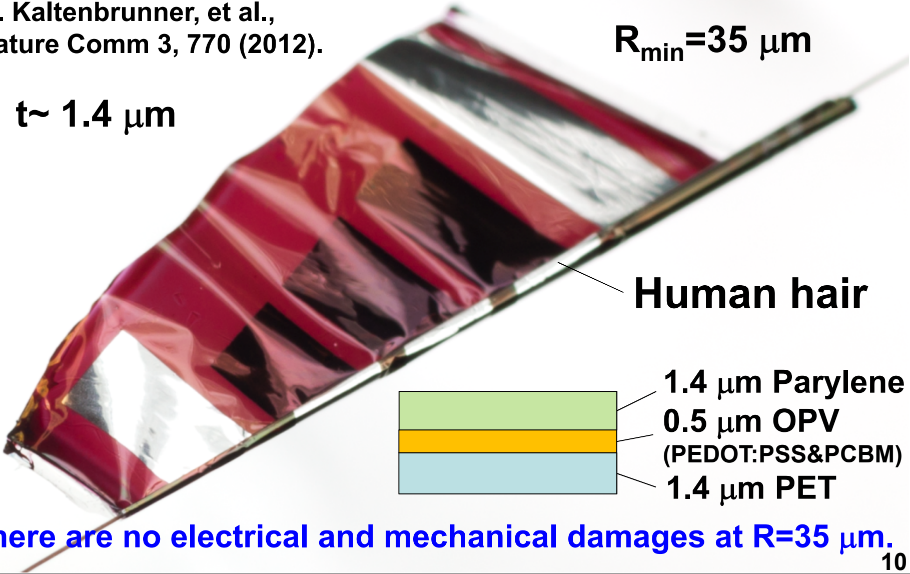
Courtesy: Professors Morikawa and Sakurai

Ultraflexible OPV & OLED

World's thinnest and lightest OPV

Ultrathin and lightweight organic solar cells with high flexibility

M. Kaltenbrunner, et al.,
Nature Comm 3, 770 (2012).

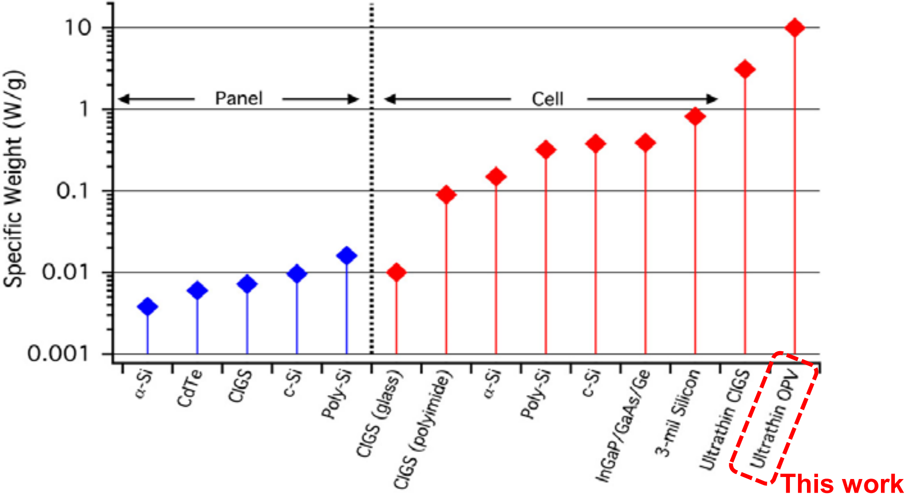


There are no electrical and mechanical damages at R=35 μm.

Performance per weight (W/g)

Martin Kaltenbrunner, et al.,
Nature Comm 3, 770 (2012).

4 g/m² and ~40 W/m²
yields 10 W/g



Highest specific weight (10 W/g) due to 1.4-μm-thick substrate

Performance per weight (W/g)

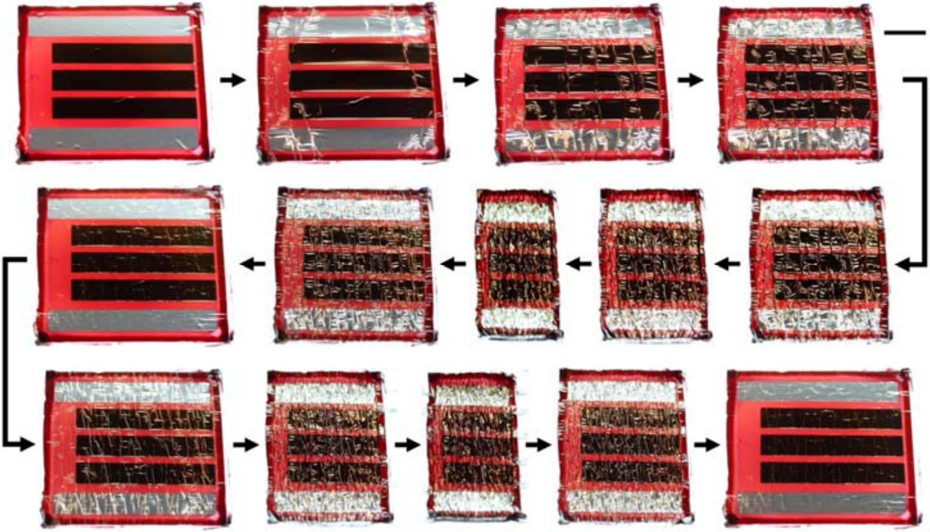
Martin Kaltenbrunner, et al., Nature Comm 3, 770 (2012).

Highest specific weight (10 W/g) due to 1.4-μm-thick substrate

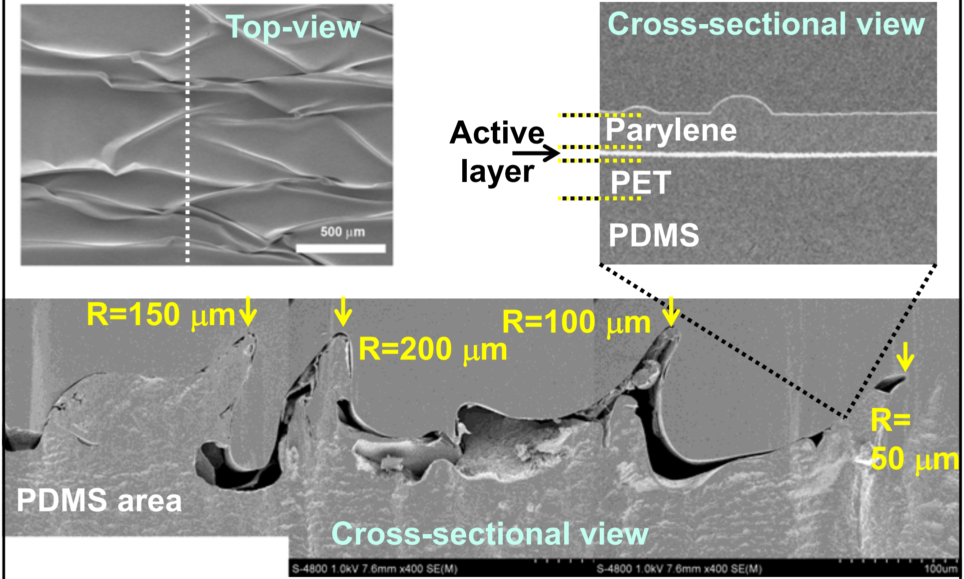
Stretchable OPVs

Martin Kaltenbrunner & TS, et al.,
Nature Communications 3, 770 (2012).

Stretchable OPV



Cross-sectional SEM image



Ultraflexible solar cell forms into steep wavy structure ➔ stretchable

Stretchable OLED

Movie

Brightness: 100 cd/m^2 Stretching >100%!

Matthew S. White, et al., TT3.01, MRS Spring 2013.

Ultraflexible organic transistor

Flexible thin-film transistors

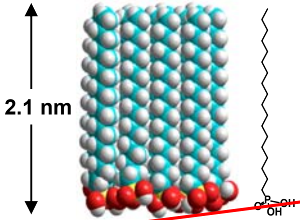
	Poly-Si TFTs (ref. 1) EPSON	Oxide TFTs (ref. 2) TIT	CNT TFTs (ref. 3) Illinois U.	Organic TFTs (ref. 4) UT	a-Si TFTs (ref. 5) Princeton U.	Organic TFTs (ref. 6) Erlangen	This Study Organic TFTs UT
Mobility	>10 cm^2/Vs	>7 cm^2/Vs	15 cm^2/vs	0.5 cm^2/Vs	1.0 cm^2/Vs	0.1 cm^2/Vs	**3 cm^2/Vs**
Voltage	4 V	10 V	20 V	40 V	15 V	2.5 V	**< 2 V**
Bending radius	10 mm	30 mm	10 mm	0.5 mm	0.5 mm	2.5 mm	**0.01 mm**

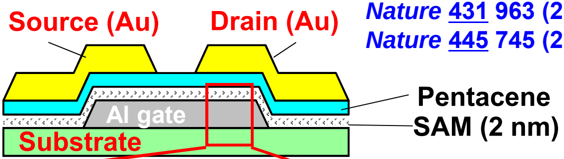
1. *Journal Soc. Inf. Displays* 16, 107(2008). 2. *Nature* 432, 488-492 (2004).
3. *Appl. Phys. Lett.* 86, 243502 (2005). 4. *Appl. Phys. Lett.* 87, 173502 (2005).
5. *Appl. Phys. Lett.* 96, 042111 (2010). 6. *Appl. Phys. Lett.* 95, 103309 (2009).

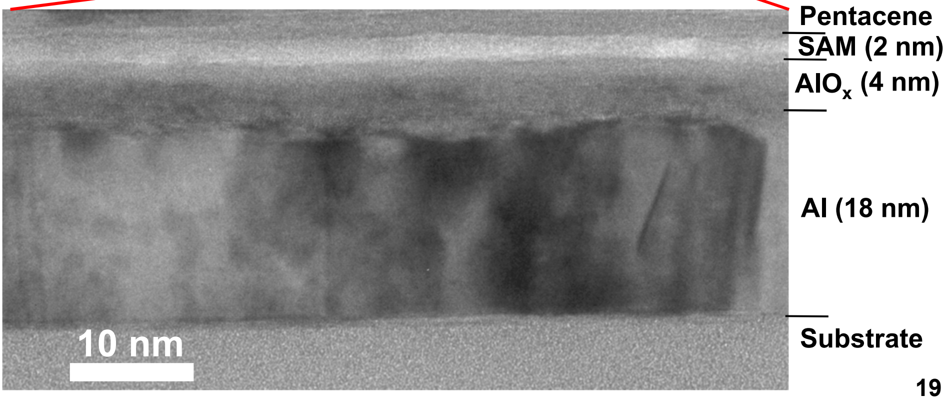
Small radius, small voltage, and high mobility?

Organic transistors with SAM

Hagen Klauk et al.
Nature 431 963 (2004)
Nature 445 745 (2007)

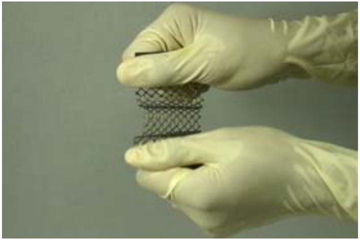


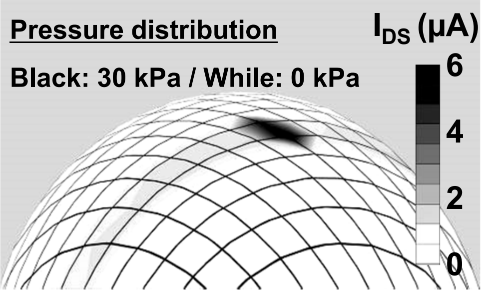


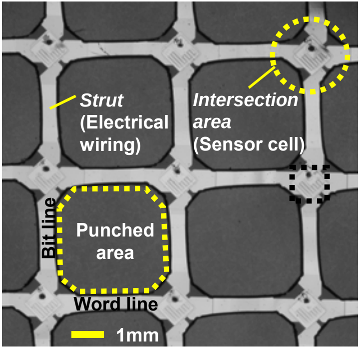


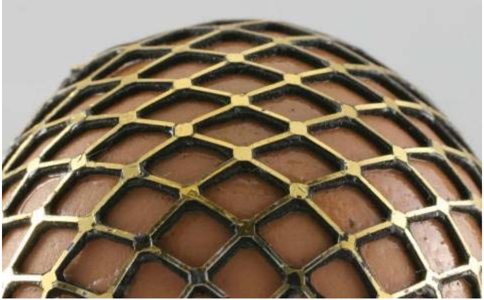

Stretchable integrated circuits

Stretchable E-skins





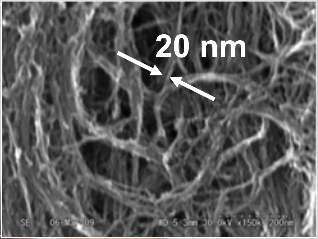




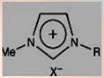
T. Someya et al., PNAS 102, 12321 (2005).

Printable elastic conductors

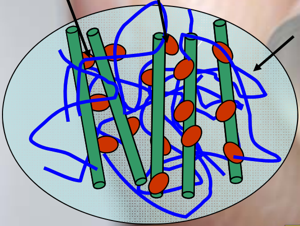
Resolution : 100 μm
Conductivity : ~100 S/cm
Stretchability : ~140%



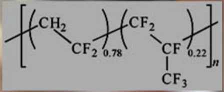
R = n-C_4H_9,
X=$(CF_3SO_2)_2N$
Ionic liquids



Carbon nanotubes

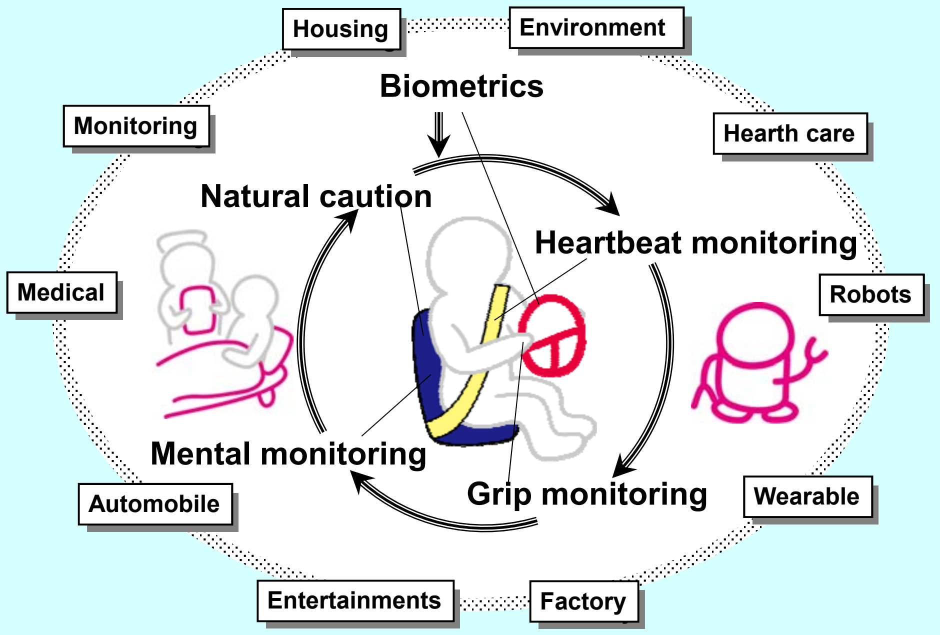


Fluorinated copolymer



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

A scene using soft electronics

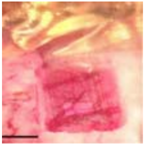


Flexible electronics: New applications

High-sensitive pressure sensor

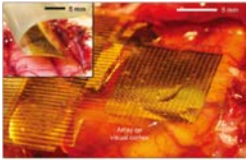
S.C.B. Mannsfeld, Z. Bao
Nature Materials (2010).

Neural interfaces



G. G. Malliaras, et al, Adv. Mater., 23, H268 (2011)
G. G. Malliaras, et al, Nature Comm., 4:1575
|DOI: 10.1038/ncomms2573 (2013)

Neural interfaces

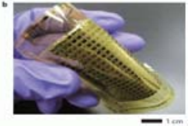


J. Viventi, J. A. Rogers et al,
Nature Neuroscience, 14, 1599 (2011)

Transparent touch skin

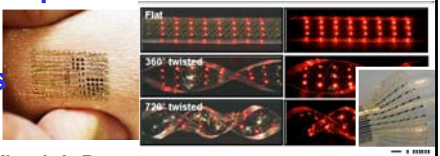
D. J. Lipomi, Z. Bao
Nature Nanotech (2011).

Artificial skin



K. Takei, J. Ali
Nature Materials (2010).

Medical sensors & lighting
Intelligent balloon catheter
Epidermal electronic skin



D. H. Kim, J. A. Rogers, Nature Materials 10, 316 (2011).
D. H. Kim, J. A. Rogers, Nature Materials 9, 316 (2010).
D. H. Kim, J. A. Rogers, Science 333, 6044 (2011).

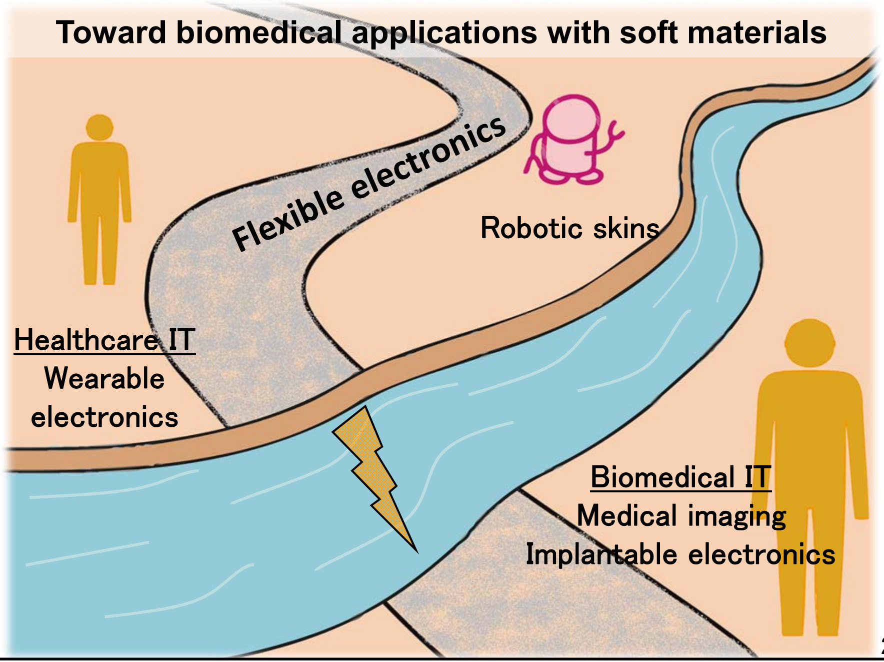
In-vitro & in-vivo neural interfaces

S.P. Lacour, S. Wagner, B. Morrison III
J.Neurotrauma, 2009, vol. 26, p. 1135-1145.

Neural Stem Cells

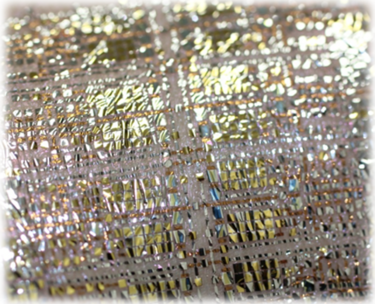
M. Berggren, et al.,
PLoS ONE, 6, e18624 (2011).

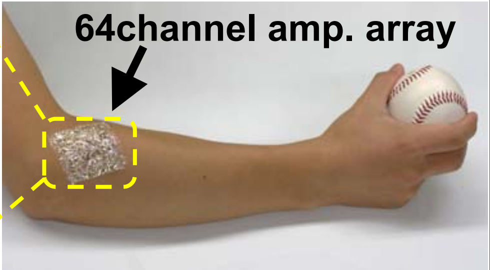
New paradigm in organic electronics

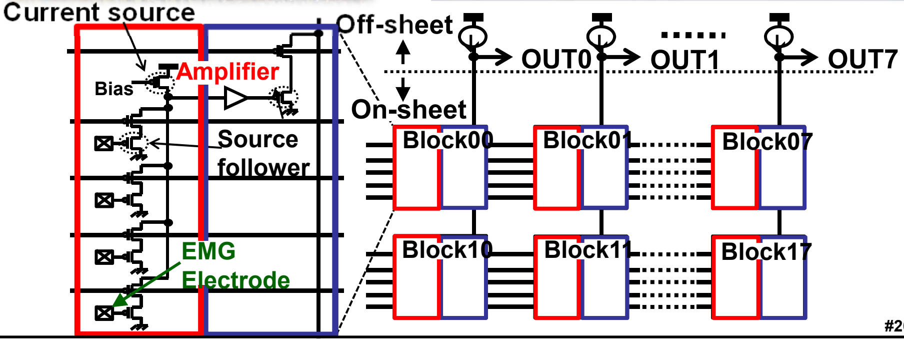


Surface electromyogram monitoring

Fuketa, et. al., IEEE/ISSCC2013 #6.4.

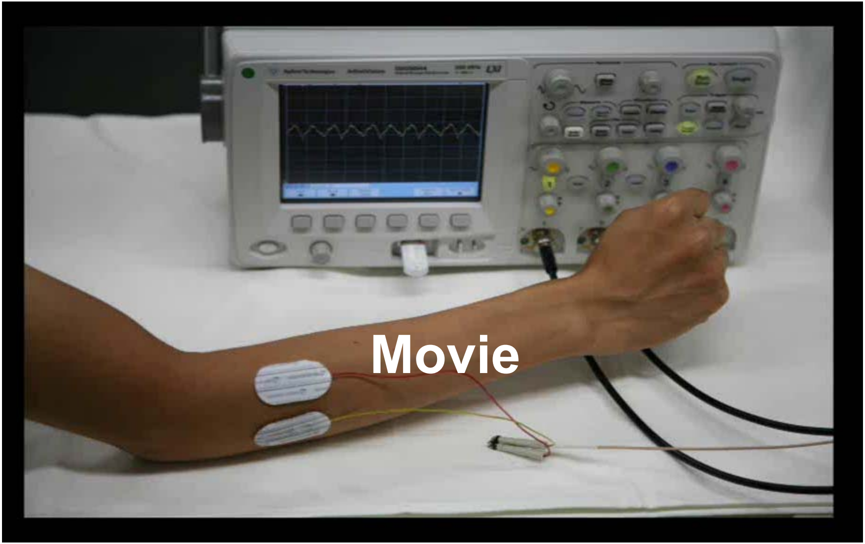






Demo: Electromyogram measurement

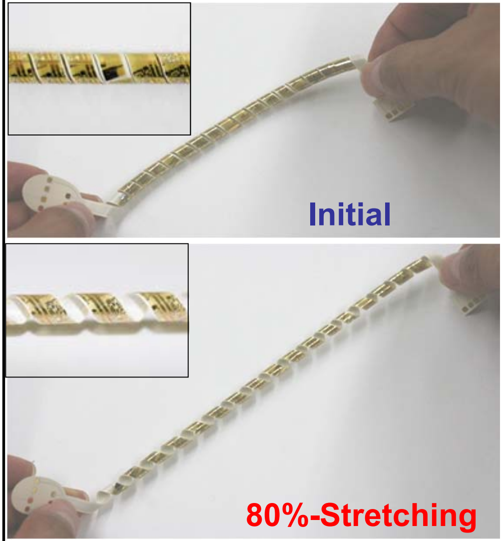
For tress-free healthcare-monitoring and welfare IT

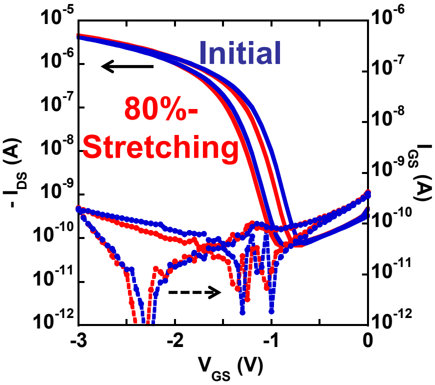


Fuketa, et. al., IEEE/ISSCC2013 #6.4.

Example: Helical organic circuits on shape-memory polymer

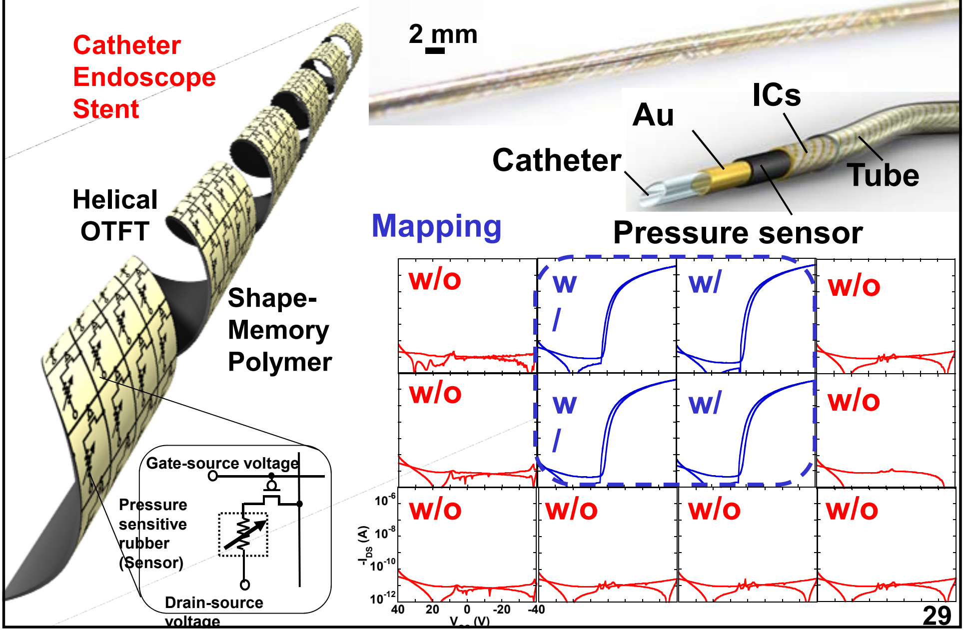
T. Sekitani, T. Someya, et al., Nature Materials 9, 1015–1022 (2010).





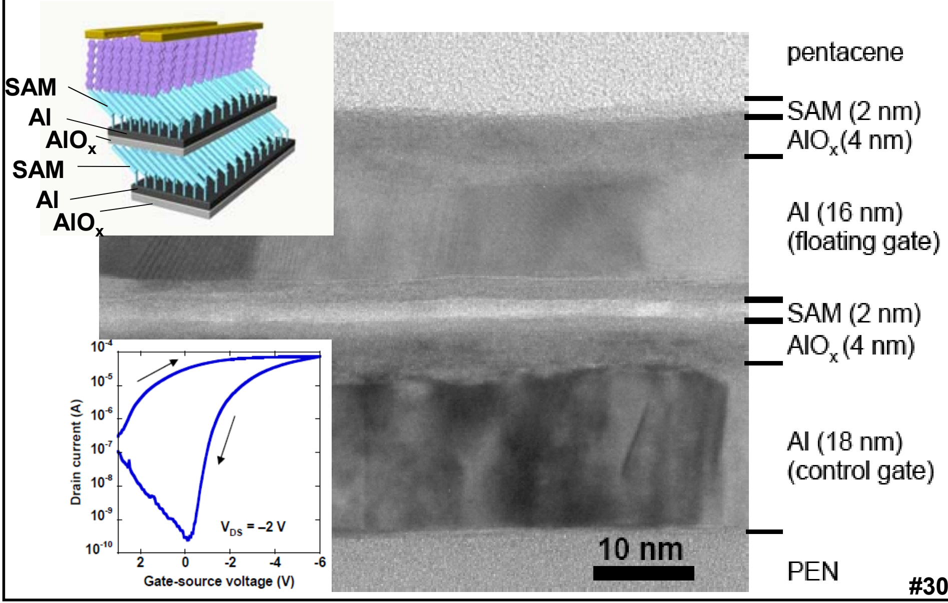
Helical circuits for catheters

T. Sekitani, T. Someya, et al., Nature Materials 9, 1015–1022 (2010).

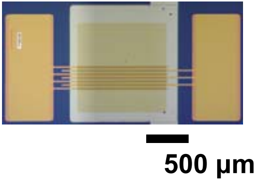


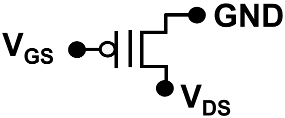
Floating gate using SAMs

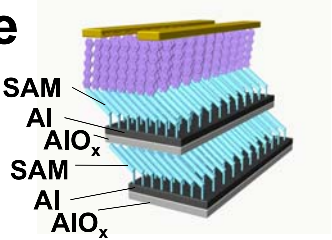
T. Sekitani, TS, et. al, Science (December 11, 2009).

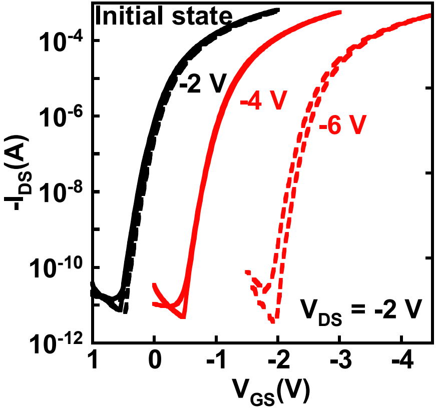


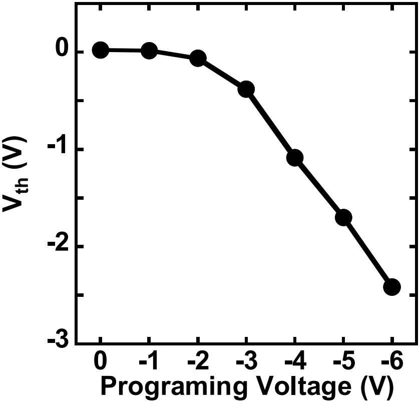
Floating gate structure





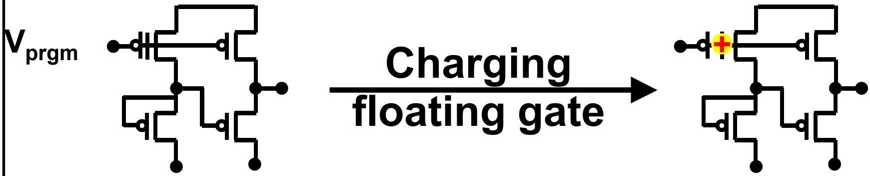


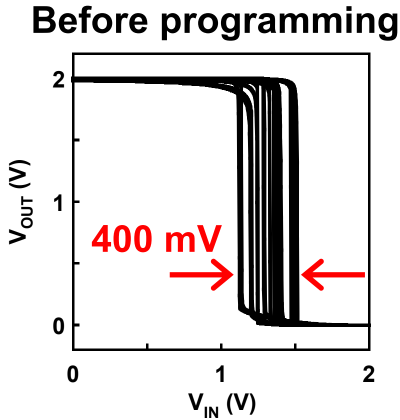


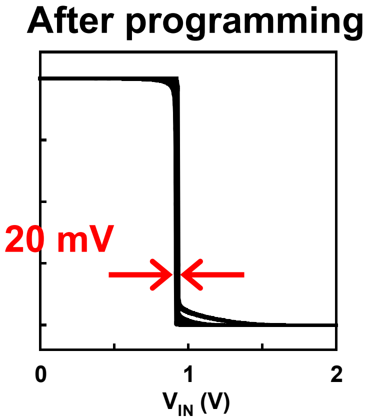


V_{TH} is shifted from 0 to -2.4 V when V_{prgm} is - 6 V

Switching voltage control







What are remaining issues?

Mechanical

Durability:	Done
Comformability:	Done

Electronic performance

Low voltage:	Done
Bandwidth:	Almost

Biocompatiblity & Safety

Environmental stability

The world’s first sterilizable flexible organic transistor

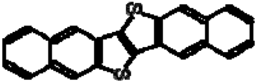
A flexible, 2V-driven, organic transistor can be sterilized in a standard sterilization process (150 ºC heat treatment).

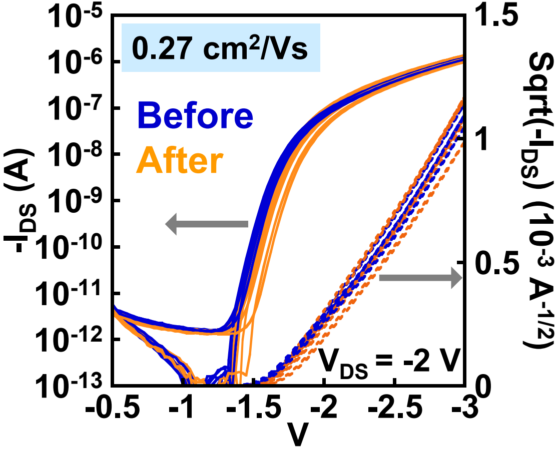
K. Kuribara, et al., Nature Comm 3, 723 (2012).

Sterilization with OTFTs

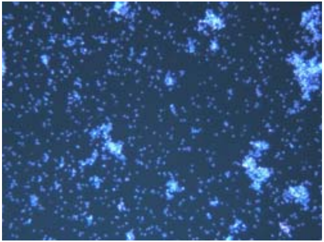
Sterilized at 150 °C for 20 sec

DNTT

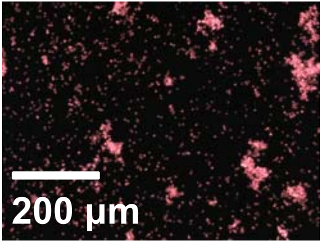




Total cells



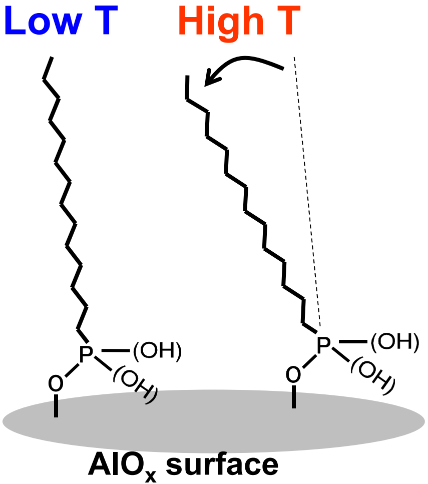
Dead cells

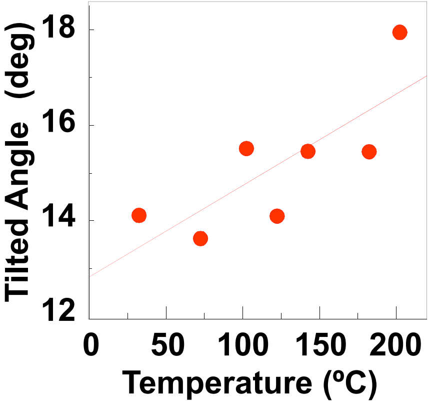


No degradation at 150 °C

Characterization of SAM by NEXAFS

Collaboration with Lynn Loo & He Wang

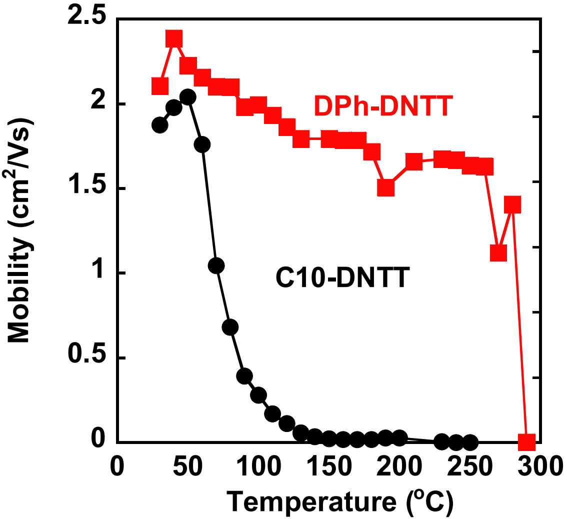


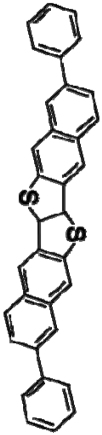


SAM is thermally stable above 200ºC.

DPh-DNTT at 250 ºC

Tomoyuki Yokota et al., Adv. Mat. Online (25 APR 2013).





<u>OTFT is thermally stable up to 250ºC.</u>

Washing & Boiling

Acknowledgements

Funding

JST/ERATO
JST/CREST
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T. Sakurai (T Tokyo)

M. Takamiya (U Tokyo)

Circuit design

T. Aida (U Tokyo)

T. Fukushima (TIT)

Elastic conductors

H. Klauk (MPI)

SAM

Lynn Loo (Princeton)

NEXSAFS

S. Bauer (JKU)

Ultrathin

M Sekino (U Tokyo)

Animal

T. Isoyama (U Tokyo)

Artificial heart

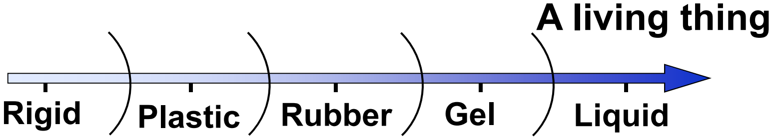
M. Hirata, MD
Osaka U, Hospital
Brain surgery
BMI

H. Onodera, MD
Nishitaga Hospital
Footprint

Y. Abe, MD
U Tokyo, Medicine
Animal Experiment
Artificial Hearts

The work will continue…..

Electronics in the future?



My approach: Step-by-step toward a living thing.

How to sense emotion electrically?