Materials and Mechanics for Human-Machine Interfaces via Epidermal Electronics

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Outline

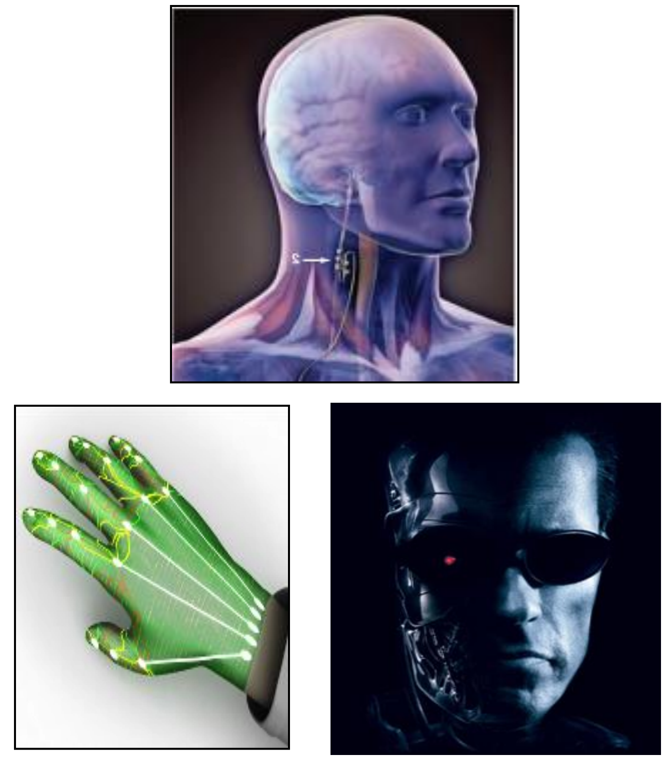
- Research Background and Device Design
- Surface EMG-based Human-Machine Interfaces
- EEG-based Brain-Computer Interfaces

Research Background

Past → **Current** → **Future?**

Industrial

Personal

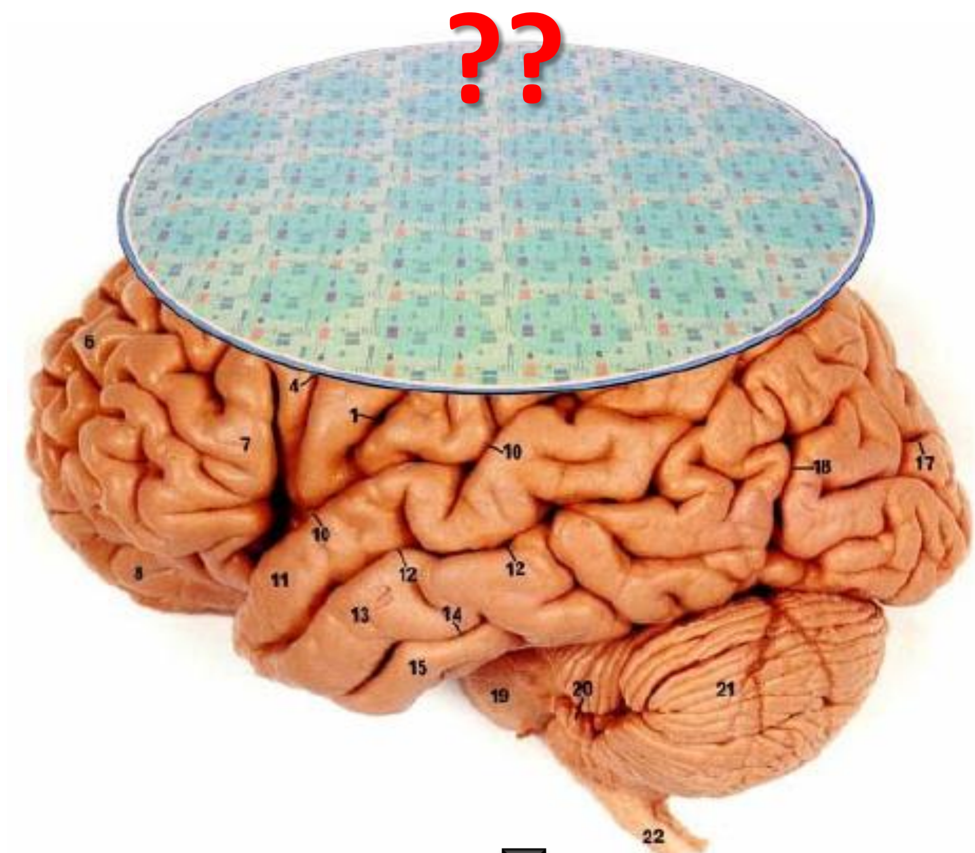


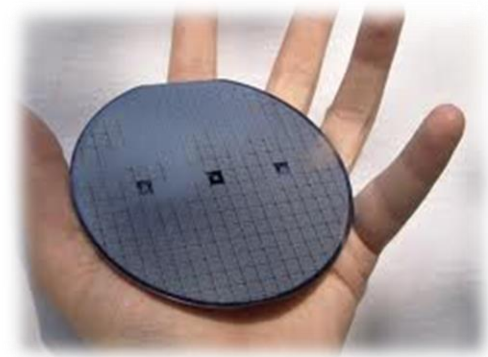
Bio-Integr. / Bio-Insp.

PNAS **106**, 10875 (2009). *Science* **327**, 1603 (2010).

Research Background

Bio-integration with Si electronics?

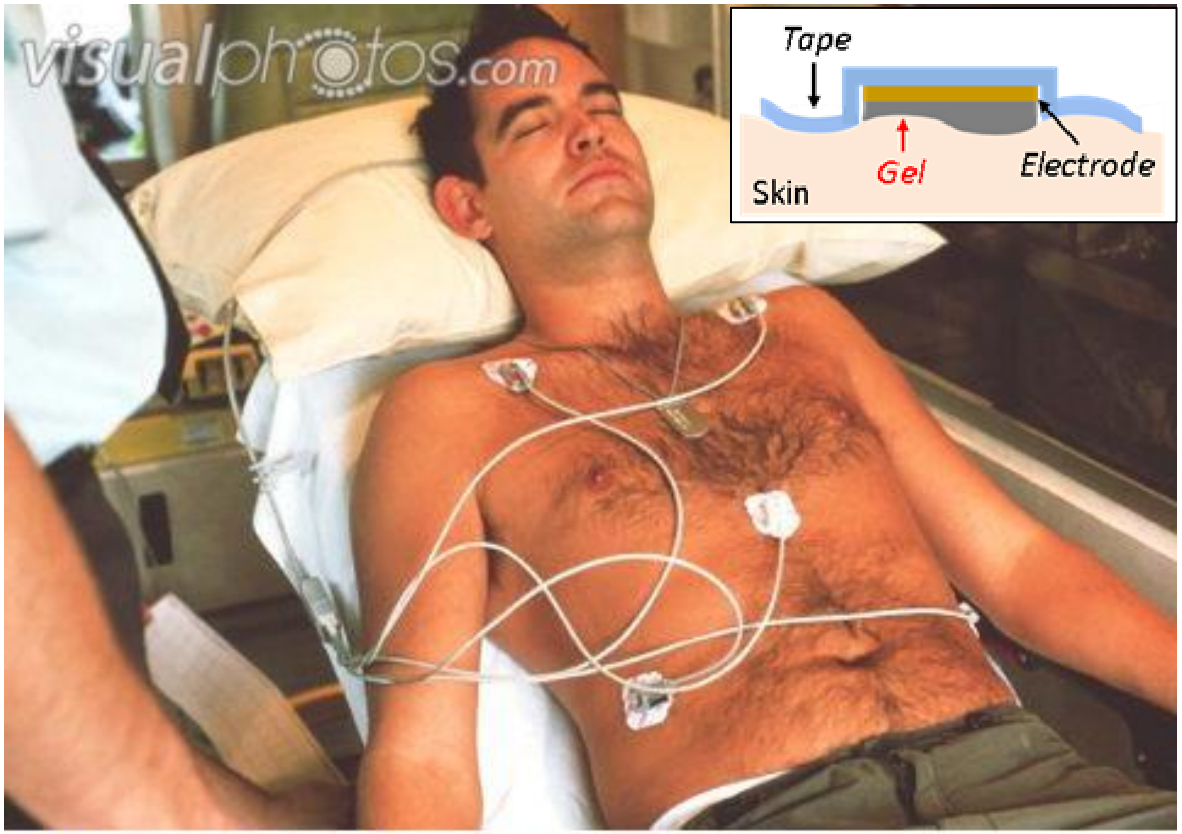




Soft Material based Stretchable Electronics

Research Background

Non-invasive monitoring of electrophysiological signals



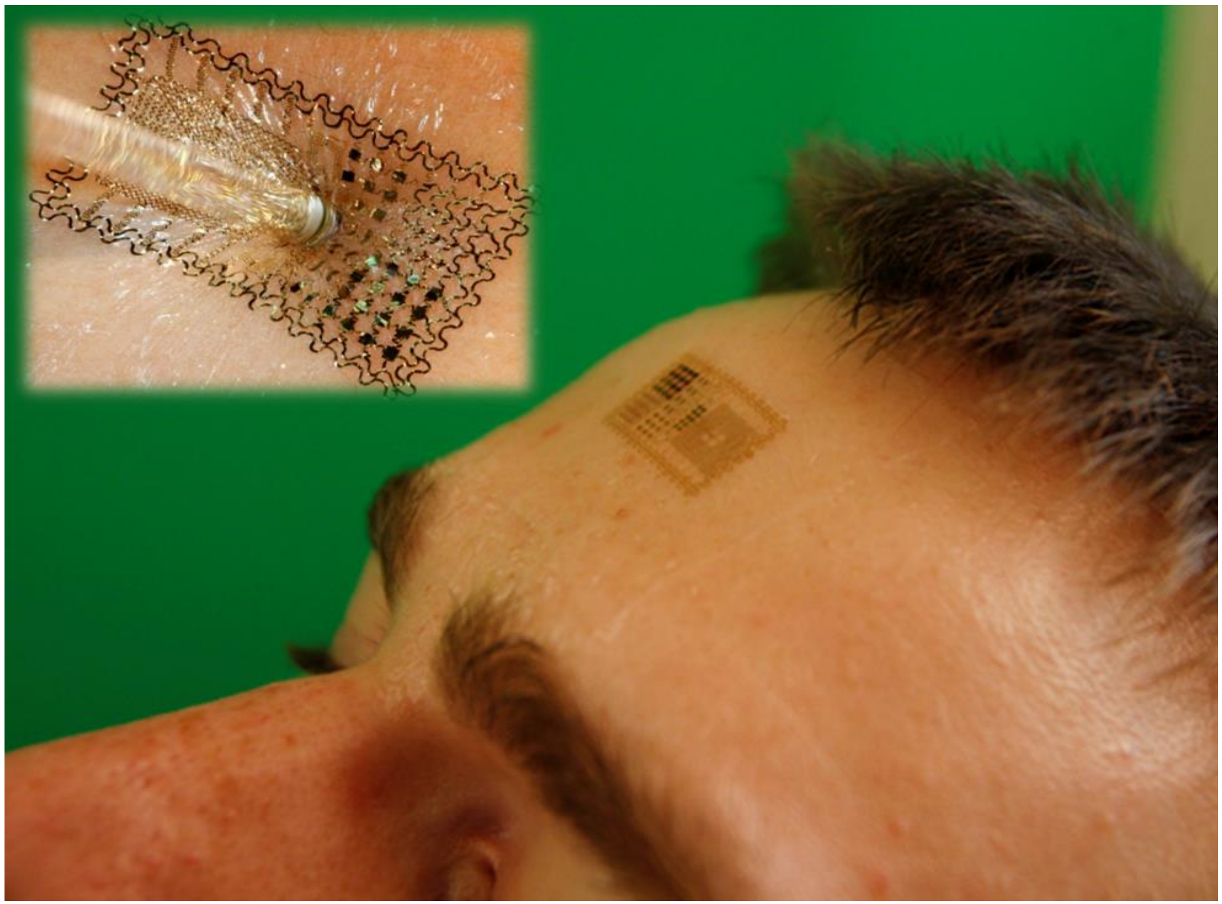
Mechanical mismatch (modulus)

Skin irritation/allergy (gel)

Uncomfortable (stiff and heavy)

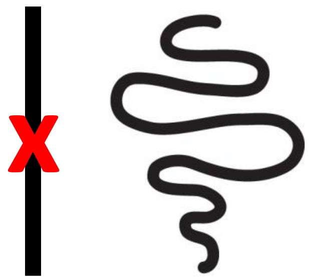
Our Method

Ultra-thin, Lightweight, Stretchable electronics system on skin
"**Epidermal Electronics System (EES)**"

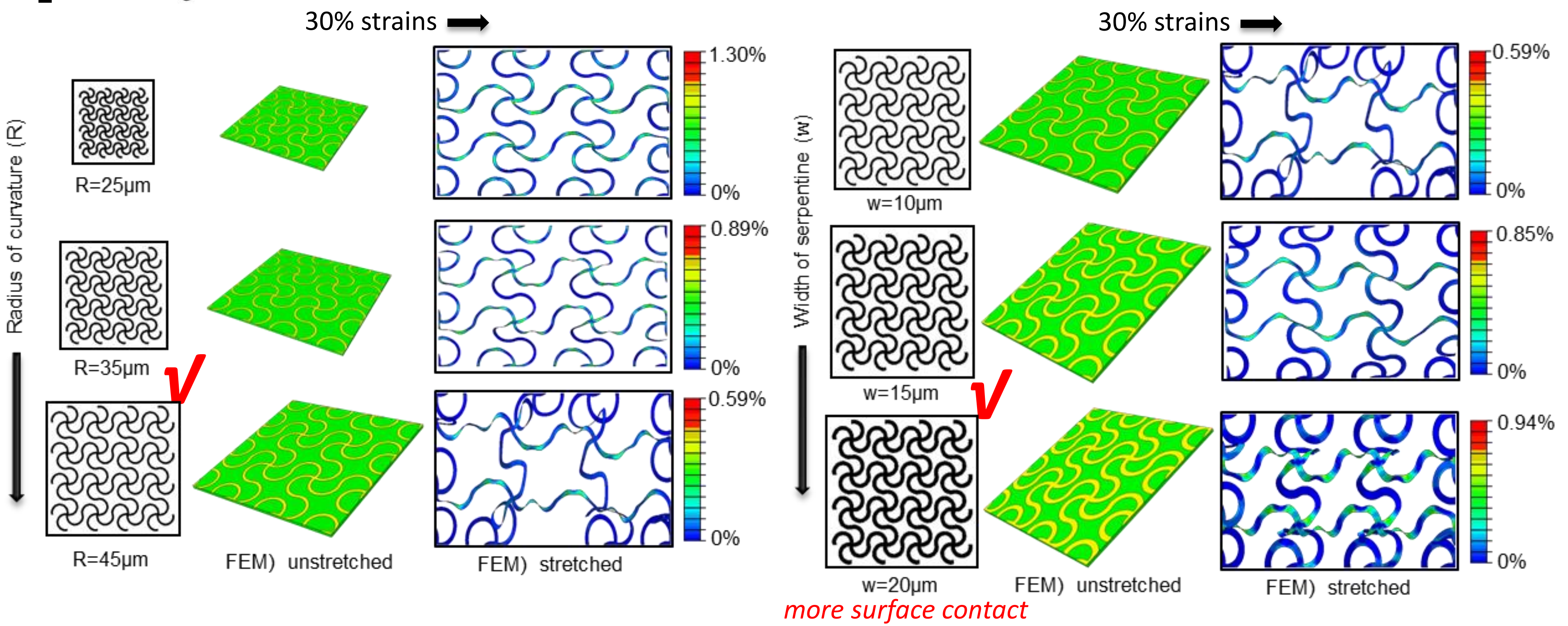


Science **333**, 838 (2011)

Mechanics and Materials



Finite Element Method (FEM): parametric study of various *filamentary serpentine (FS)*-based, open mesh structures

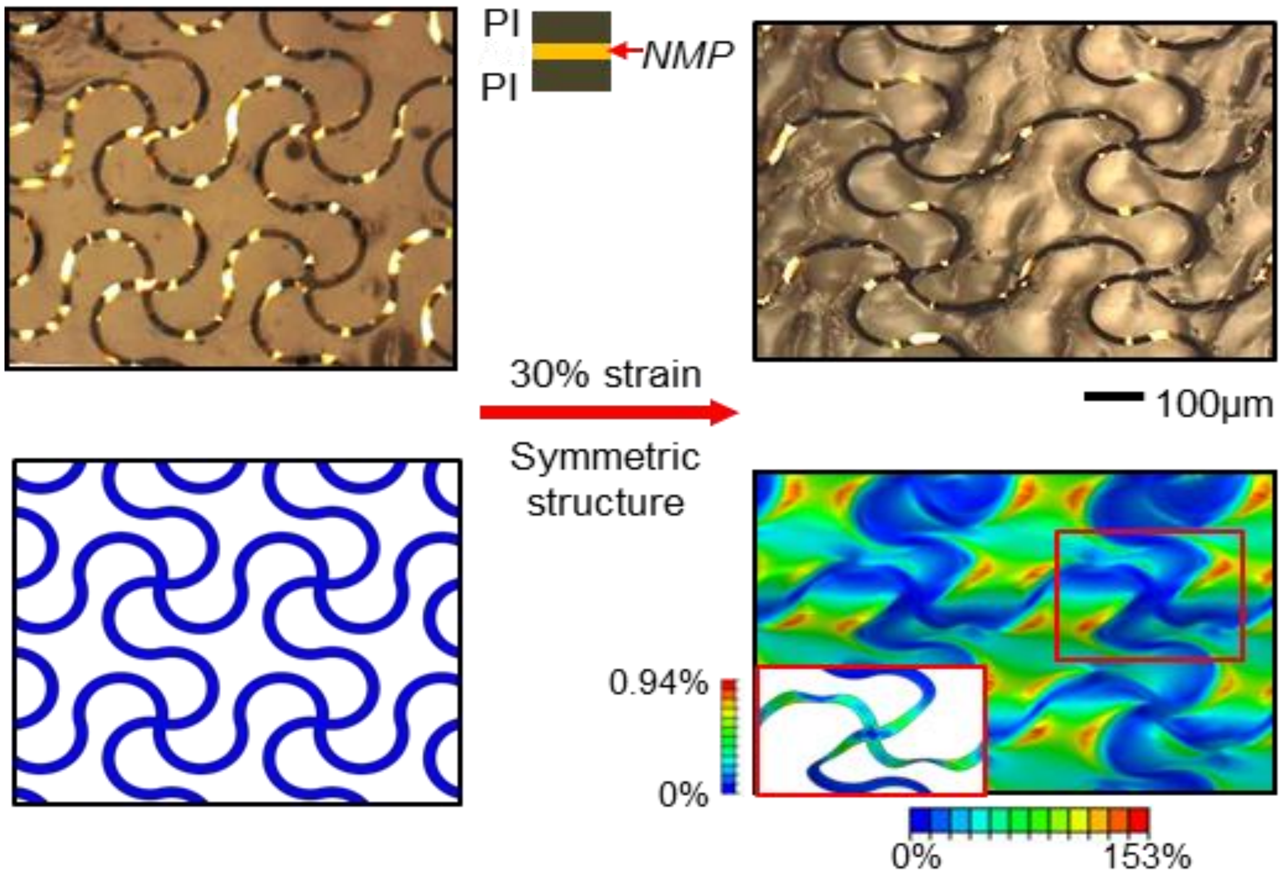


FEM estimates the mechanical stability upon stretching and bending

Max. prin. strain < materials' fracture strain (1 %)

Mechanics and Materials

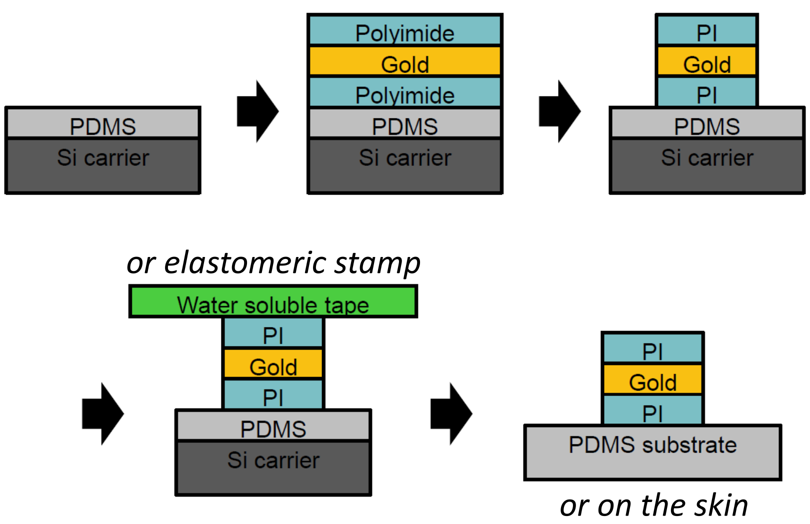
R=45µm, w=20µm, t=200nm
Gold in polyimide (PI)



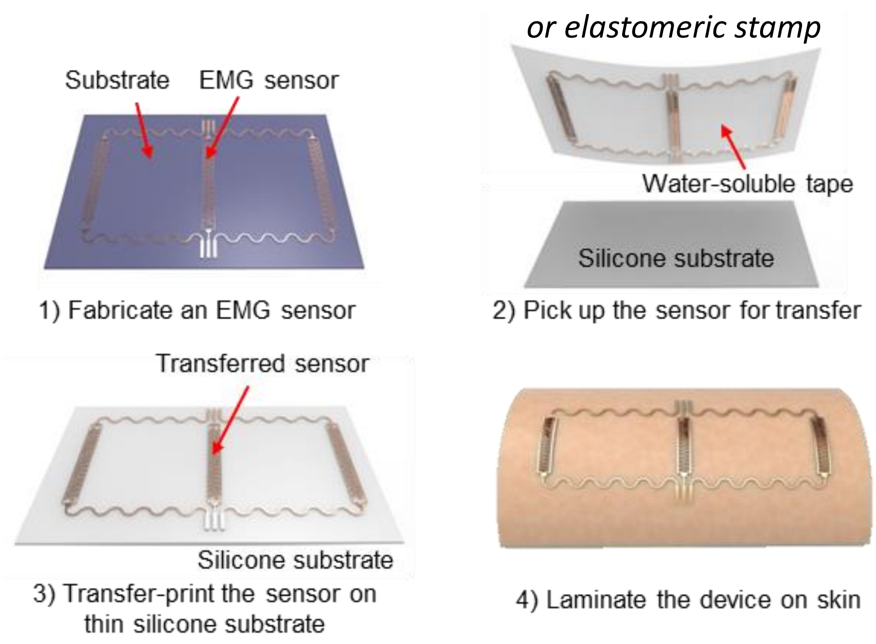
*YEO, **Advanced Materials**, 6837, 2013*

Mechanics and Materials

Fabrication?



Side view of fabrication process

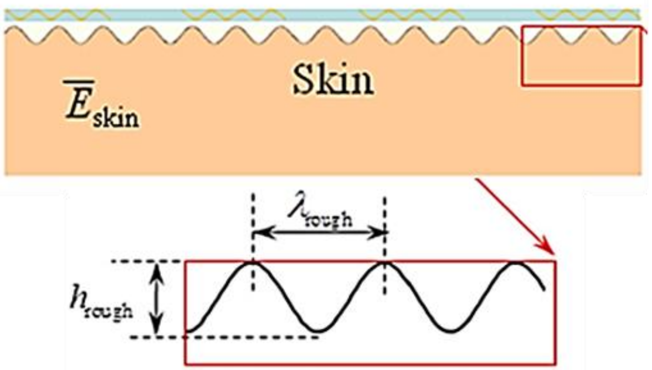


Schematics of fabrication

Movie) printing of stamp-mounted EES to the skin

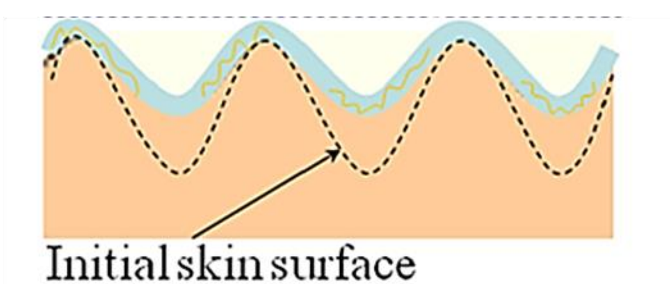
Mechanics and Materials

THICKNESS of EES for conformal and intimate contact?



$$y(x) = h_{rough} \cos\left(\frac{2\pi}{\lambda_{rough}} x\right)$$

Skin morphology in a sinusoidal form



On conformal lamination*,

$$U_{interface} = U_{EES\ bending} + U_{skin\ \ elasticity} + U_{adhesion}$$

$U_{EES\,bending} \propto EI_{EES}$	Bending stiffness
$U_{skin\,elasticity} \propto E_{skin}$	Modulus
$U_{adhesion} \propto \gamma$	Work of adhesion

Conformal contact: when the adhesion energy is bigger than the sum of the EES bending and skin elastic energy.

$$\frac{\pi E_{skin} {h_{skin}}^2}{\gamma_{EES} \lambda_{skin}} - \frac{E_{skin} {\lambda_{skin}}^3}{\pi^3 (EI_{EES})} - 16 < 0$$

**Local deformation energy at EES edges are negligible.*
Skin is regarded as a semi-infinite body

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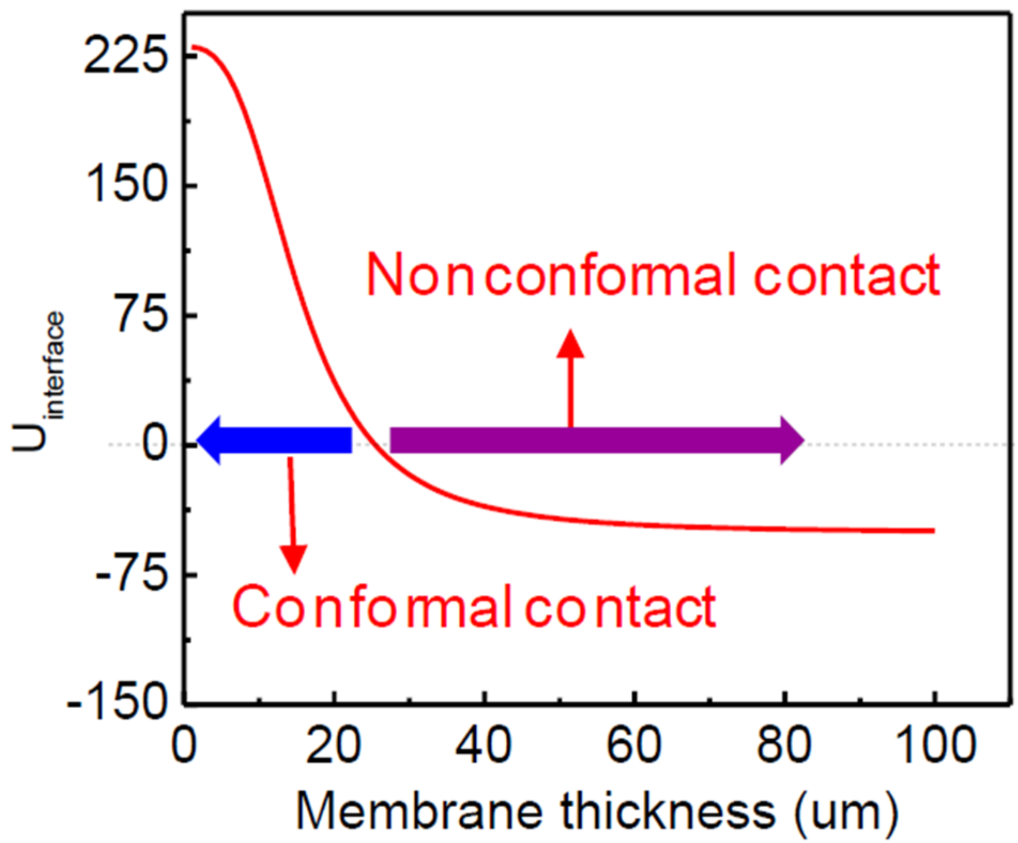
Mechanics and Materials

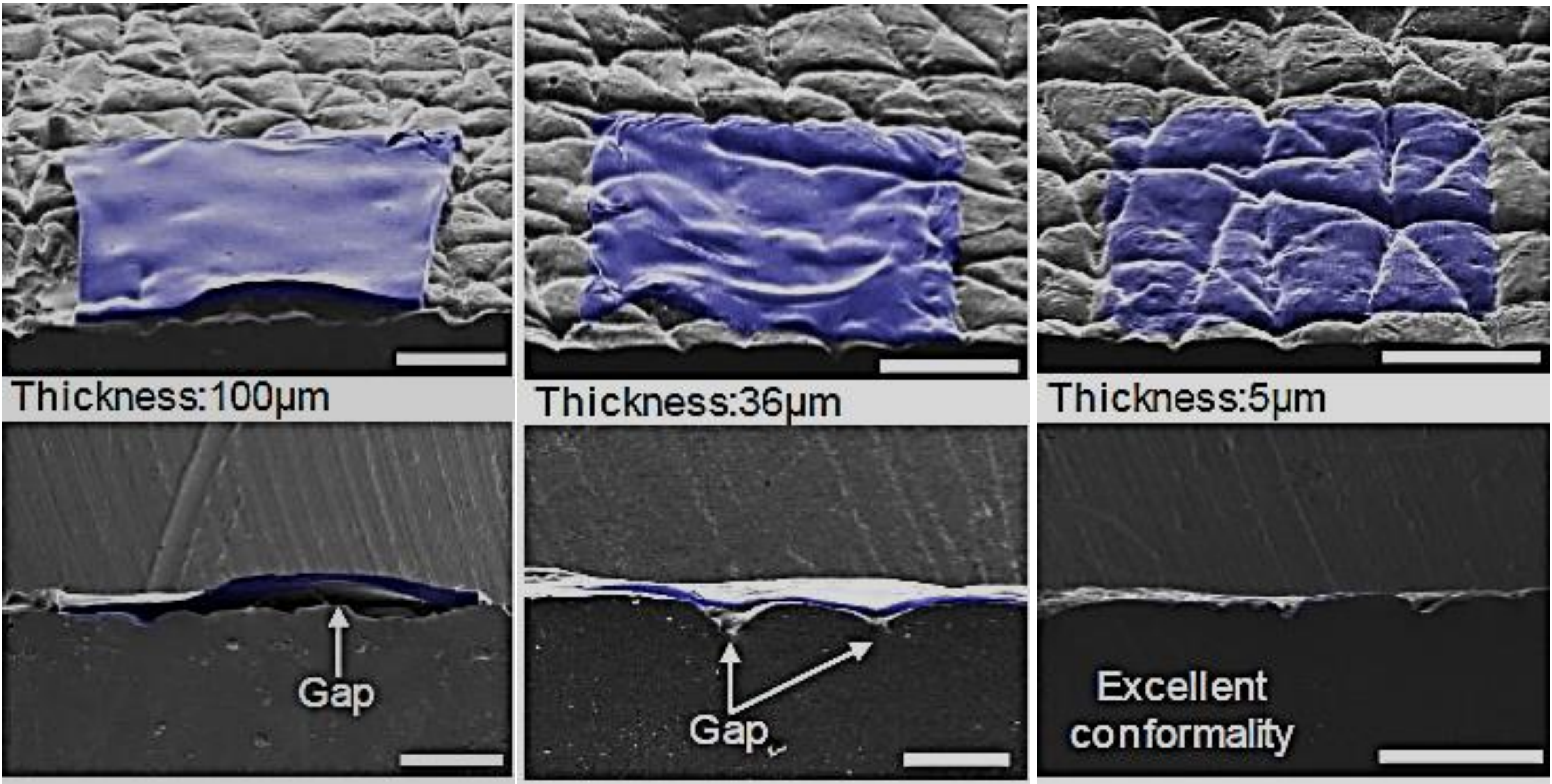


Critical thickness≈25µm
when amplitude is 100µm* and wavelength is 140µm** (max values)

**Tchvialeva, InTech, 2010, **Schwindt, Acta. Derm. Venereol, 1998*

Mechanics and Materials

Scanning electron microscopy (tilted and x-sectional view) √



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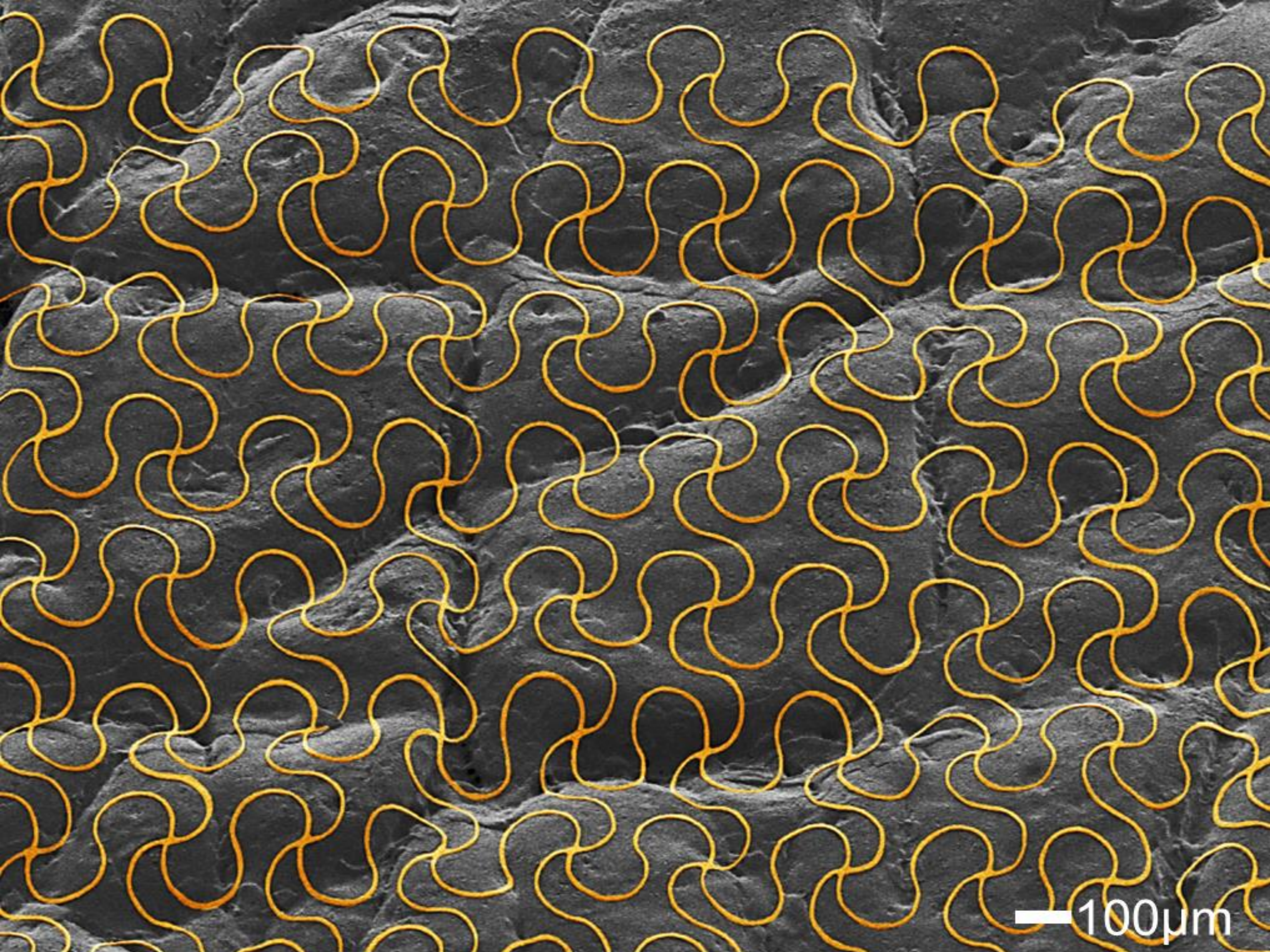
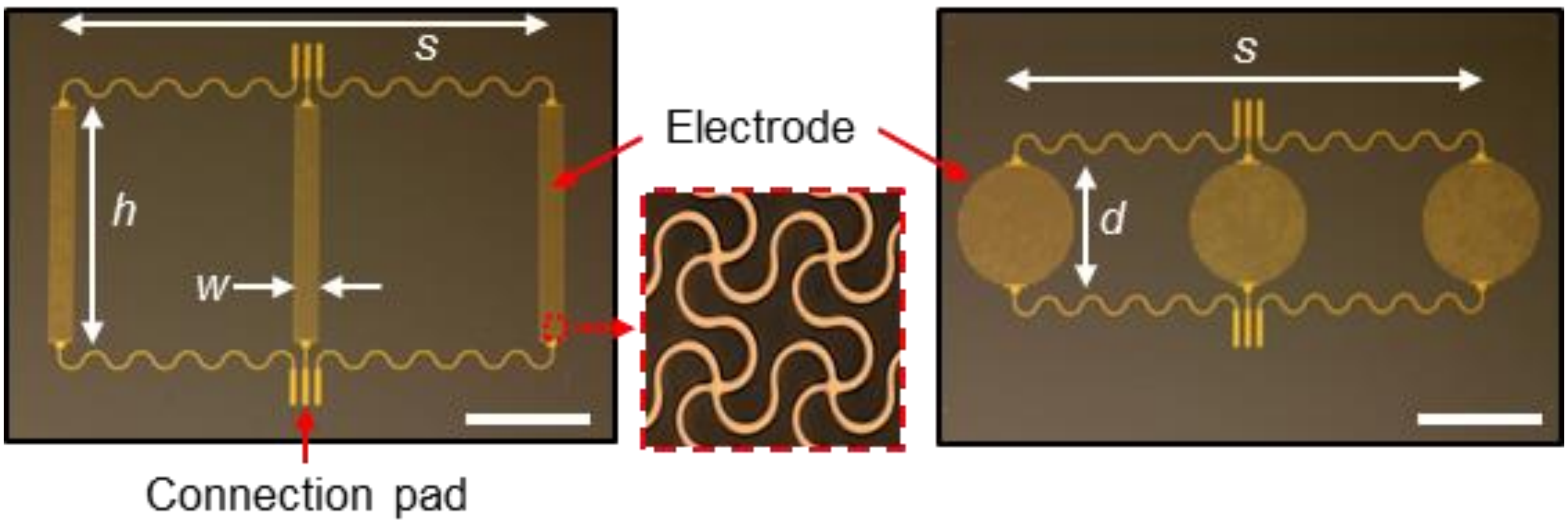

100μm

Surface EMG-based Human-Machine Interfaces

Materials and Characterization

Design optimization of EES for surface EMG recording on forearm

Bar-type electrode *Circle-type electrode*



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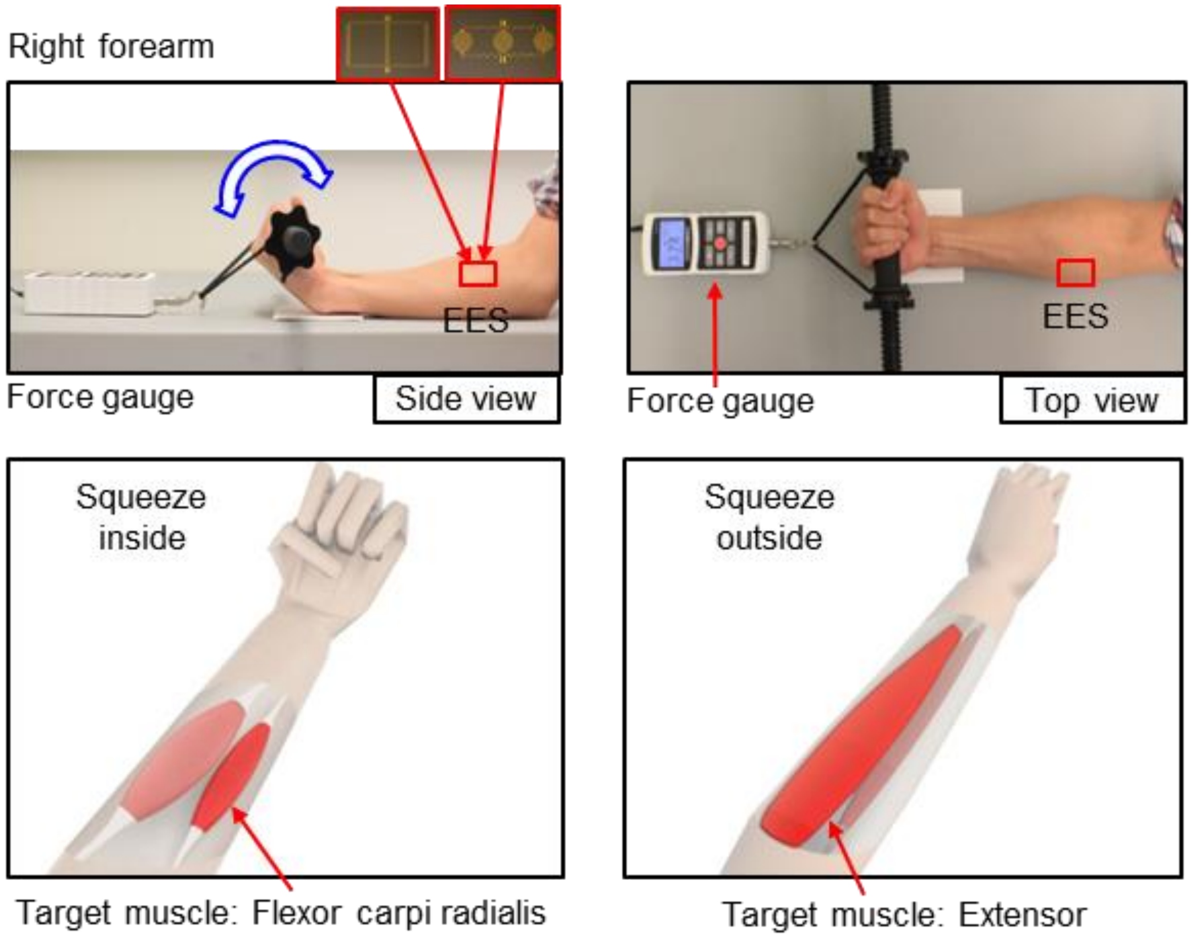
Materials and Characterization

surface EMG on forearm by muscle flexion



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Materials and Characterization

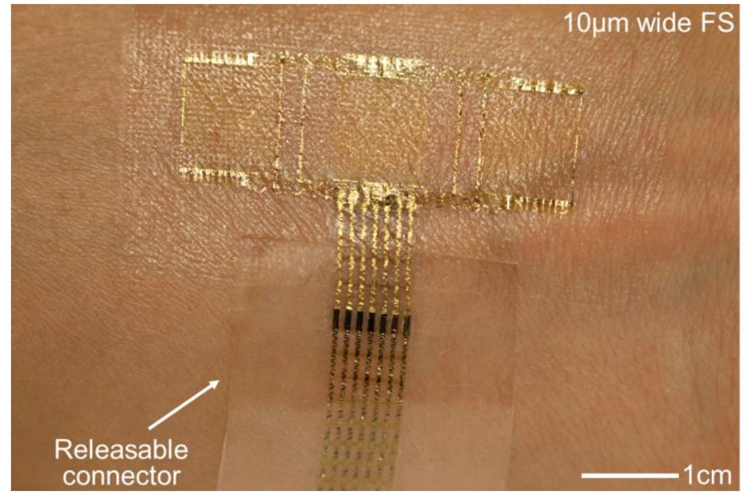
Data acquisition with BioCapture^{TM}, Great Lakes Neurotechnologies

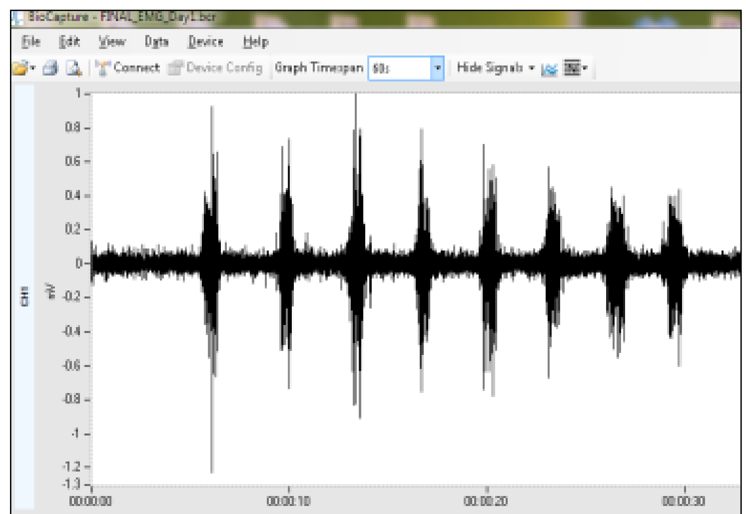
Electronics on forearm

Wireless transmitter

Transmitter

Receiver





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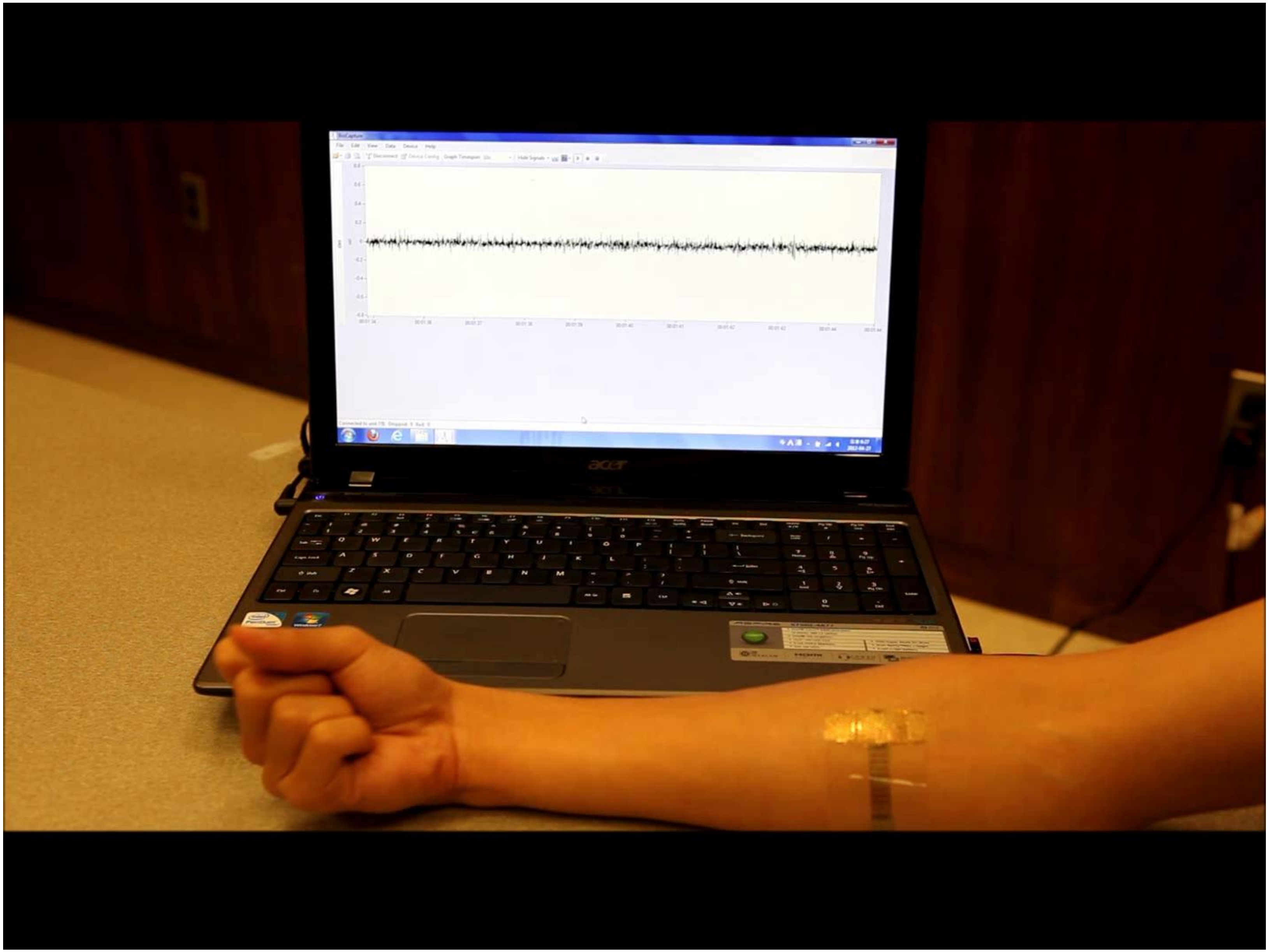
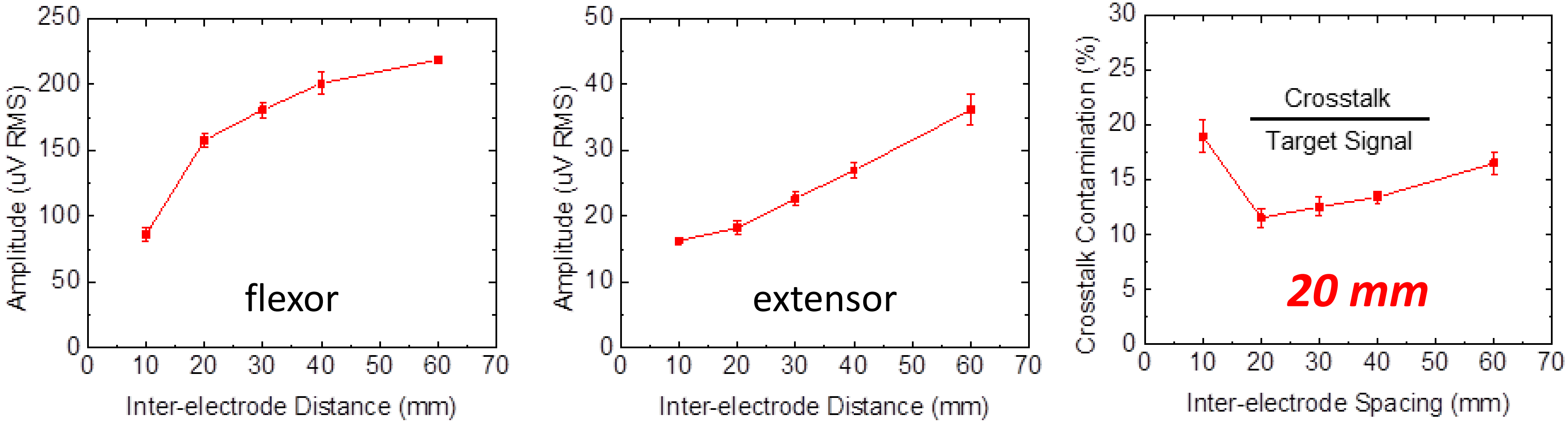
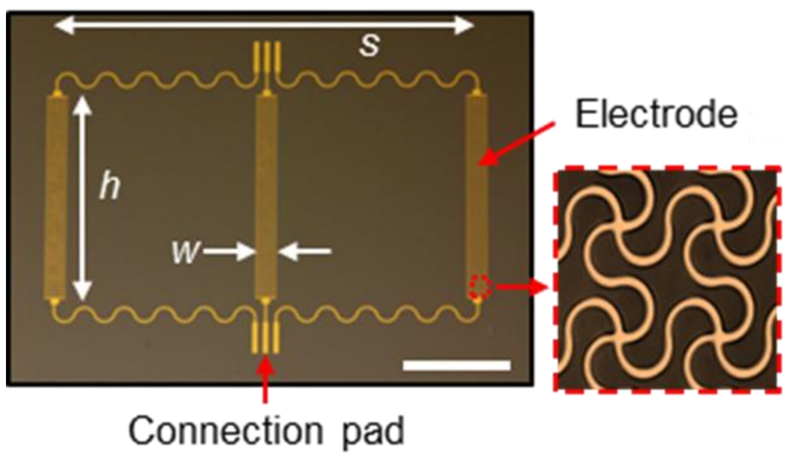
Movie) sEMG recording with EES on forearm



Materials and Characterization

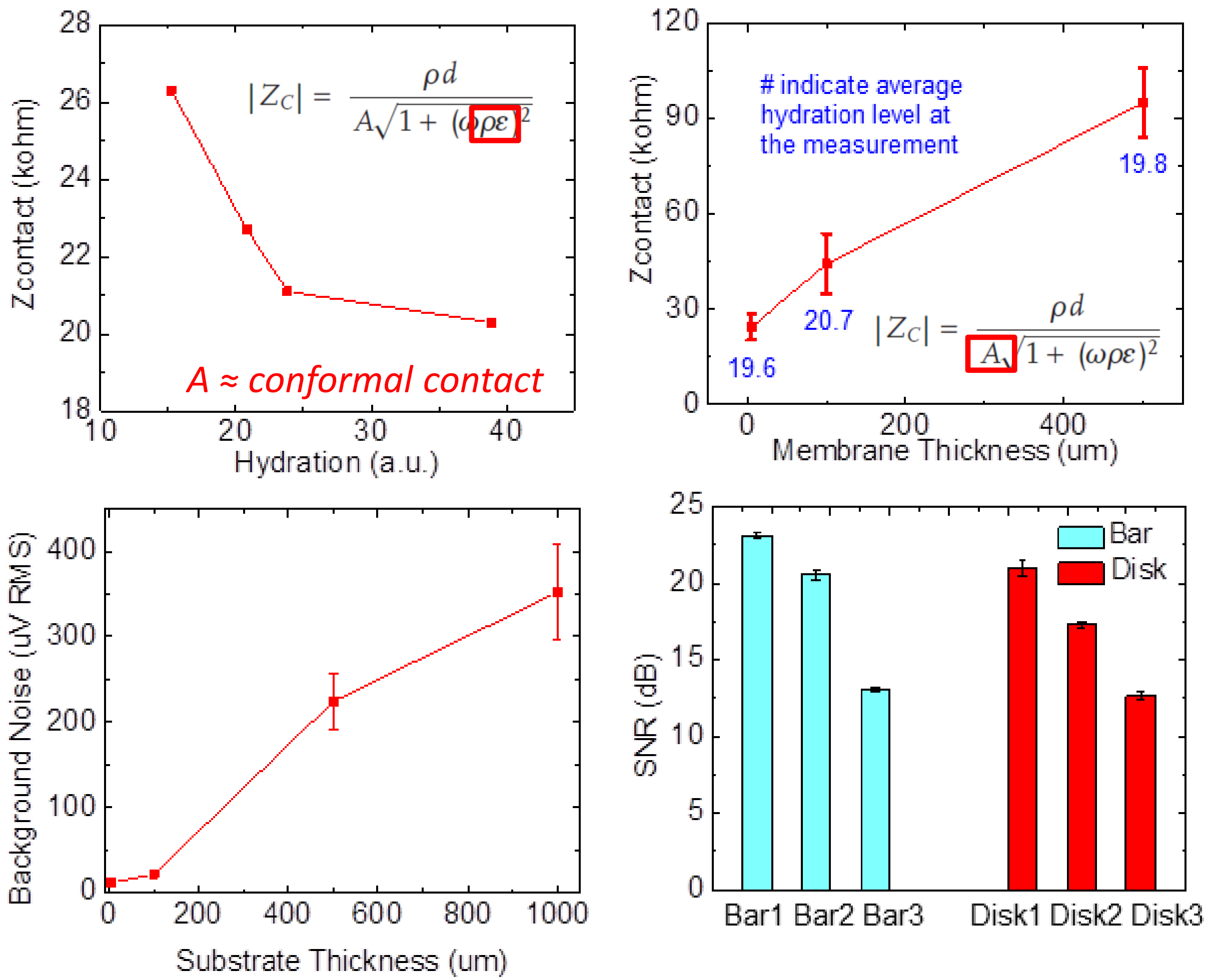
1) Inter-electrode spacing?





Materials and Characterization

2) Membrane thickness and 3) Device type?



5μm in thickness

Bar 1

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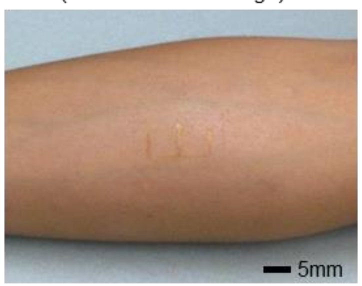
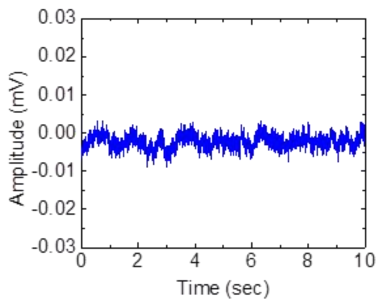
Materials and Characterization

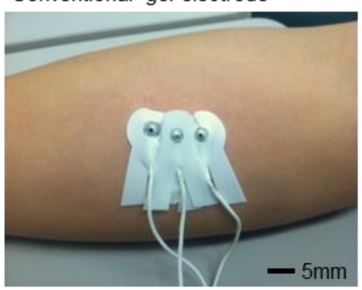
EES vs conventional?
(signal and motion artifact)

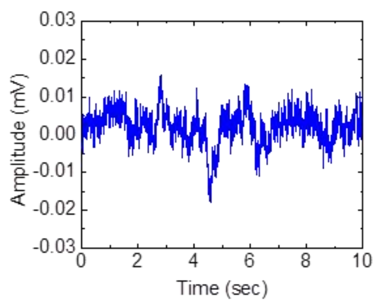
EES (48.1% areal coverage)

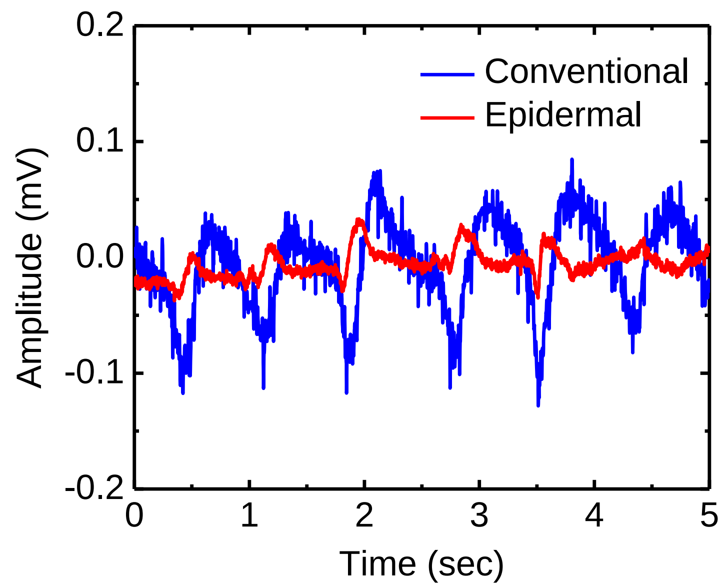


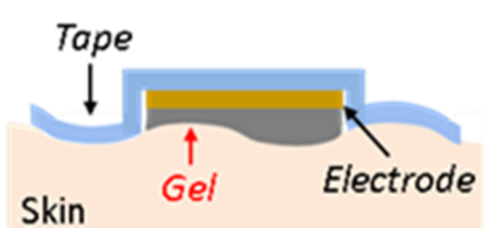


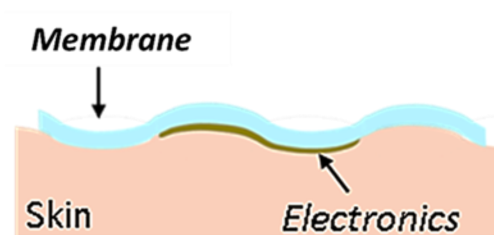
Conventional gel-electrode







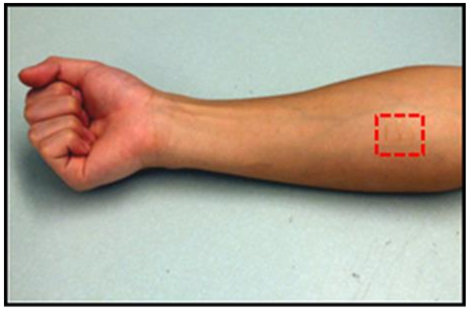


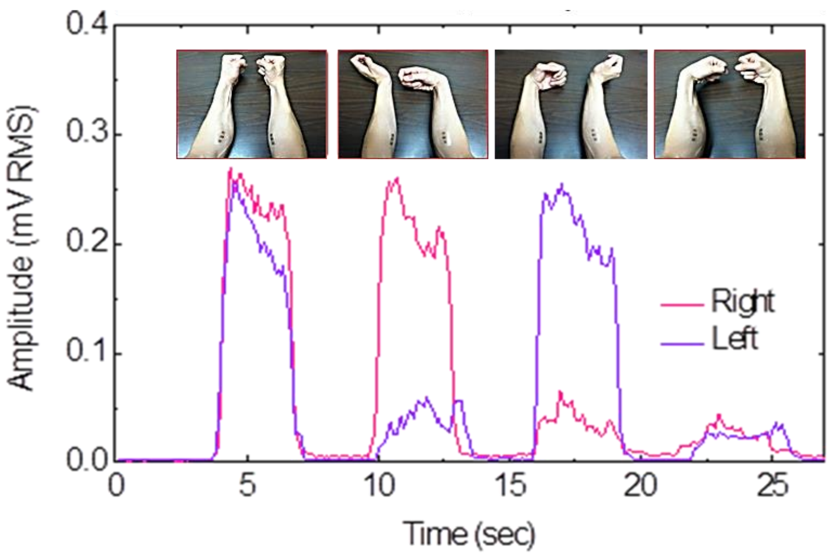


Epidermal, dry electrode w/o gel

Human-Machine Interfaces via EES

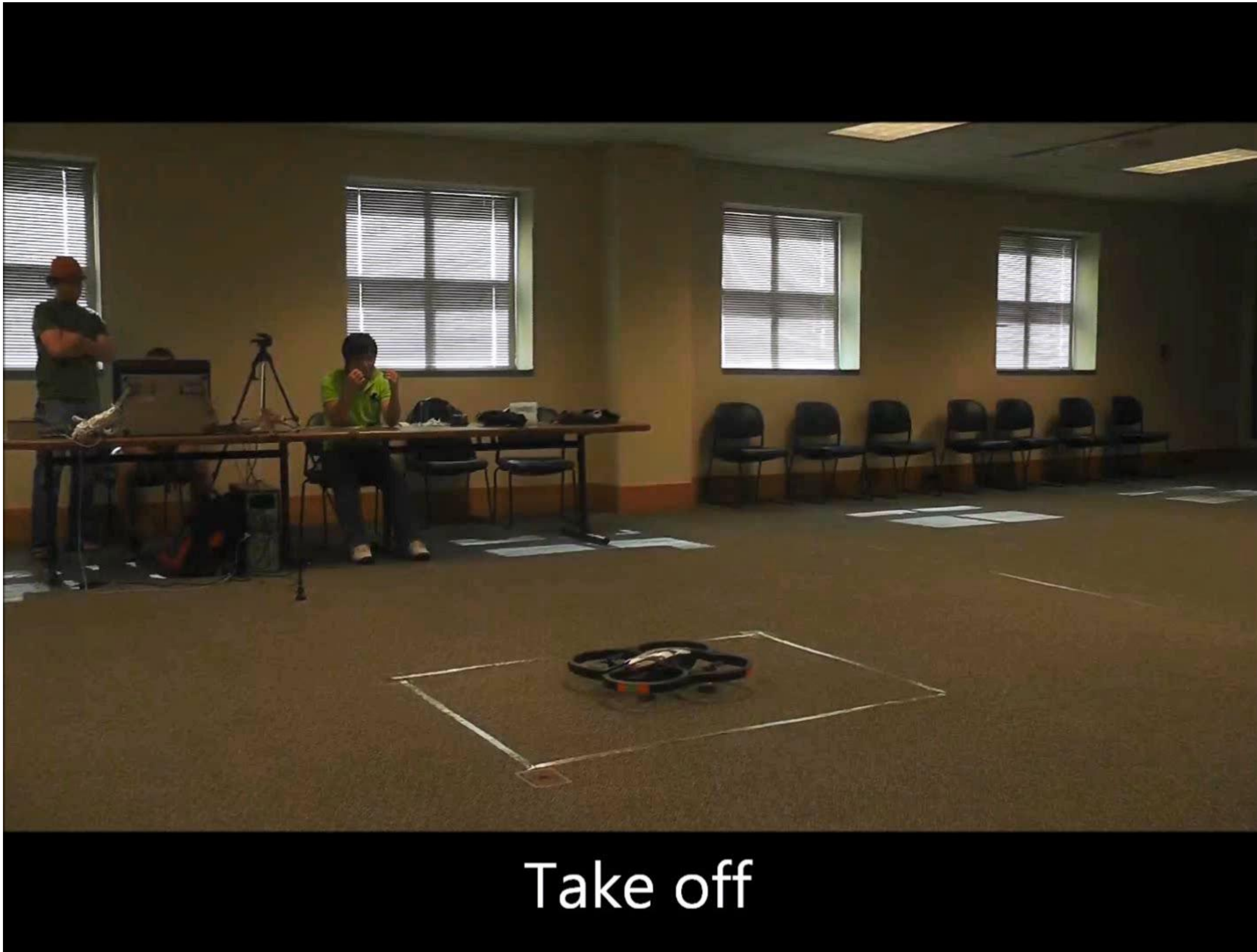
sEMG for quadrotor control





Rotation: ‘take off’ and ‘land’, Left: ‘clockwise rotation’,
Right: ‘counter-clockwise rotation’, Squeeze: ‘fly forward’

Movie of quadrotor control



EEG-based Brain-Computer Interfaces

Unpublished data

Summary

Materials and mechanics for epidermal electornics
sEMG and EEG electrodes and applications for human-machine interfaces

Smart Healthcare System

Thank you !

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