Fabrication of Novel Stretchable Devices

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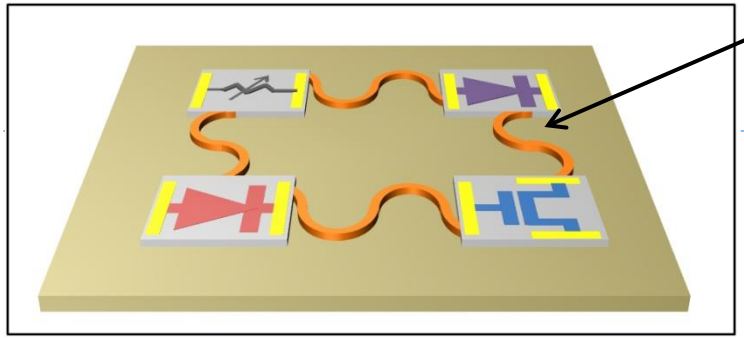
Outline

1. Introduction
2. Design concept of novel stretchable devices
3. Fabrication
4. Stretchable nano-material based devices
5. Summary

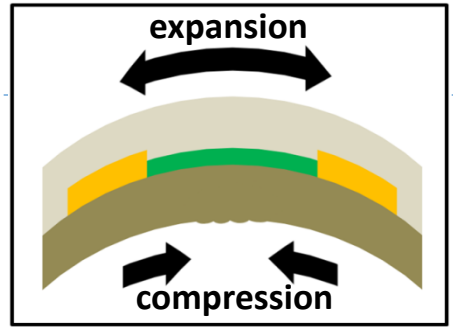
Stretchable electronics?

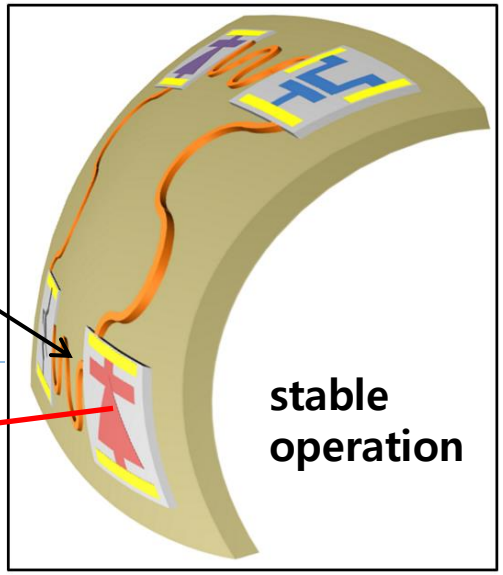
- ✓ *Expandable*
- ✓ *Twistable*
- ✓ *Compressible*

stretchable device

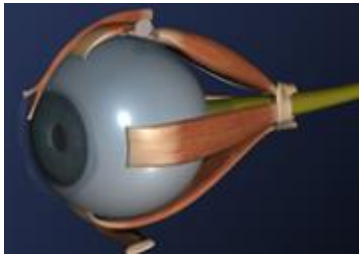


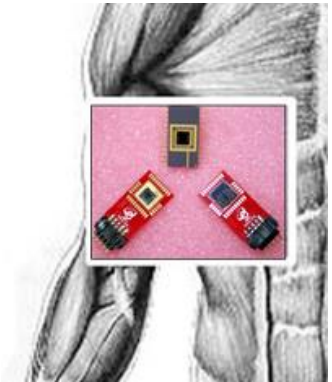
interconnection

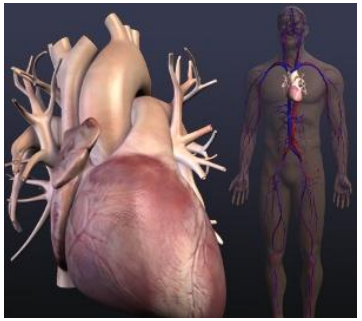




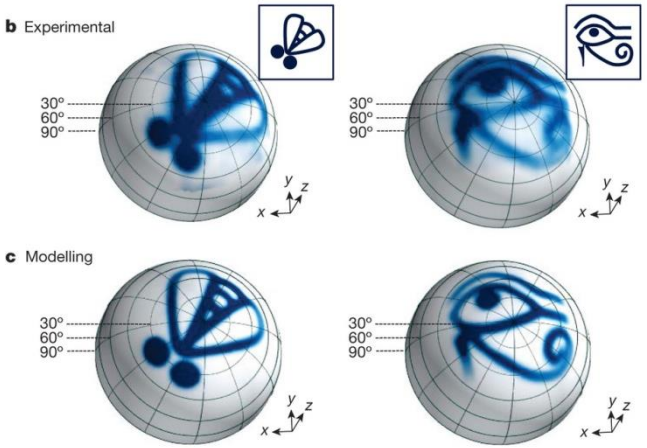
Electronics on curved surfaces





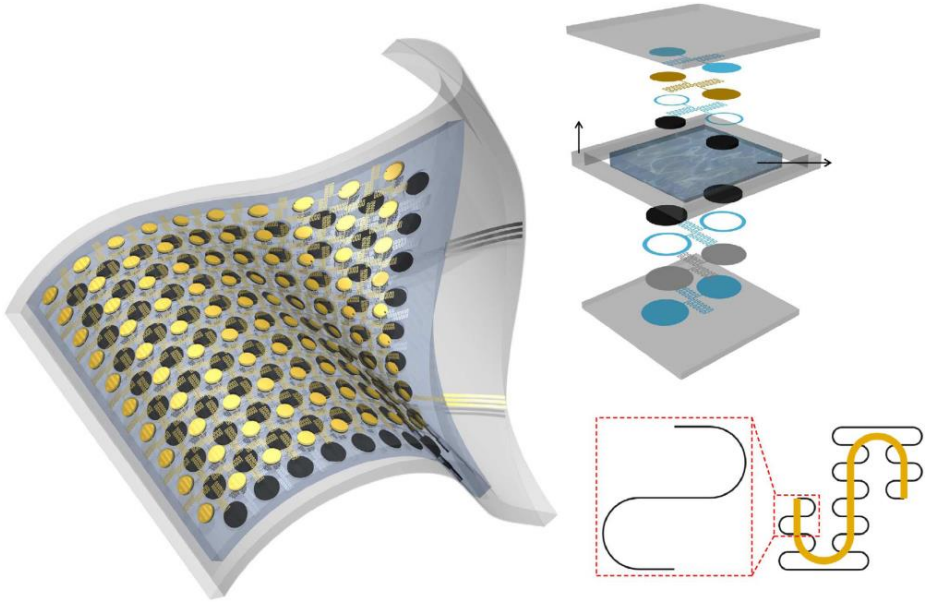


Stretchable devices



▶ Digital cameras with designs inspired by the arthropod eye

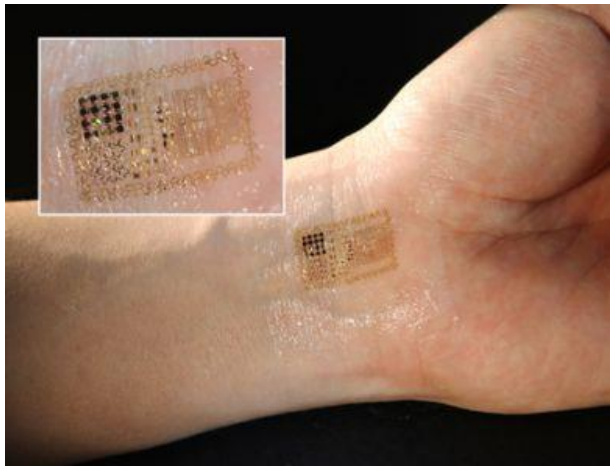
Rogers et al., Nature 497, 95 (2013)

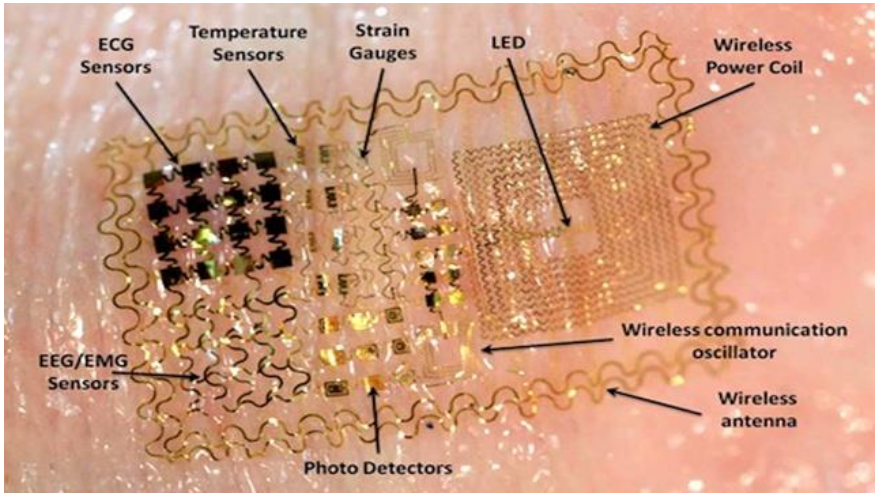


▶ Stretchable batteries with self-similar serpentine interconnects

Rogers et al. Nat. Comm. 4, 1543 (2013)

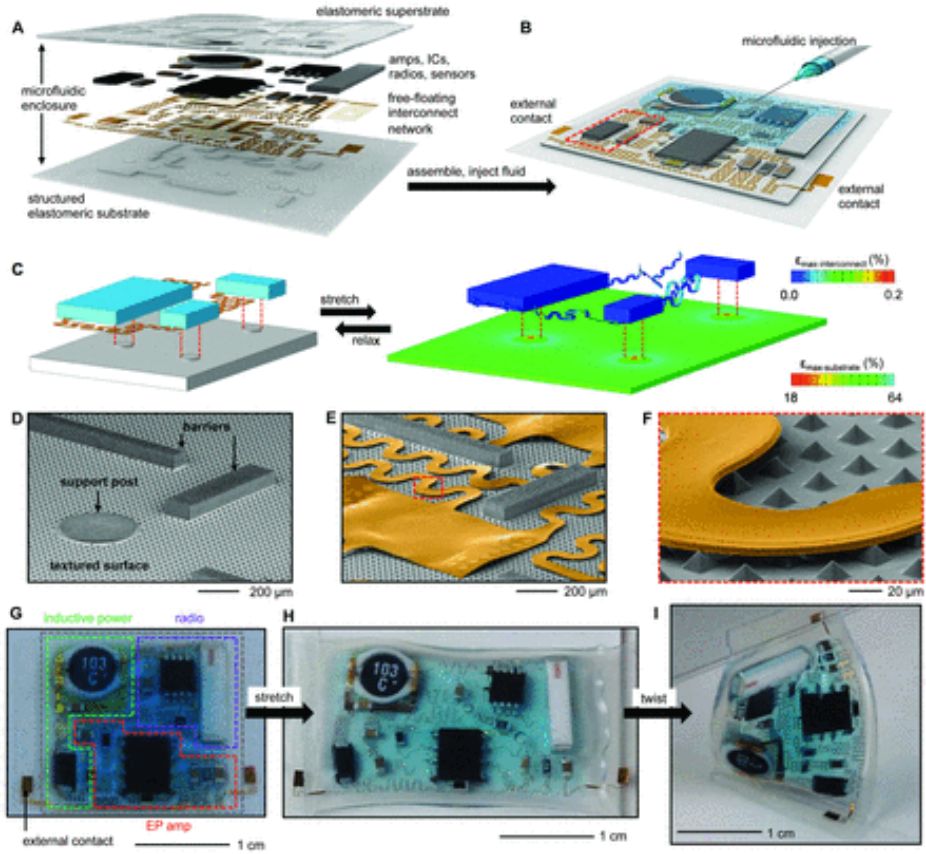
Epithermal electronics & integrated circuits





▶ Epidermal Electronics

Rogers et al. Science 333, 838 (2011)



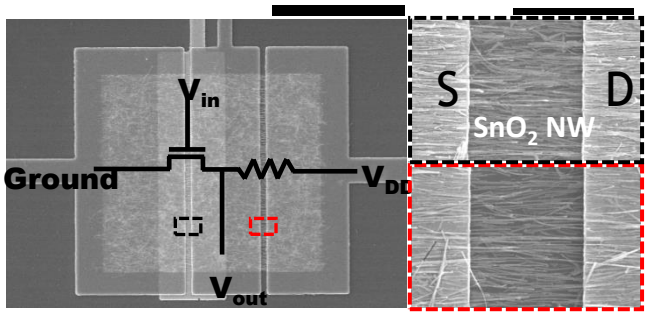
▶ Thin, conformable device softly laminating onto the surface of the skin to enable advanced, multifunctional operation for physiological monitoring in a wireless mode

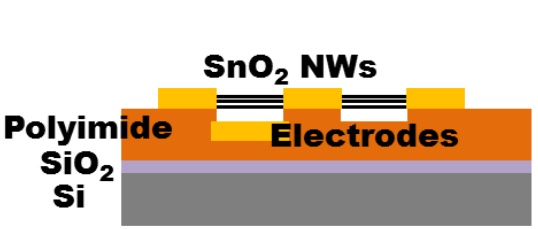
Rogers et al. Science 344, 70 (2014)

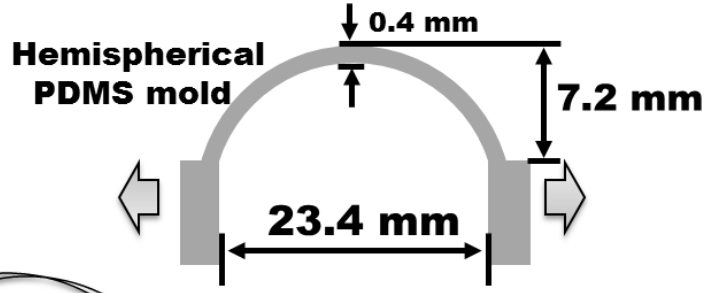
Our recent work on stretchable nanowire devices

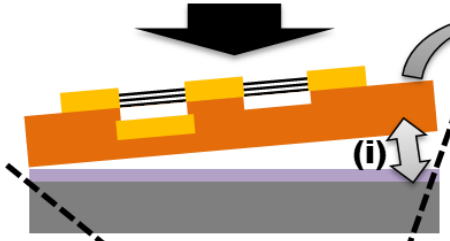
1. "Stretchable Field-Effect-Transistor Array of Suspended SnO_2 Nanowire", Small 7, 1181 (2011).
2. "SnO_2 Nanowire Logic Devices on Deformable Nonplanar Substrates" , ACS Nano 5, 10009 (2011).
3. "Fabrication of a Stretchable Solid-State Micro-Supercapacitor Array", ACS Nano 7, 7975 (2013).
4. "Fabrication of Stretchable Single-Walled Carbon Nanotube Logic Devices", Small 10, 2910 (2014).
5. "Design and Fabrication of Novel Stretchable Device Arrays on a Deformable Polymer Substrate with Embedded Liquid-Metal Interconnections", Adv. Mater., in press (2014). DOI: 10.1002/adma.201402588 (2014).
6. "High-Density, Stretchable, All-Solid-State Microsupercapacitor Arrays", ACS Nano, in press (2014). DOI: 10.1021/nn503799j

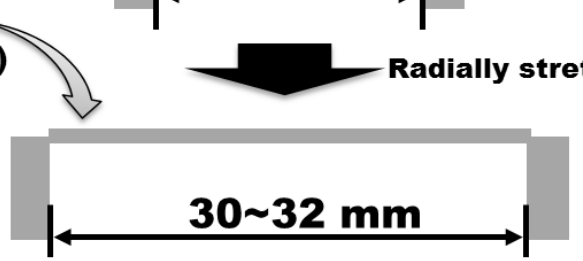
Stretchable SnO_2 nanowire inverter array

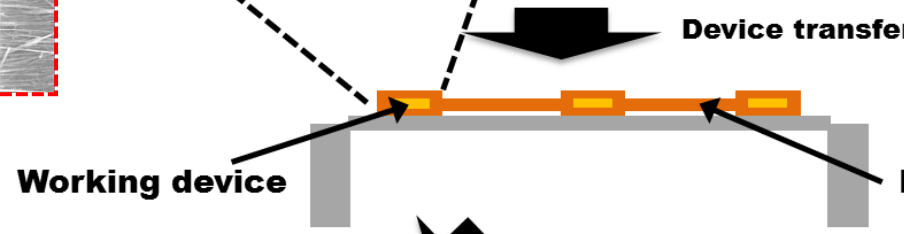


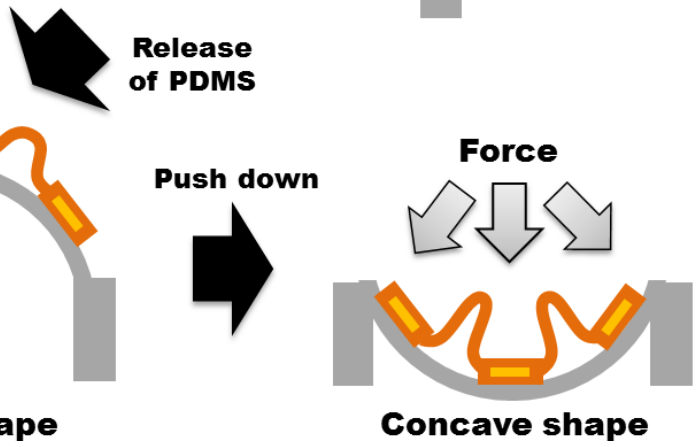






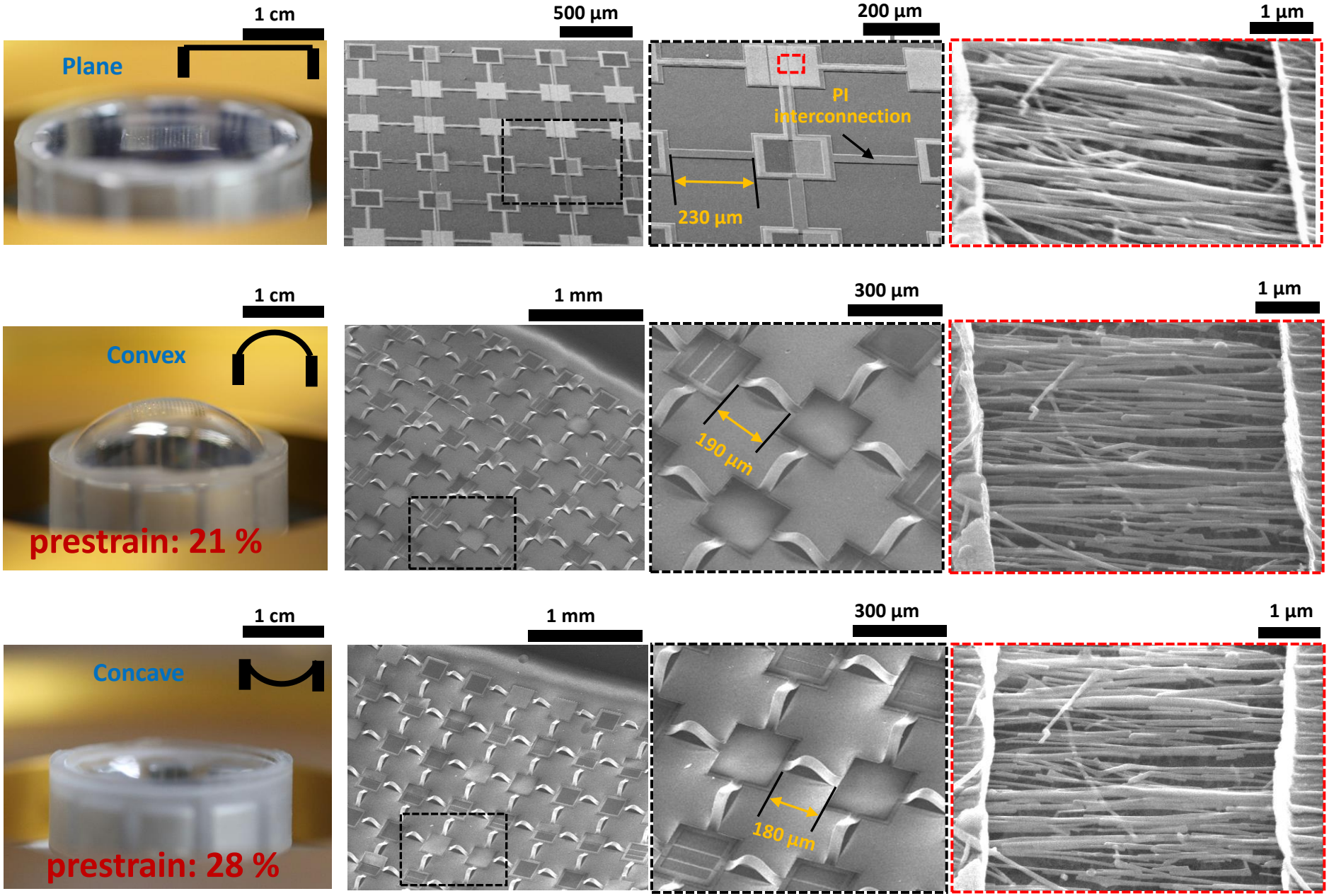


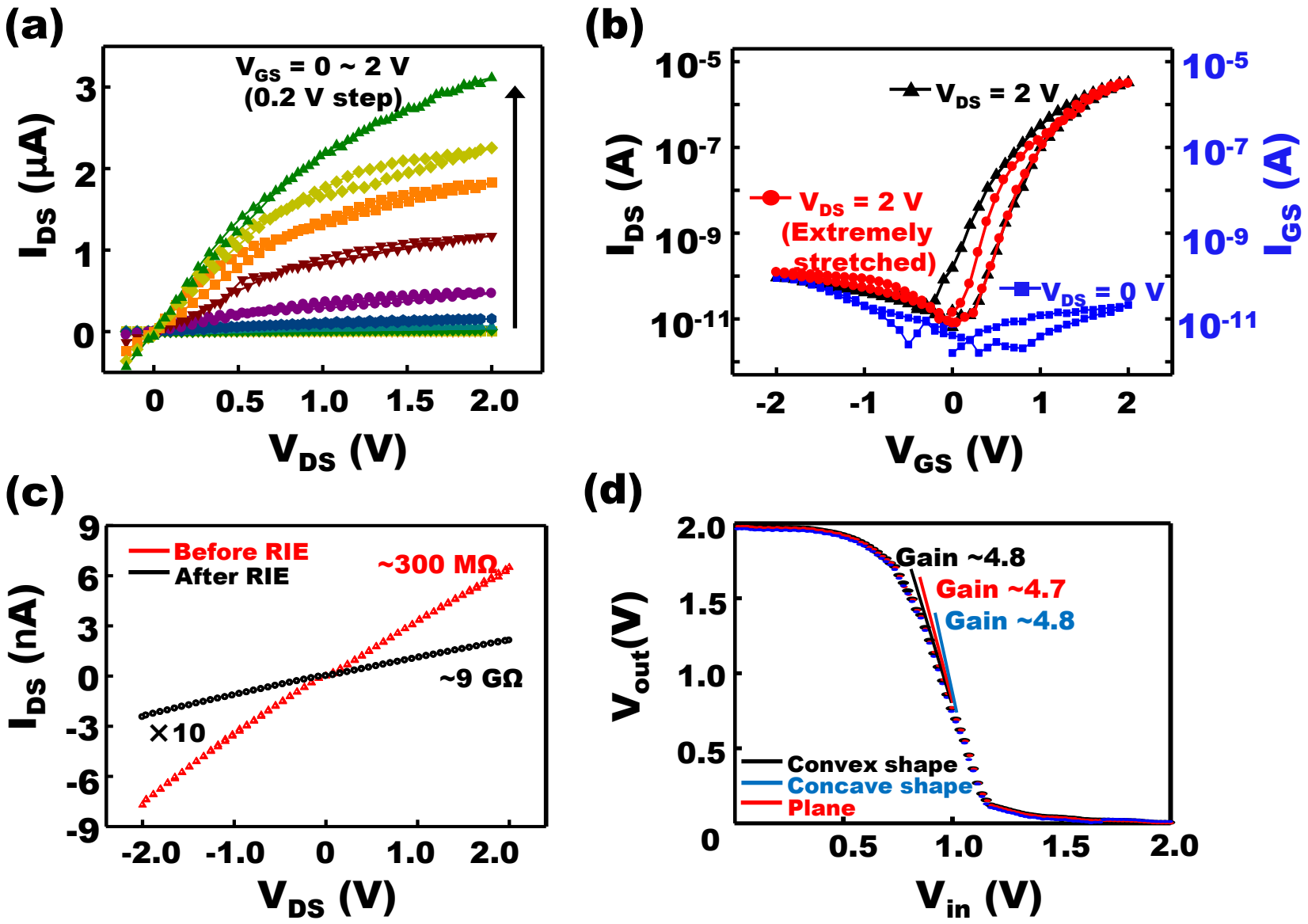




Shin et al. ACS Nano 5, 10009 (2011)

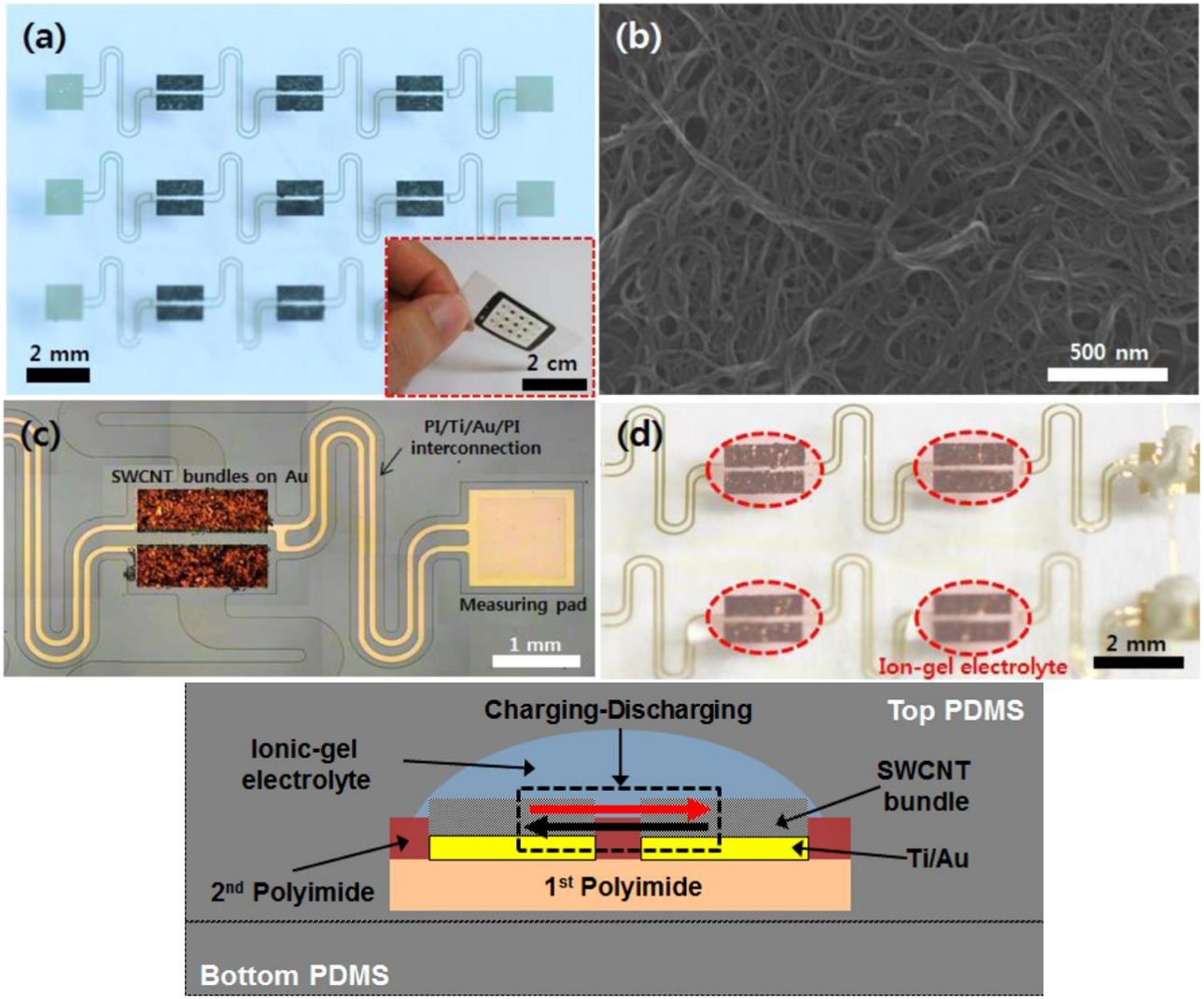
SEM images after deformation





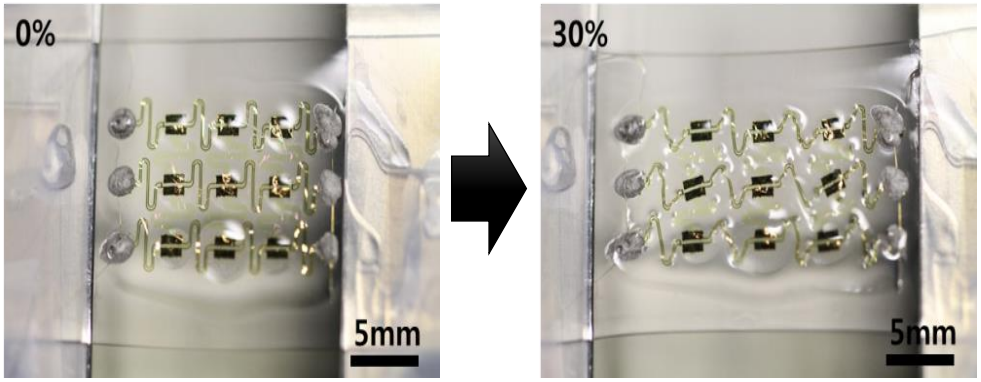
▶ No deterioration of electrical performance upon deformation

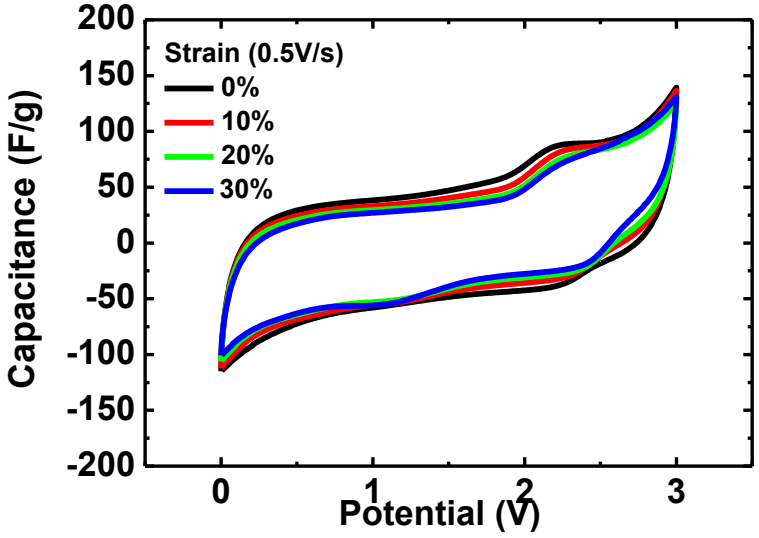
Stretchable micro-supercapacitor array



▶ **micro-supercapacitor with SWNT electrodes and ionic-gel electrolyte**

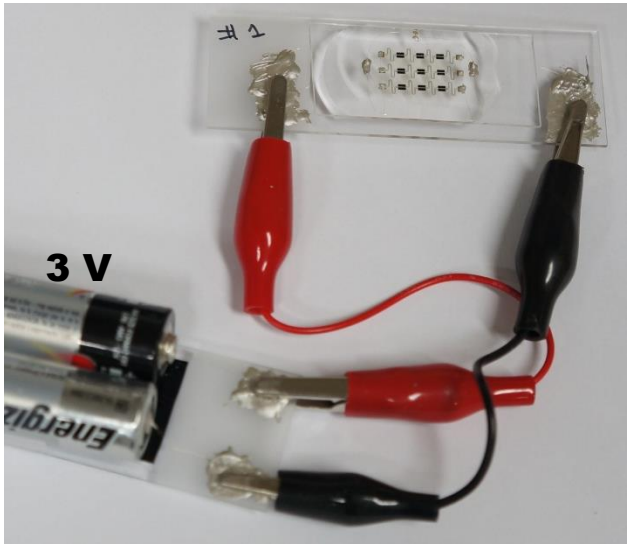
Kim et al. ACS Nano 7, 7975 (2013).

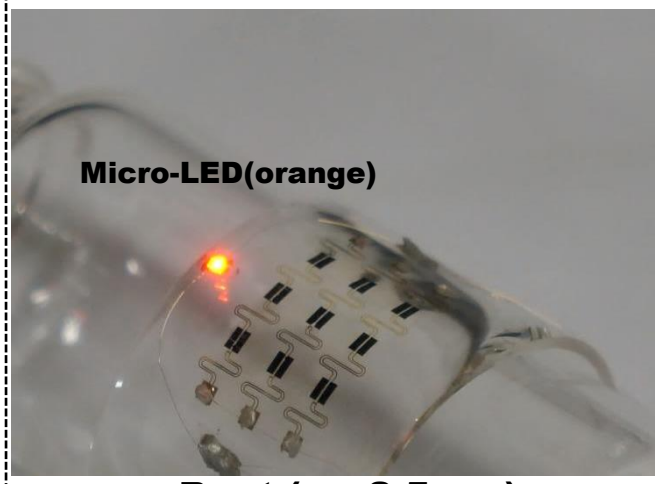




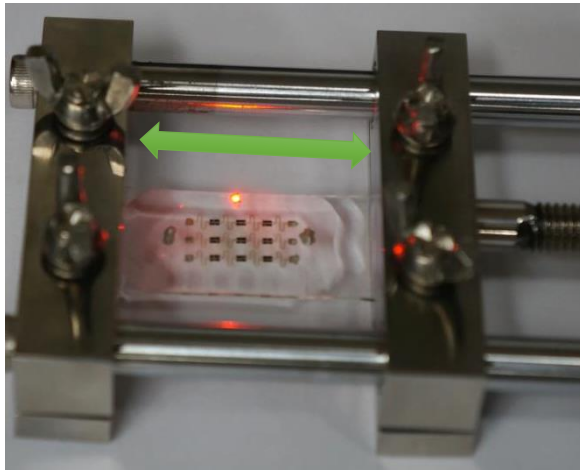
▶ No noticeable deterioration in electrochemical performance with stretching

Charging → **Discharging**





Bent (r ~ 2.5 cm)

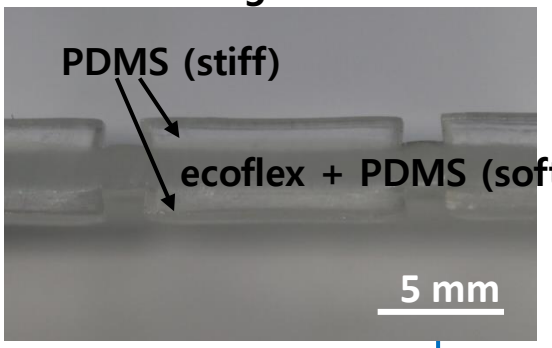


Stretched (~ 20 %)

2. Design concept of novel stretchable devices

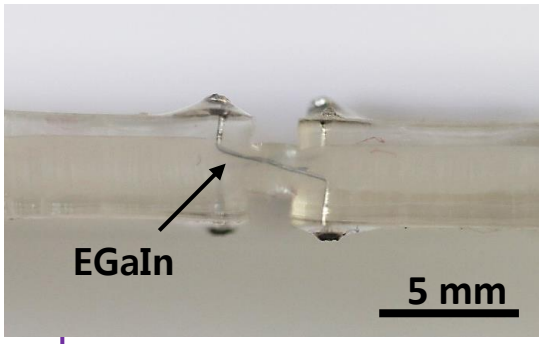
Main concept of our novel stretchable device

a heterogeneous structure



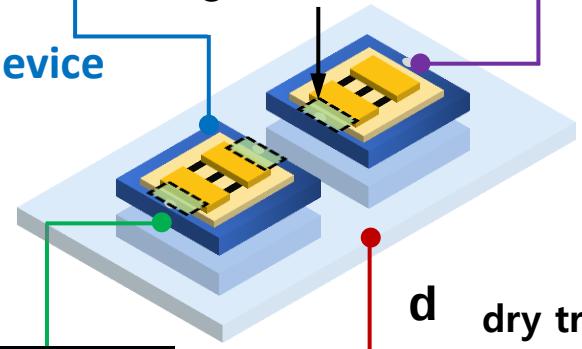
Difference in Young's Modulus
→ Minimized strain on active device

b embedded EGaIn interconnection

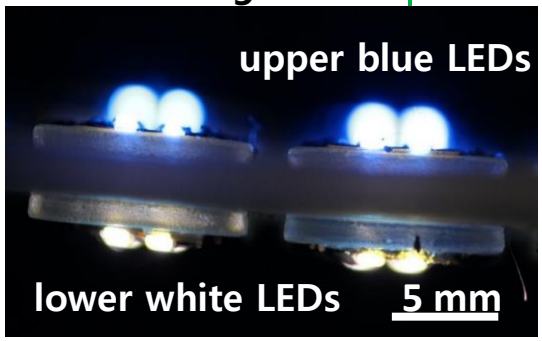


→ Simple fabrication/
Protection from external impact/
Increase in fill factor

e silver sticker

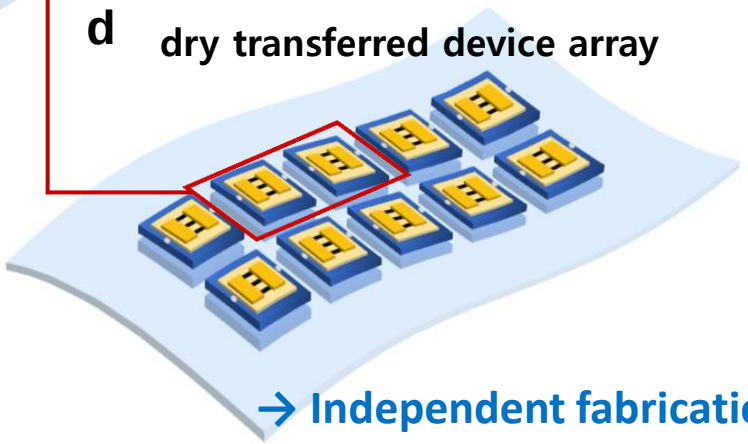


c double integration



→ Doubling the fill factor

d dry transferred device array

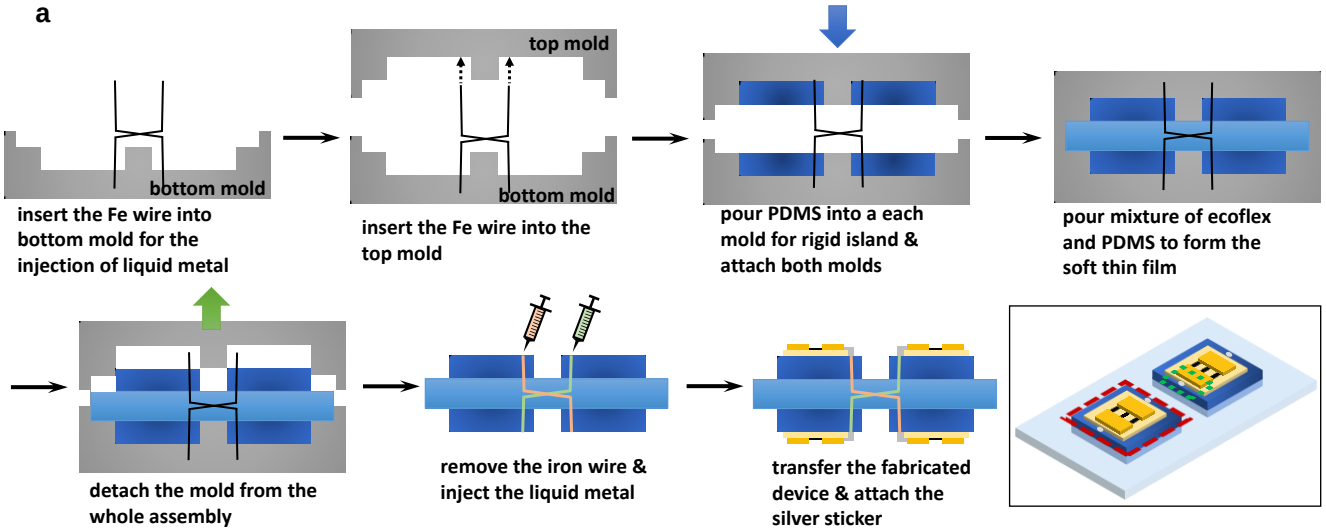


→ Independent fabrication of
active devices from the substrate

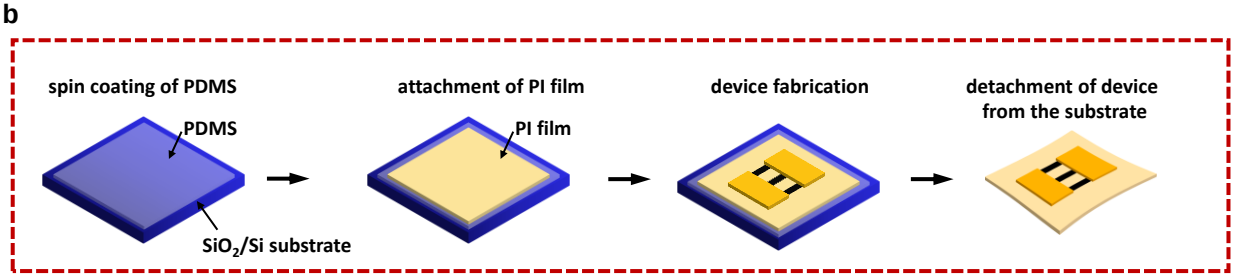
3. Fabrication

Schematics of fabrication process

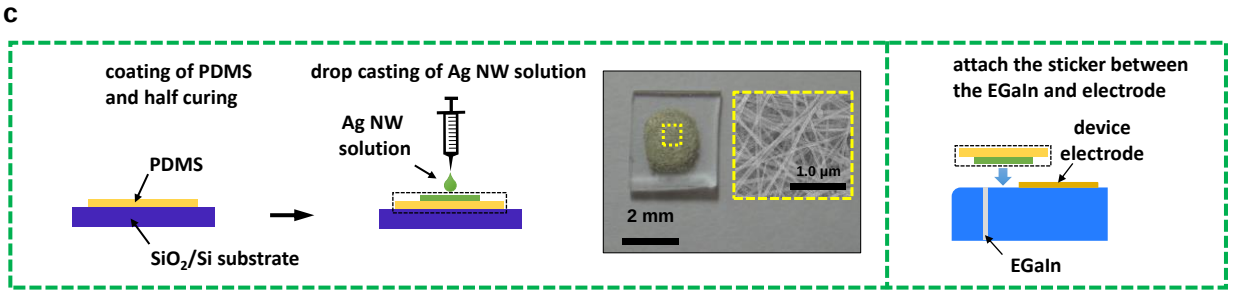
a. Preparation of deformable substrate



b. Preparation of active device and dry transfer



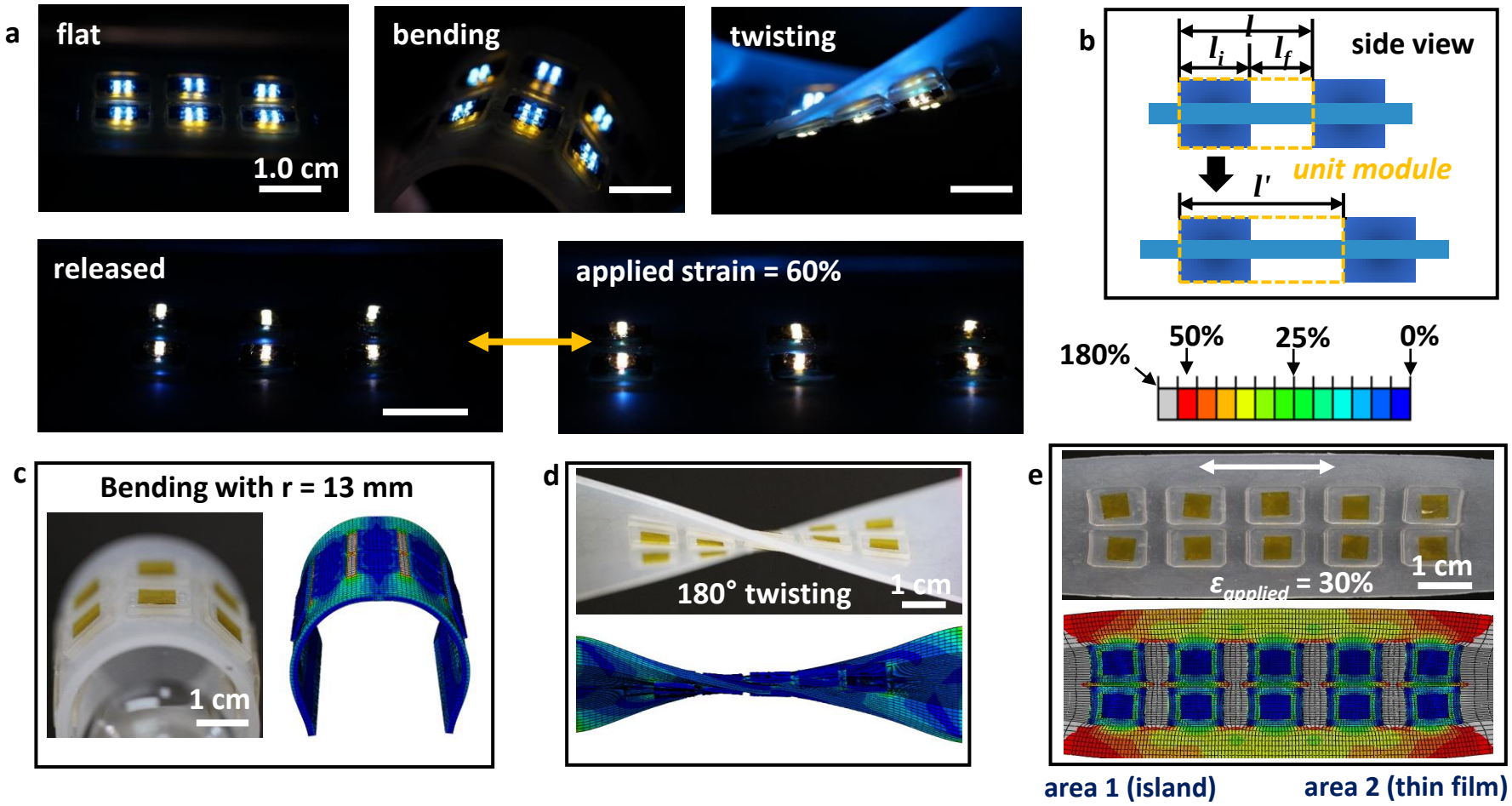
c. Preparation of Ag nanowire sticker



Yoon et al. Adv. Mater. In press (2014)

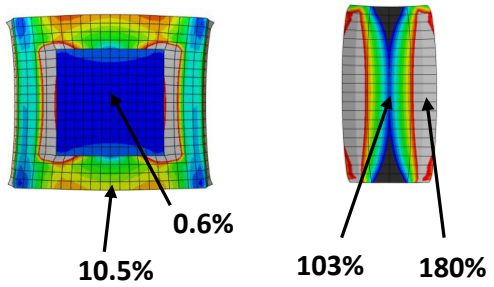
4. Stretchable nano-material based devices

Stretchable array of LEDs & strain distribution

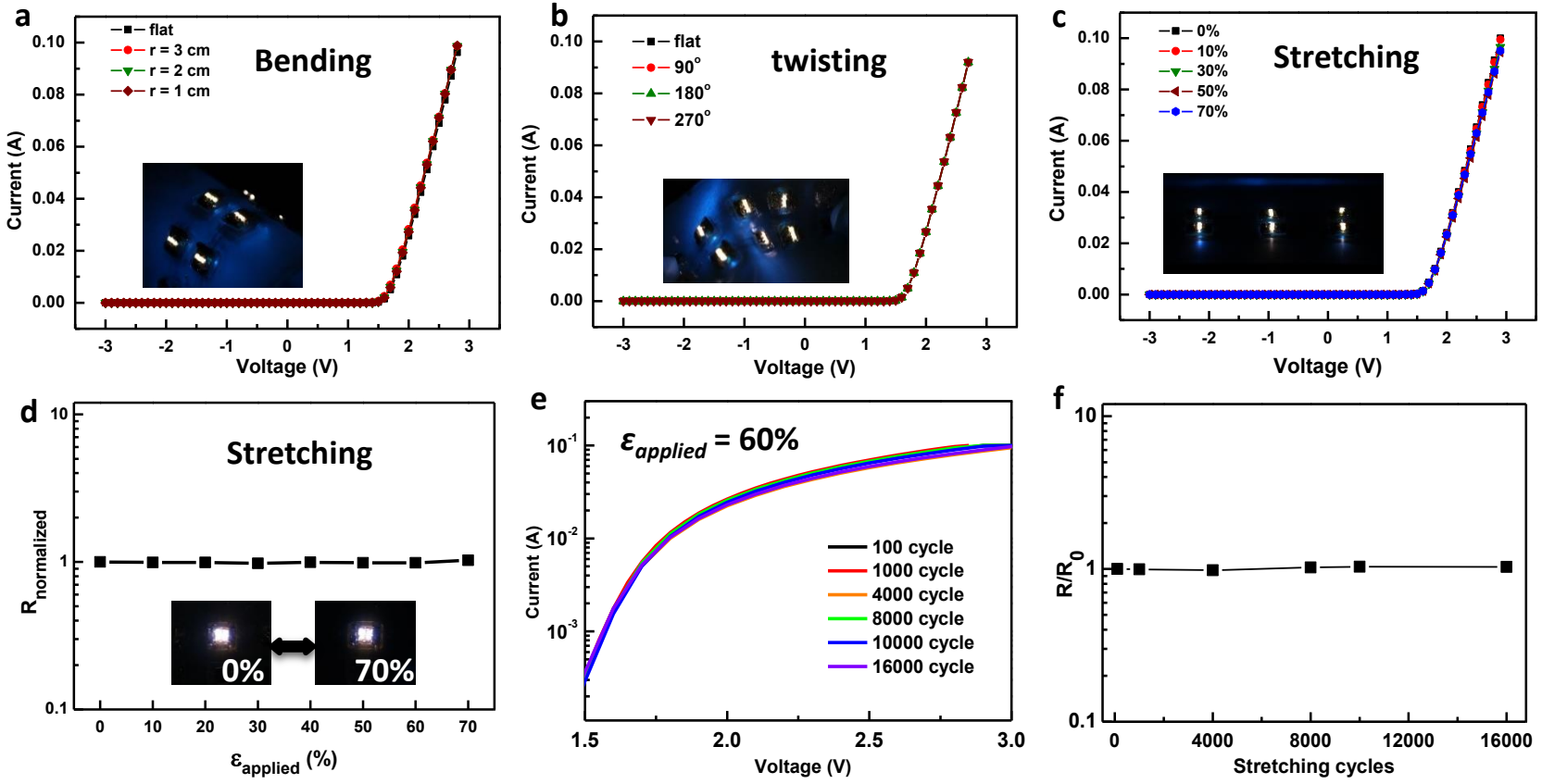


→ Stable performance upon deformations of stretching, bending, and twisting

→ Minimized strain on island (<1%) with concentrated strain on thin film (>100%) upon 30% stretching



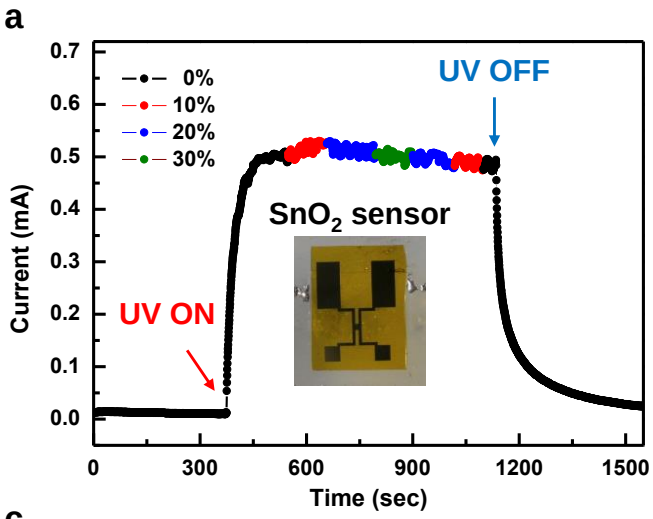
I-V characteristics of LED arrays upon deformation

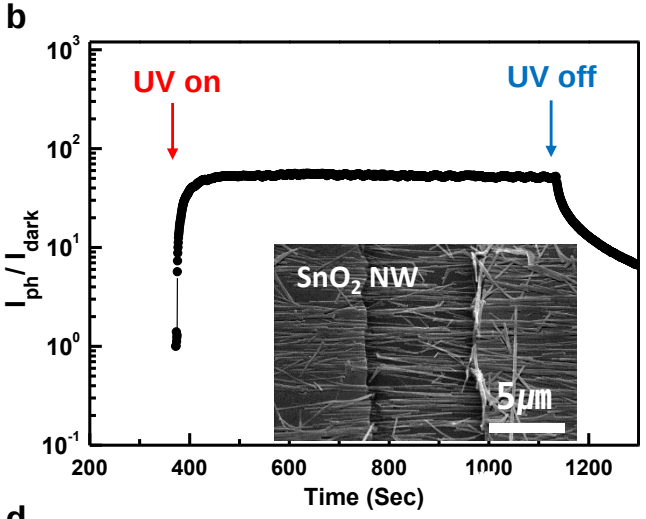


→ Stable performance upon bending, twisting, and stretching

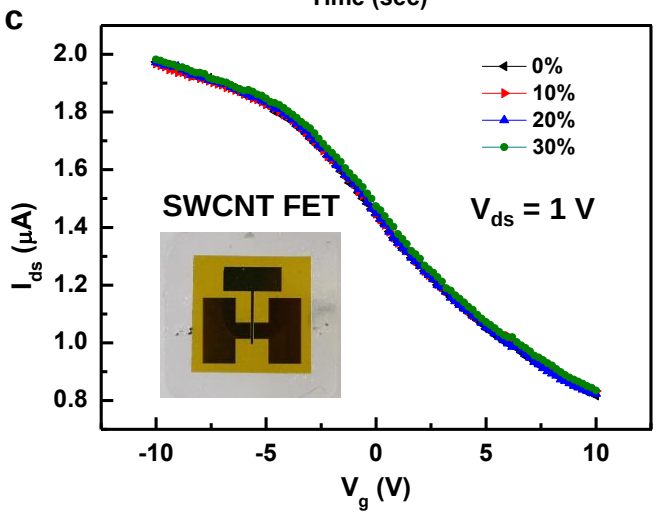
→ Mechanically stable upon repeated stretching cycles of 16,000 under external strain of 60%

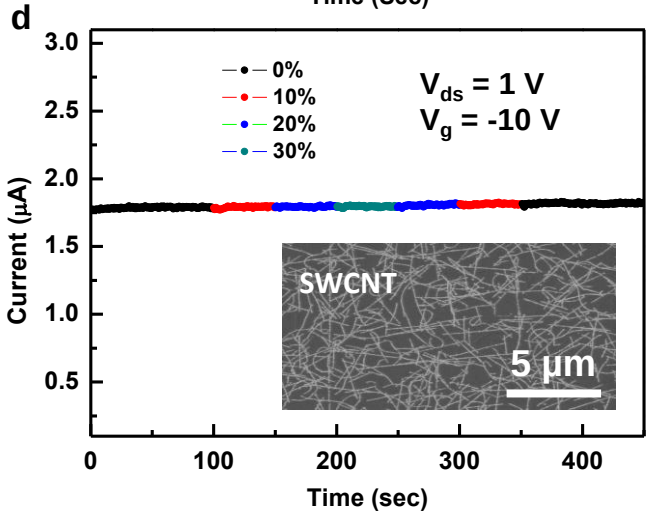
Stretchable SnO_2 nanowire UV sensor & SWCNT FET





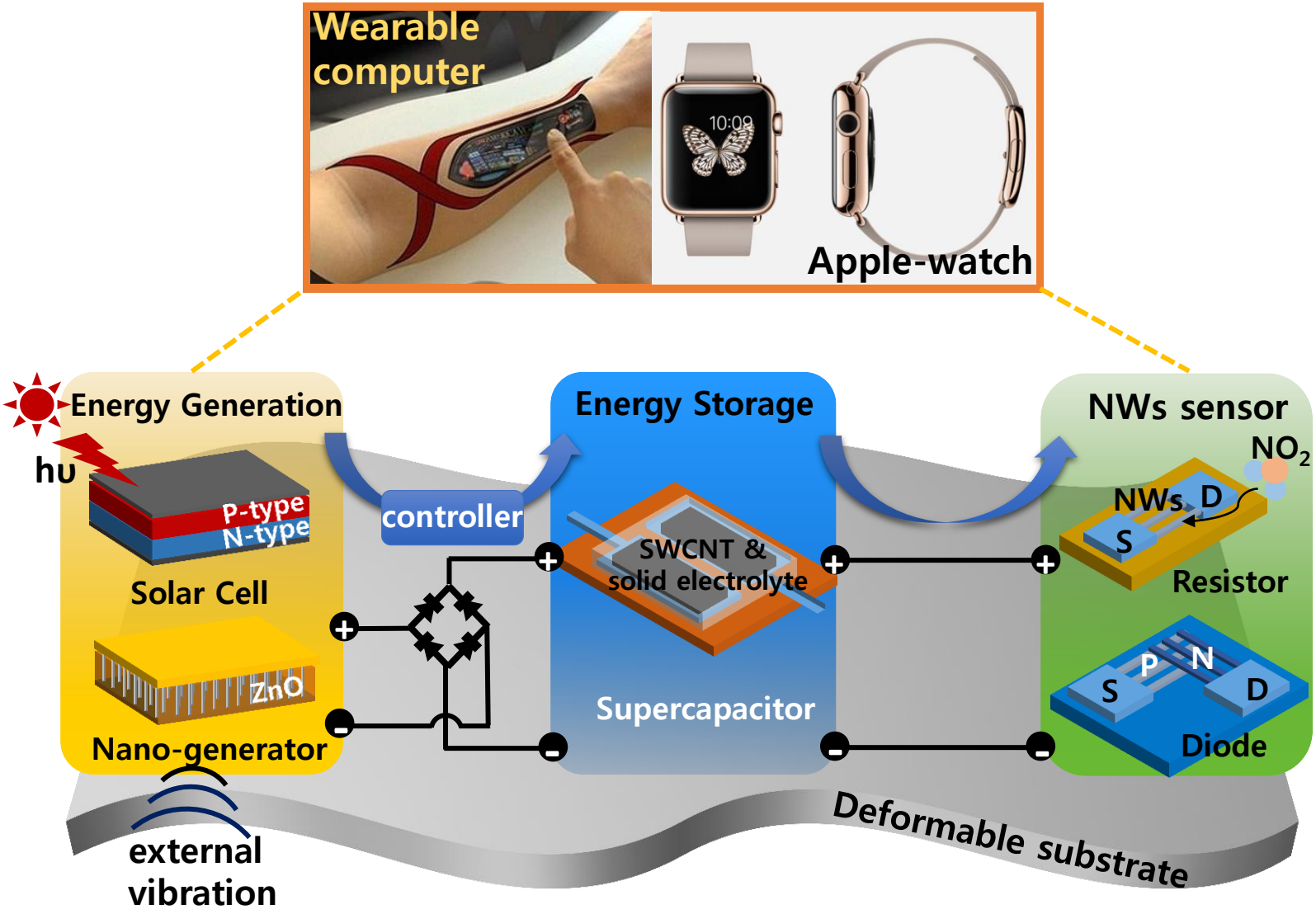
→ stable photo-current upon uniaxial stretching
→ I_{ph}/I_{dark} ~ 60



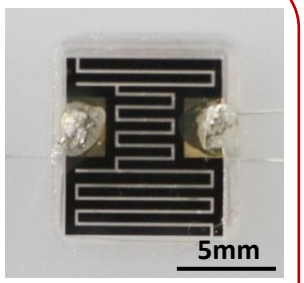


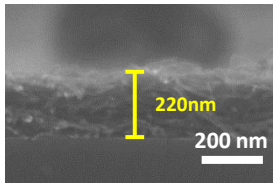
→ stable transfer curve upon stretching
→ stable I_{ds} value

Stretchable electronics with integrated energy generation and storage devices



Fabrication of micro-supercapacitor with LbL assembled MWNT/MnO_x electrodes





Channel length = 150 µm
Active area = 0.6 cm^2
Thickness = 220 nm
Volume = 1.32 x $10^{-4}cm^3$

Solidification of solid electrolyte

PVA-H_3PO_4 gel

MWNT-COOH/MnO_x

PDMS

PET film

SiO_2/Si substrate

Photo Lithography

Metallization

Ti/Au current collector

Layer-by-Layer (LbL) assembly

Repeat

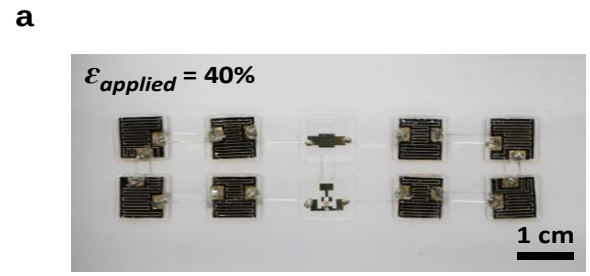
MWNT-NH_3^+ → Washing → MWNT-COO^- → Washing → MWNT-COO^-/MnO_x

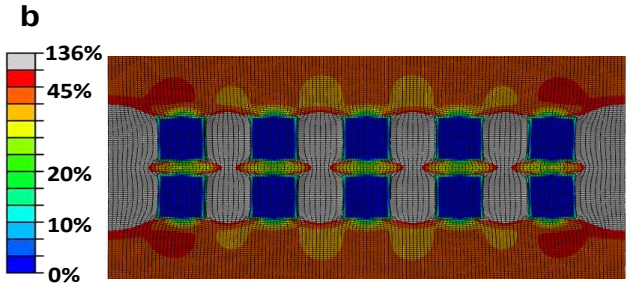
LbL assembly

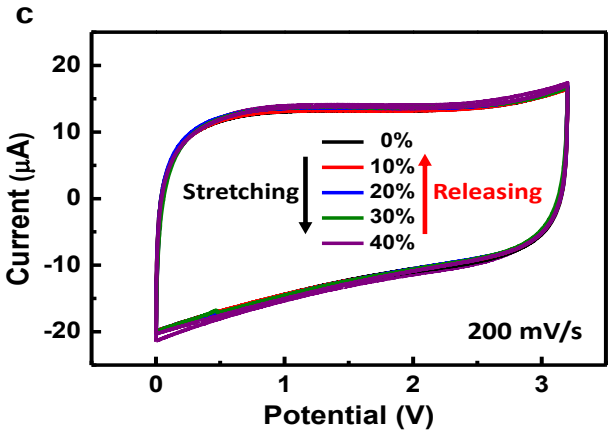
LbL assembly

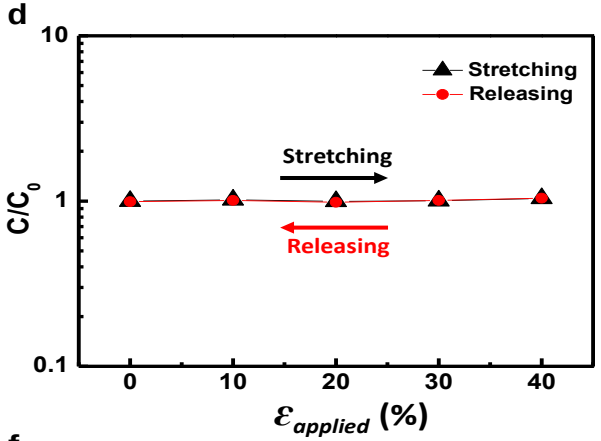
Functionalized MWNT

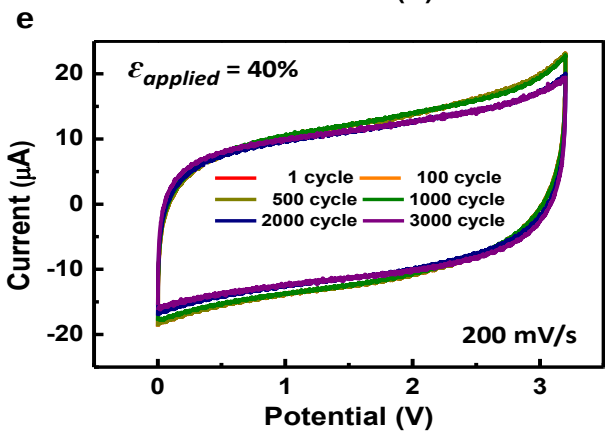
Stretchable micro-supercapacitor array

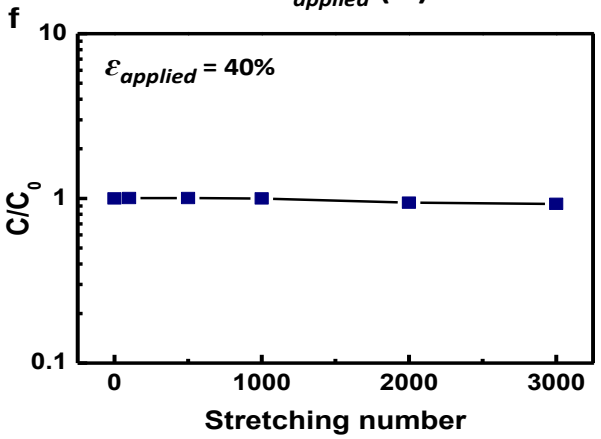




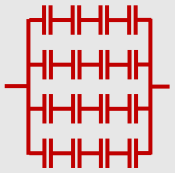






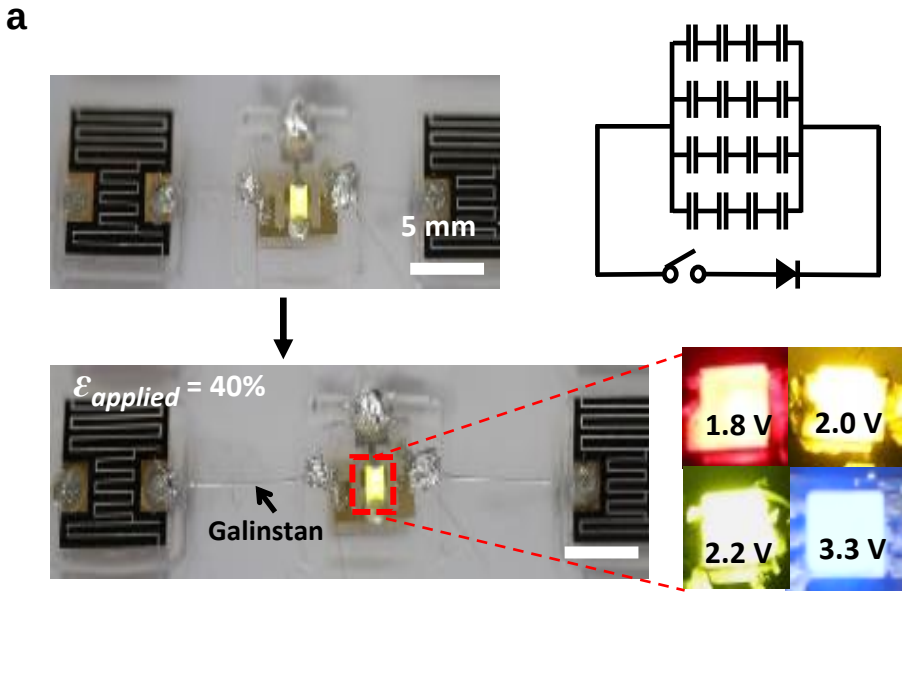


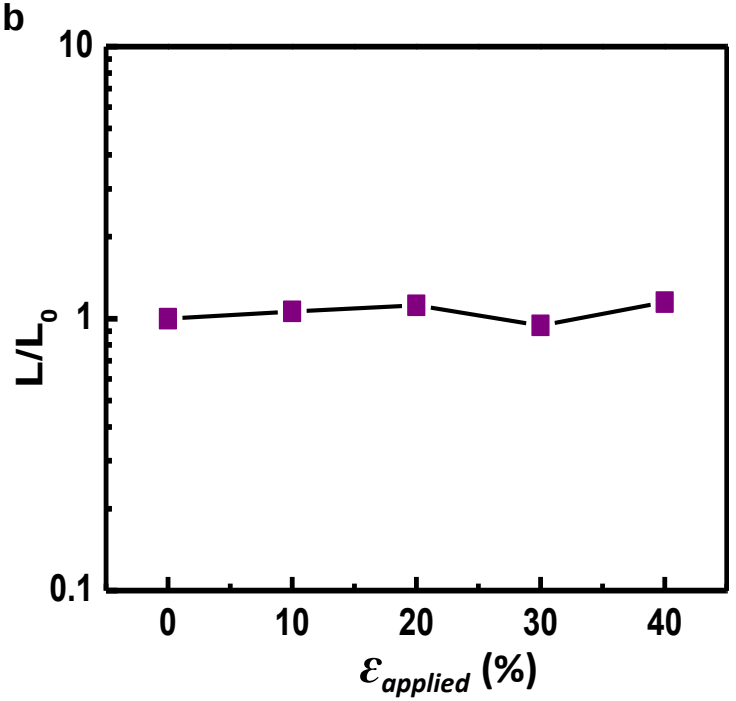
→ Stable electrochemical performance upon repeated stretching up-to 40%

	Single	Array
	⊣⊢	
E_{cell} (mWh/cm³)	2.6	2.4
P_{cell} (Wh/cm³)	23	8

Hong et al. ACS Nano, In press (2014)

Integrated energy storage devices





- Powering various μ-LEDs with different operating voltages by integrated circuit of MSCs
- Stable illumination of μ-LEDs under applied strain of 40%

Summary

▶ We present the fabrication of stretchable electronic devices on newly designed deformable substrates.

▶ Integrated devices, such as μ-LEDs, SnO_2-NW UV sensors, SWCNT FETs, and planar all-solid-state micro-supercapacitors exhibit mechanically stable device performance after bending, twisting, and uniaxial stretching, which corresponds with the FEM analysis of the distribution of strains.

▶ This study demonstrates the successful performance of our newly designed deformable device and the potential for its application in the field of wearable nano-electronics.

Acknowledgments

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▶This work was done with

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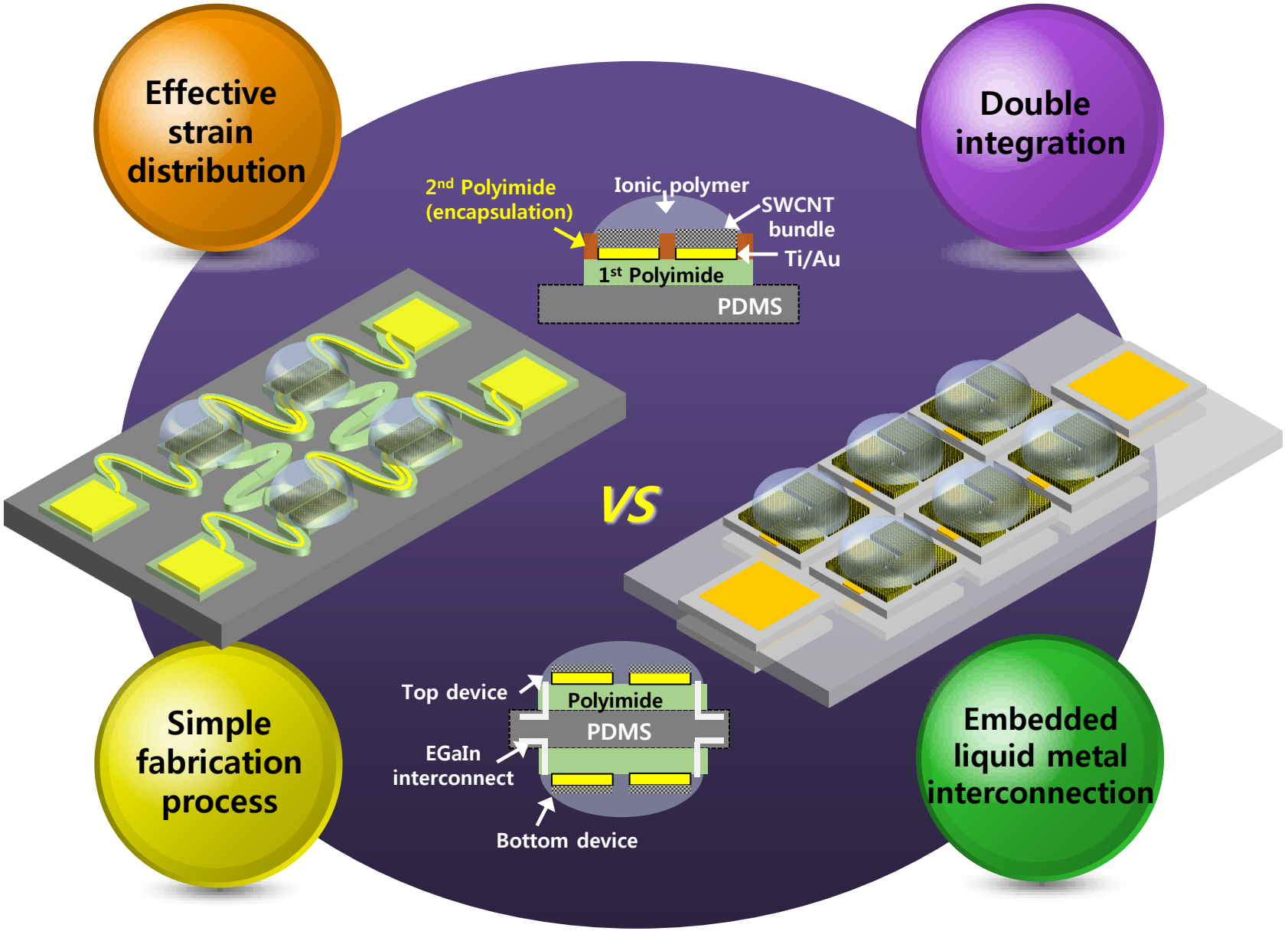
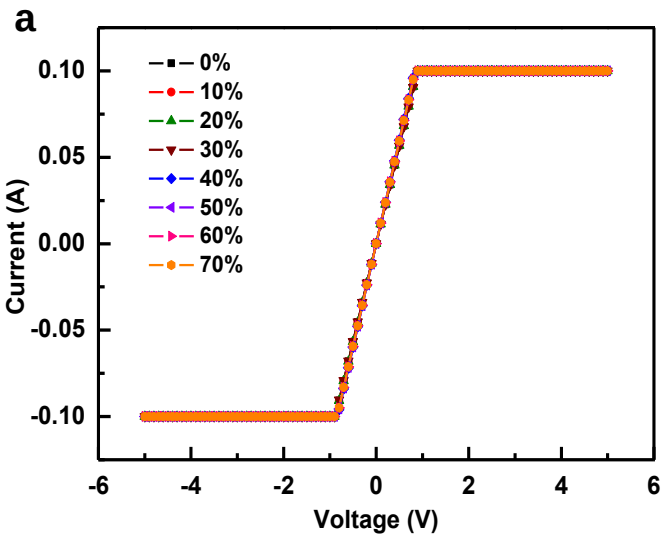
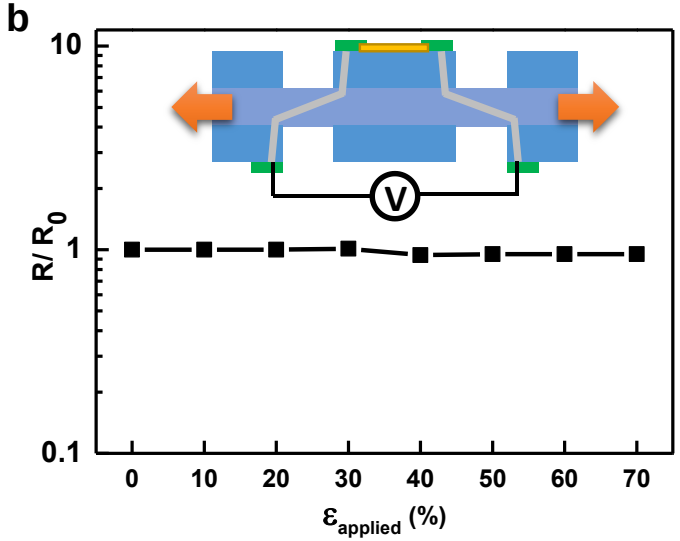
Comparison with previous design

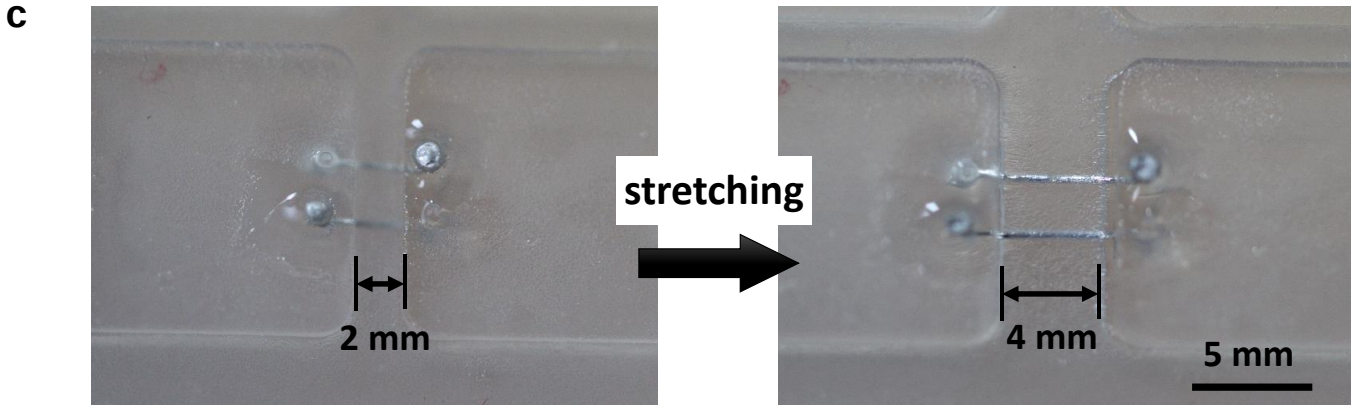


Conducting properties of EGaIn upon stretching



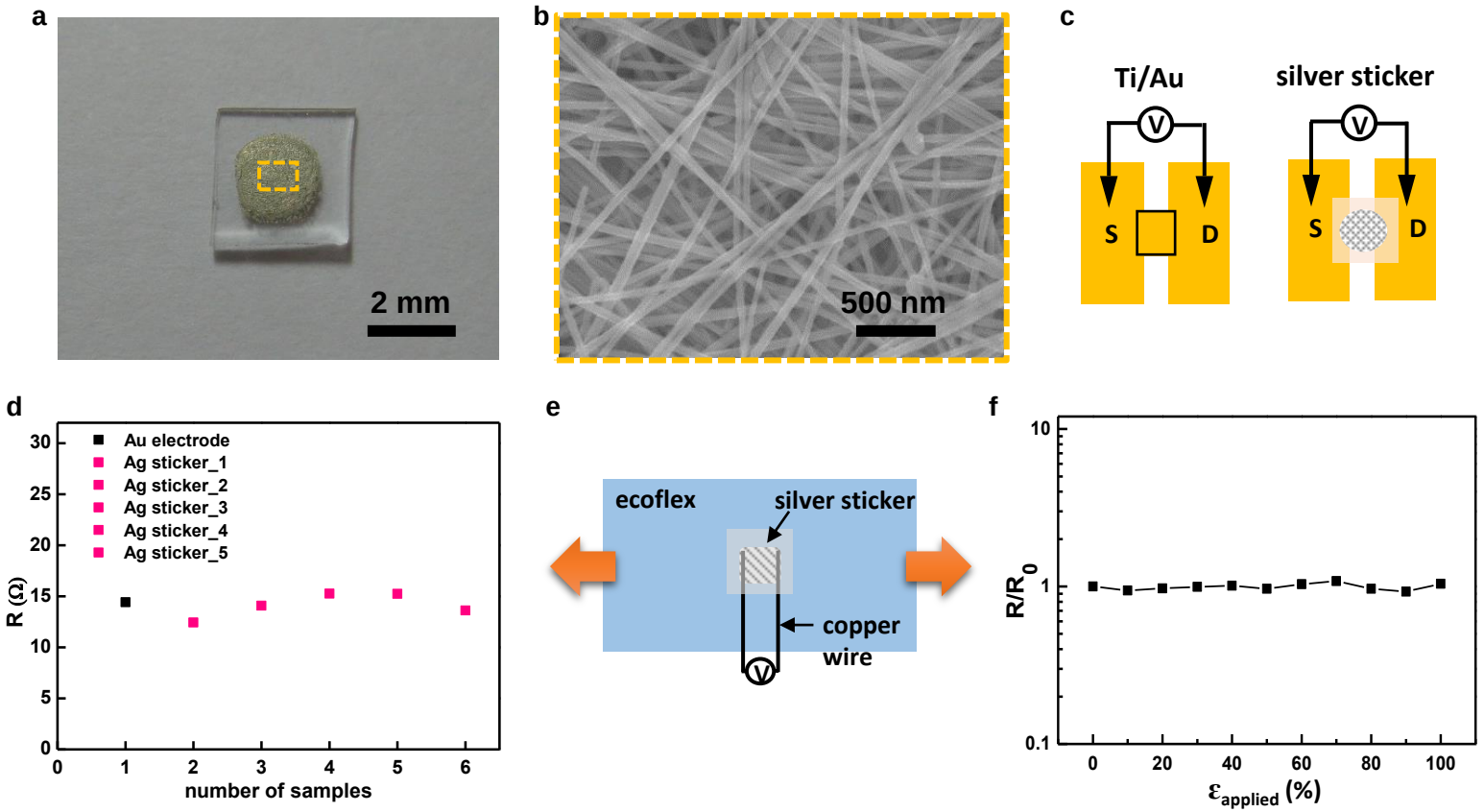


→ Stable conduction upon uniaxial strain up-to 70% (conductivity of EGaIn : 3.4×10^4 S/cm)



→ No noticeable volume change of EGaIn

Conduction through Ag nannowire sticker upon stretching



→ Electrical conduction comparable to Au thin film

→ No change in conductivity upon uniaxial stretching up-to 100%