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Chip on a Fiber Toward the E-Textile Computing Platform

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전북대학교

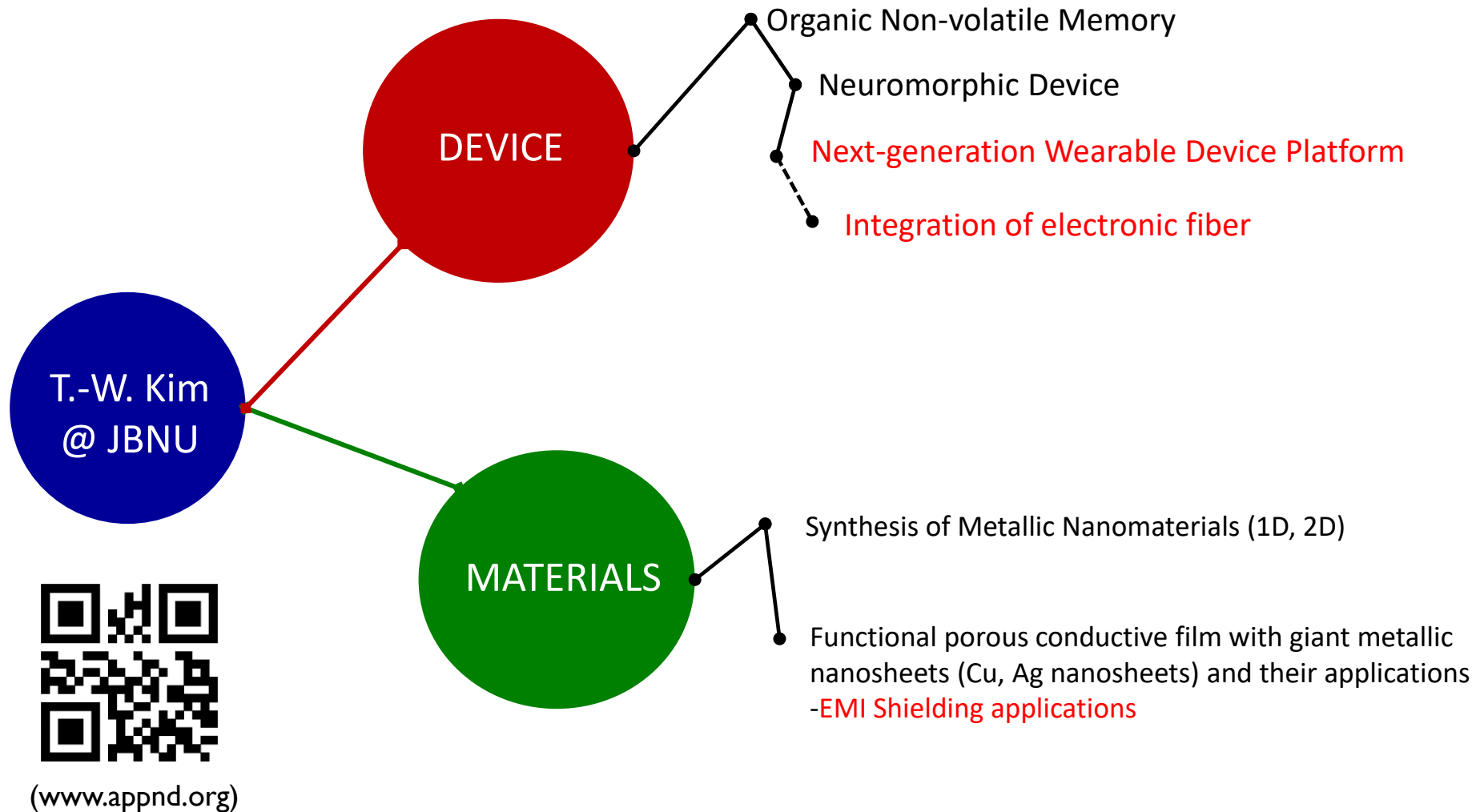
유연인쇄전자전문대학원 유연인쇄전자공학과
JBNU-KIST 산학연융합학과

Applied Nanomaterials & Devices Lab.

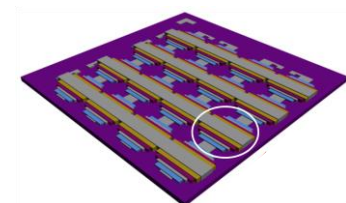
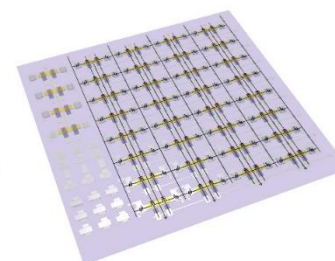
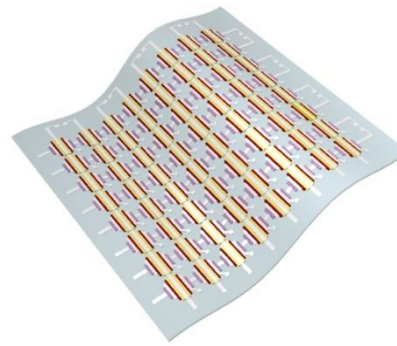
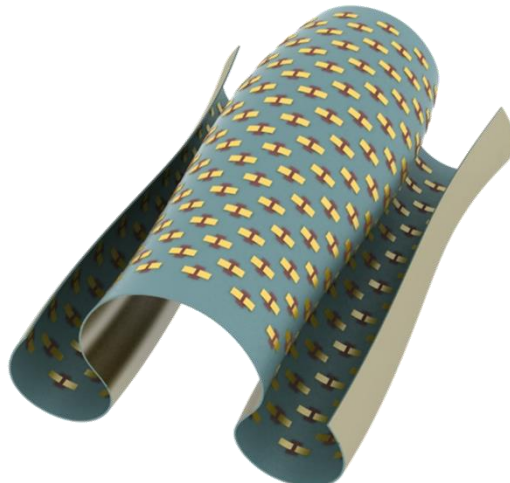
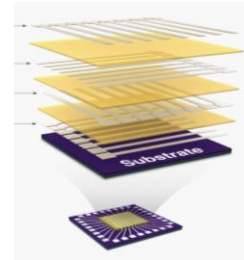
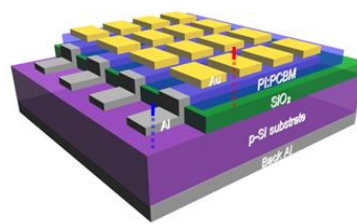
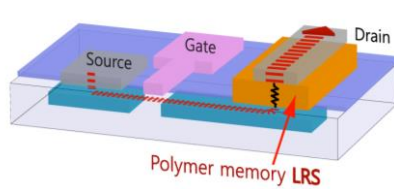
E-mail: twk@jbnu.ac.kr



Research Interests



Organic Non-volatile Memory, Transistors & Neuromorphic Devices

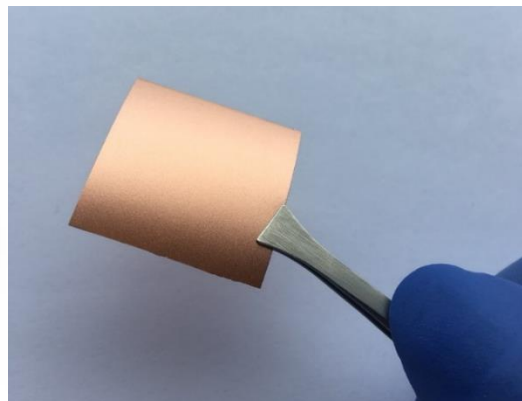


- Kim *et al*, **Advanced Materials**, 21, 2497 (2009)
- Cho, Kim *et al*, **Advanced Materials**, 22, 1228 (2010)
- Ji, Kim *et al*, **Advanced Materials**, 22, 3071 (2010)
- Song, Kim *et al*, **Advanced Materials**, 22, 5048 (2010)
- Kim *et al*, **Advanced Materials**, 24, 828 (2012)
- Ji *et al*, **Nature Communications**, 4:2707 (2013)
- Ji *et al*, **Organic Electronics**, 18, 77 (2015)
- Ji *et al*, **Organic Electronics**, 29, 66-71 (2016)
- Cha *et al*, **ACS Applied Materials & Interfaces**, 9, 2730-2738 (2017)
- Kwon *et al*, **Nano Letters**, 17, 7462-7470 (2017)
- Kim *et al*, **ACS Applied Materials & Interfaces**, 9, 34015-34023 (2017)
- Jang *et al*, **ACS applied materials & interfaces** 11, 1071 (2019)
- Kang *et al*, **ACS applied materials & interfaces** 11, 25358-25368 (2019)
- Hwang *et al*, **ACS applied materials & interfaces** 11, 22575-22582 (2019)
- Ham *et al*, **Science Advances** 6 (28), eaba1178 (2020)
- Hwang *et al*, **Nature Communications** 13 (1), 1-10 (2022)
- B. J. Moon *et al*, **Small Science** 2300068 (2023)

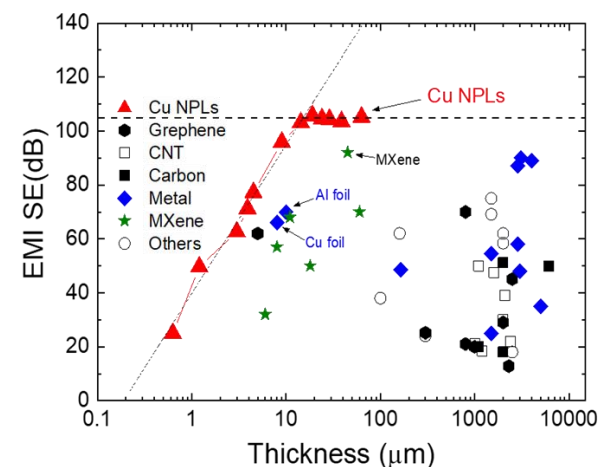
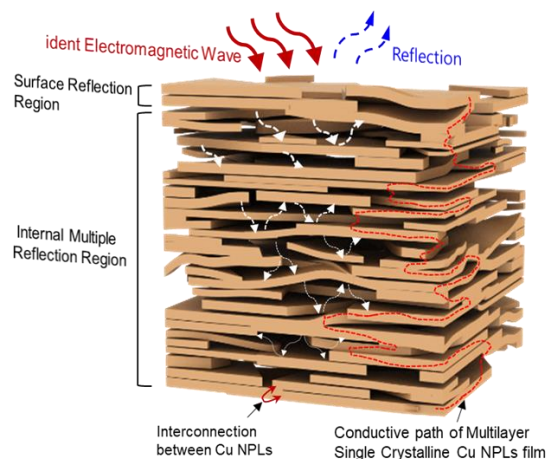
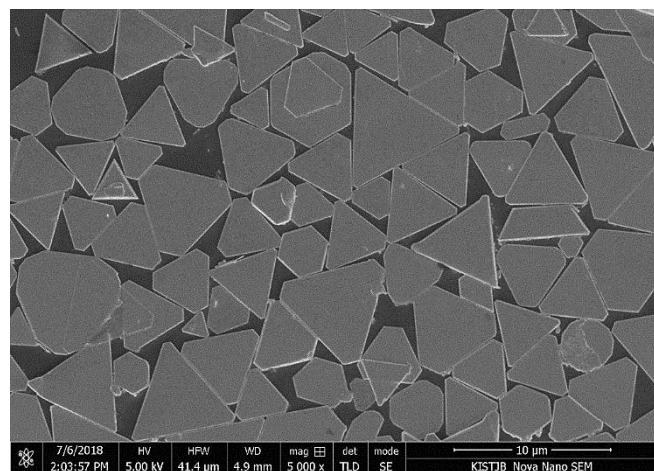
Synthesis of Metallic Nanomaterials (1D, 2D)



Copper Nanoplates (**Cu NSs**)



Giant Silver Nanosheets (**Ag NSs**)



The most efficient EMI shielding materials !

Lee et al, Small, 14, 1703312 (2018)

Choi et al, ACS nano 15 (1), 829-839 (2021)

Choi et al, Materials Science and Engineering: B 278, 115611 (2022)

Contents

Issues and Challenge on Wearable electornics

Recent Progress of Fiber Electronics

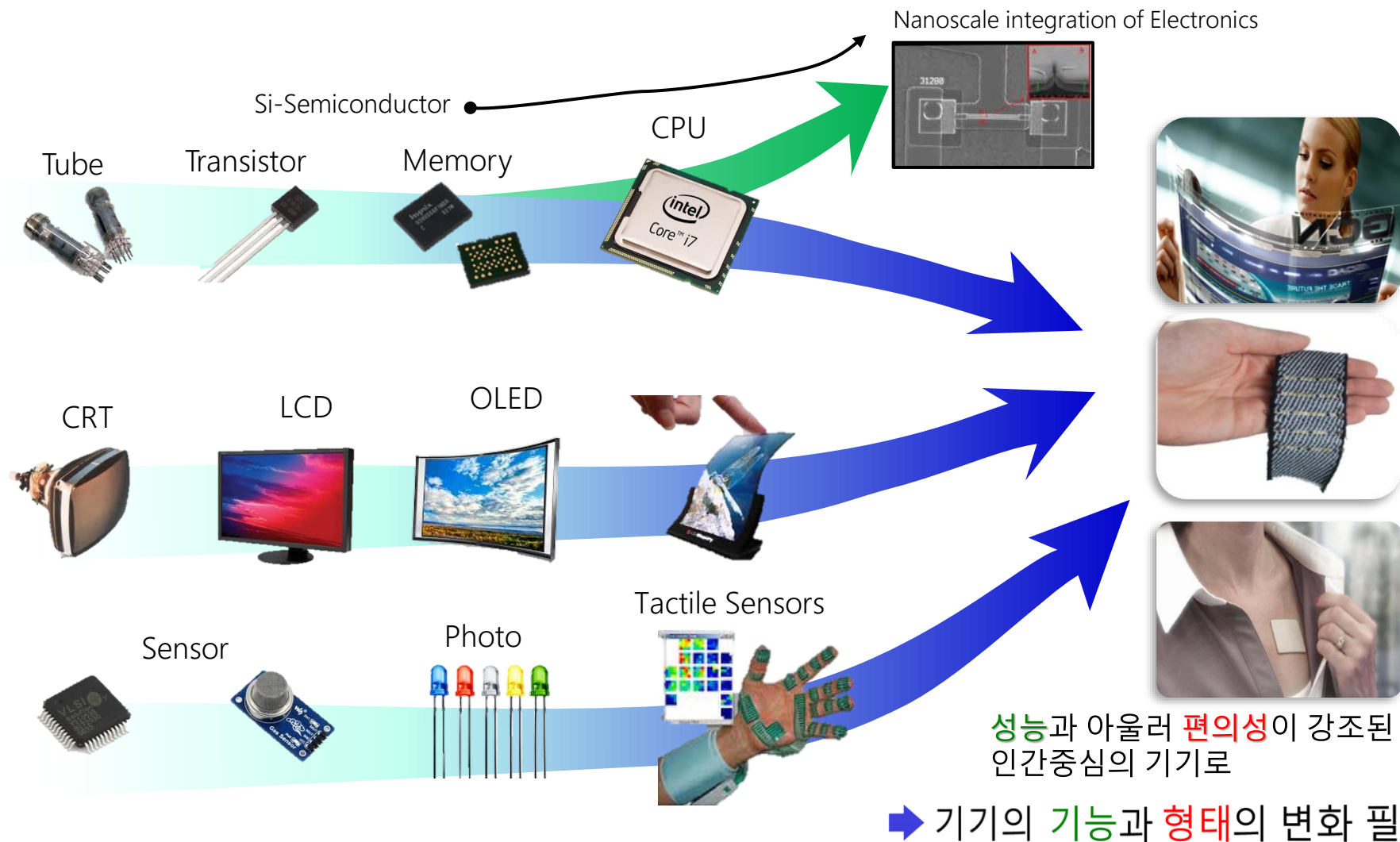
One-dimensional artificial multi-synapses

Chip on a Fiber Toward the E-Textile Computing Platform

Summary

연구배경

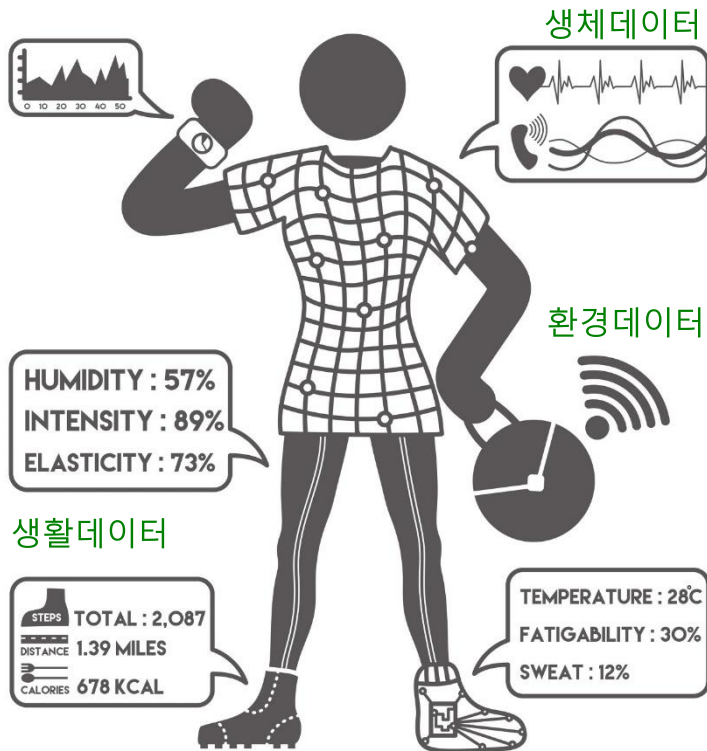
● 차세대 전자 및 소자플랫폼 연구의 필요성



미래 유망분야로의 웨어러블 기술

● 웨어러블 디바이스의 필수 요건

■ 웨어러블 디바이스기술 개요



출처: 디자인라운지

인터랙티브(Interactive) 디바이스 기술

; 인체에 근접하여 작동하여 생체 및 외부 환경데이터의 수집, 처리, 저장, 표시, 전송가능한 기술

■ 웨어러블 디바이스의 기능적 요소



■ 웨어러블 디바이스의 형태적 요소



기술 및 시장동향

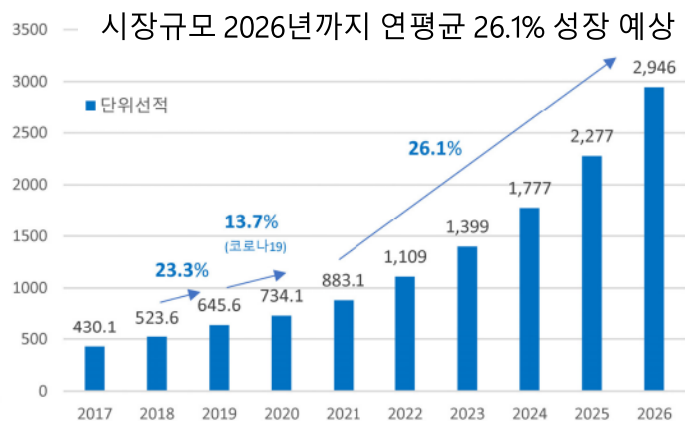
웨어러블 디바이스 산업 및 시장

글로벌 웨어러블 시장의 성장



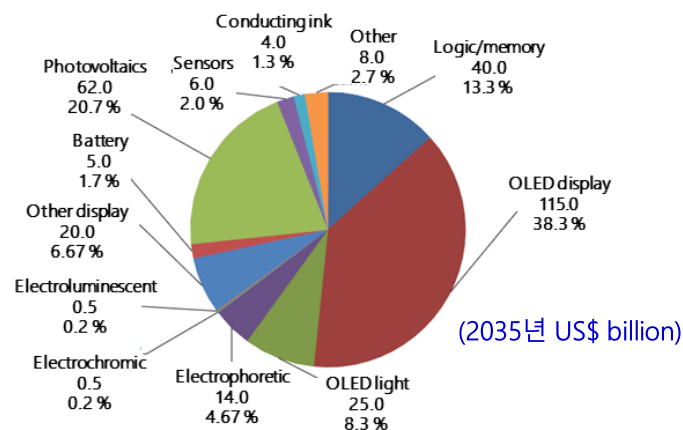
출처: Credit Suisse(2013.5) The Next Big Thing-Wearable Are In Fashion

향후 글로벌 웨어러블 시장의 성장 전망



출처: Frost & Sullivan (2021)

글로벌 웨어러블 기술별 시장 예측



출처: IDTechEx 2015-2025

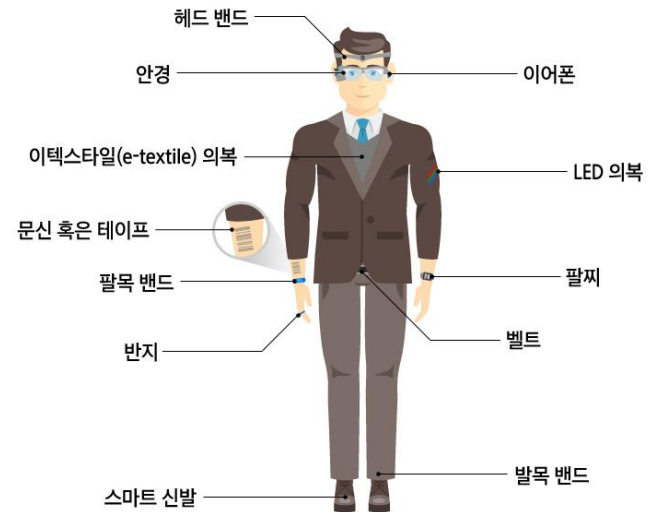
웨어러블 디바이스 개발현황

● 웨어러블 디바이스의 발전과 요구기능

■ 세대에 따른 웨어러블 디바이스 구분

1 세대	단독형 컴퓨터장치 웨어러블 컴퓨터형태
2 세대	악세서리형/직물의류형 시계, 목걸이형태 / 의류일체화 형태
3 세대	신체부착형 신체에 부착할 수 있는 형태
4 세대	생체이식형 신체에 이식할 수 있는 형태

■ 구현가능한 웨어러블 기술



출처: www.samsung.com

■ 웨어러블 디바이스의 (5대)기본요구기능

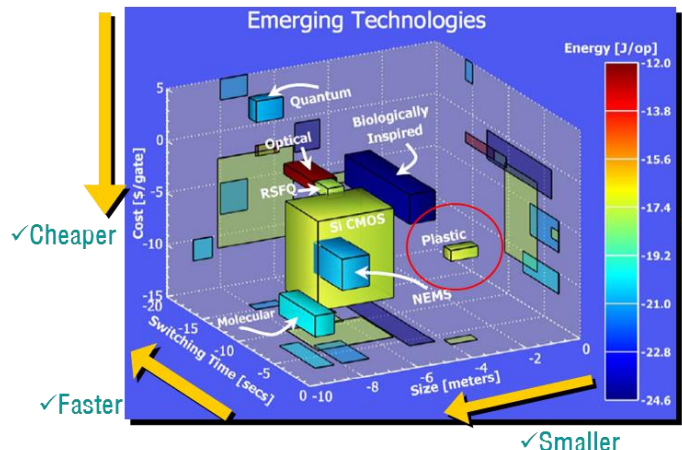
착용감	항시성	편리성	안전성	사회성
의식하지 않을 정도의 무게감과 자연스러운 착용감 제공	즉각적인 반응을 제공하기 위한 컴퓨터와 사용자의 연결	기능상에 있어서 사용자와의 자연스러운 일체감과 통합감	장시간 착용에 따른 불쾌감과 신체적 피로감의 최소화	착용에 따른 사회·문화적 이질감이 없으며 개인 프라이버시 보호

출처: 웨어러블 스마트 기기 기술동향과 산업전망 (2016)

웨어러블 전자소자 연구방향

● 전자소자 연구방향의 변화

■ 기존 전자기기 구성요소로의 전자소자의 이슈



- 저비용
- 저발열성
- 합성
- 유연성
- 인쇄기법
- 안정성
- 신뢰성
- Scaling down
- Uniformity

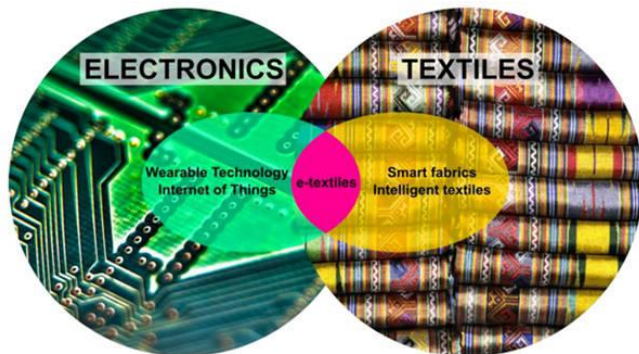
● From ITRS (International Technology Roadmap for Semiconductors) Roadmap Emerging Technologies*

■ 차세대 전자기기로의 변화



■ 기능이 다양하고 형태가 자유로운 전자기기의 연구

직물의류형(의류일체화형태): 비정형기재(직물 또는 섬유)에 전자기기를 구현하는 기술



웨어러블 디바이스의 기본 기능적인 측면을 고려한 비교

착용감

항시성

편리성

안전성

사회성

웨어러블 디바이스의 5대 기본기능

직물의류형

단독형 컴퓨터장치

악세서리형

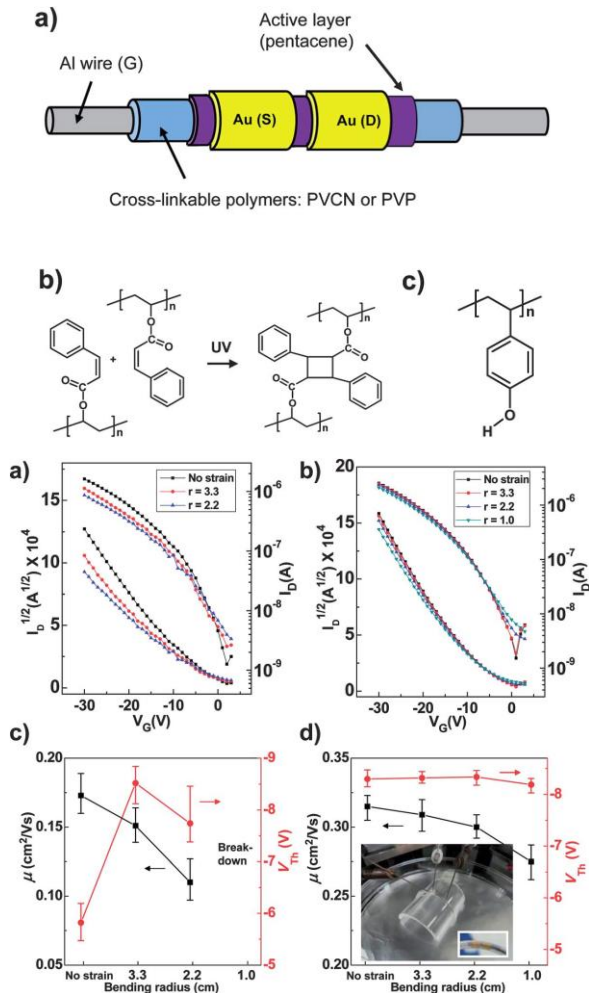
신체부착형

생체이식형

Recent Progress of Fiber Electronics

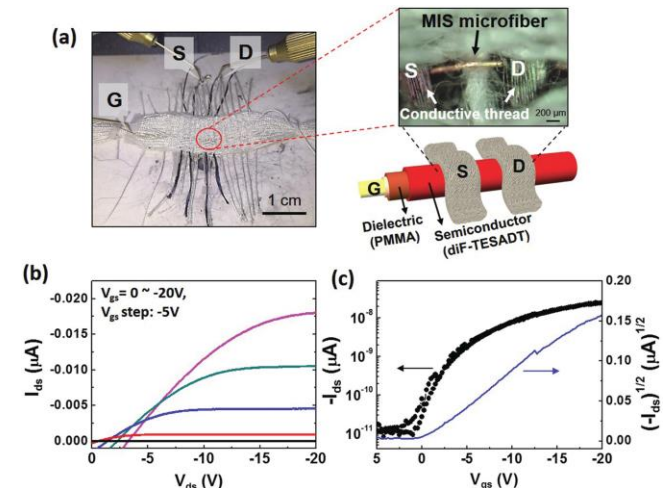
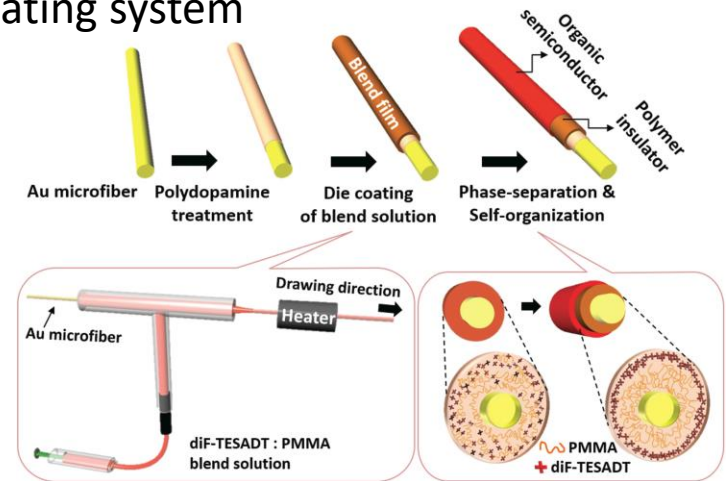
Application : Field-effect transistors

- Cross-linked PVP or poly(vinyl cinnamate) (PVCN) gate dielectrics



J. Mater. Chem. 2012, 22, 1054.

- Self-organization of organic semiconductor:polymer blend using die-coating system

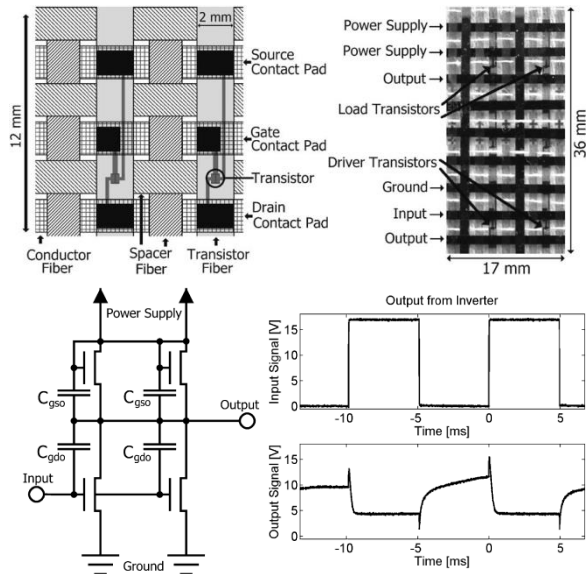


Adv. Funct. Mater. 2016, 26, 2706.

Applied Nanomaterials & Device Lab.

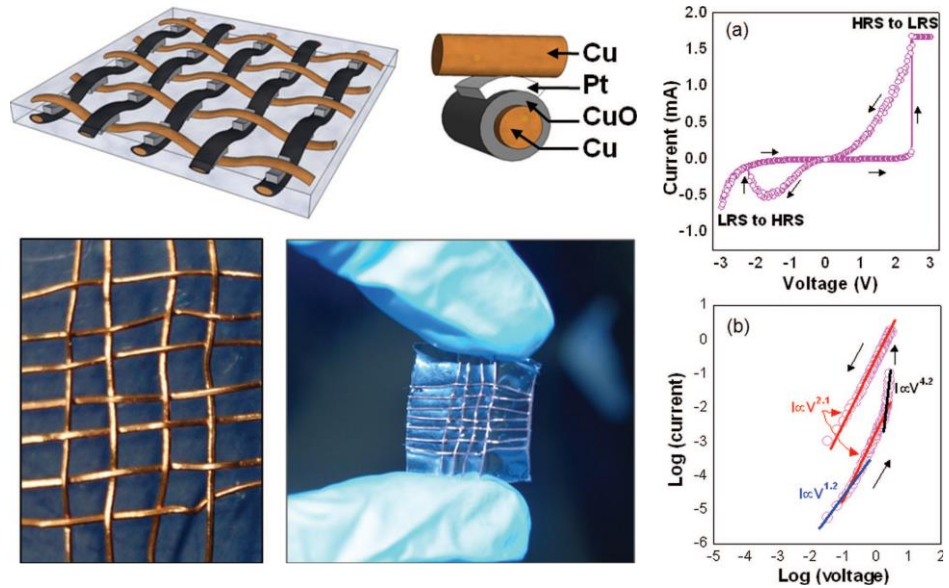
Application : Memory

- Woven Inverter circuit



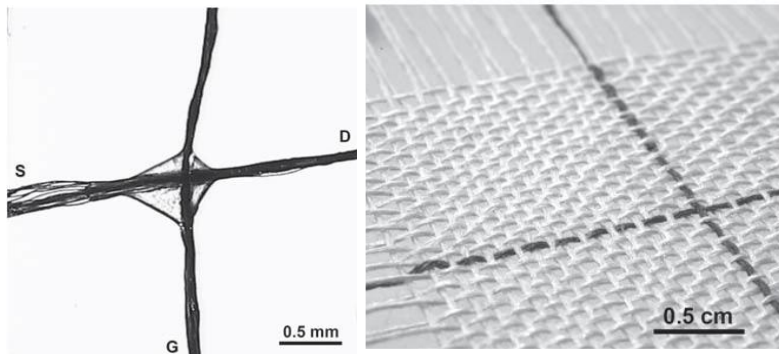
IEEE EDL, 25, 295 (2004)

- Woven Resistive Memory Array



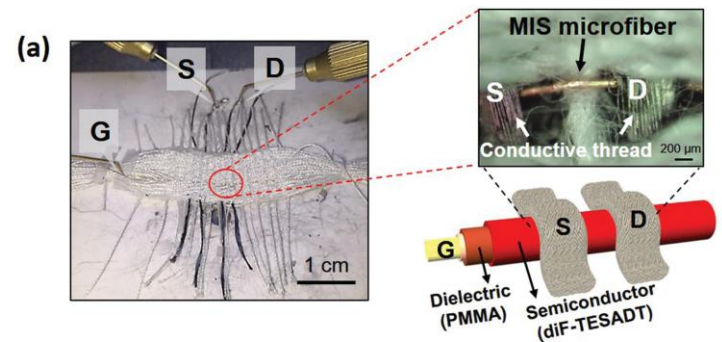
AIP Advances 1, 032162 (2011)

- Weaving with silk fabric



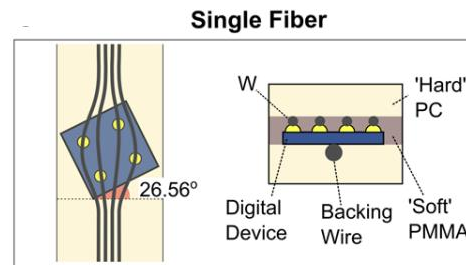
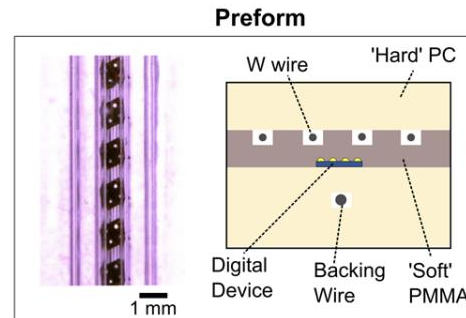
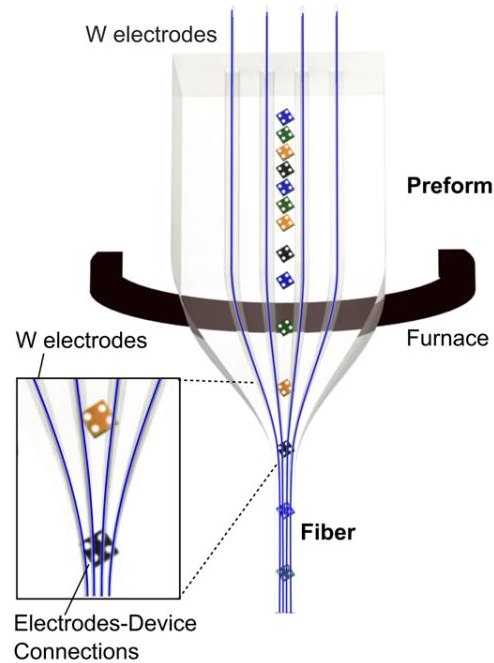
Adv. Mater., 23, 898 (2011)

- Fibriform OFET embedded in the textile

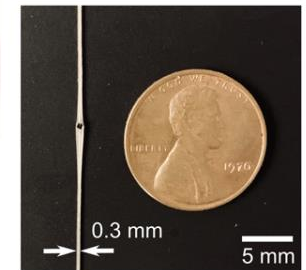
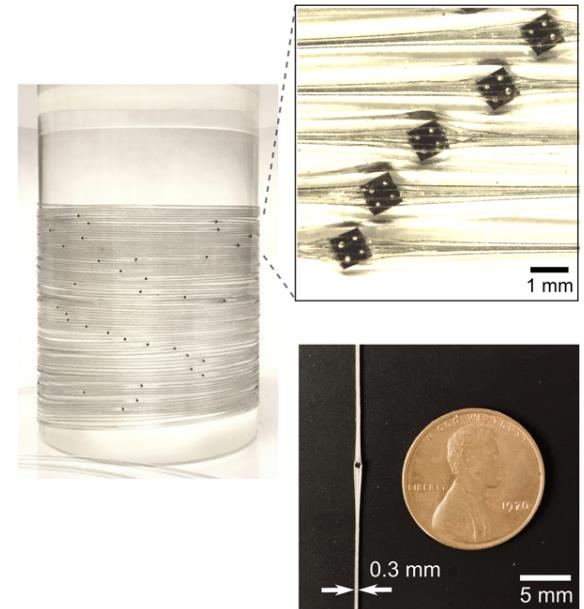


Adv. Funct. Mater. 26, 2706 (2016)

Digital electronics in fiber



Continuous Fiber with 100 devices



Fabrication approach of digital fibres.

/ Thermal drawing of the digital fibre preform by feeding conductive tungsten wires into the empty channels

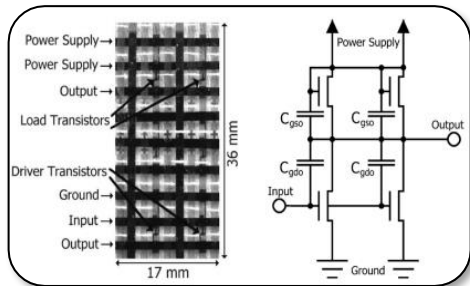


G. Loke et al, Nature Communications (2021) 12:3317

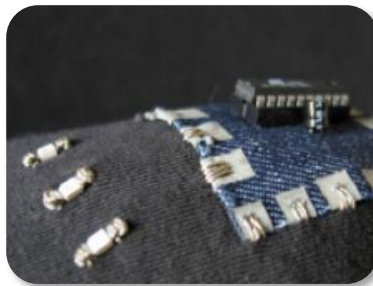
기존 직물의류형 웨어러블 기술

● 직조기반의 전자섬유 연구

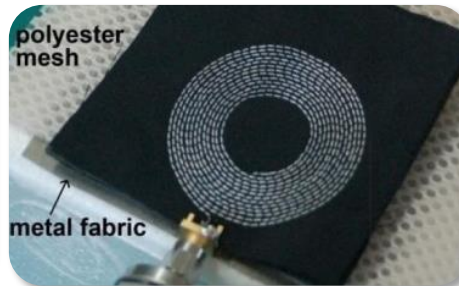
■ 직조를 통한 직물형 전자섬유기술



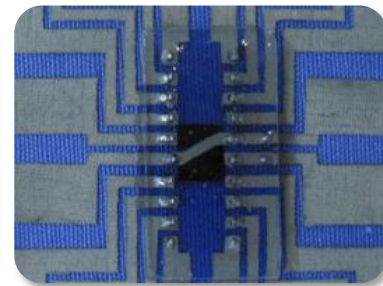
반도체, 스페이서, 전도성파이버 등의 직조를 통한 연결과 회로구현



전도성파이버를 이용한 반도체칩의 단순 연결



구리와이어와 자수용 전도성 원사를 적용한 자수회로 구현



직물에 원하는 모양의 전도성 원단을 부착하여 구현한 섬유형 PCB

출처: 전자섬유(E-textile) 기술개발 동향, 패션정보와 기술 Vol. 11.

■ 직조기반 전자섬유의 한계

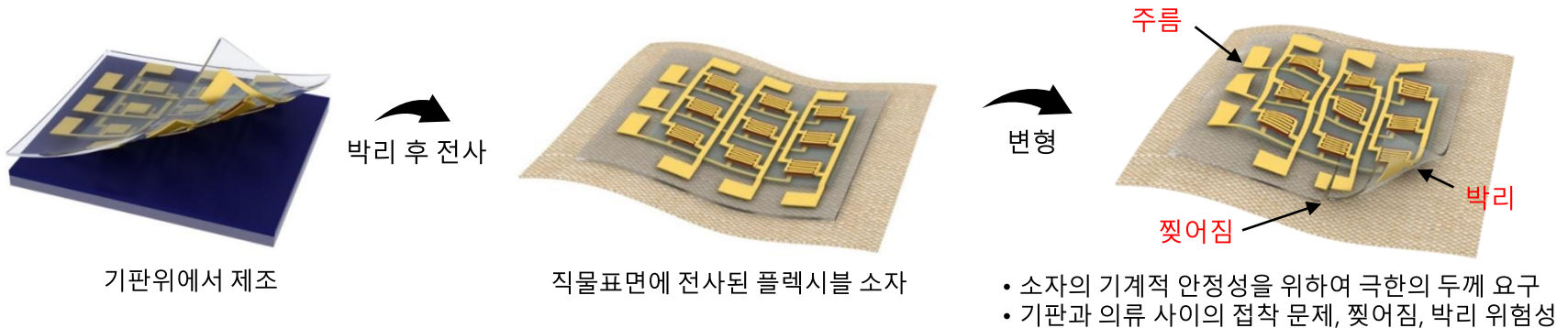
- ✓ 기능별로 다른 파이버가 서로 직조되어 전자회로를 구성하므로 **고성능의 소자구현이 어려움**
- ✓ 기존 반도체칩을 직물표면에 부착하여 전도성 파이버로 연결하므로 **착용감의 한계**를 가짐
- ✓ 직조를 통한 회로구현으로 **다양한 전자소자의 구현이 어려움**
- ✓ 직조된 파이버를 이용하여 전자소자 구현과 연결을 수행하므로 **Scaling down이 어려움**

▶ 직조라는 섬유의 통념을 넘어서는 **전자섬유기술이 필요**

기존 웨어러블 전자소자 플랫폼의 한계

● 차세대 섬유유기반전자소자 및 플랫폼 연구의 필요성

■ 평면형 유연전자소자 플랫폼



■ 직조형 섬유전자소자 플랫폼



- 전통적 직물제조법인 직조를 통해 소자와 회로를 구현하므로 소형화(집적화)/고성능화의 한계

▶ 전혀 다른 방식의 **혁신적인 웨어러블 소자 플랫폼**이 필요

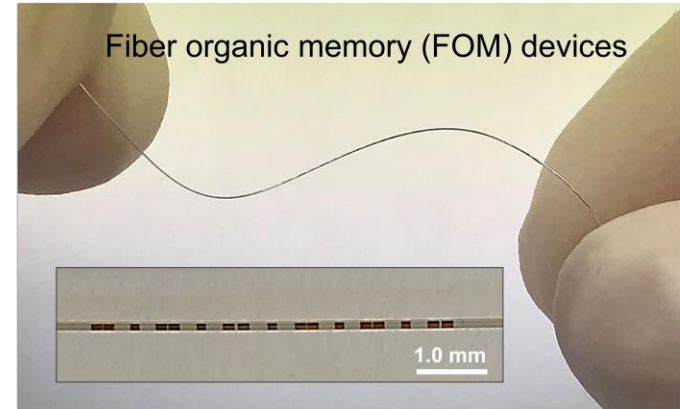
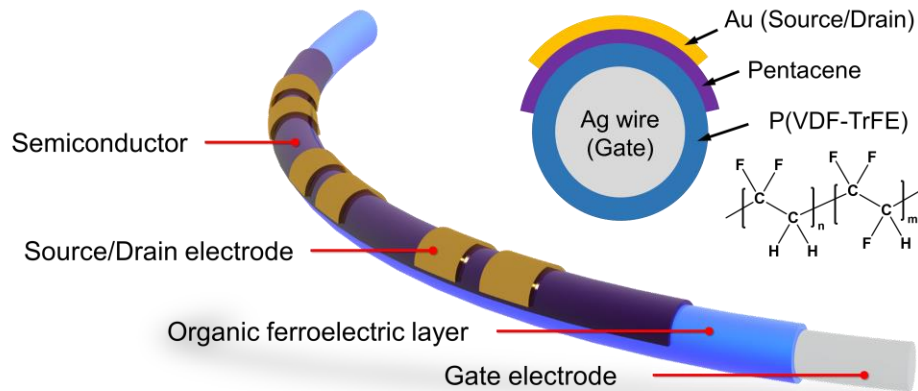
One-dimensional artificial multi-synapses

Collaboration with Gunuk Wang /KOREA University

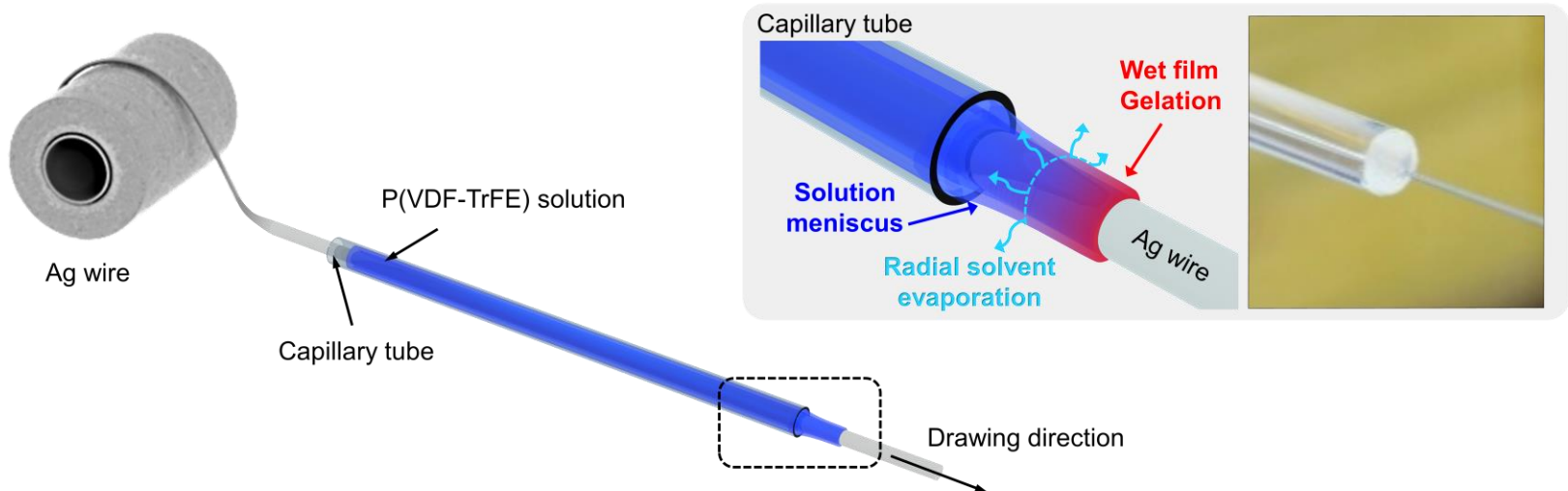
One-dimensional organic artificial multi-synapses enabling electronic textile neural network for wearable neuromorphic applications *Science Advances*, 6, (28), eaba1178 (2020)

Fabrication of Low-Voltage memory Fiber

- Optimization of Coating process

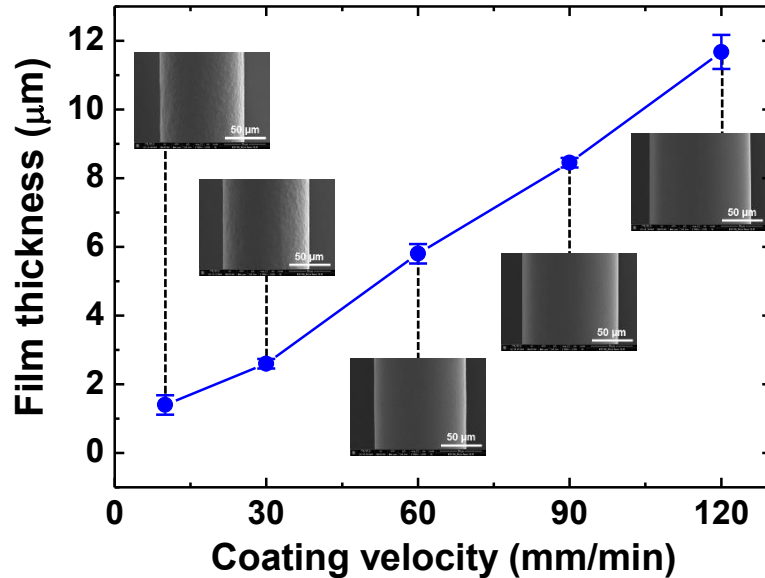


Capillary Tube-Assisted Coating (CTAC) Process

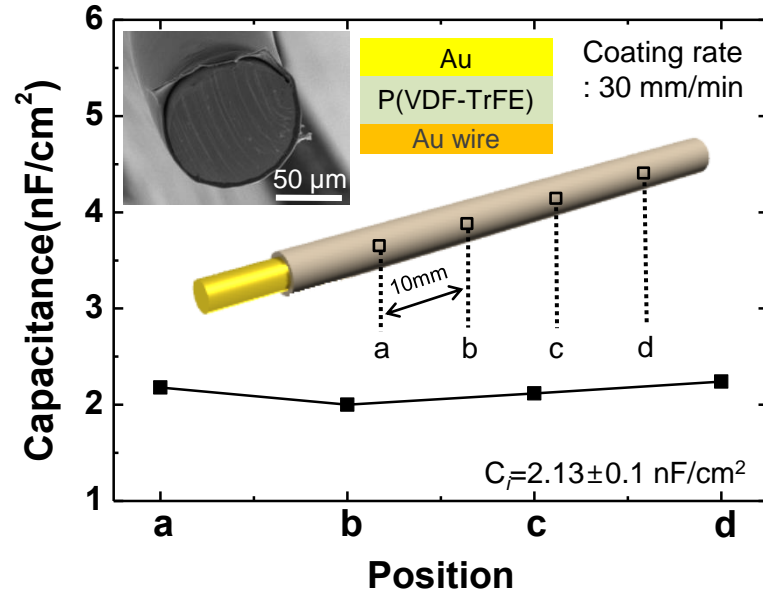


Uniformity of coated P(VDF-TrFE) film on the Au wire

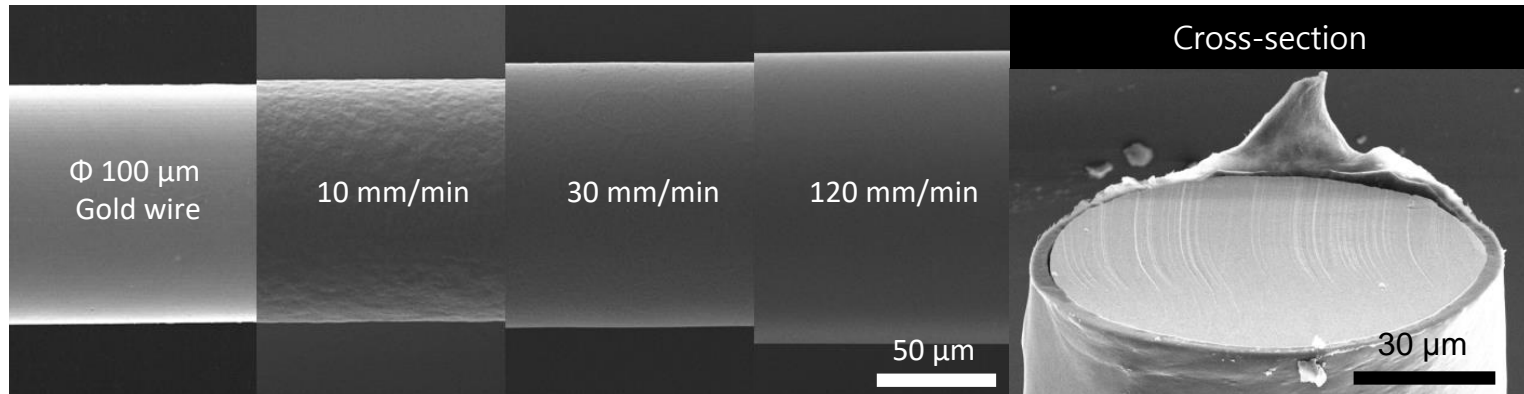
- Film thickness of P(VDF-TrFE)



- Capacitance of P(VDF-TrFE)

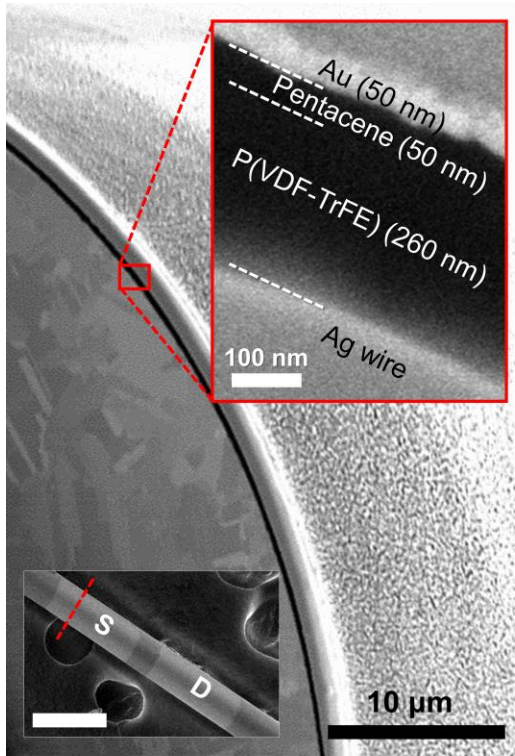


- Film thickness control depending on the coating speed

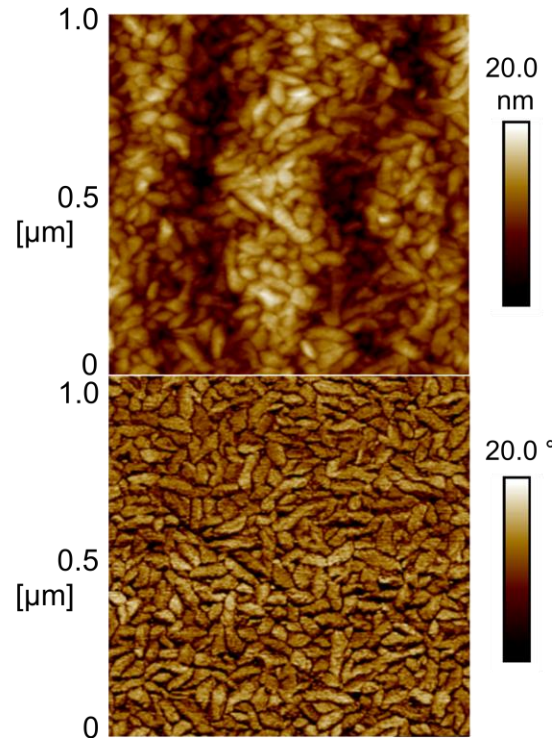


Low-Voltage memory Fiber

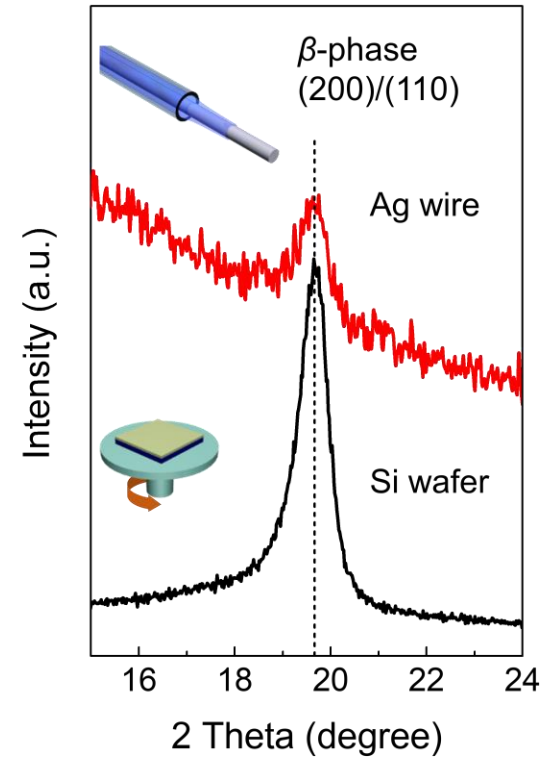
- SEM image



- AFM image

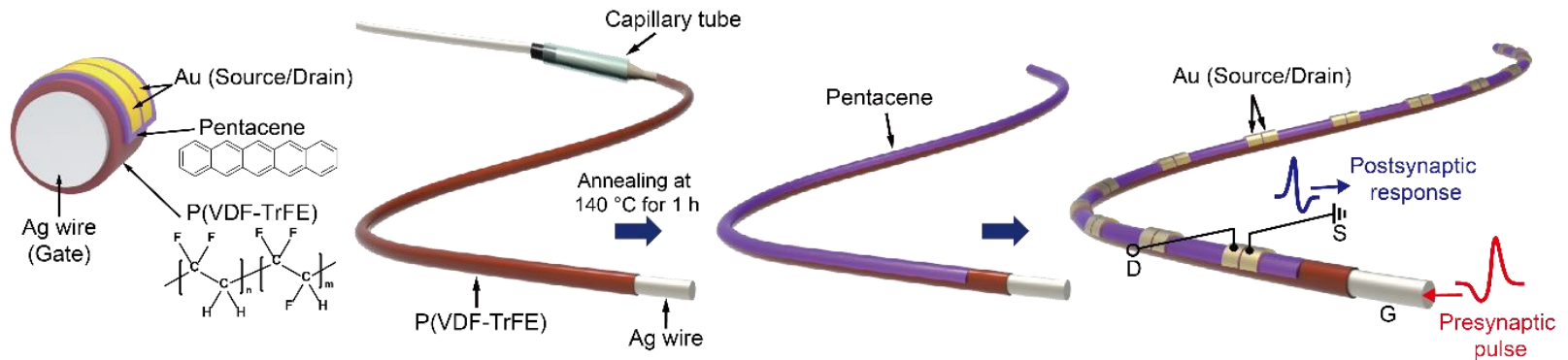


- XRD analysis

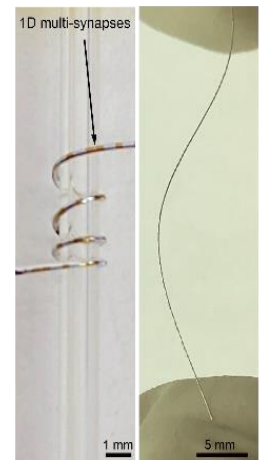
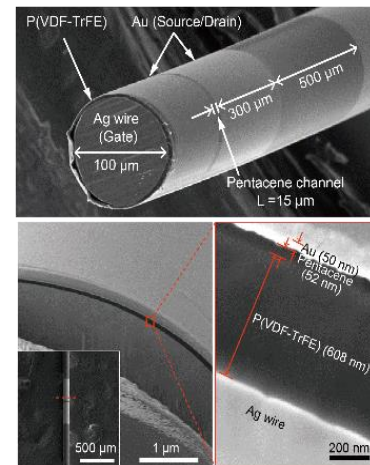
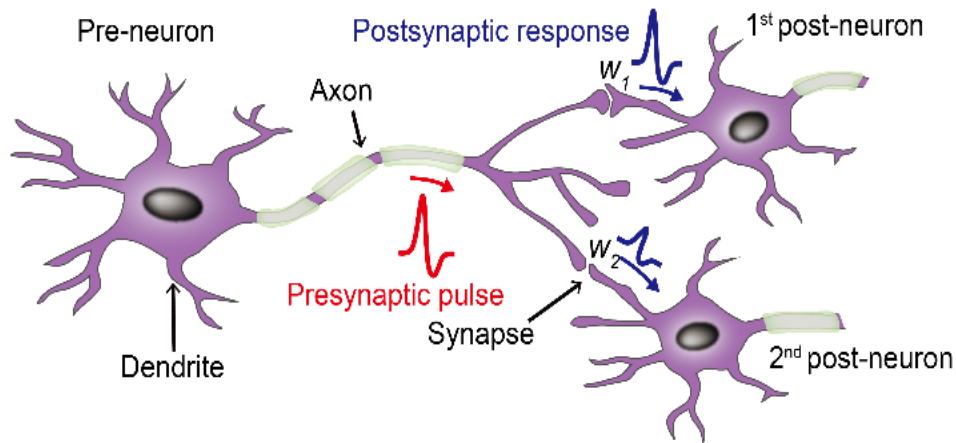


One-dimensional artificial multi-synapses

- Capillary Tube-Assisted Coating (CTAC) Process



- Schematics of the biological multipolar neurons

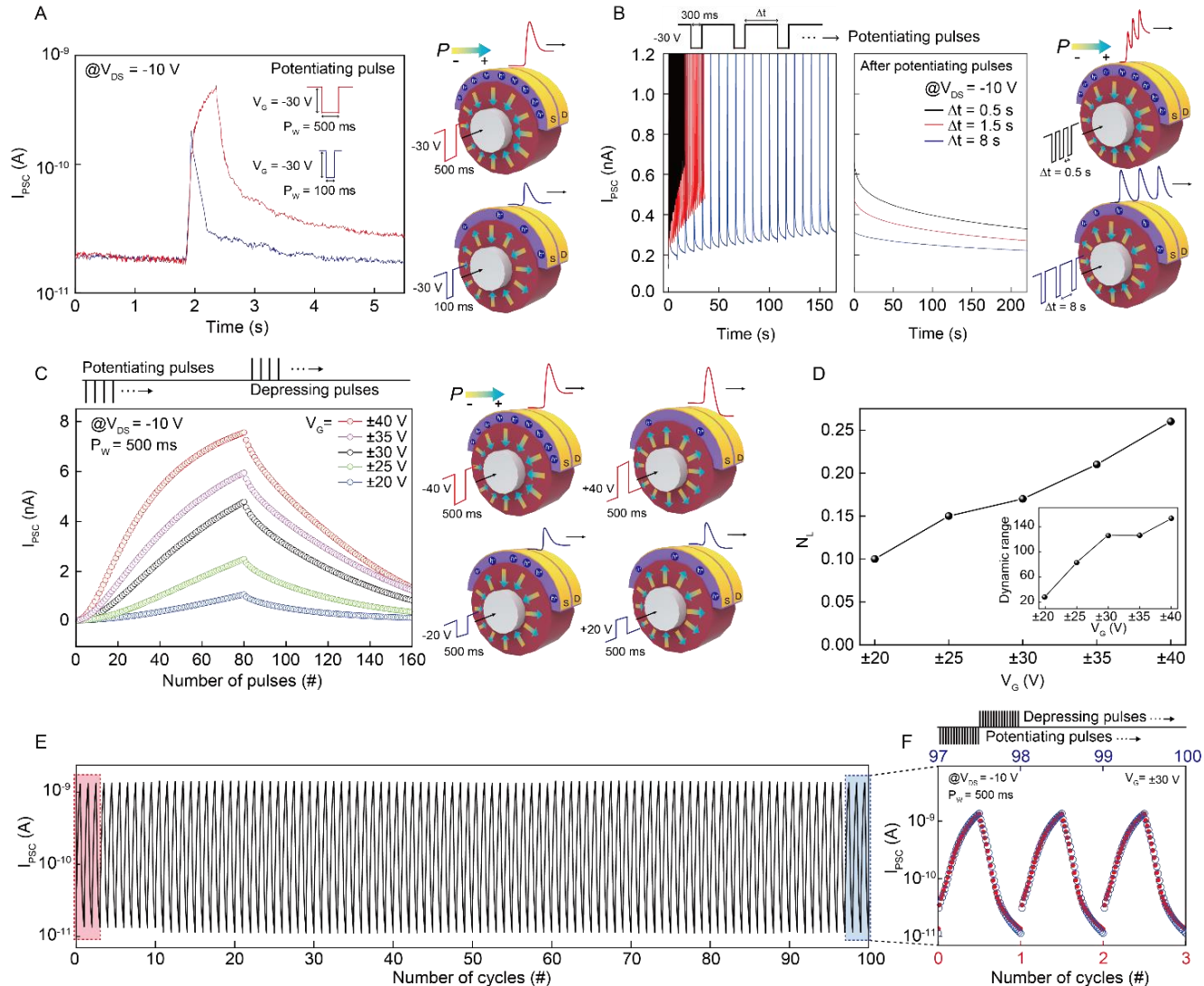


Glass tube with a diameter of 1.2 mm

Ham, Kang *et al.* **Science Advances**, 6, (28), eaba1178 (2020)

One-dimensional artificial multi-synapses

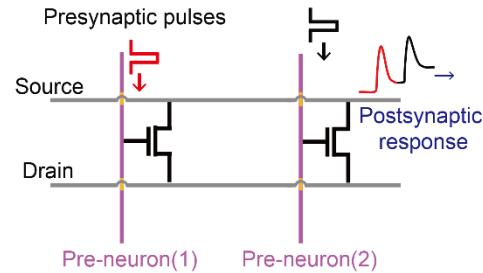
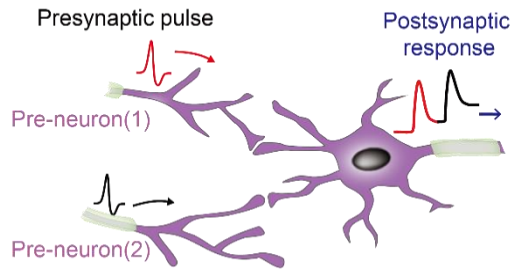
- Synaptic characteristics and switching mechanism of the 1D organic multi-synapses



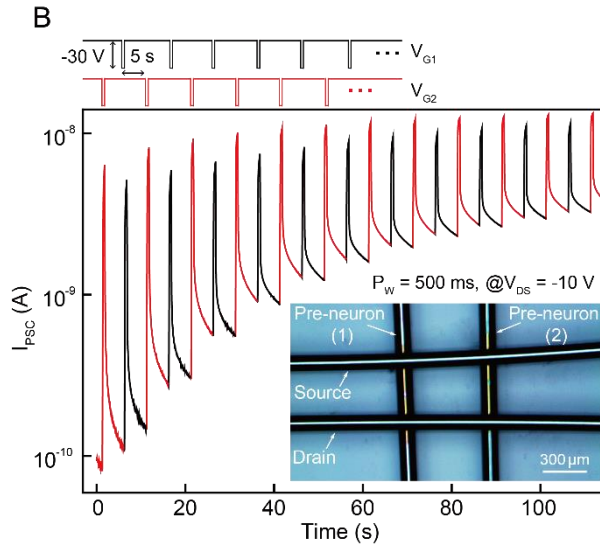
One-dimensional artificial multi-synapses

- The NOR-type textile array structure of the 1D organic multi-synapses

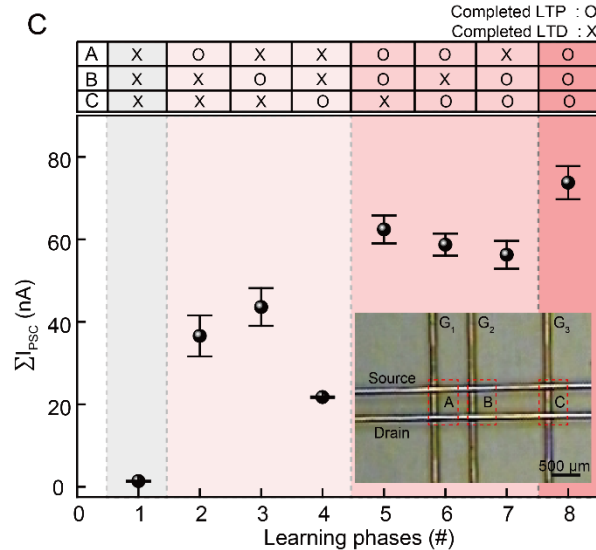
- Schematics of the signal transmission in a biological neural network



- The circuit diagram of NOR-type 2×2 array



- Plot of the integrated IPSC in the NOR-type 3×2 array



Chip on a Fiber Toward the E-Textile Computing Platform

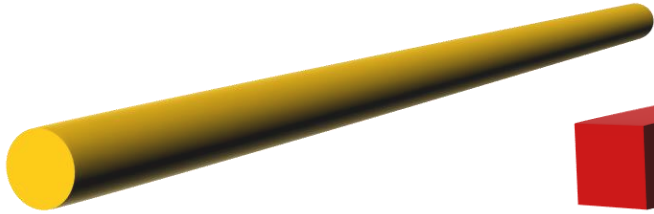
Integration of multiple electronic components on a microfibre towards an emerging electronic textile platform ***Nature Communications***, 13 (1), 1-10 (2022)

Future of Wearable Computer ?

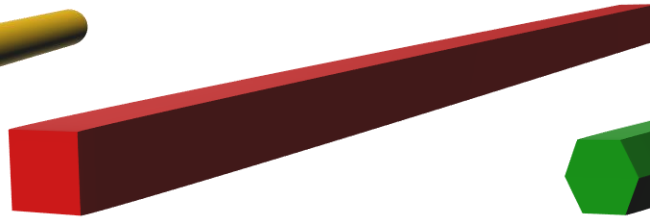


Chip on a Fiber

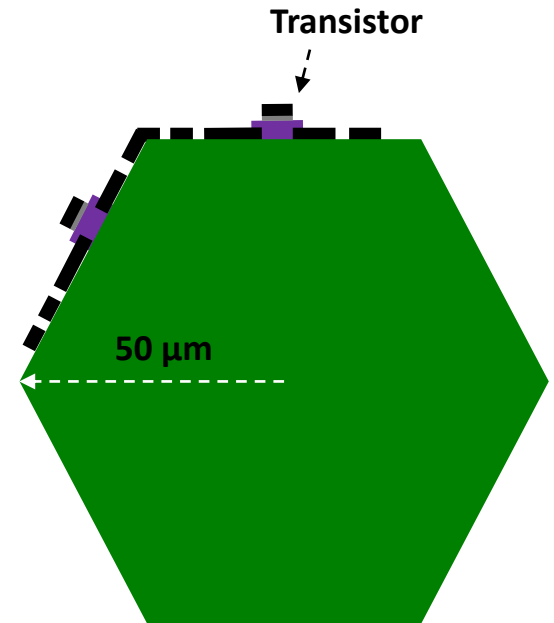
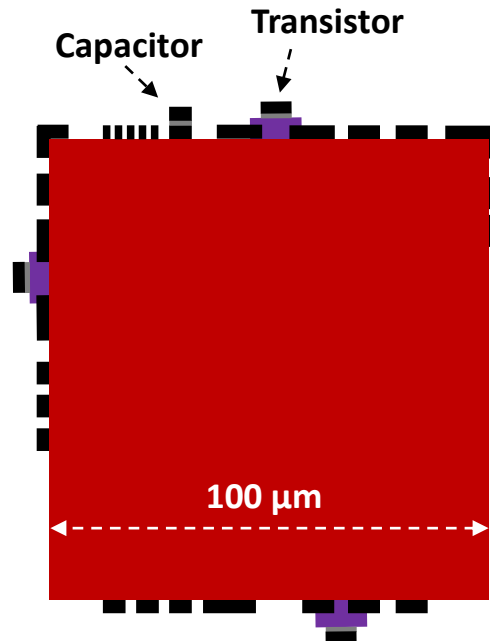
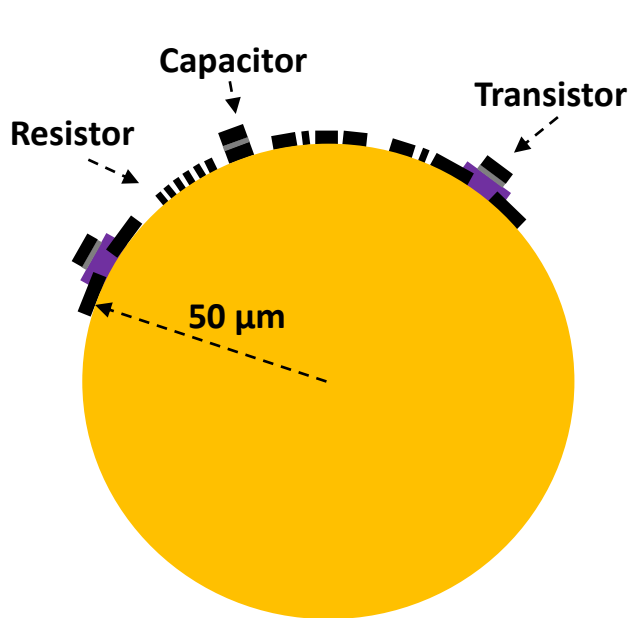
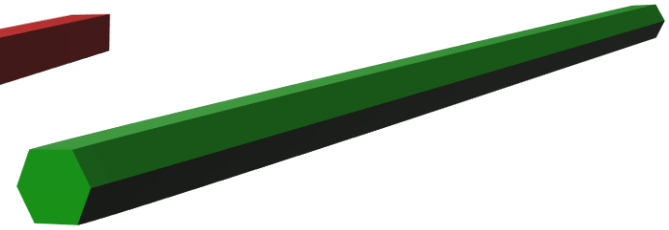
Circular



Rectangular

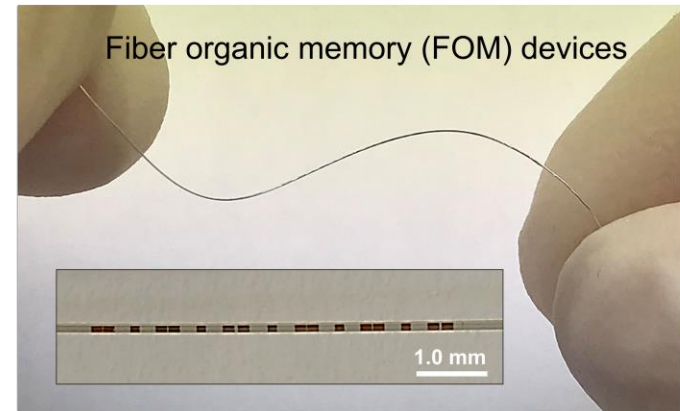
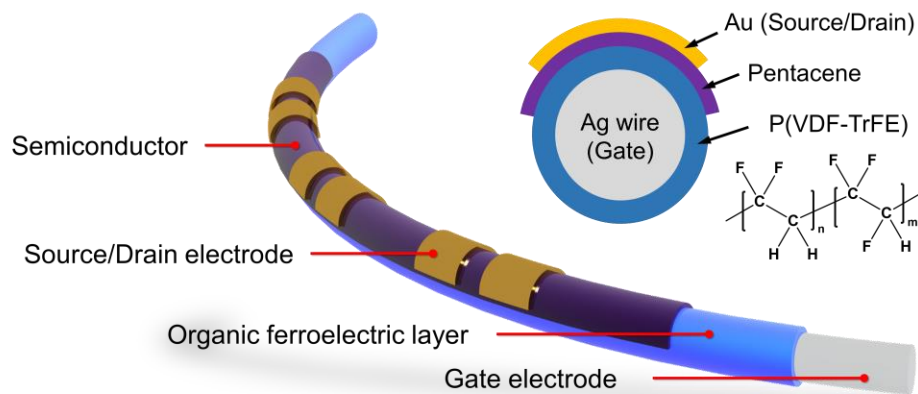


Polygonal

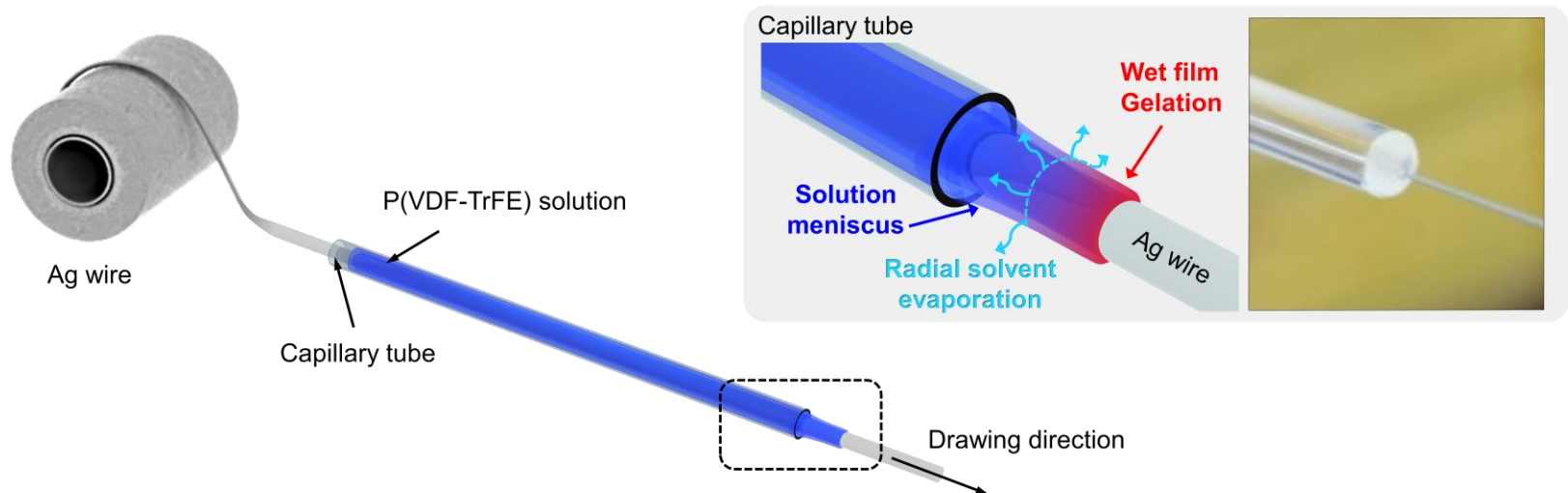


Coating process for Chip on a fiber

- Capillary Tube-Assisted Coating (CTAC) Process for memory fiber



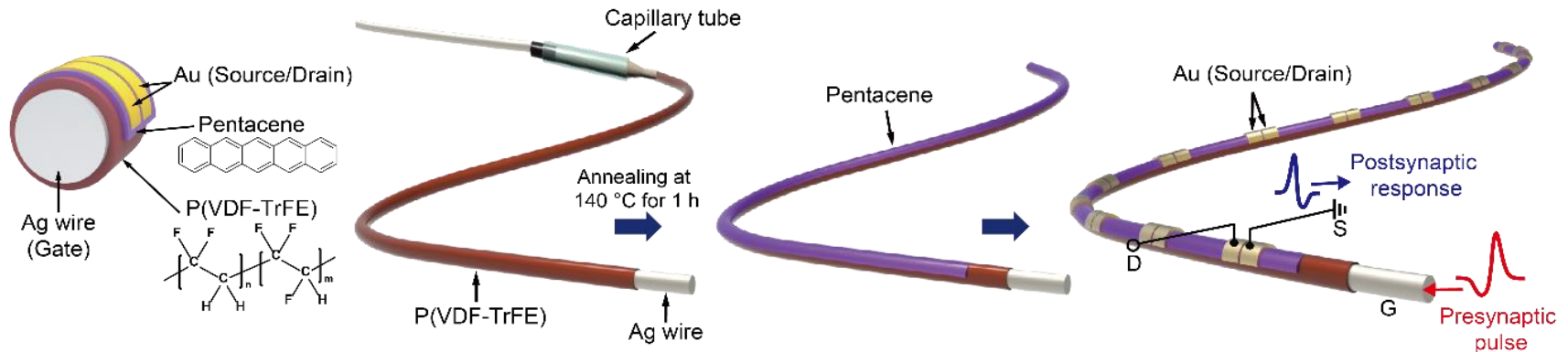
Capillary Tube-Assisted Coating (CTAC) Process



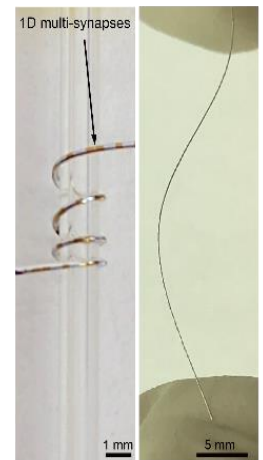
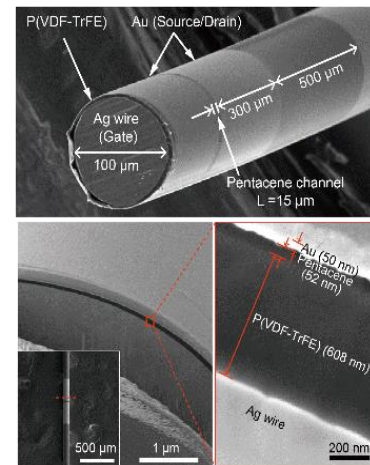
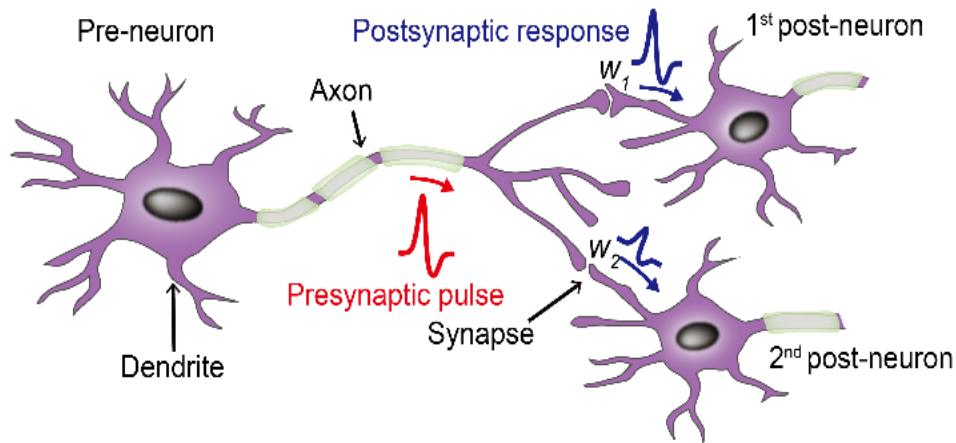
Kang et al, *ACS applied materials & interfaces* 11 (25), 22575-22582 (2019)

Coating process for Chip on a fiber

- One-dimensional artificial multi-synapses



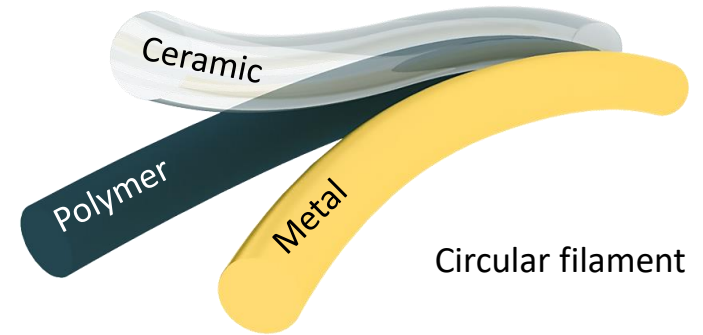
- Schematics of the biological multipolar neurons



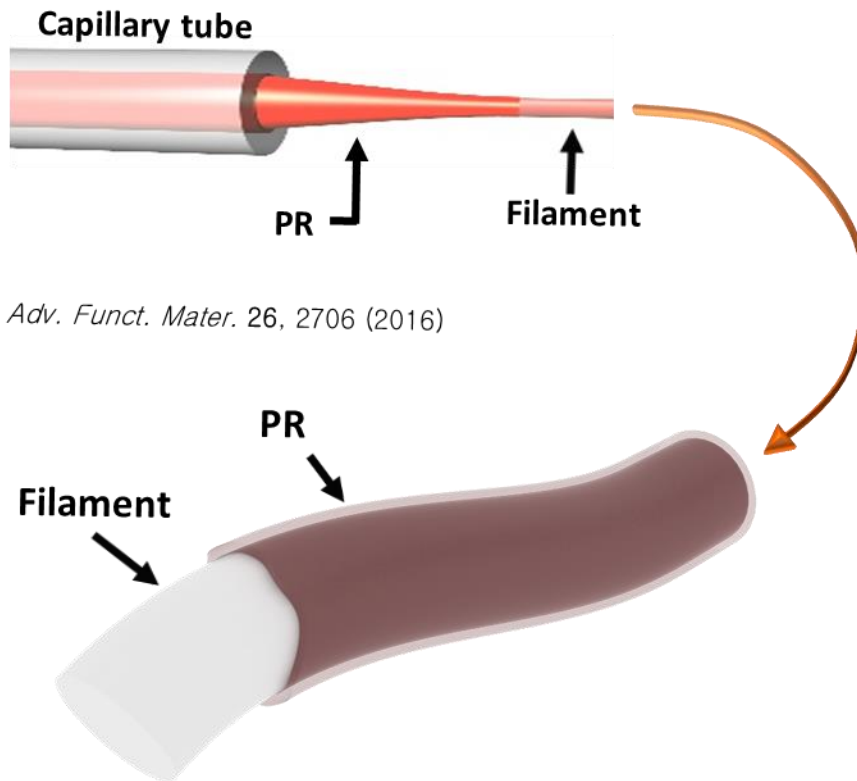
Glass tube with a diameter of 1.2 mm

Ham, Kang *et al.* **Science Advances**, 6, (28), eaba1178 (2020)

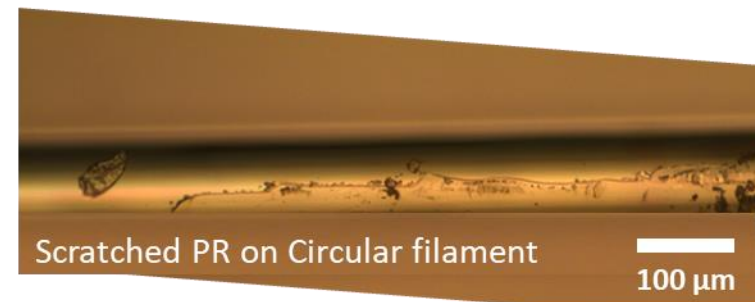
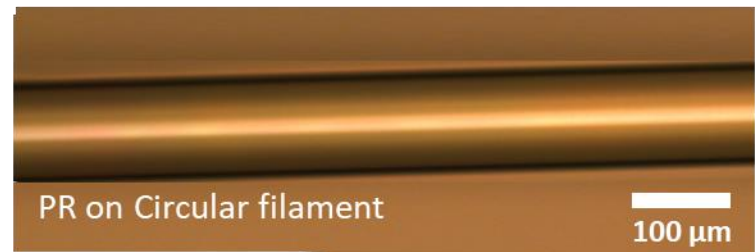
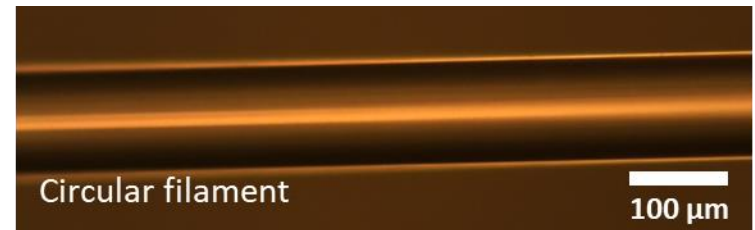
Coating process for Chip on a fiber



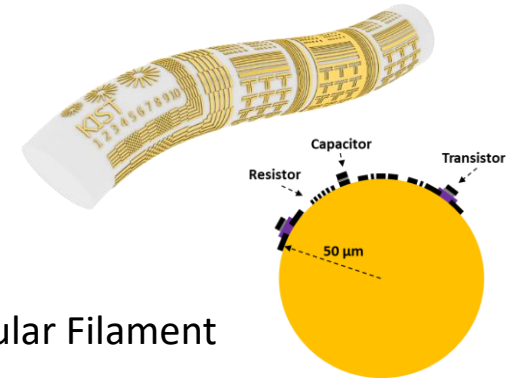
PR coating process on filament



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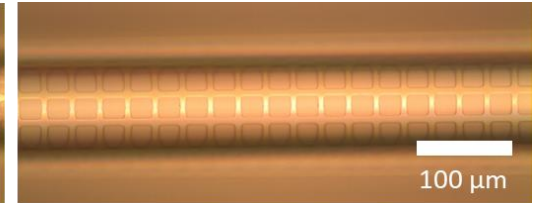
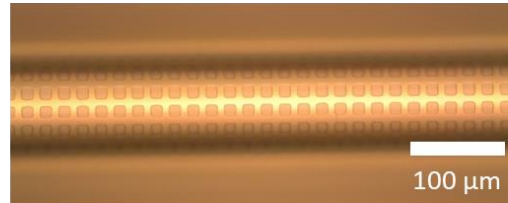
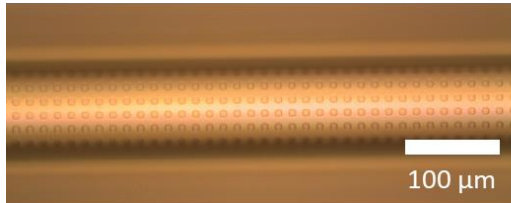


Chip on a fiber

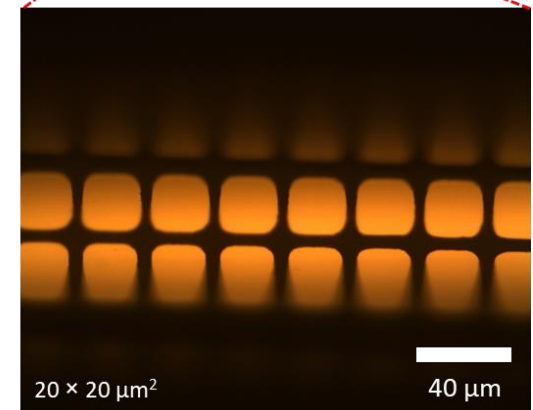
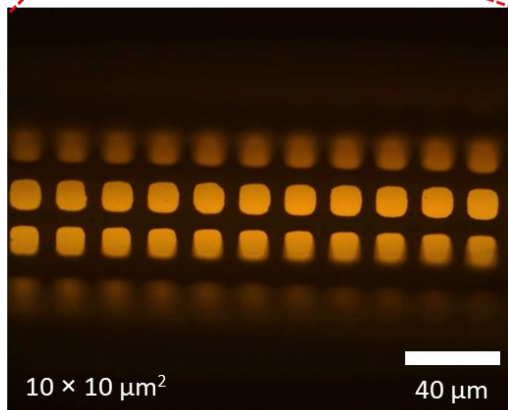
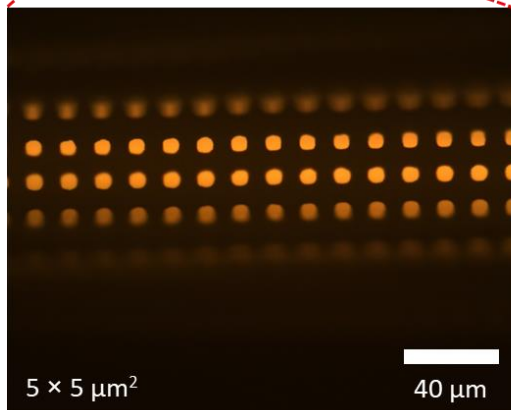
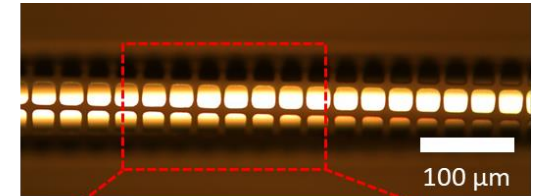
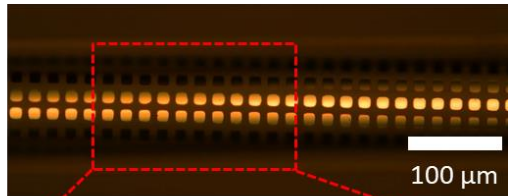
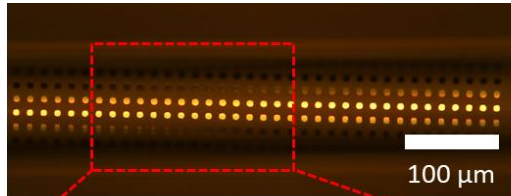


Metal pattern array on fiber

PR pattern

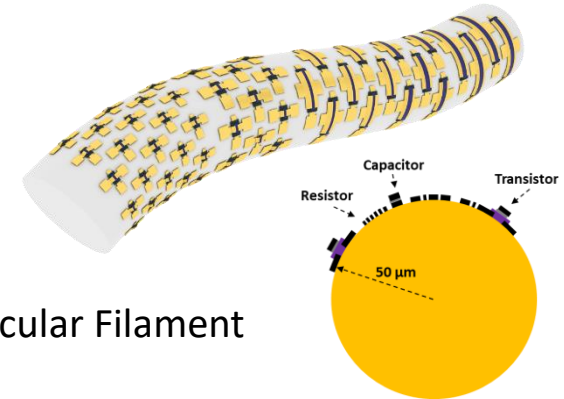


Metal array

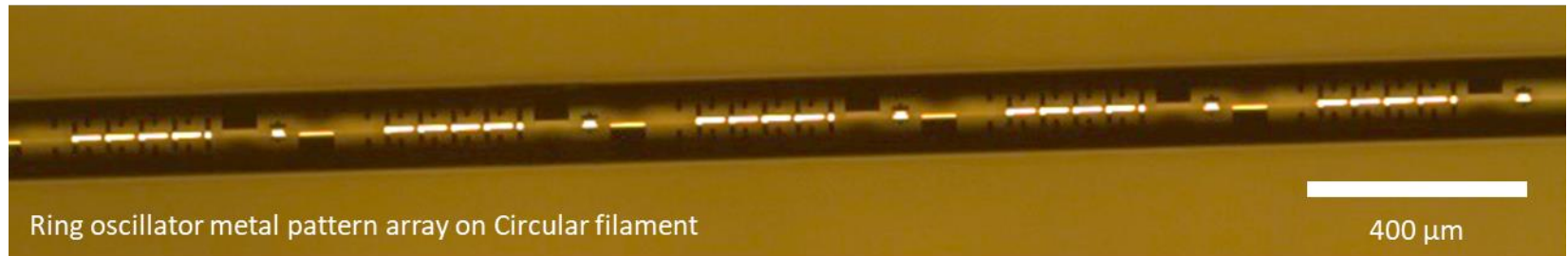
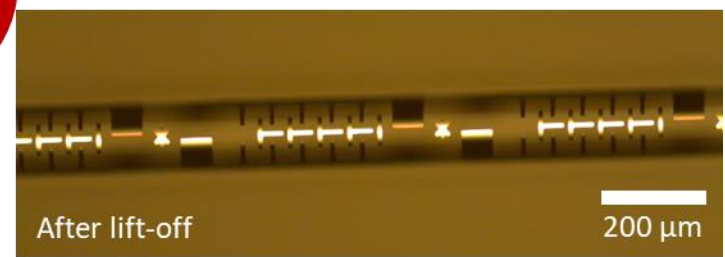
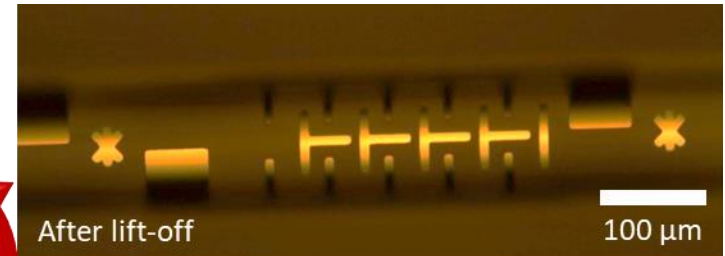
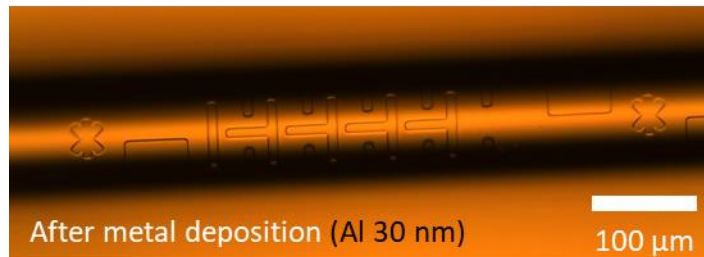


Circular Filament

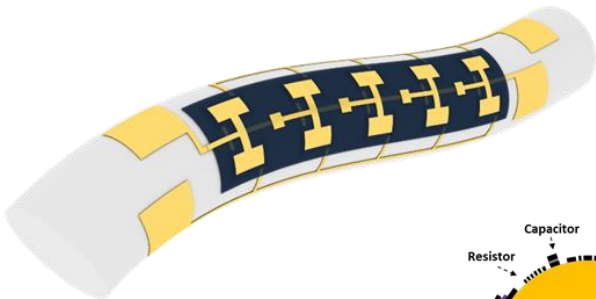
Chip on a fiber



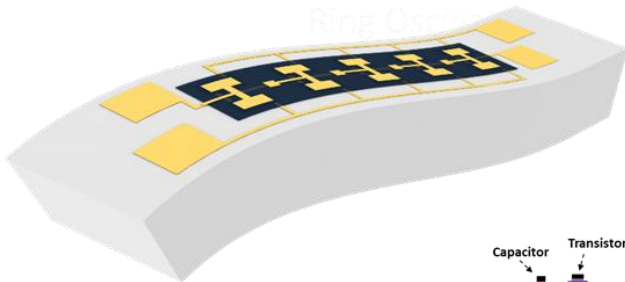
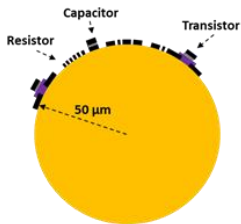
Circuit electrode on fiber



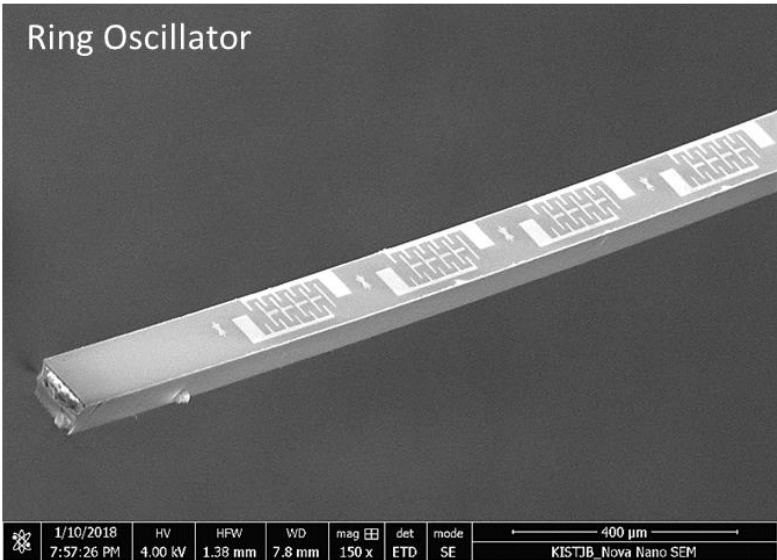
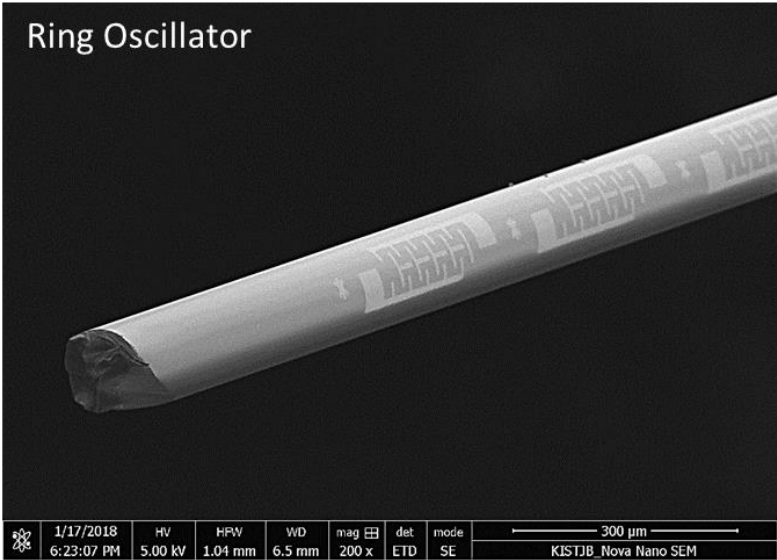
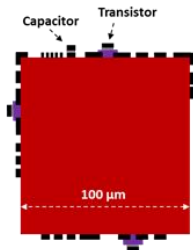
Chip on a Fiber



Circular Filament

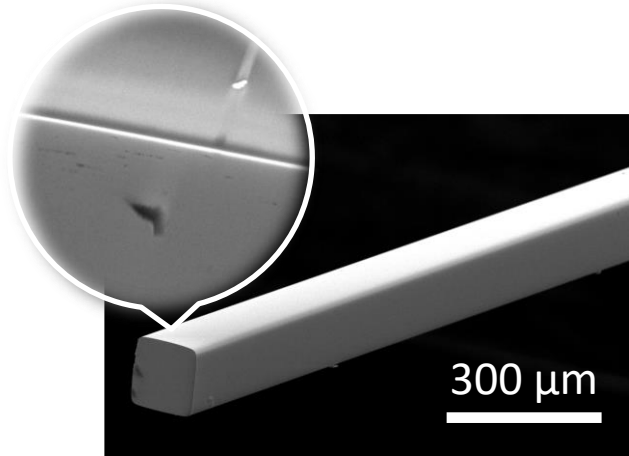
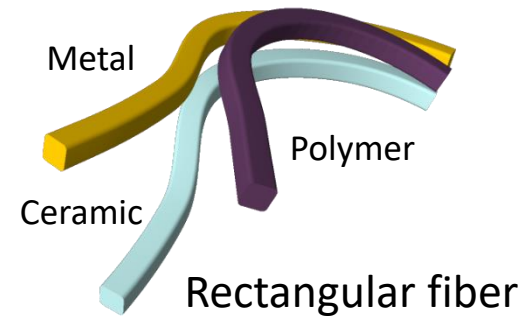


Rectangular Filament

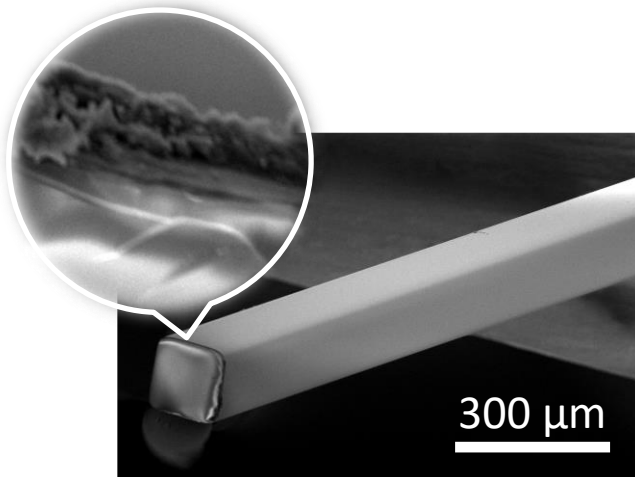


Chip on a Fiber

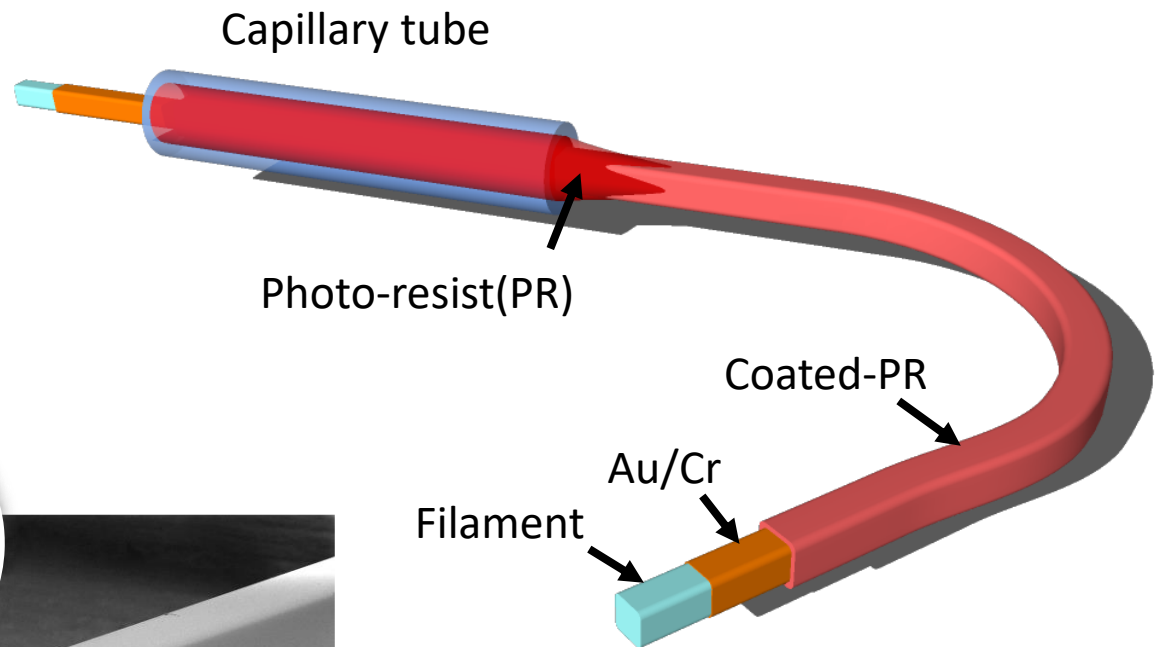
Photo-resist coating process on fiber



Metal on filament



PR on metal/filament

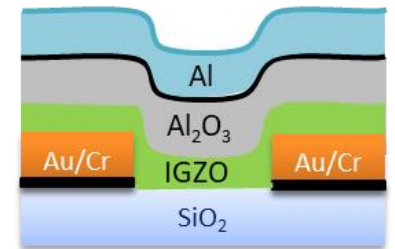
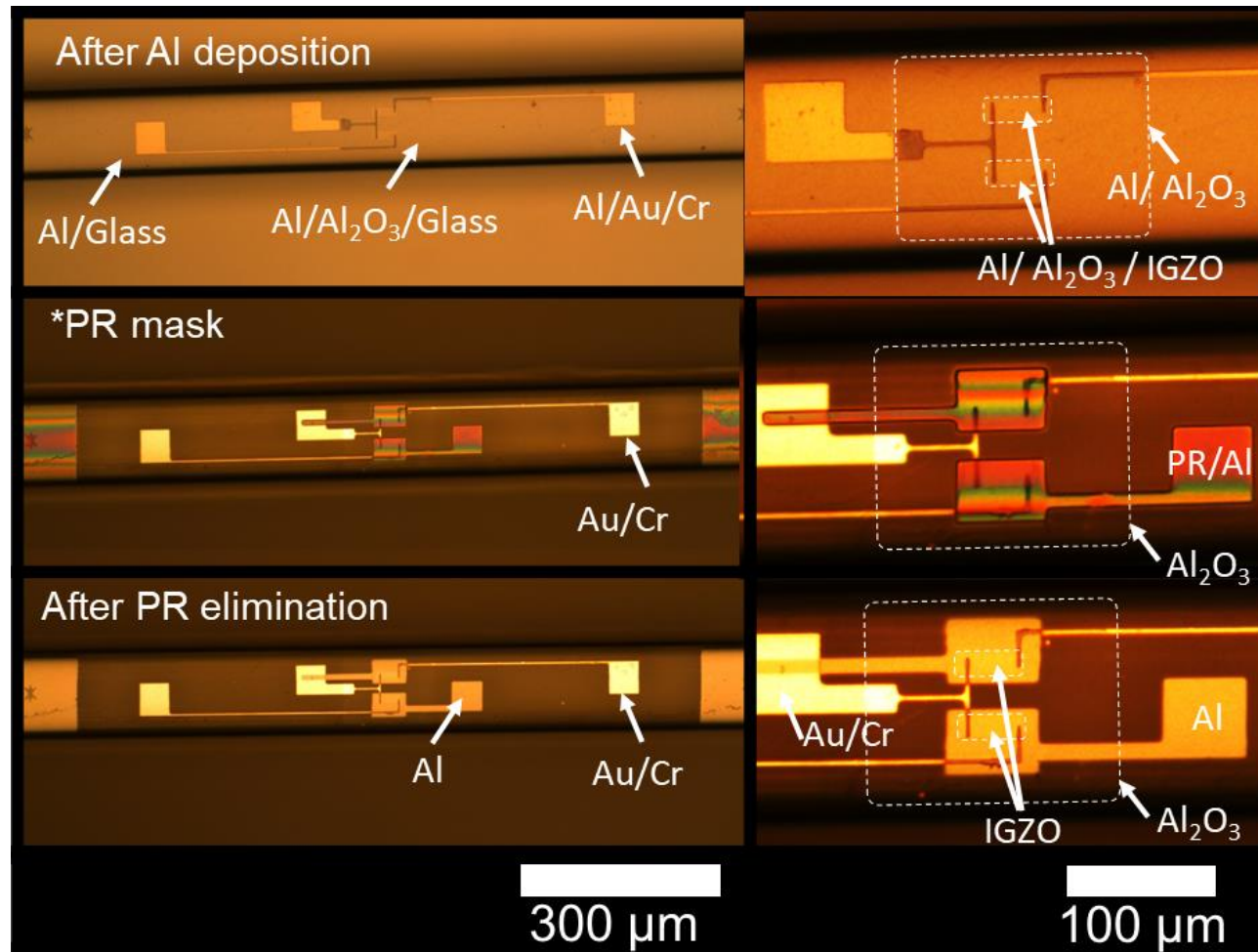


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*□ 150 μm x 150 μm x 7.5 cm glass filament

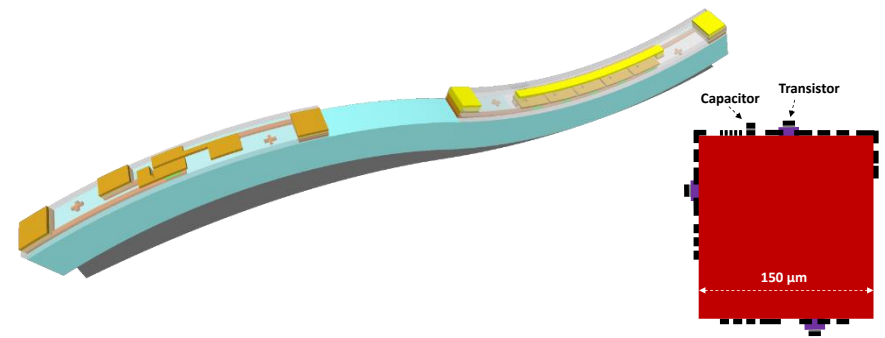
Chip on a fiber

150 μm x 150 μm monofilament type device fabrication

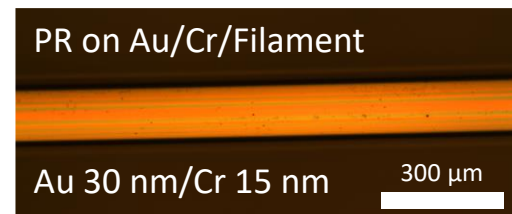
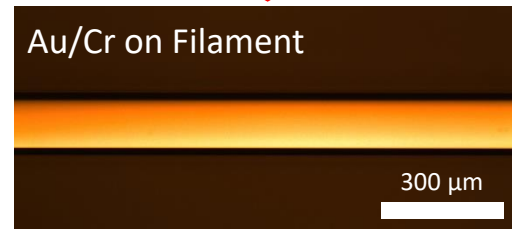


Chip on a fiber

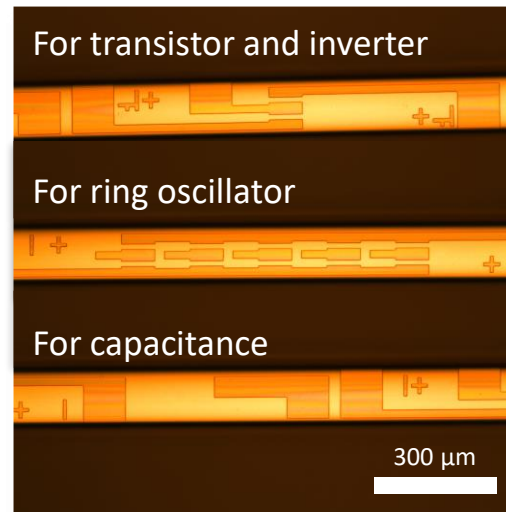
Circuit electrode on fiber



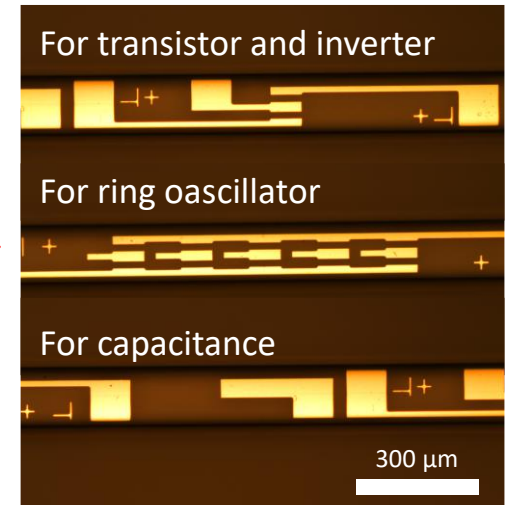
Electrodes and PR coating



After Lithography and PR develop

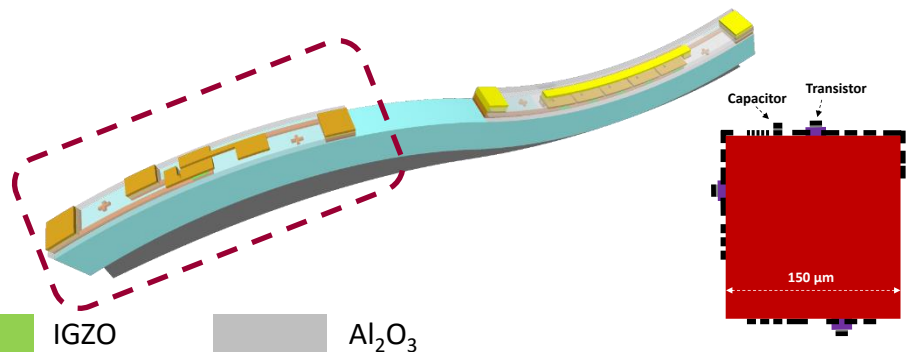


After wet-etching



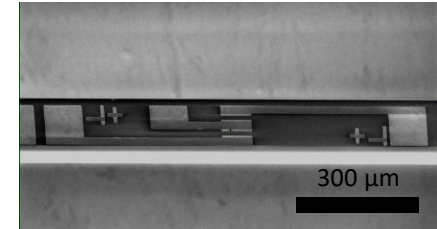
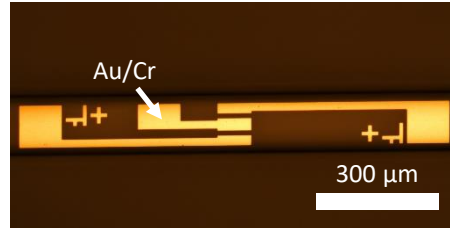
Chip on a fiber

Transistor and inverter on fiber

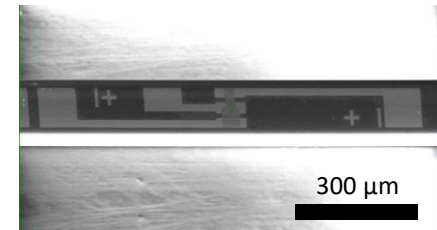
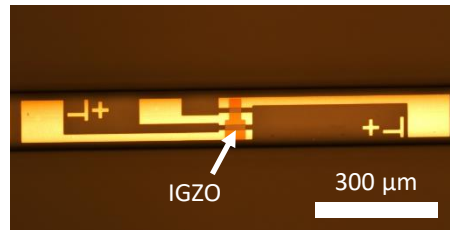


SiO_2
 Au/Cr
 IGZO
 Al_2O_3

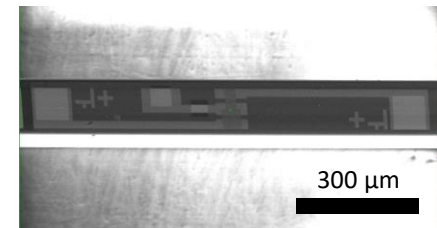
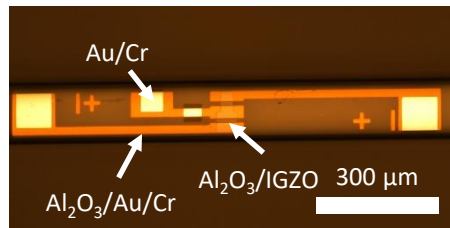
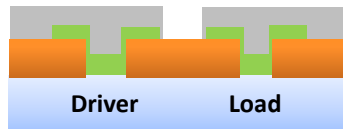
1. Au 30 nm /Cr 15 nm (Bottom electrodes)



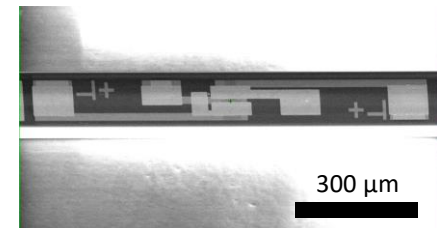
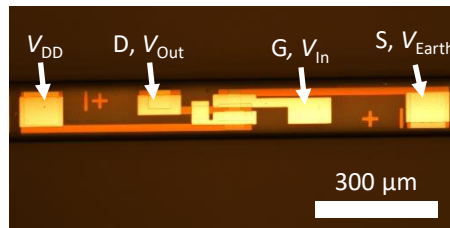
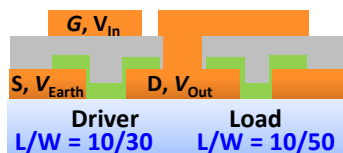
2. IGZO 15 nm (Active layer)



3. Al_2O_3 36 nm (Dielectric layer)

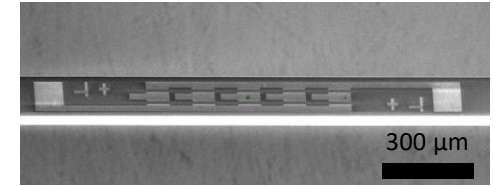
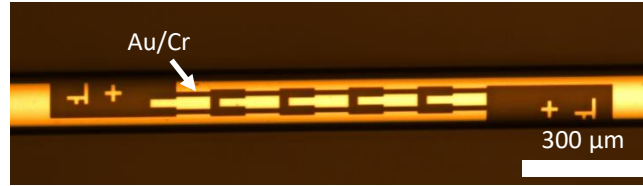


4. Au 30 nm /Cr 15 nm (Top electrodes)



Chip on a fiber

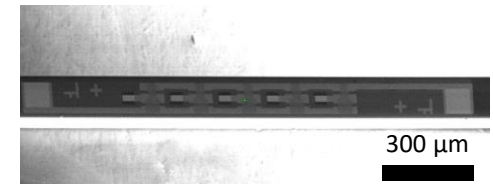
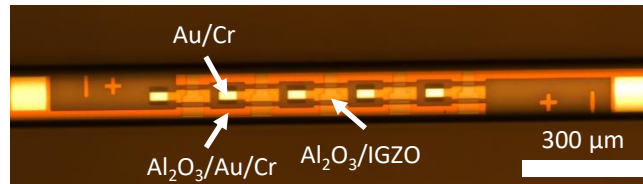
1. Au 30 nm /Cr 15 nm (Bottom electrodes)



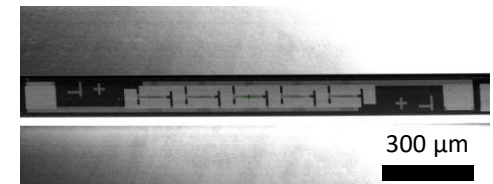
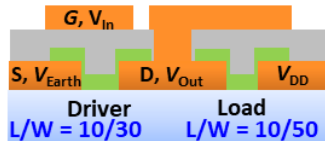
2. IGZO 15 nm (Active layer)



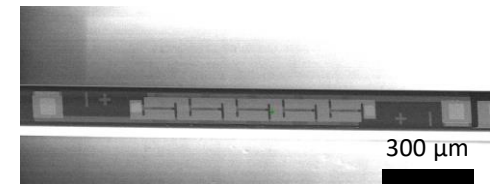
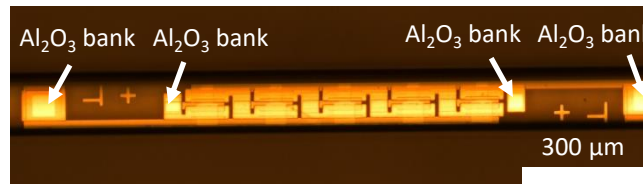
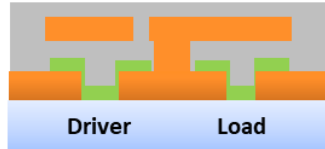
3. Al₂O₃ 36 nm (Dielectric layer)



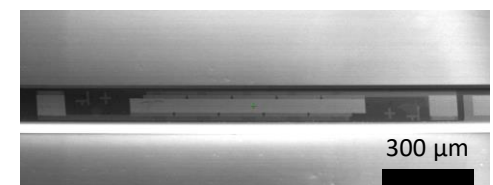
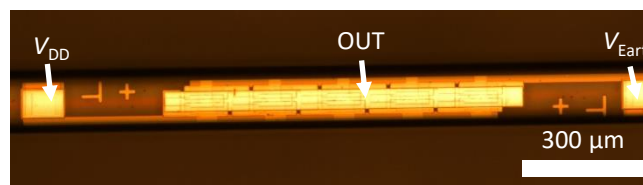
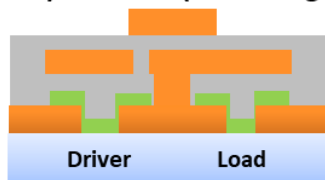
4. Au 30 nm /Cr 15 nm (Top electrodes)

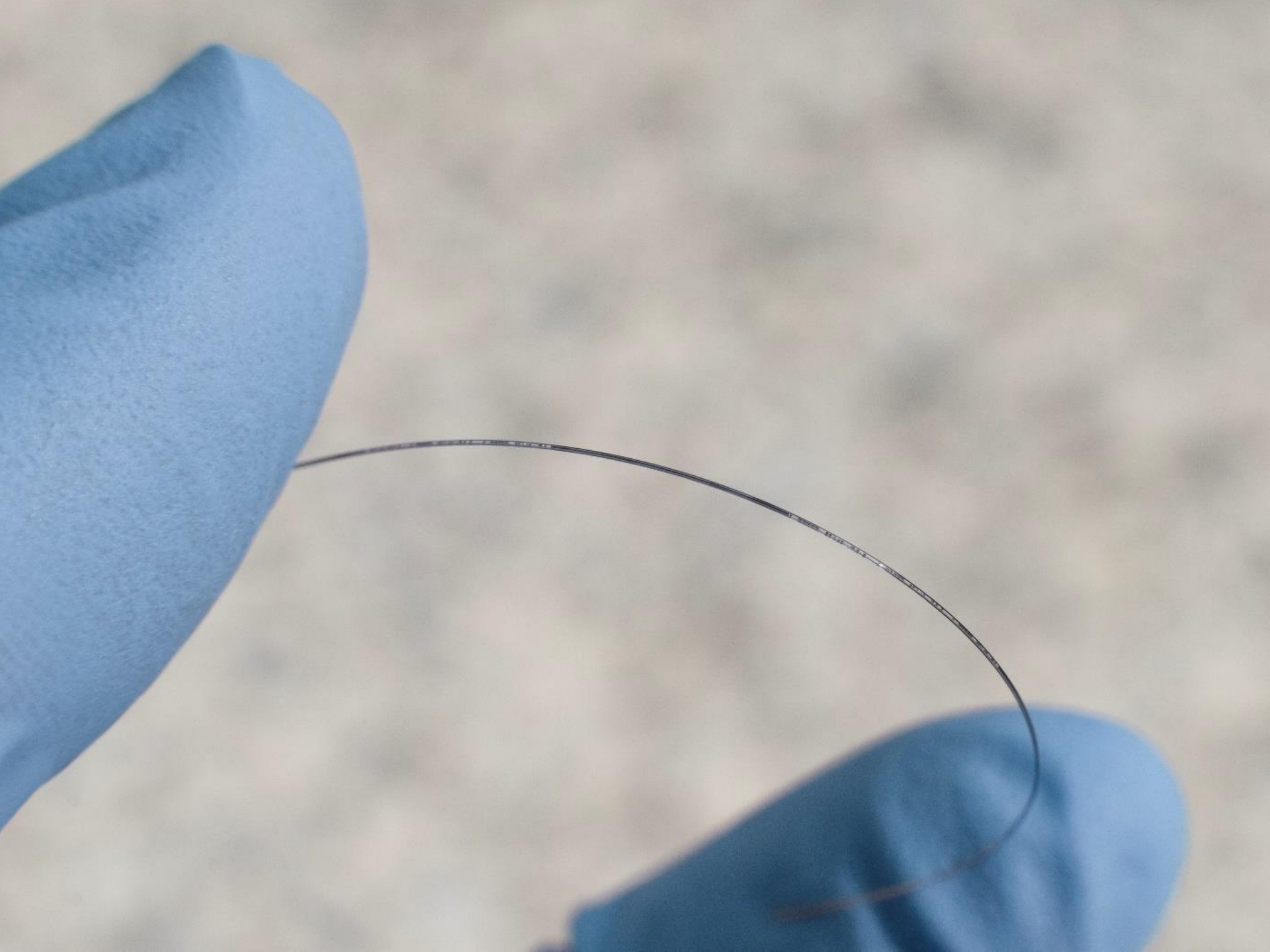


5. Al₂O₃ 36 nm (Insulating layer)



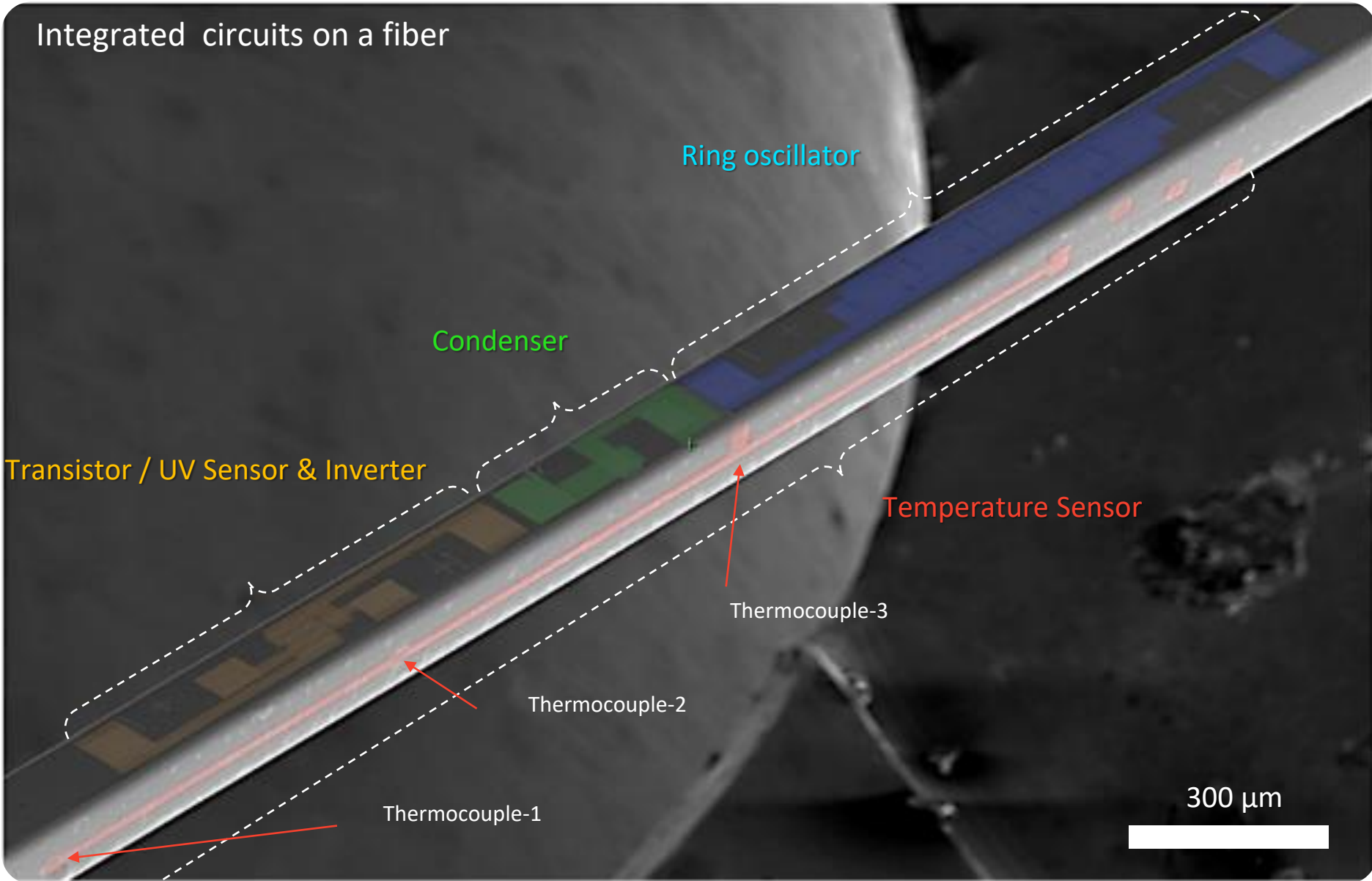
6. Au 30 nm /Cr 15 nm (1 to 5 stage connection)





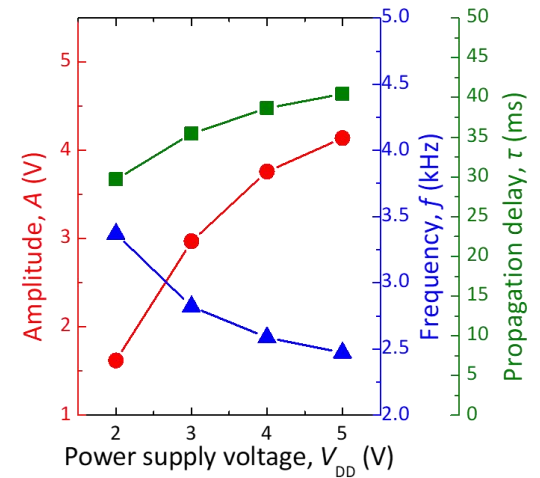
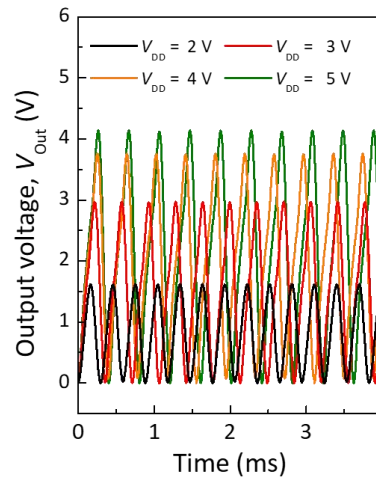
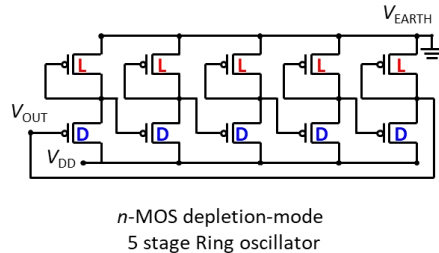
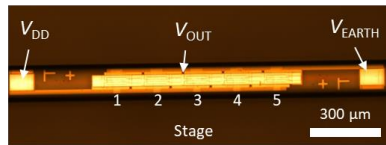
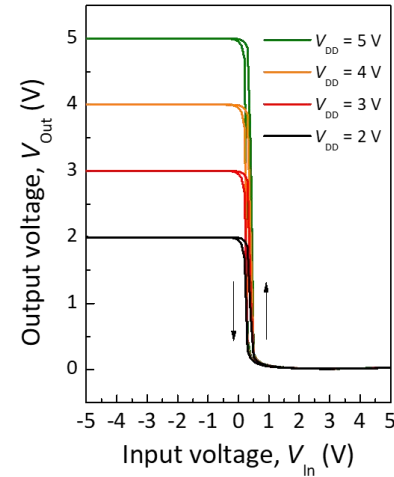
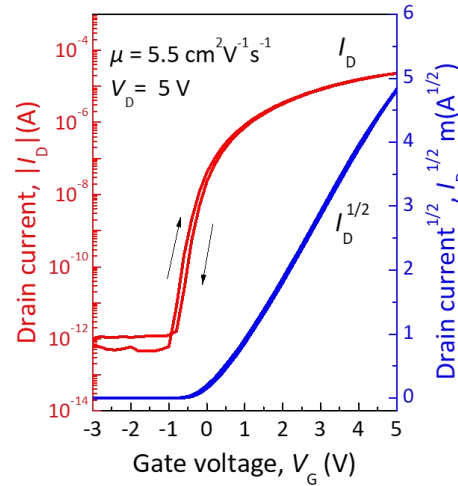
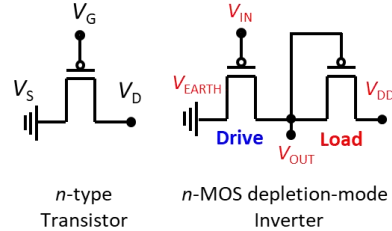
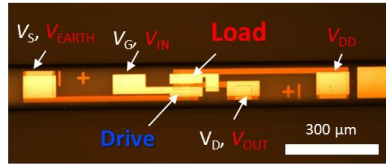
Chip on a Fiber

Integrated circuits on a fiber



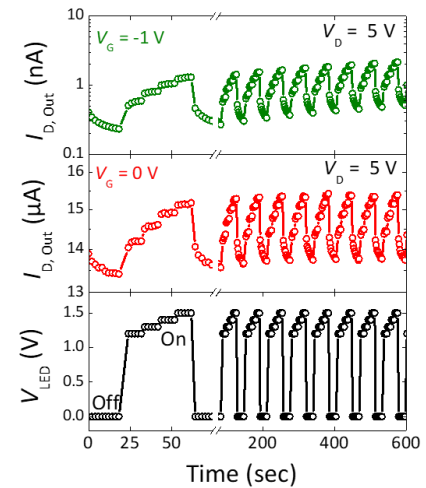
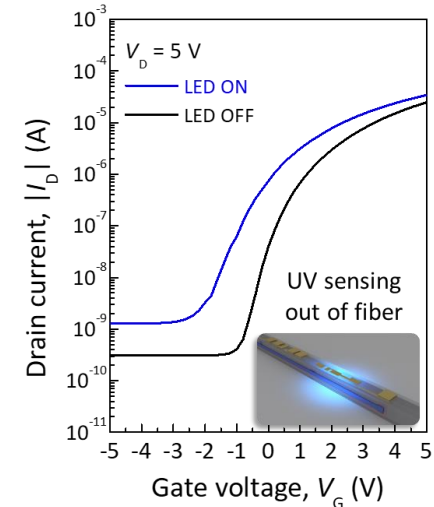
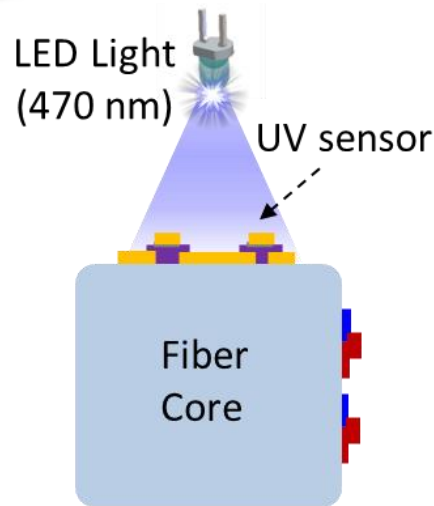
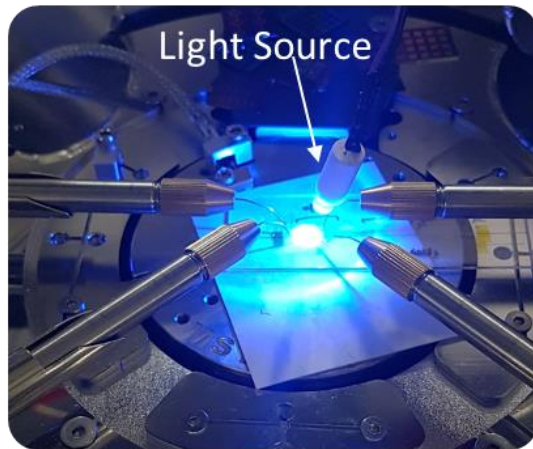
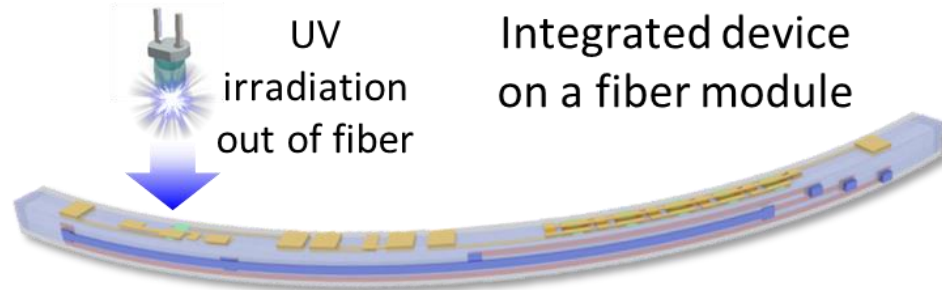
Chip on a fiber

- Transistor and inverter on a fiber substrate



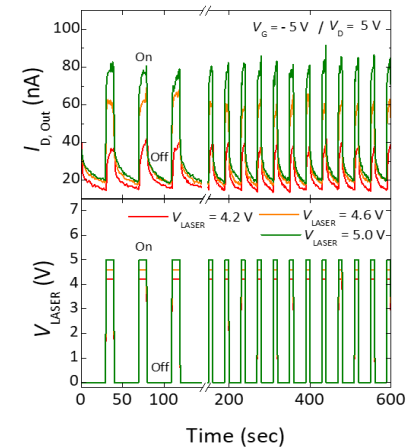
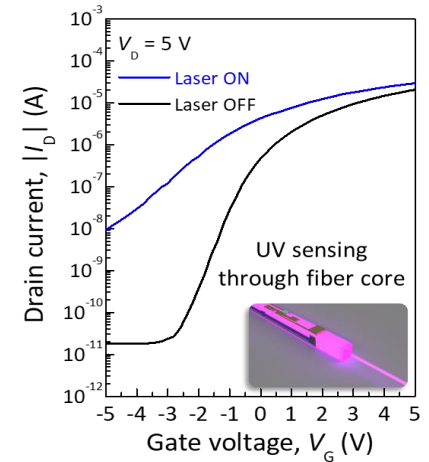
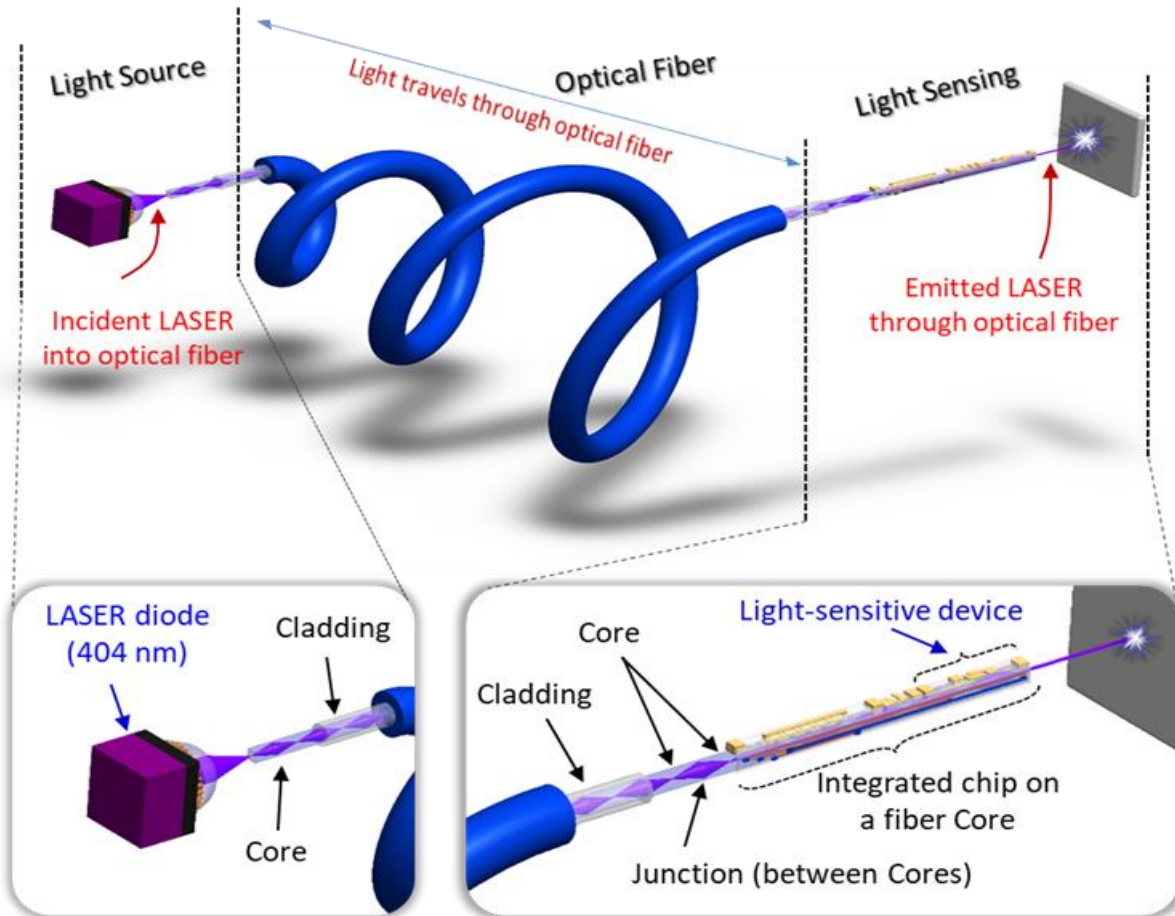
Chip on a fiber

- Photo Detector ([Light out of Fiber](#))



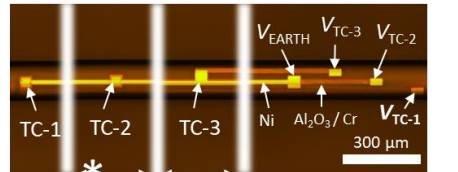
Chip on a fiber

- Photo Detector (Light through Fiber)

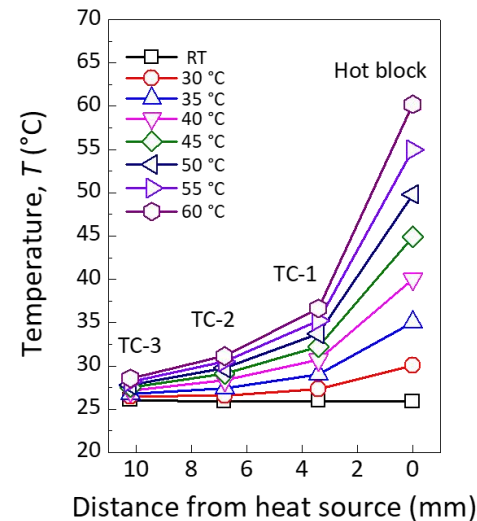
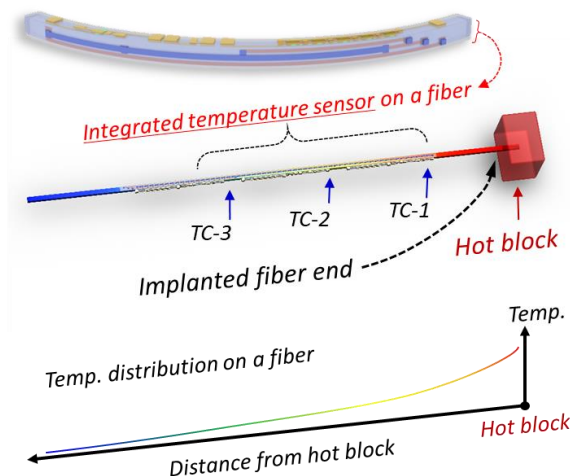
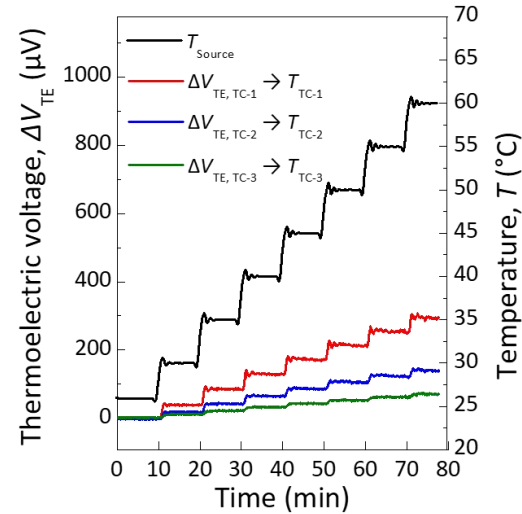
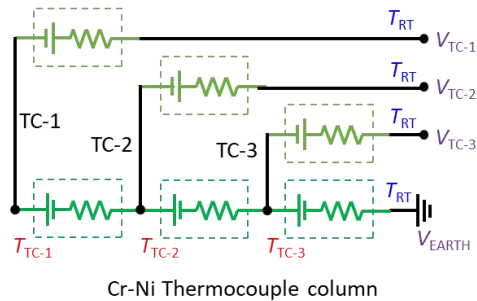


Chip on a fiber

- Temperature sensor

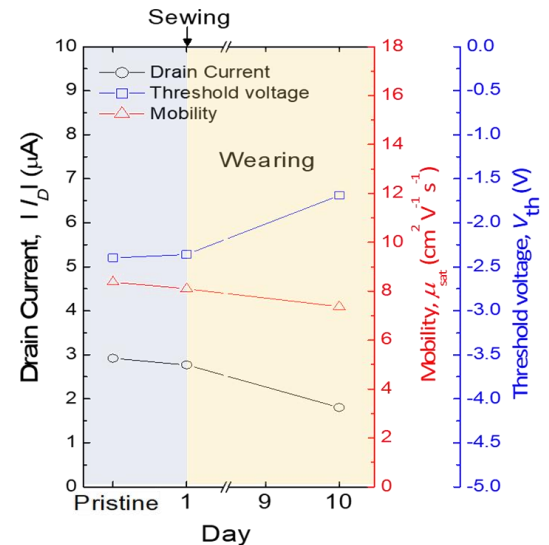
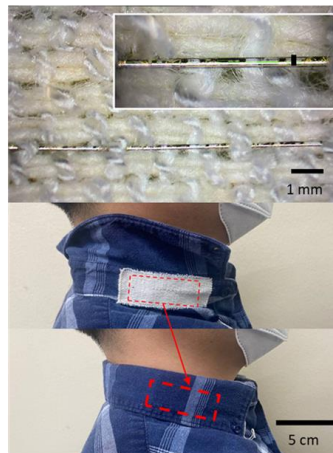
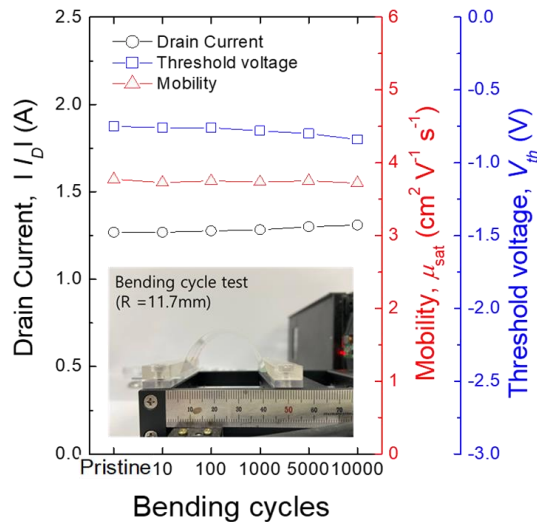
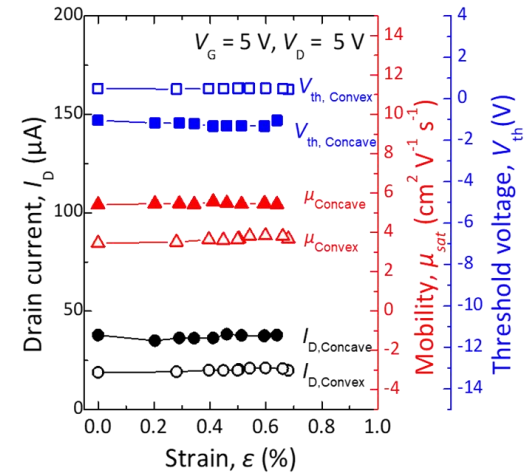
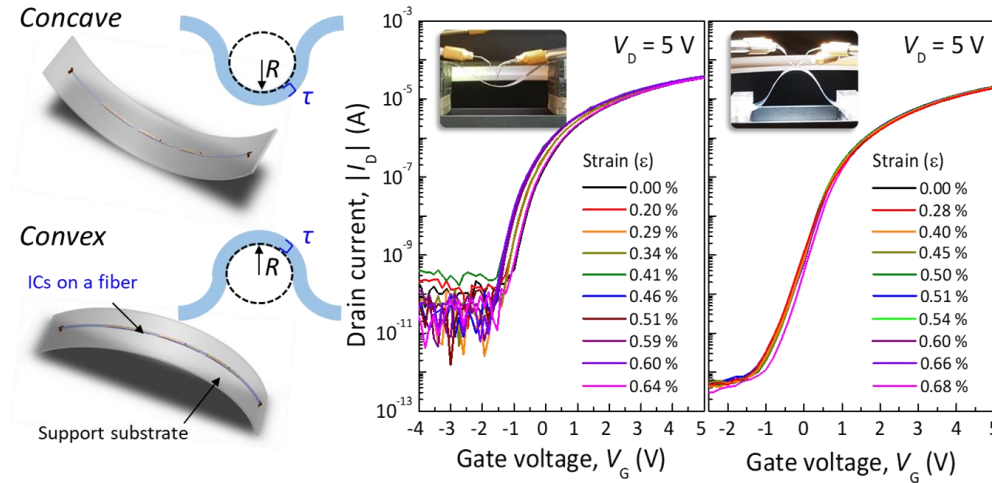


*Distance between each TCs is 3.4 mm



Chip on a fiber

- Integrated electronic fiber under various bending conditions and embedding in a fabric

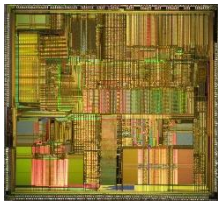


Pentium Processor vs. Processor on a Fiber

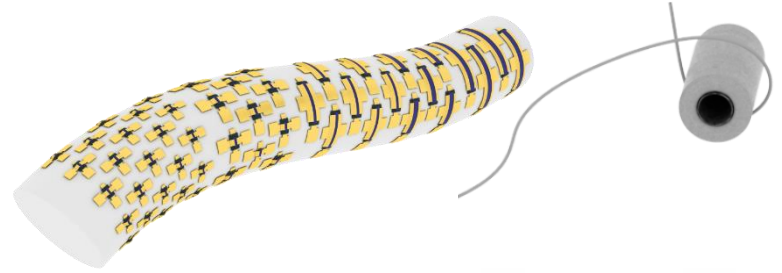


Code name: P54CS
Clock speed: 200 MHz
Introduce: 1996-6-10

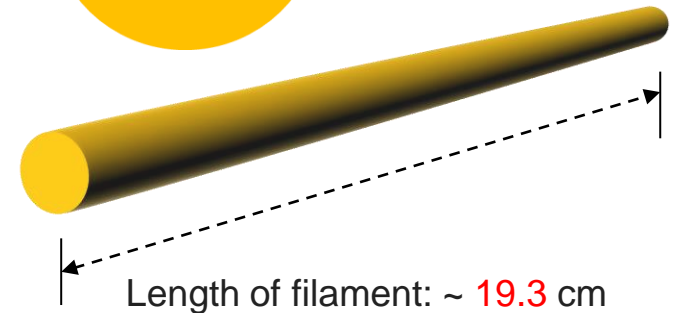
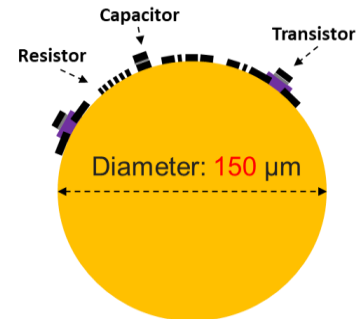
Process size: 0.35 μm
Number of Transistor: 3.3 millions



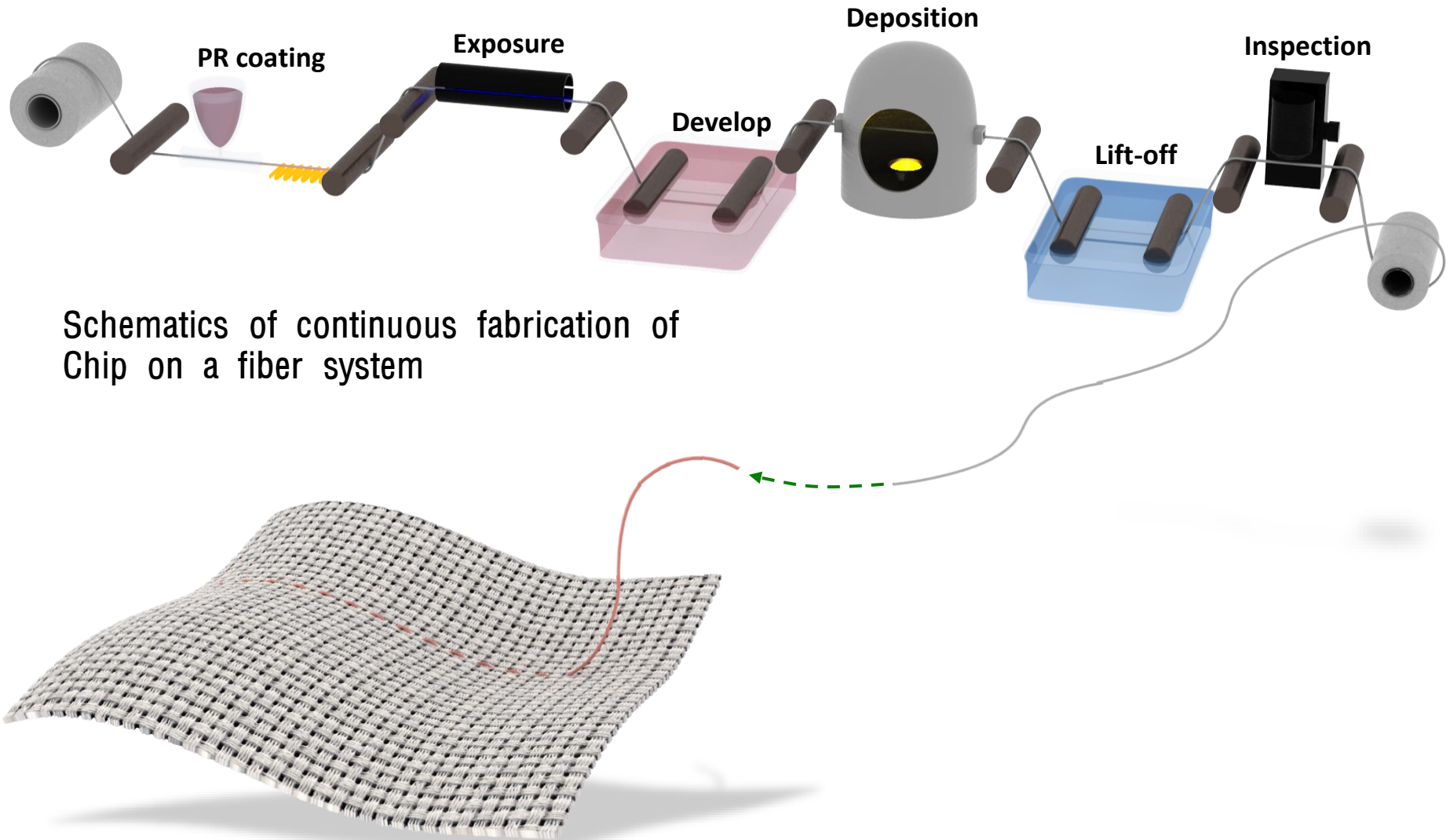
Die area: 91 mm^2



Process size: 0.35 μm
Number of Transistor: 3.3 millions



Chip on a Fiber

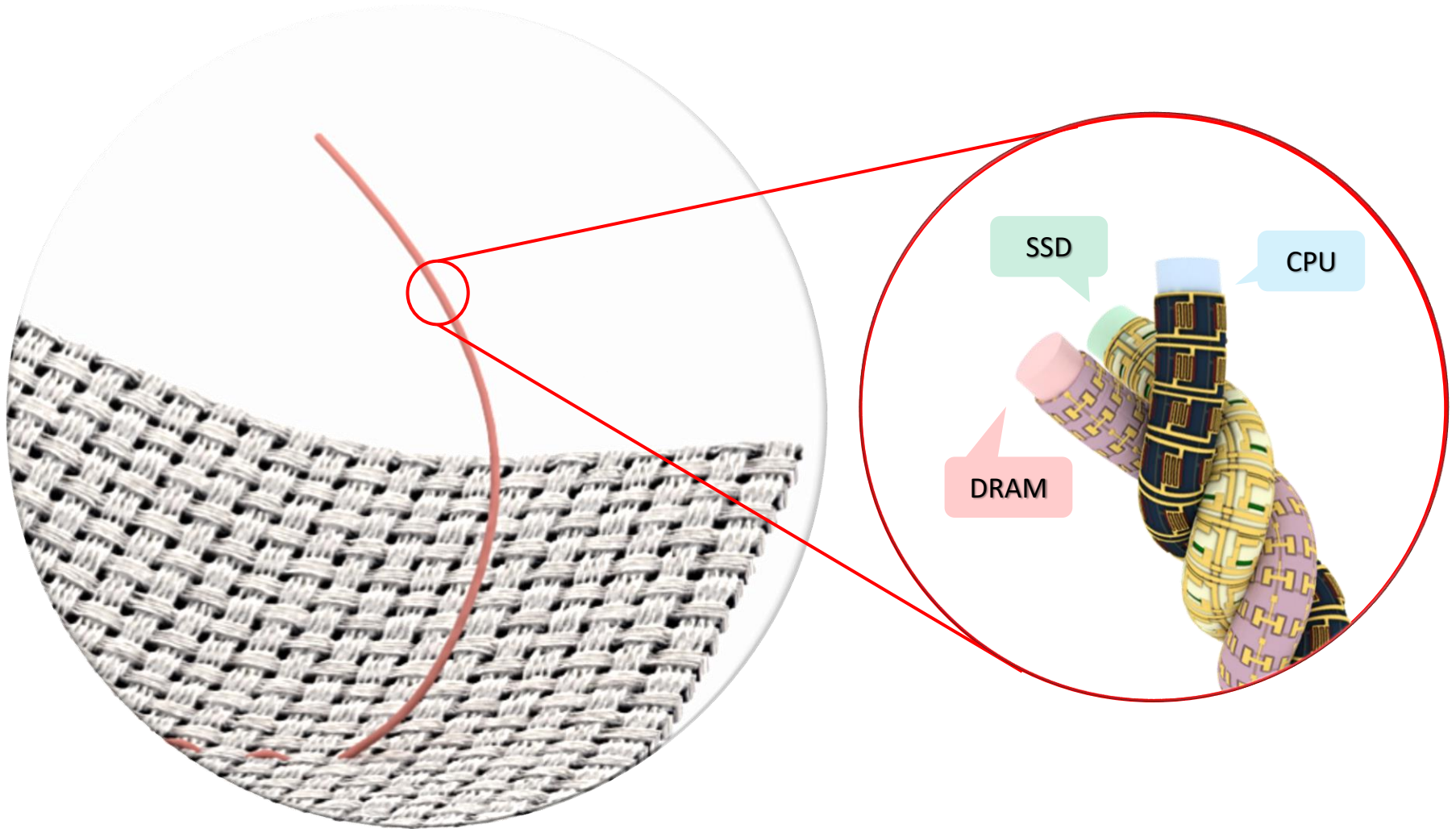


Schematics of continuous fabrication of
Chip on a fiber system

Chip on a fiber(filament) system for wearable processor, memory, sensor

Chip on a Fiber

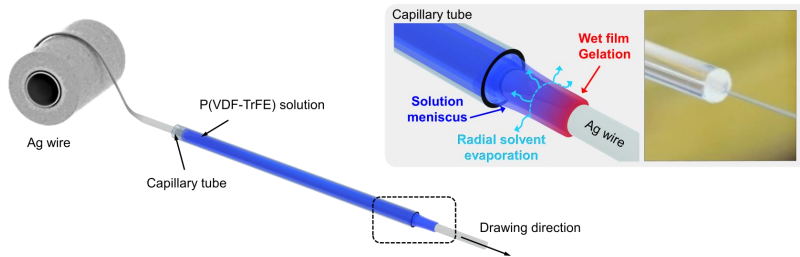
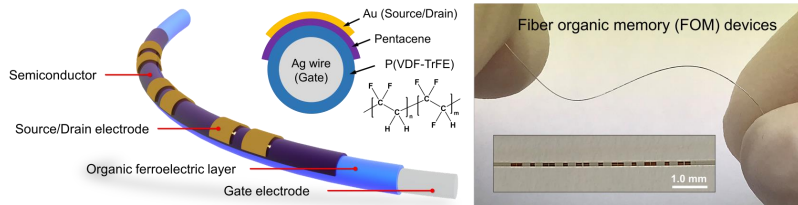
“Fiber computing module based on New E-textile platform”



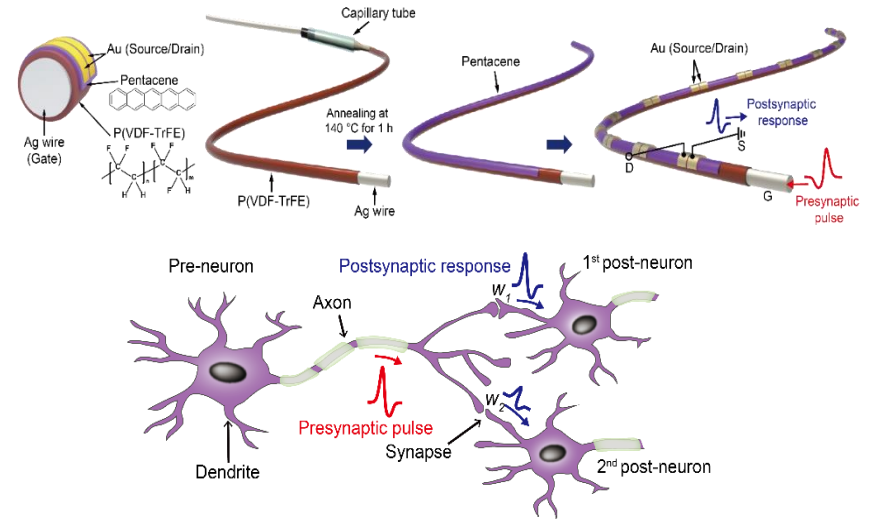
Toward next generation E-Textile

Summary

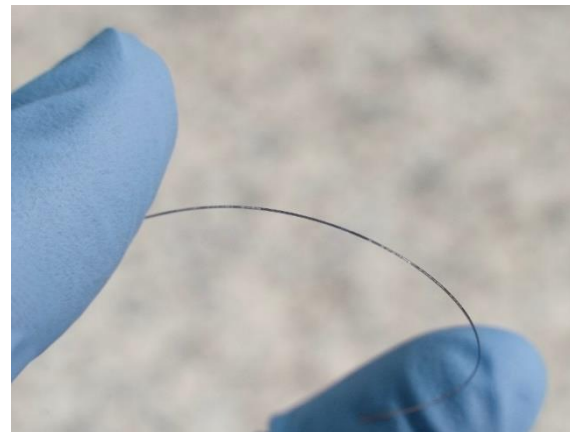
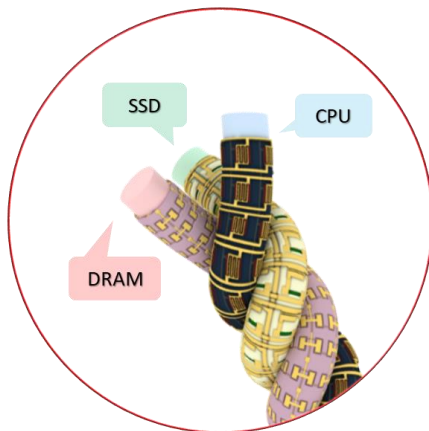
Low-voltage Organic Memory Fiber



One-dimensional artificial multi-synapses



Chip on a Fiber



Funding



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한국연구재단 나노소재기술개발사업 나노커넥트



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2차원 단결정 구리판상 소재의 합성과 응용기술 상용화
KIST-Industry Bridge Program (2021년 10월 ~ 2023년 9월)



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지역 산학연 융합연구사업



차세대 플렉서블 인쇄전자 연구팀

Thanks for your attention

감사합니다

