



Wireless theranostic smart contact lens for monitoring and control of intraocular pressure in glaucoma

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Department of Material Science and Engineering

Pohang University of Science and Technology (POSTECH)



Contents

1

Introduction - Wearable Electronics

2

Smart Electrochemical Contact Lens

3

Smart Photonic Contact Lens

4

Smart Piezoelectric Contact Lens

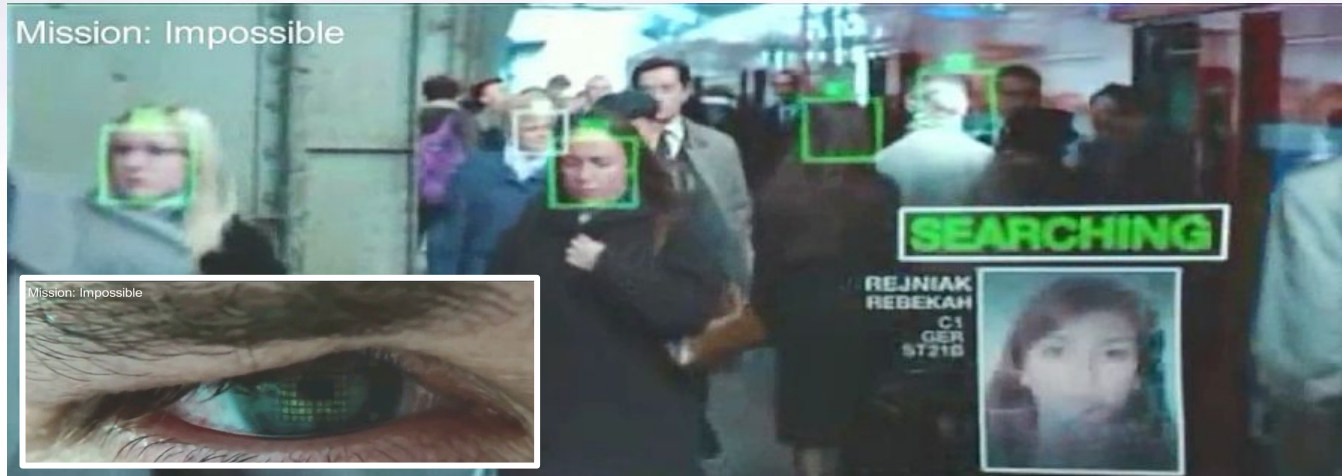
5

Summary and Future Works

1. Introduction

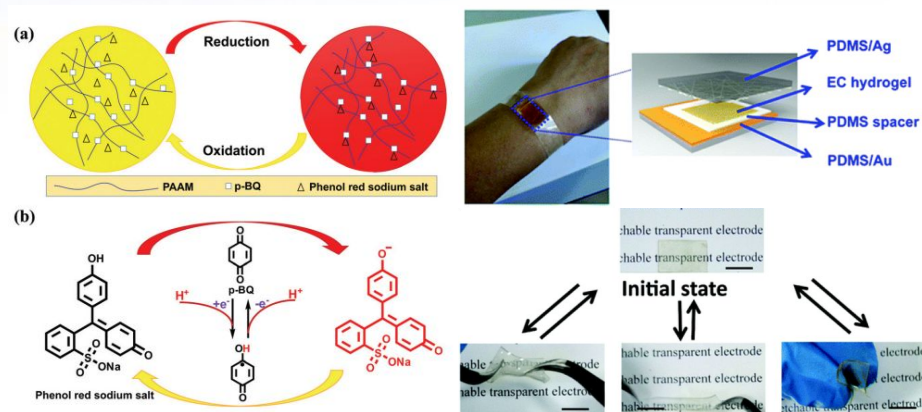
- Wearable Electronic Devices
- Multifunctional Nanomaterials

❖ Futuristic wearable electronic systems and devices



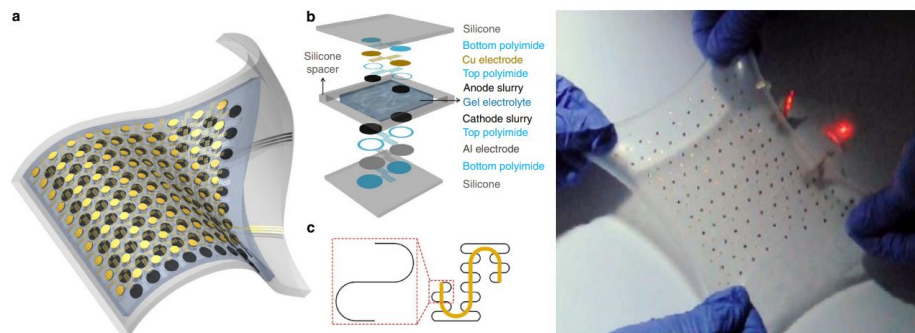
◆ Stretchable electronic devices

Stretchable display



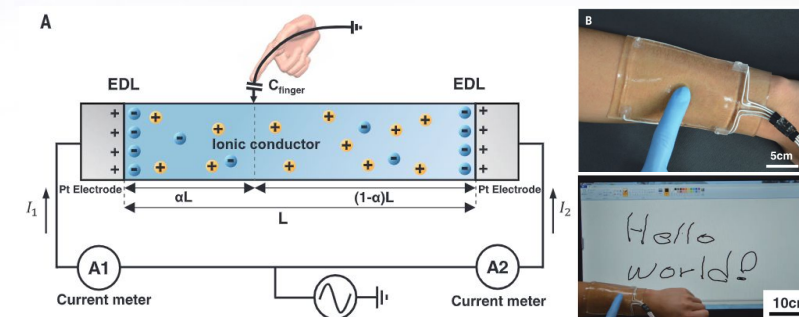
J. Mater. Chem. C 7, 9481-9486, 2019

Stretchable battery



Nature Commun. 4, 1-8, 2013

Stretchable touch panel



Science 353 682-687, 2016

Stretchable sensor



Nature Nanotechnol. 6, 296-301, 2011

❖ Wearable electronic medical devices market

WEARABLE MEDICAL DEVICES MARKET

Global Wearable Medical Devices Market Size (US\$ Mn), 2018 to 2026



Global Wearable Medical Devices Market Share, By Product, 2018

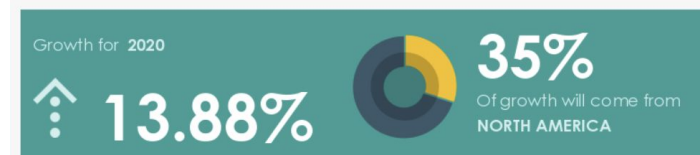


Diagnostic & Monitoring Wearable Devices

Therapeutic Wearable Medical Devices



North America Wearable Medical Devices Market Size (US\$ Mn), 2018



GLOBAL DIAGNOSTIC WEARABLE MEDICAL DEVICES MARKET 2021-2025



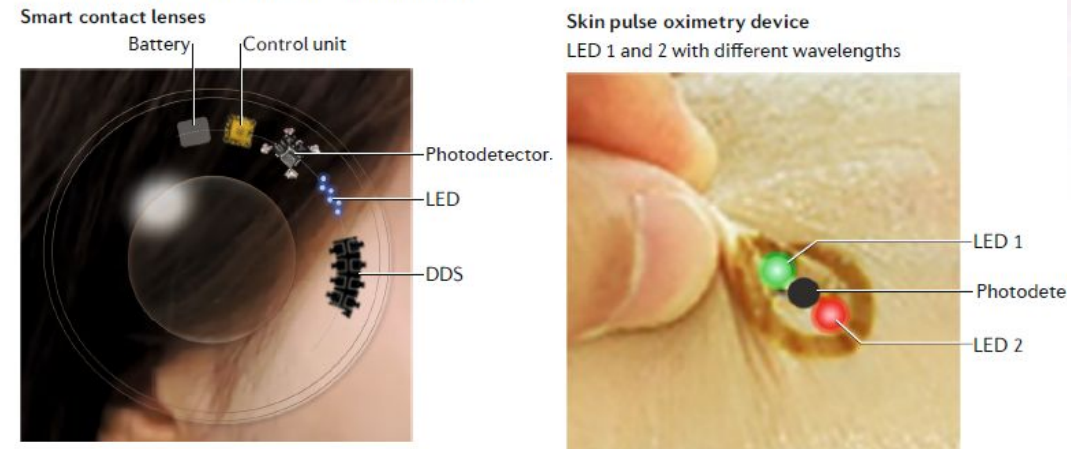
❖ Multifunctional materials for smart healthcare devices

NATURE REVIEWS | MATERIALS

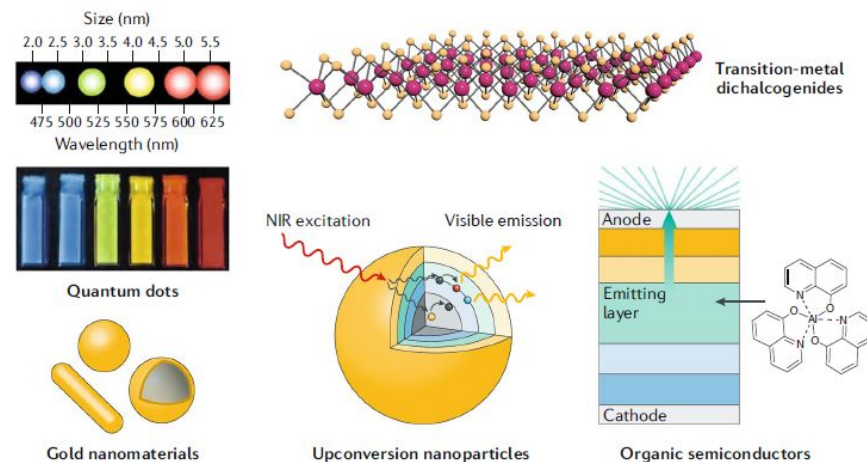
Multifunctional materials for implantable and wearable photonic healthcare devices

Geon-Hui Lee^{1,2,9}, Hanul Moon^{2,3,9}, Hyemin Kim^{4,9}, Gae Hwang Lee^{2,5}, Woosung Kwon⁶, Seunghyup Yoo⁵, David Myung^{2,7}, Seok Hyun Yun^{8*}, Zhenan Bao^{10*} and Sei Kwang Hahn^{1,2,4*}

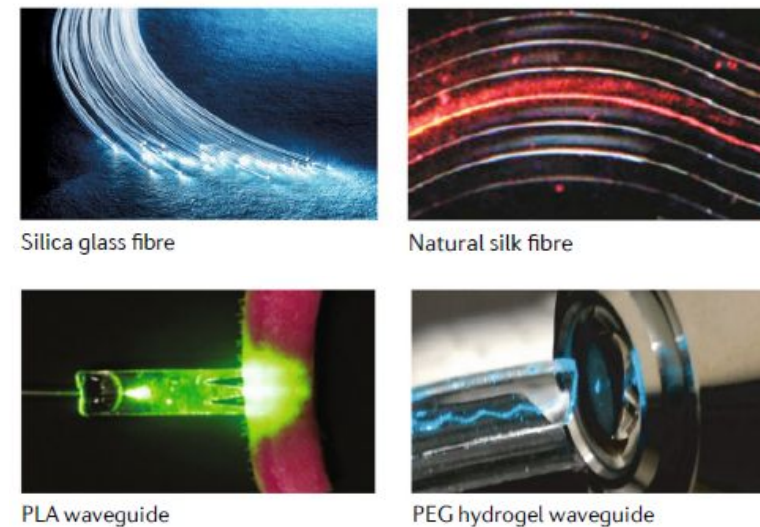
[Nature Reviews Materials 2020, IF = 83.5, Citation 350]



Light-responsive materials



Light-delivering materials



2. Smart Electrochemical Contact Lenses

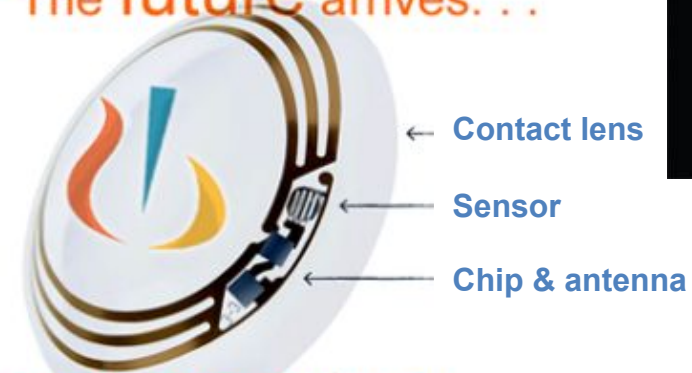
- Smart Electrochemical Contact Lens
- Smart Photonic Contact Lens
- Smart Piezoelectric Contact Lens

2. Smart Electrochemical Contact Lens

9



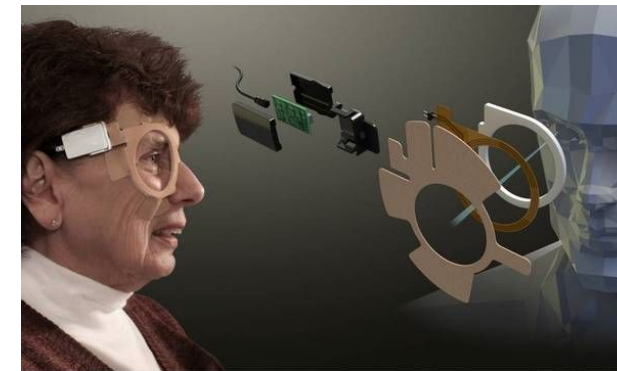
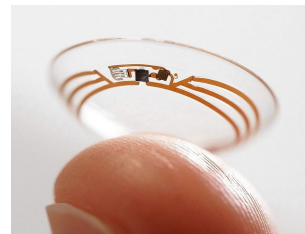
The future arrives. . .



just a little early, at. . .



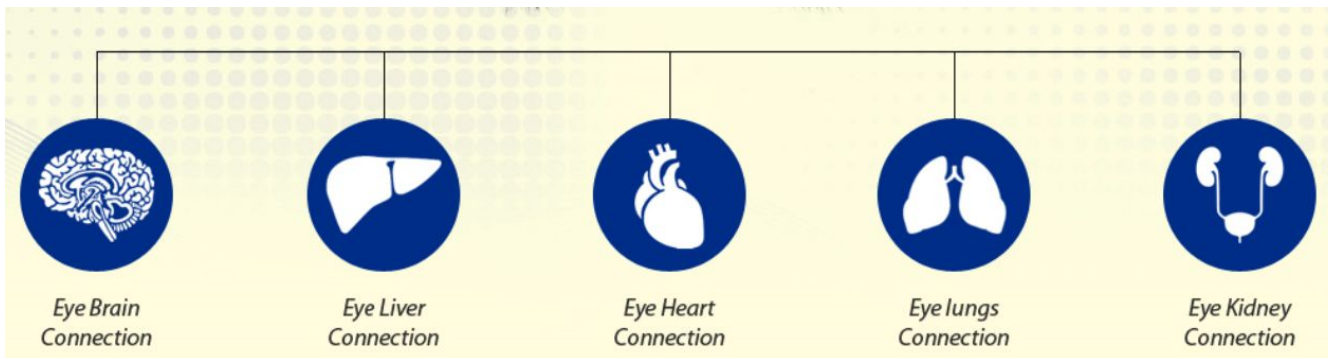
**FDA
APPROVED**



2. Smart Electrochemical Contact Lens

10

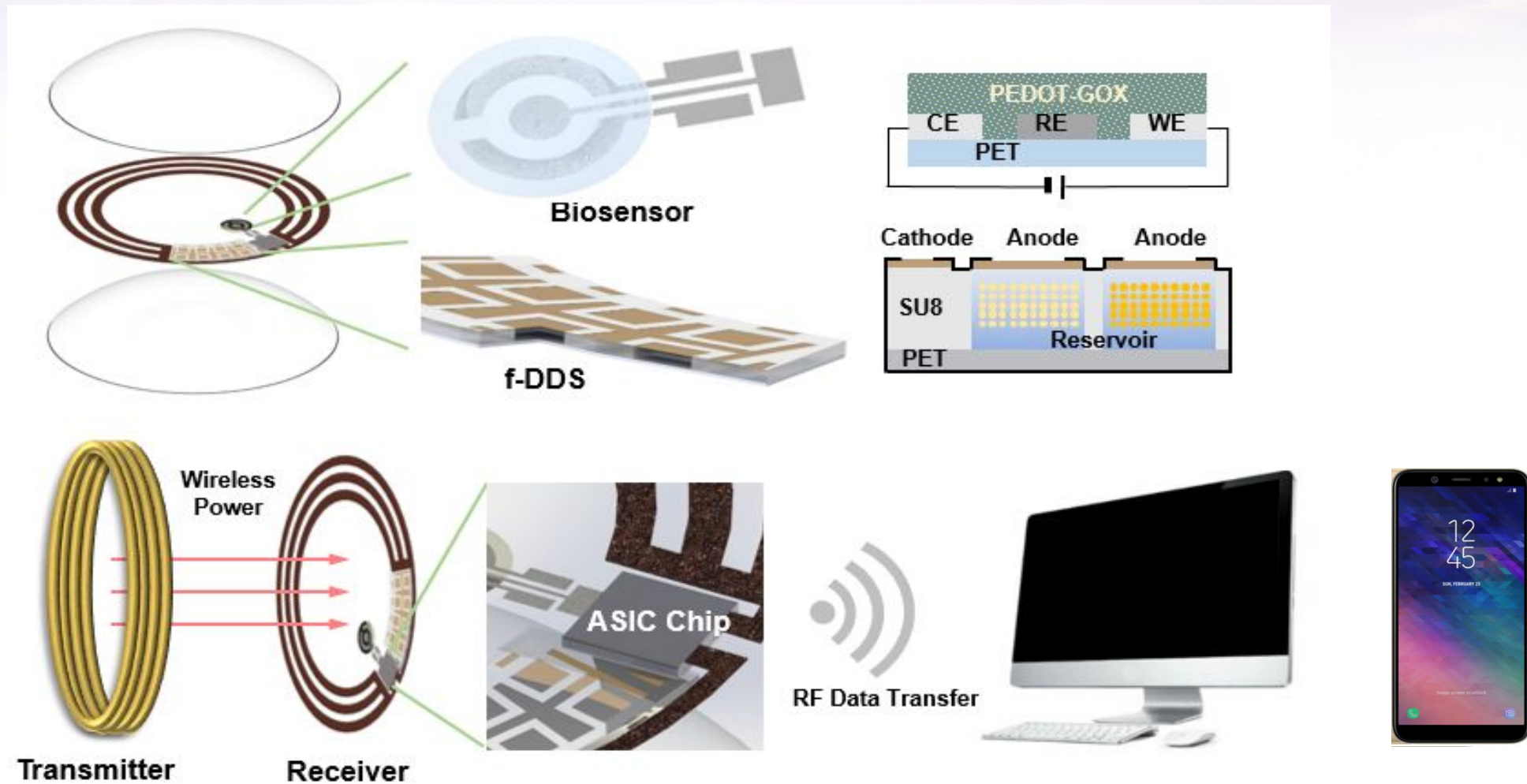
◆ Eye as an interface between the human body and an electronic device



2. Smart Electrochemical Contact Lens

11

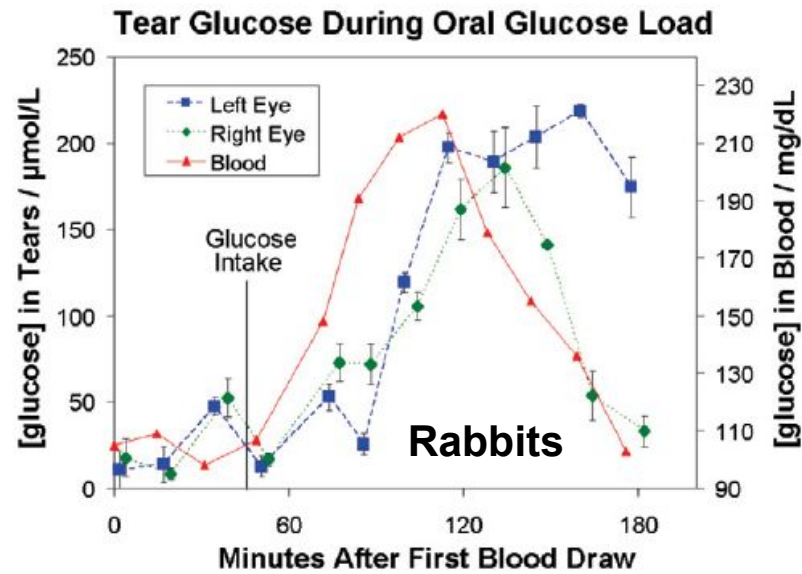
◆ Smart electrochemical contact lens for monitoring and control of diabetes



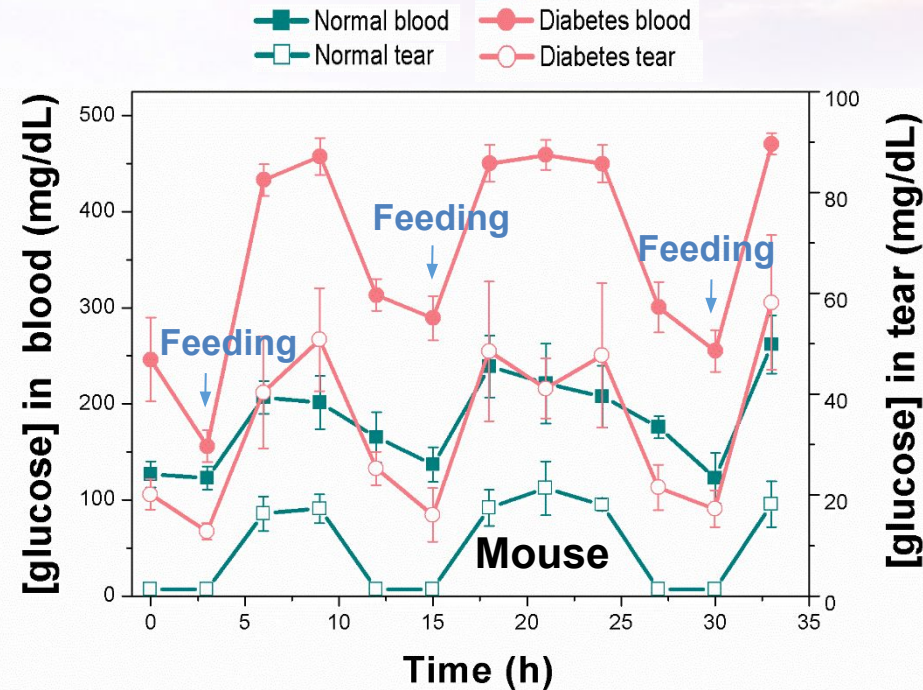
2. Smart Electrochemical Contact Lens

12

❖ Strong correlation between glucose concentration in tear & blood



[Source: Ocular Surface 5, 280, 2007]

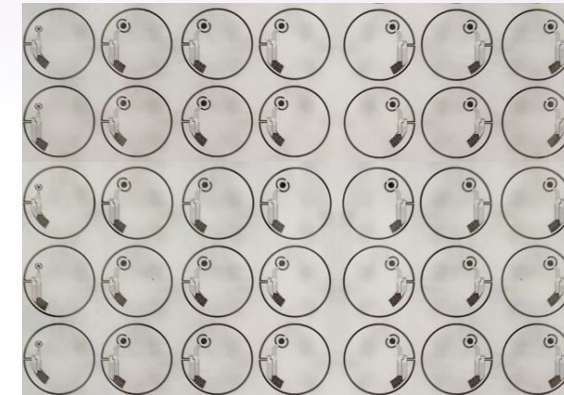
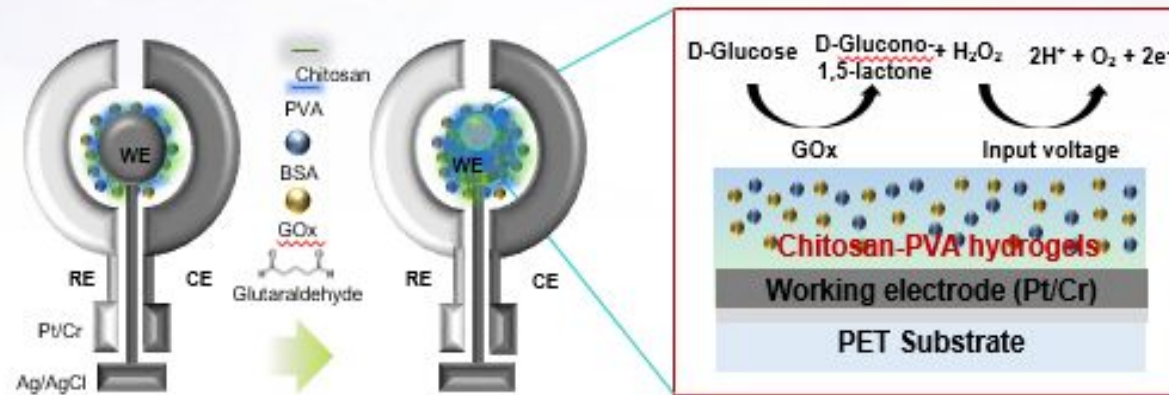


Type	Samples	Mouse	Rabbit	Human
Normal	Blood (mg/dL)	120~250	140~200	100~140
	Tear (mg/dL)	0~20	0~36	0~20
Diabetes	Blood (mg/dL)	150~500	150~400	126~200
	Tear (mg/dL)	15~60	15~60	40~100

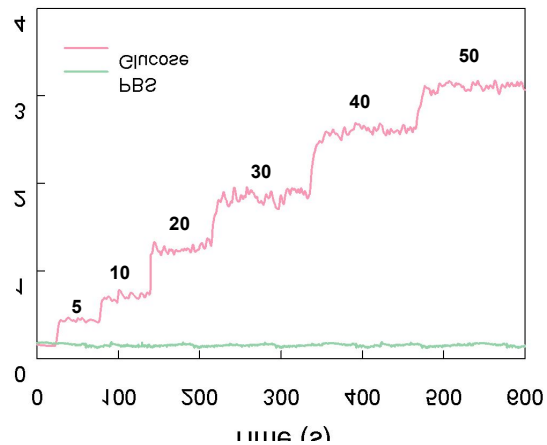
2. Smart Electrochemical Contact Lens

13

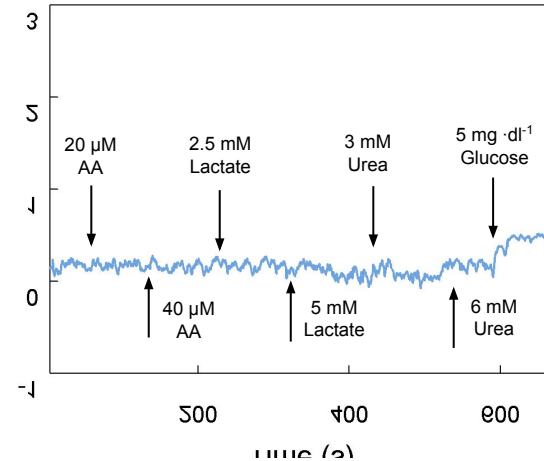
◆ 3-Electrodes glucose biosensor system



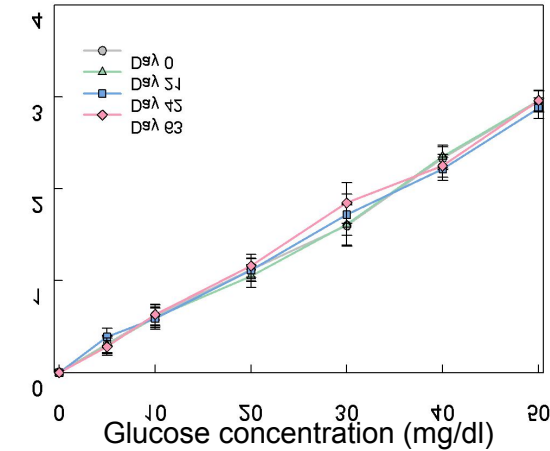
In vitro glucose detection



Glucose-specific detection



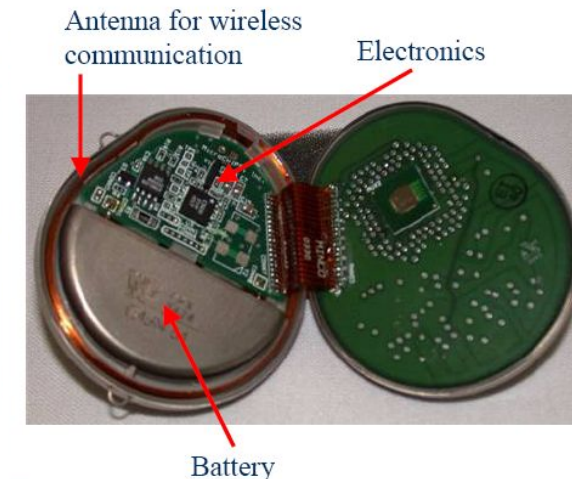
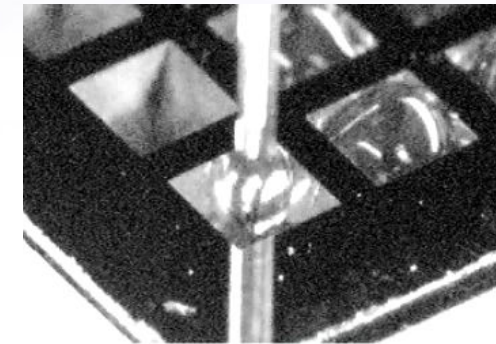
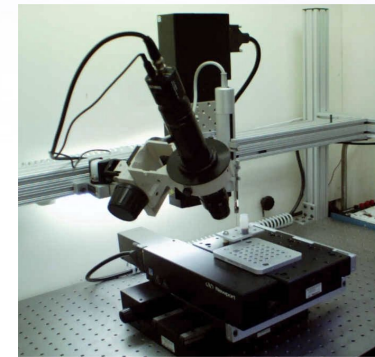
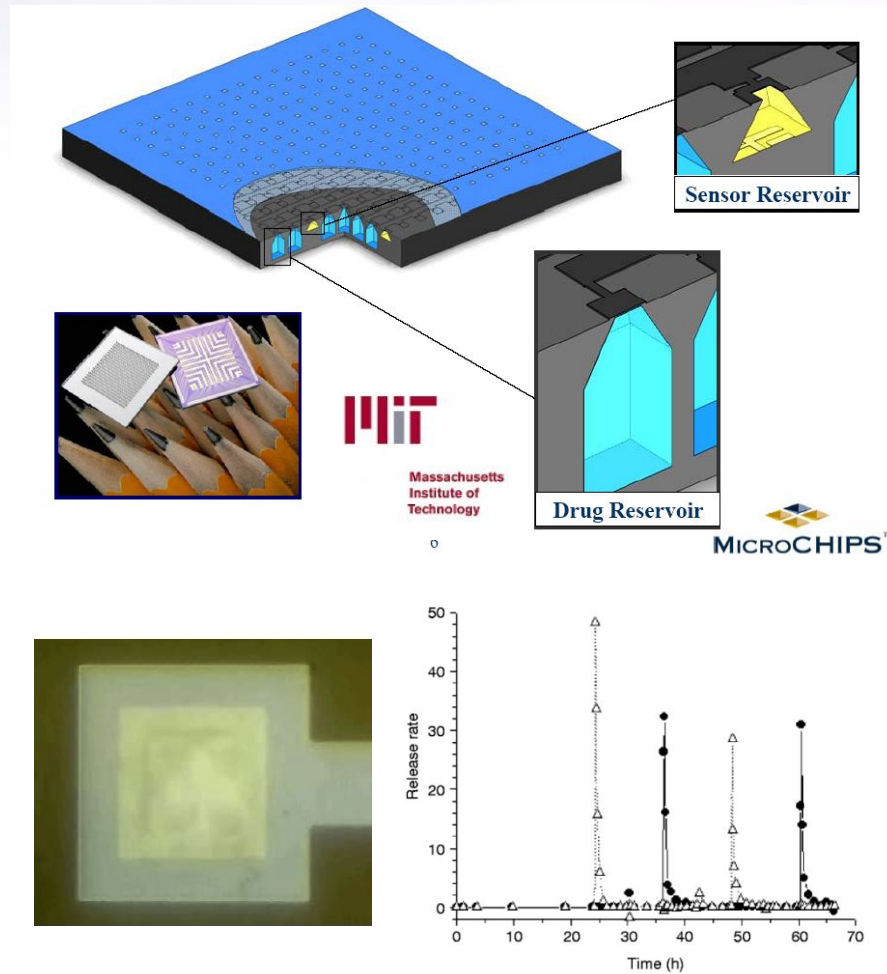
Long-term storage stability



2. Smart Electrochemical Contact Lens

14

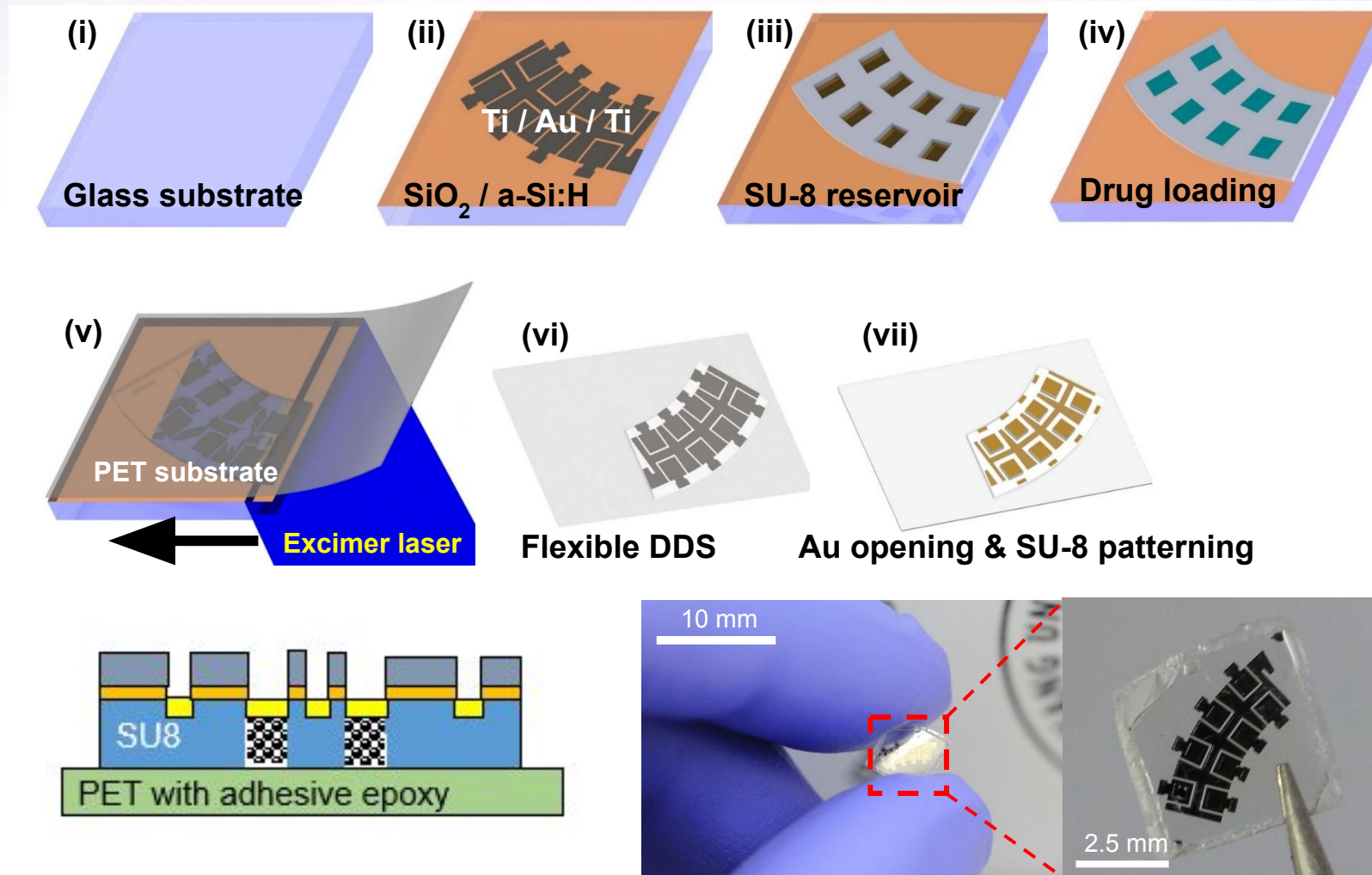
◆ Gold coated drug reservoirs developed by Robert Langer at MIT



2. Smart Electrochemical Contact Lens

15

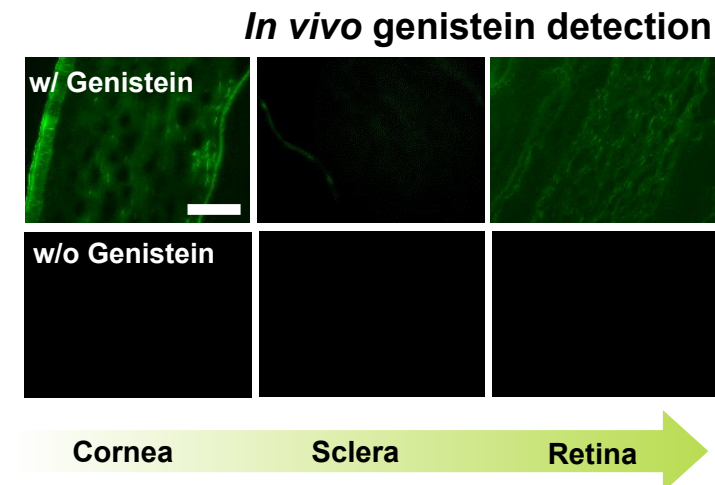
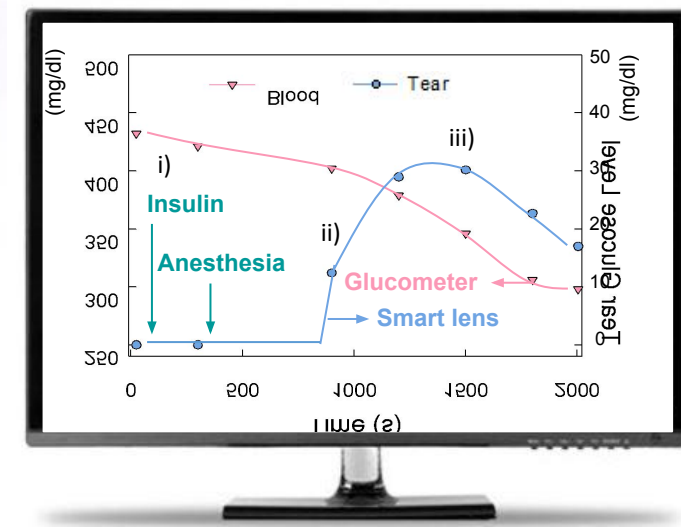
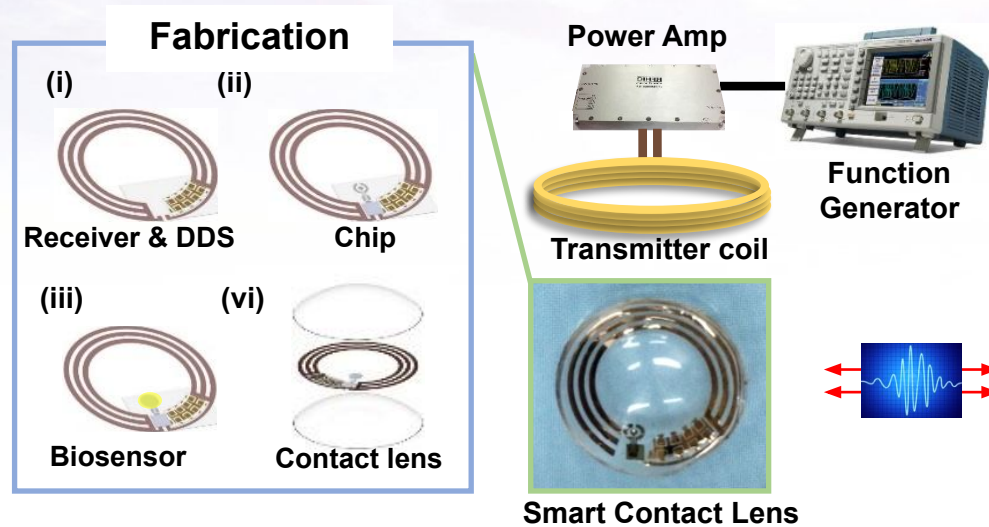
❖ Fabrication of flexible drug delivery systems (f-DDS)



2. Smart Electrochemical Contact Lens

16

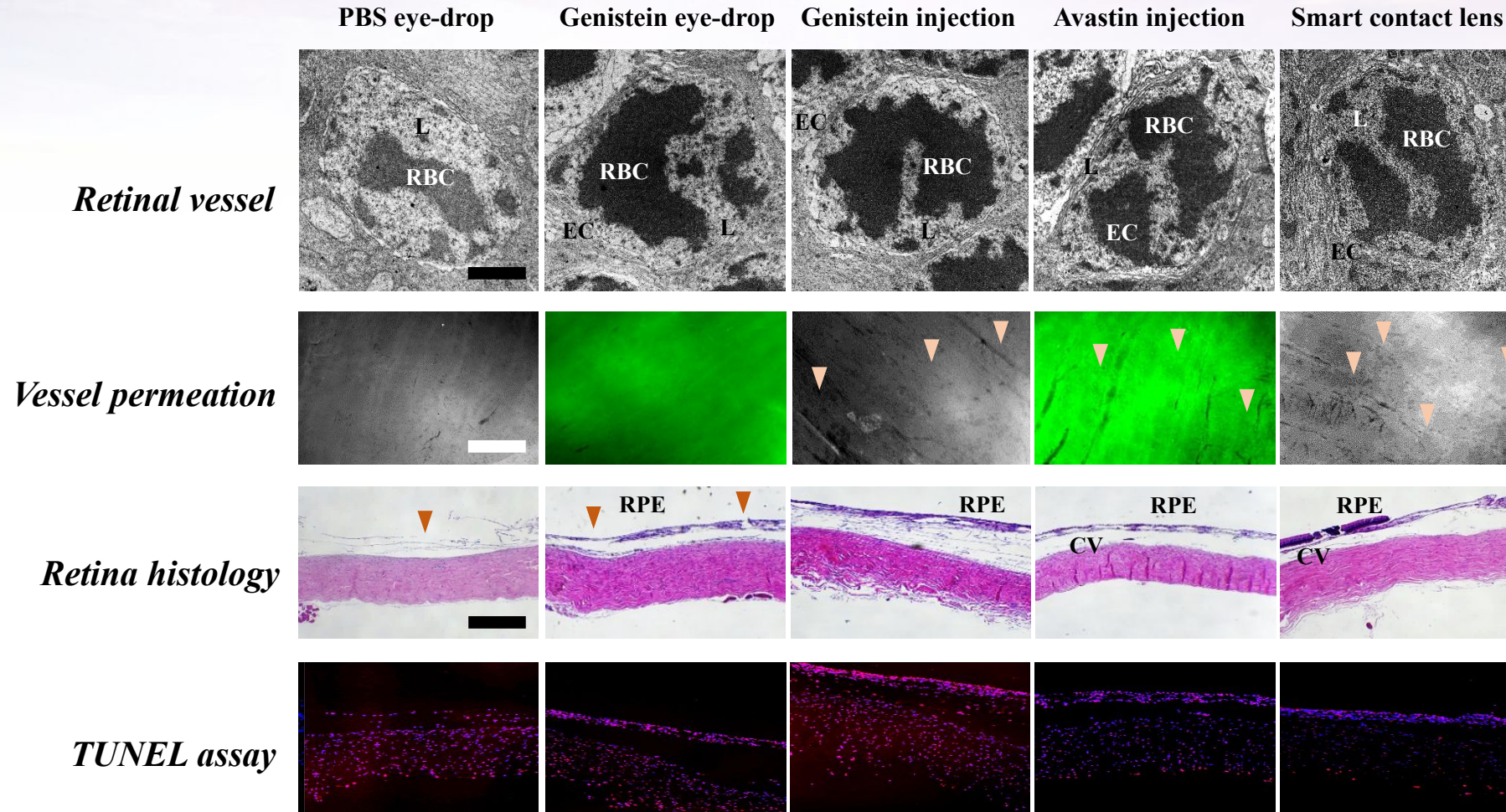
❖ Theranostic application of smart contact lens



2. Smart Electrochemical Contact Lens

17

◆ Smart contact lens for therapeutic applications on diabetic retinopathy

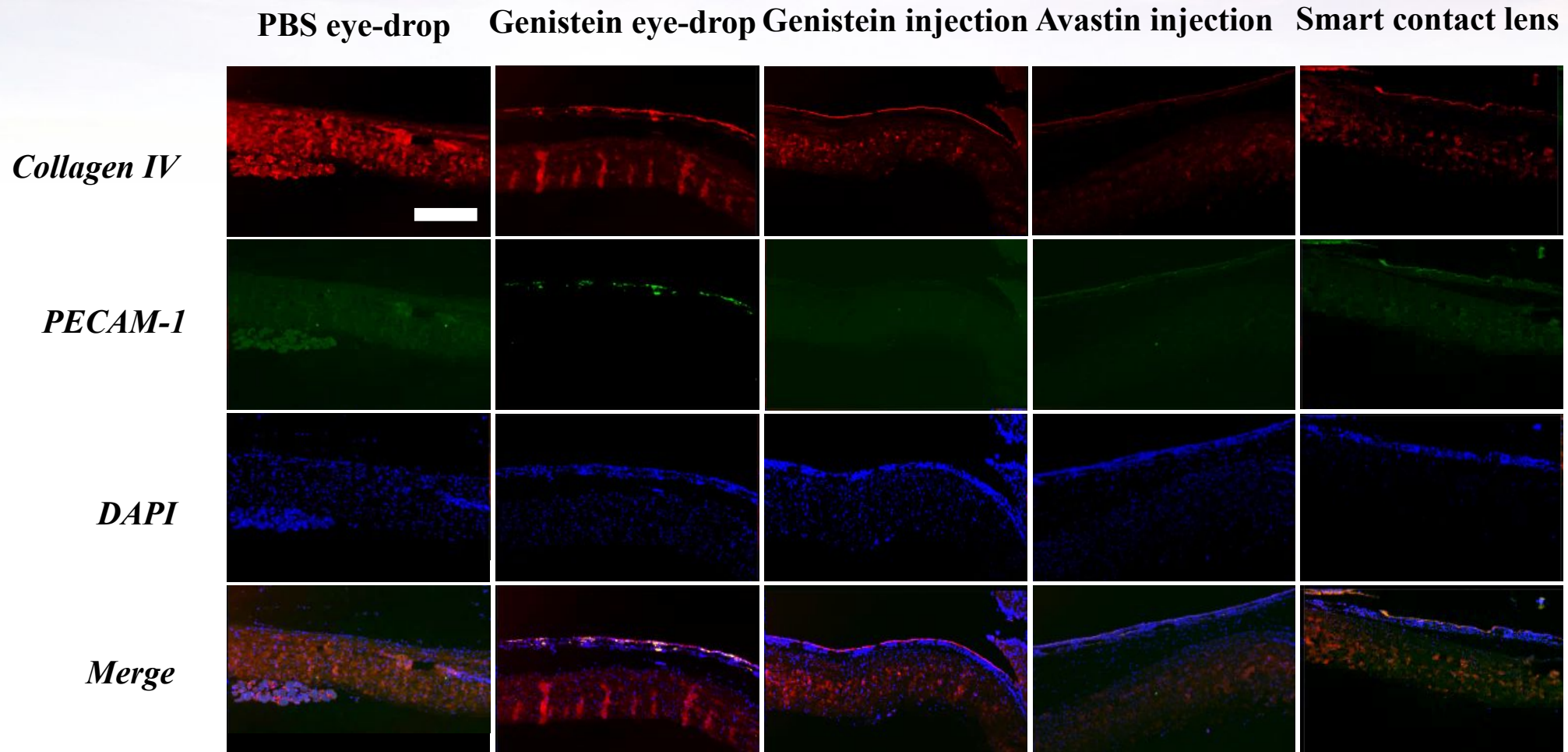


(L: lumen of vessel, EC: endothelial cell, RPE: retinal pigment epithelium, CV: choroidal vessel)

2. Smart Electrochemical Contact Lens

18

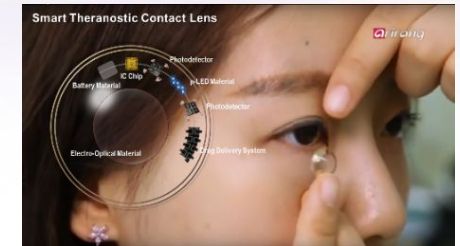
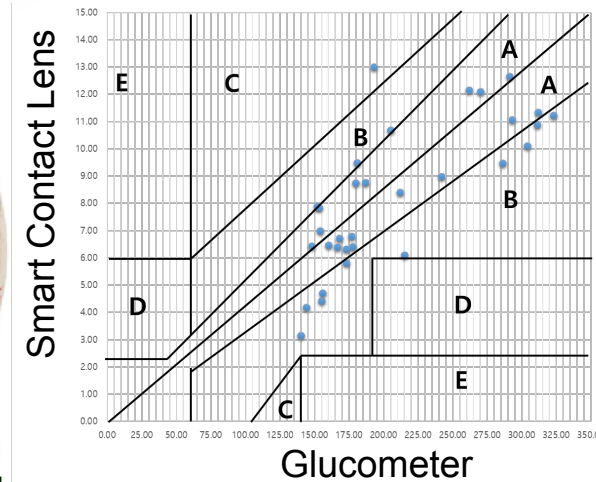
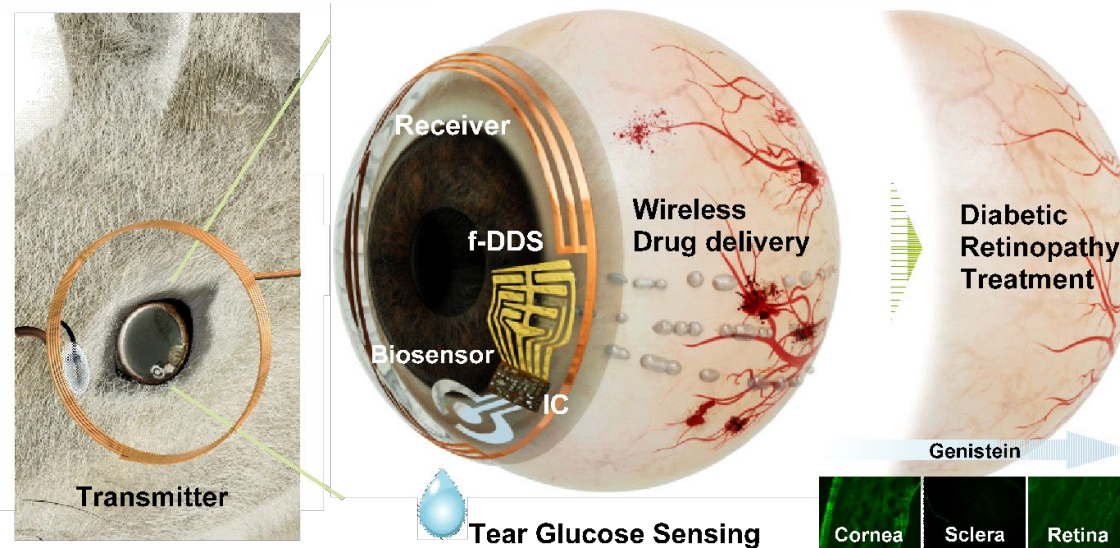
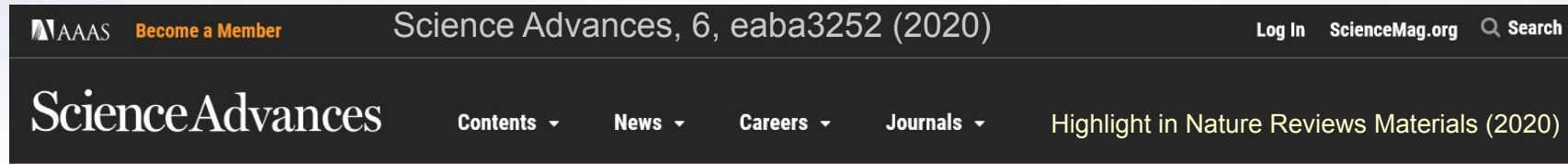
◆ Immunohistochemical analysis for the therapeutic effect



2. Smart Electrochemical Contact Lens

19

Smart contact lens for diabetes diagnosis and therapy



2. Smart Electrochemical Contact Lens

20

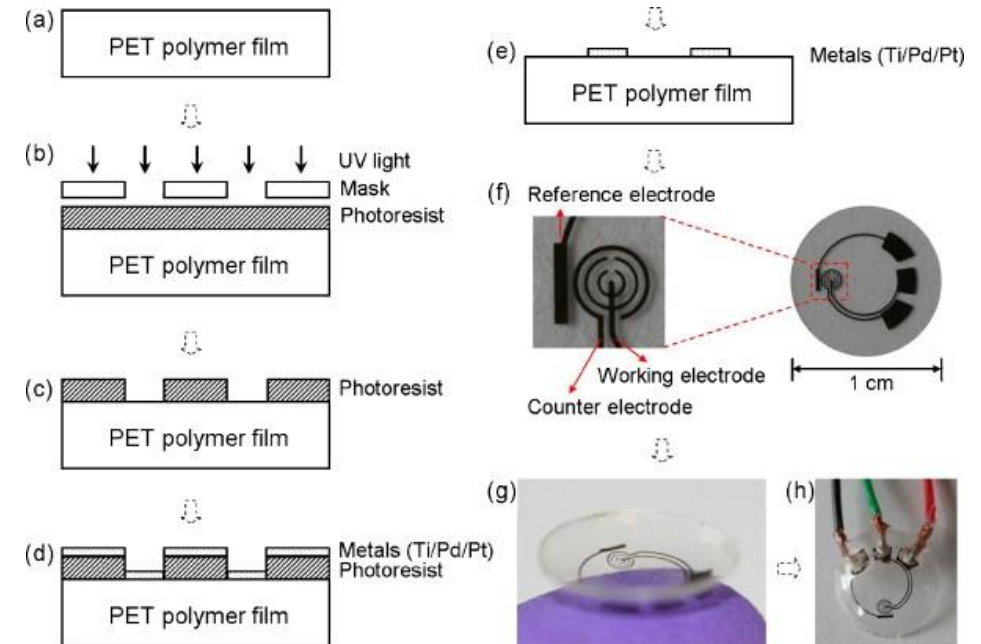
❖ Google lens for diabetes diagnosis



A contact lens with embedded sensor for monitoring tear glucose level

Huanfen Yao¹, Angela J. Shum¹, Melissa Cowan, Ilkka Lähdesmäki, **Babak A. Parviz***

Department of Electrical Engineering, University of Washington, Seattle, WA 98195, United States

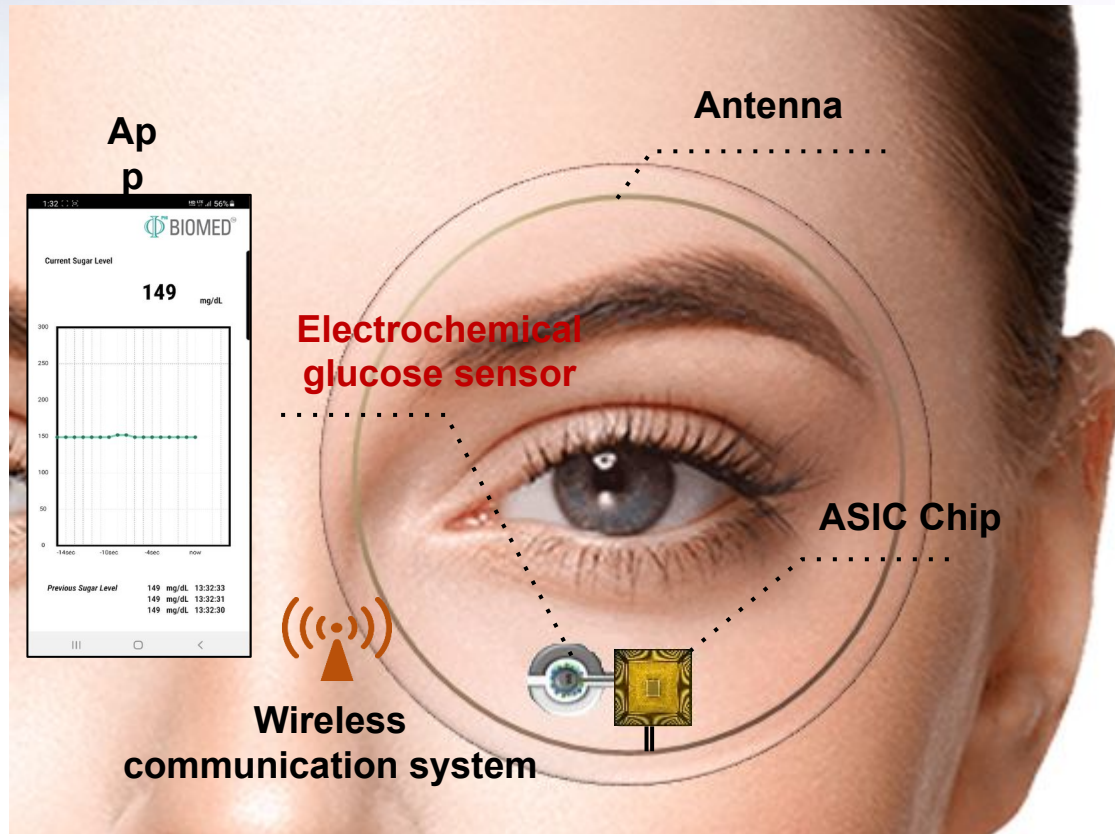


Enzyme layer: GOx +Ti sol-gel layer + Nafion layer → Low diffusion flux, sensitivity, response time

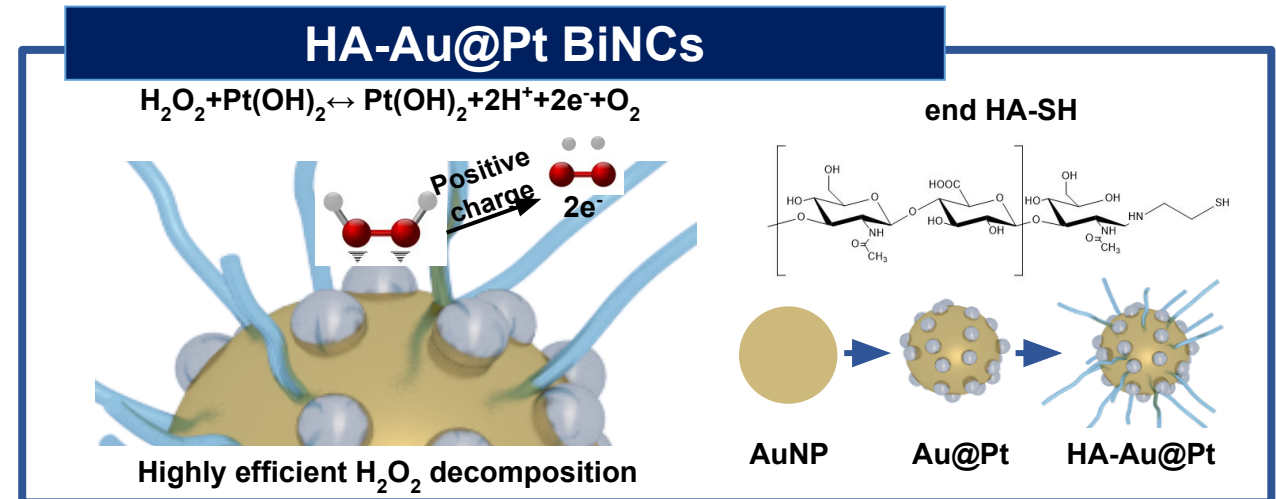
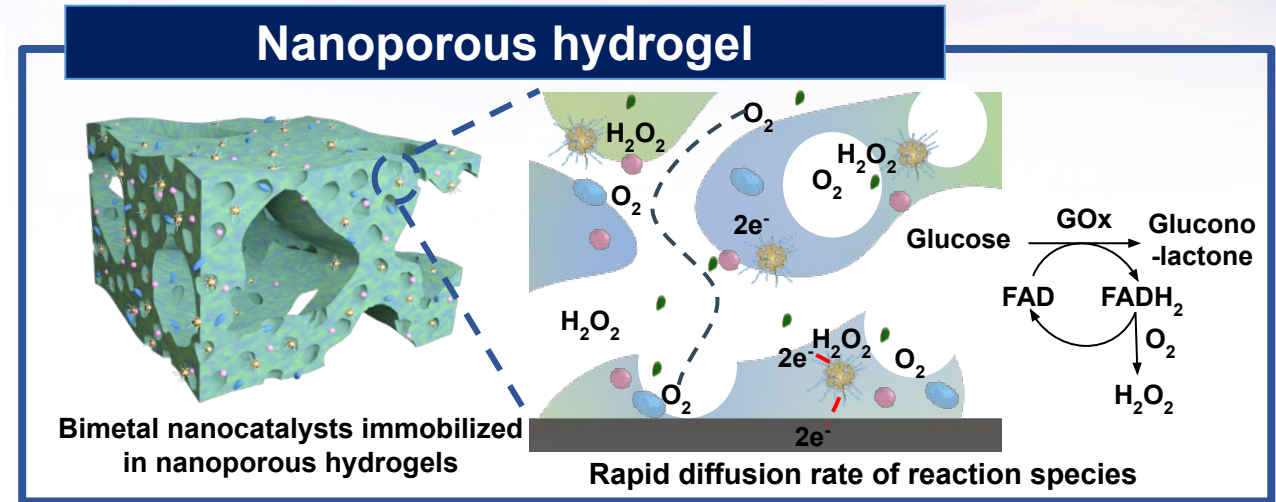
2. Smart Electrochemical Contact Lens

21

◆ Smart contact lens for highly sensitive and long-term stable diabetes diagnosis



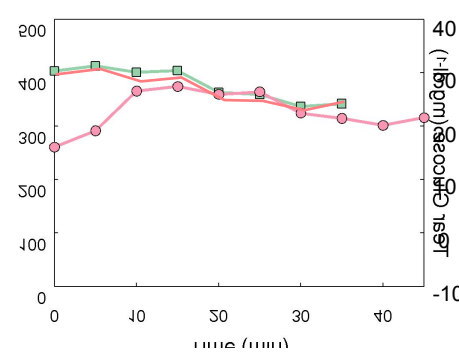
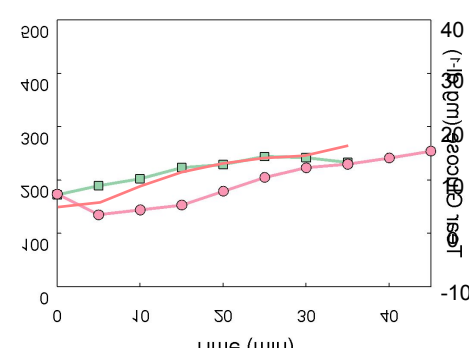
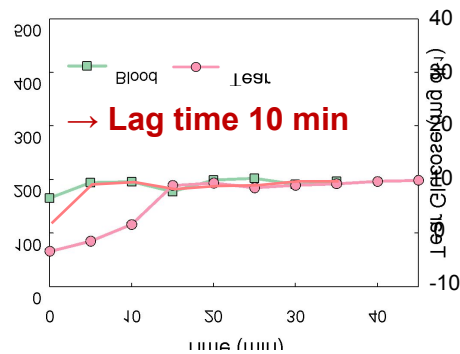
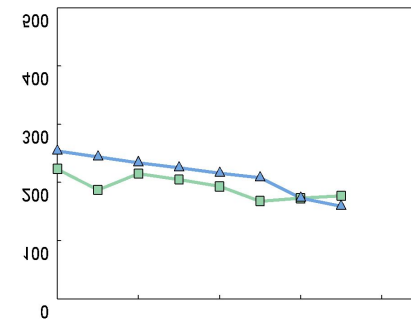
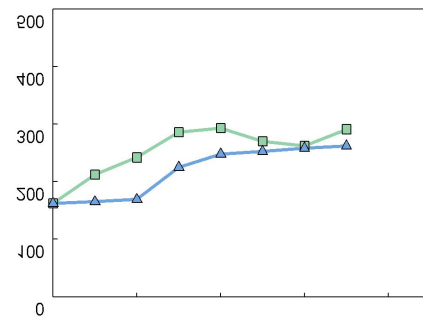
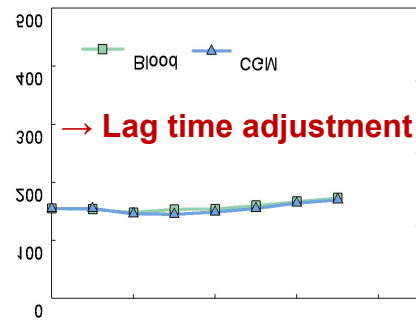
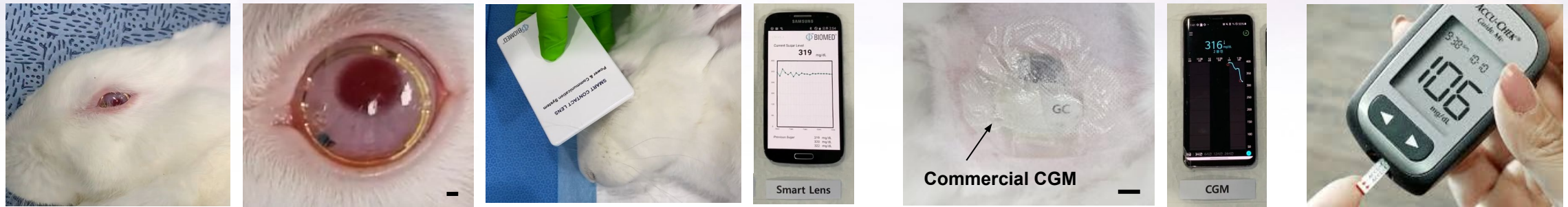
Core Tech: Bimetal nanocatalysts and glucose oxidase immobilized in nanoporous hydrogels



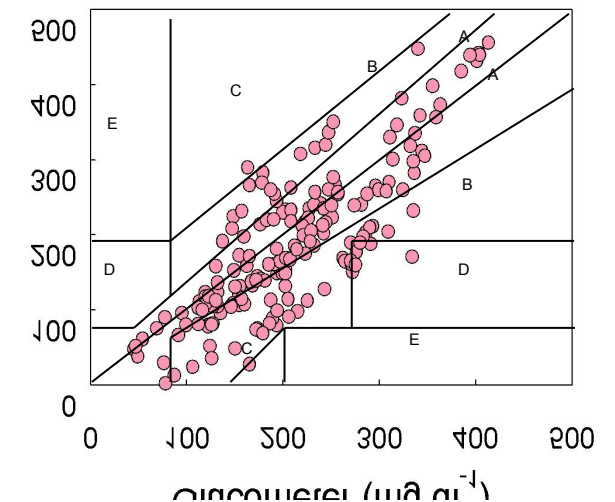
2. Smart Electrochemical Contact Lens

22

◆ Smart contact lens for long-term stable and highly sensitive diabetes diagnosis



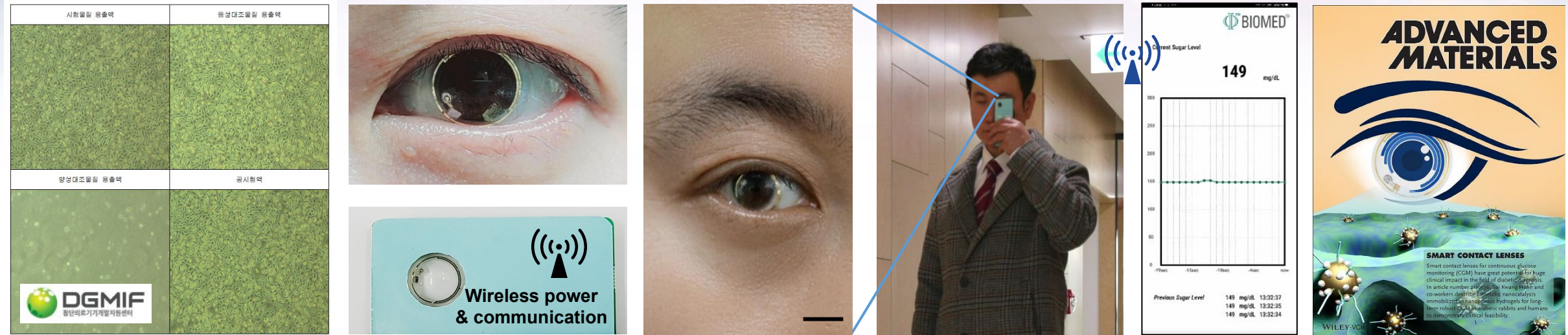
[Clark-error grid analysis]



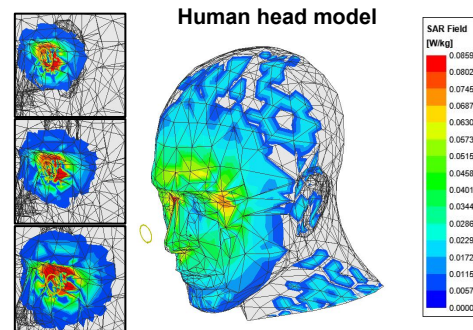
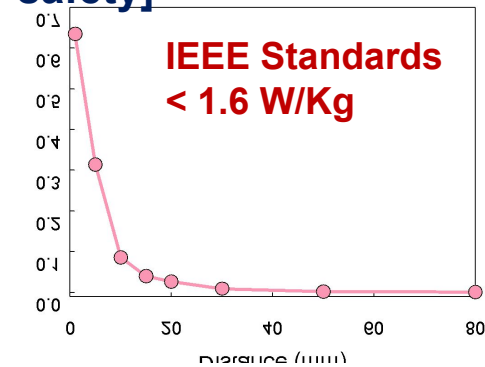
2. Smart Electrochemical Contact Lens

23

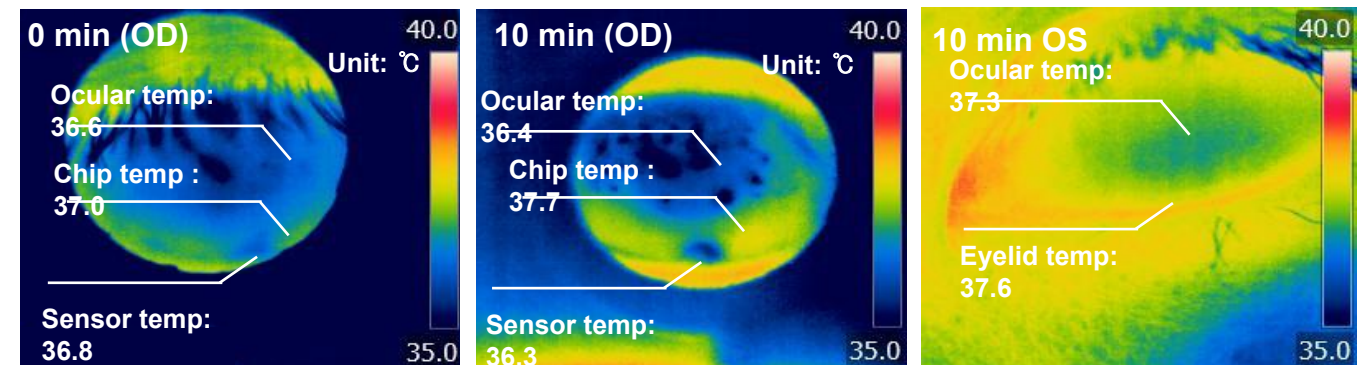
◆ Biological and electrical safety of smart contact lens for diabetes diagnosis



[Electromagnetic wave safety]



[Thermal safety]

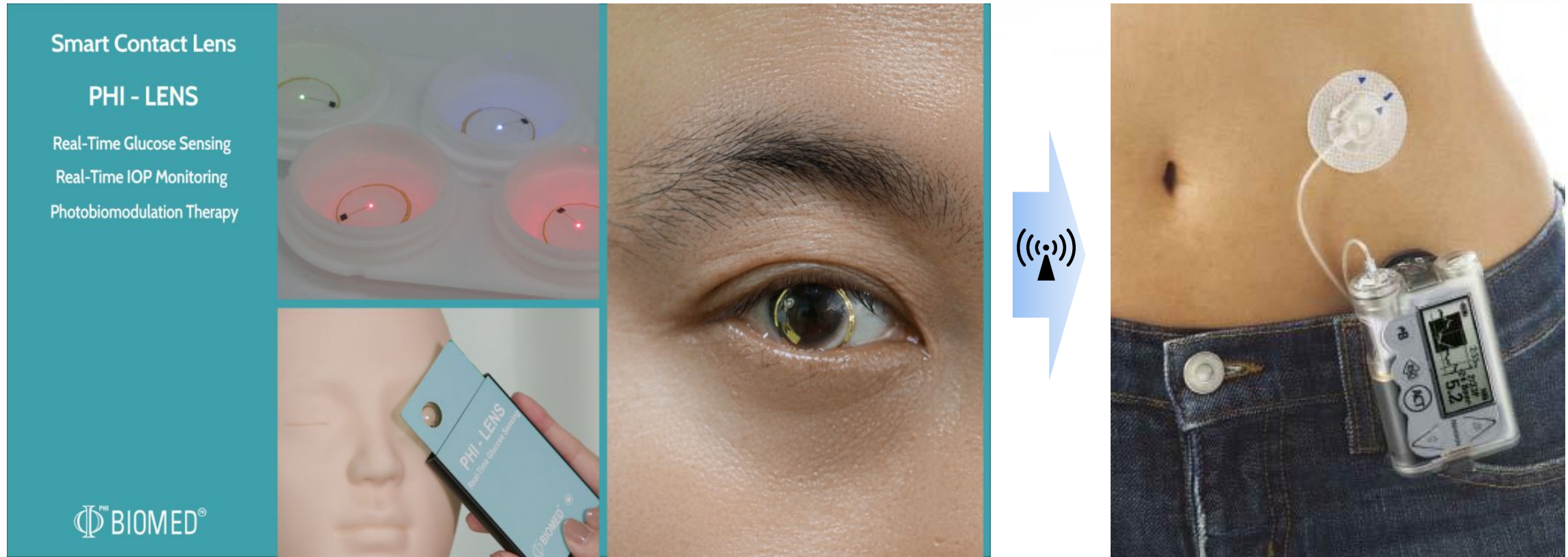


2. Smart Electrochemical Contact Lens

24

Summary Smart contact lens for diabetes diagnosis and therapy

- Smart contact lens in combination with insulin pump for diabetes theranosis



3. Smart Photonic Contact Lens

- Smart Electrochemical Contact Lens
- Smart Photonic Contact Lens
- Smart Piezoelectric Contact Lens

3. Smart Photonic Contact Lens

26

Photomedicine for diagnosis and therapy

nature
biomedical engineering

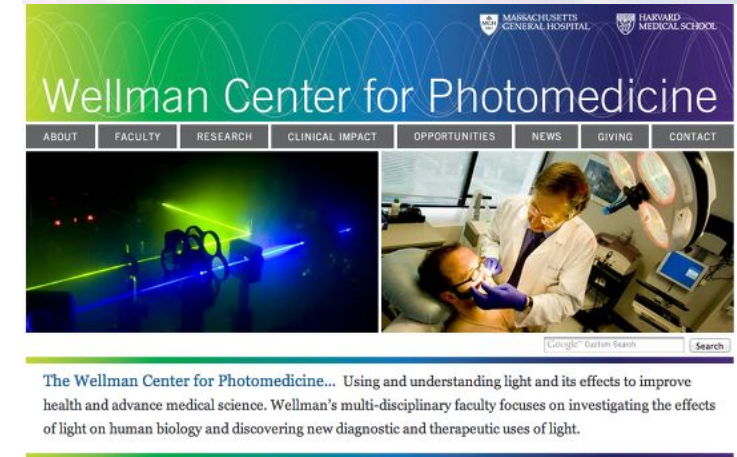
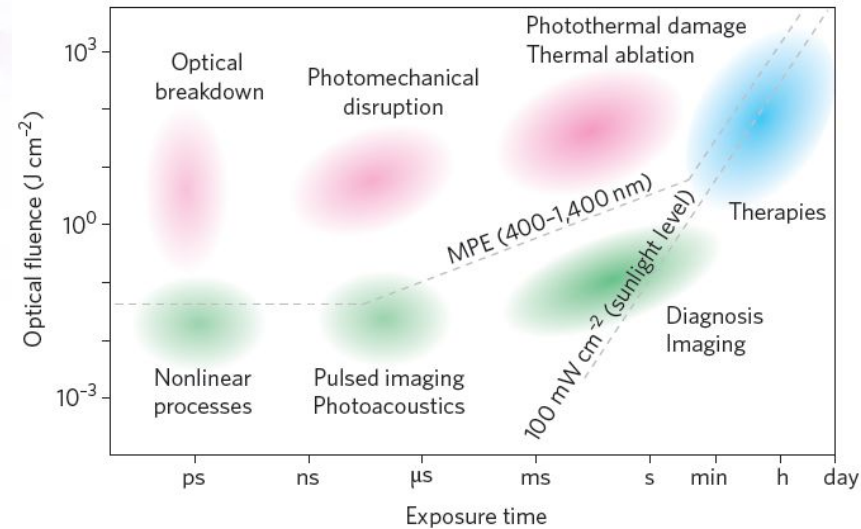
REVIEW ARTICLE

PUBLISHED: 10 JANUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0008

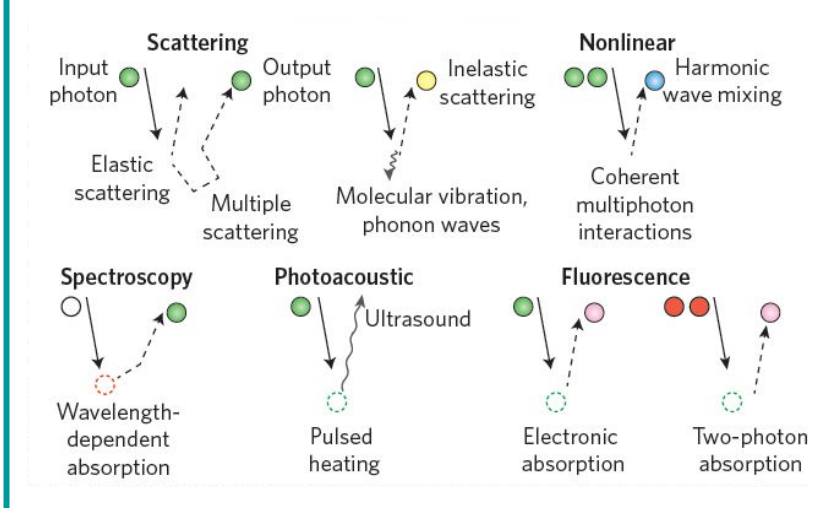
Light in diagnosis, therapy and surgery

Seok Hyun Yun^{1,2,3*} and Sheldon J. J. Kwok^{1,3}

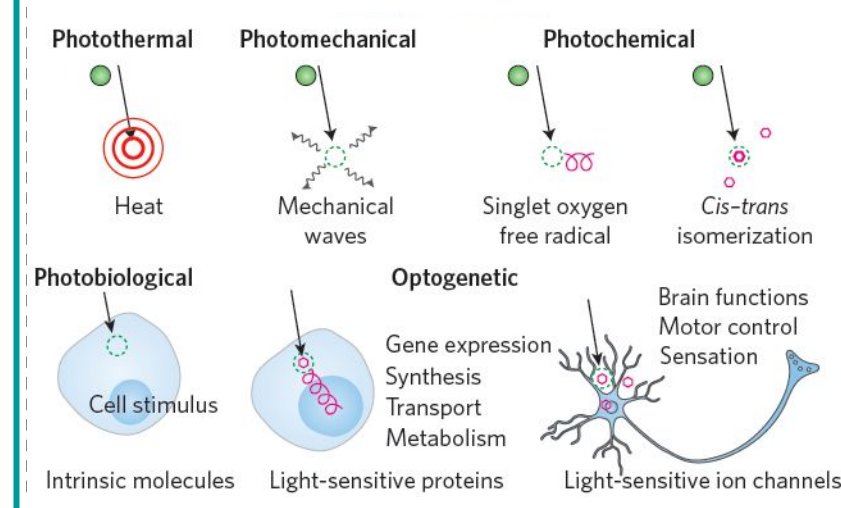
[Nature Biomedical
Engineering 2017;1:0008]



Diagnostics and imaging



Surgery and therapy



The Wellman Center for Photomedicine:

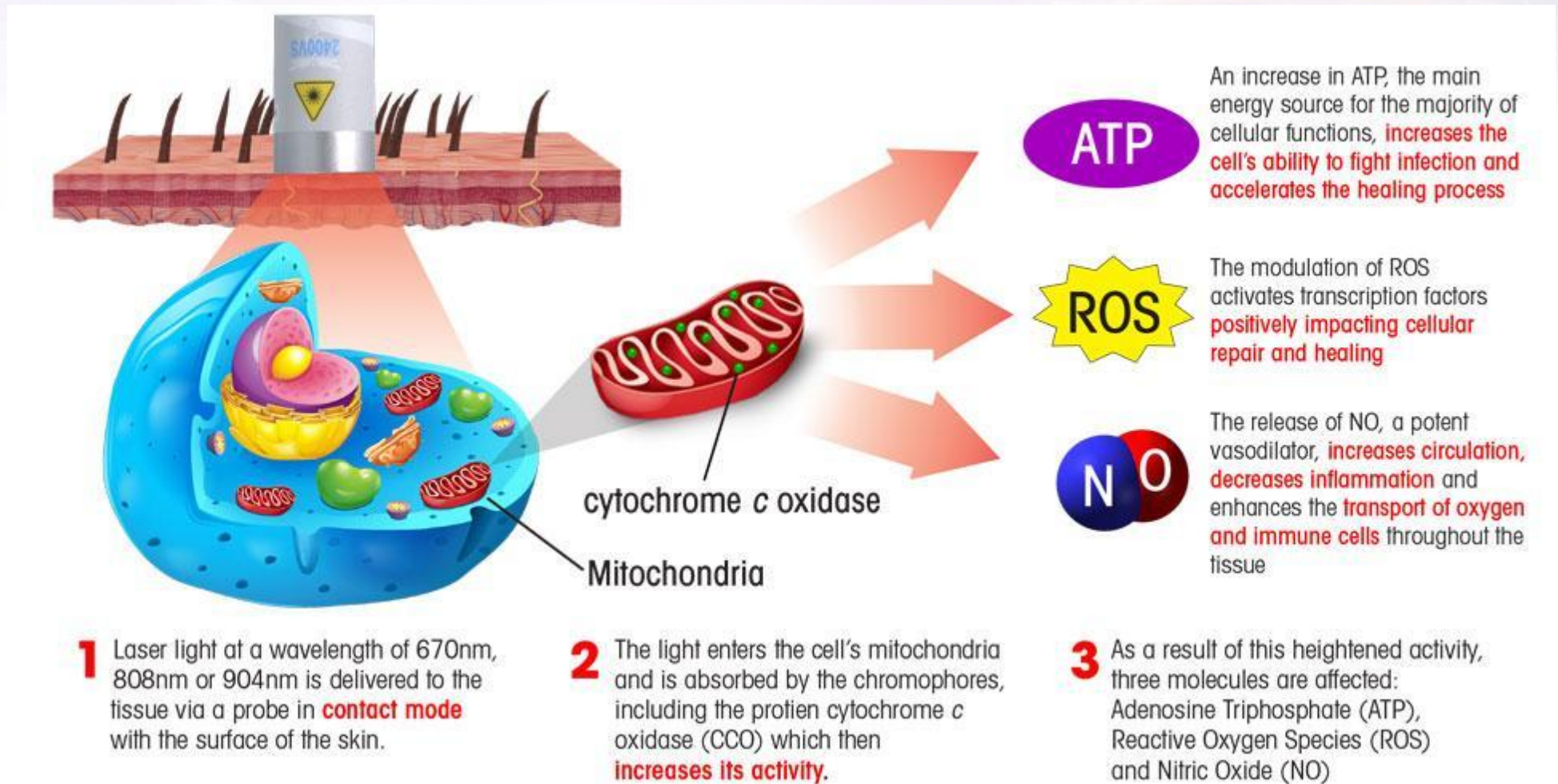
- discovering new diagnostic and therapeutic uses of light
- inventing new technologies for medicine
- partnering with industry to bring biomedical science to the patient
- training the next generation of scientists

Improving health and quality of life

3. Smart Photonic Contact Lens

27

◆ The photobiomodulation mechanism for light therapy in tissue



3. Smart Photonic Contact Lens

28

❖ Wearable photonic devices

Photobiomodulation



Purpose: Skin rejuvenation, hair growth, and wound healing

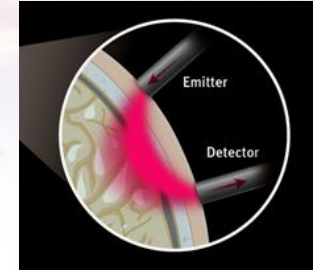
Display



Purpose: To deliver the information for users

- fNIR: functional near-infrared spectroscopy

fNIRs



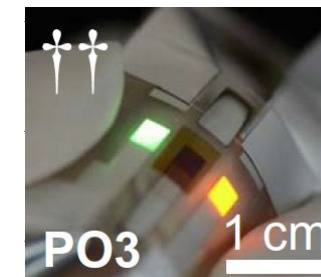
Purpose: To measure the brain activity using oxygen consumption in brain

Life cycle



Purpose: To control sleep by changing serotonin secretion using blue light

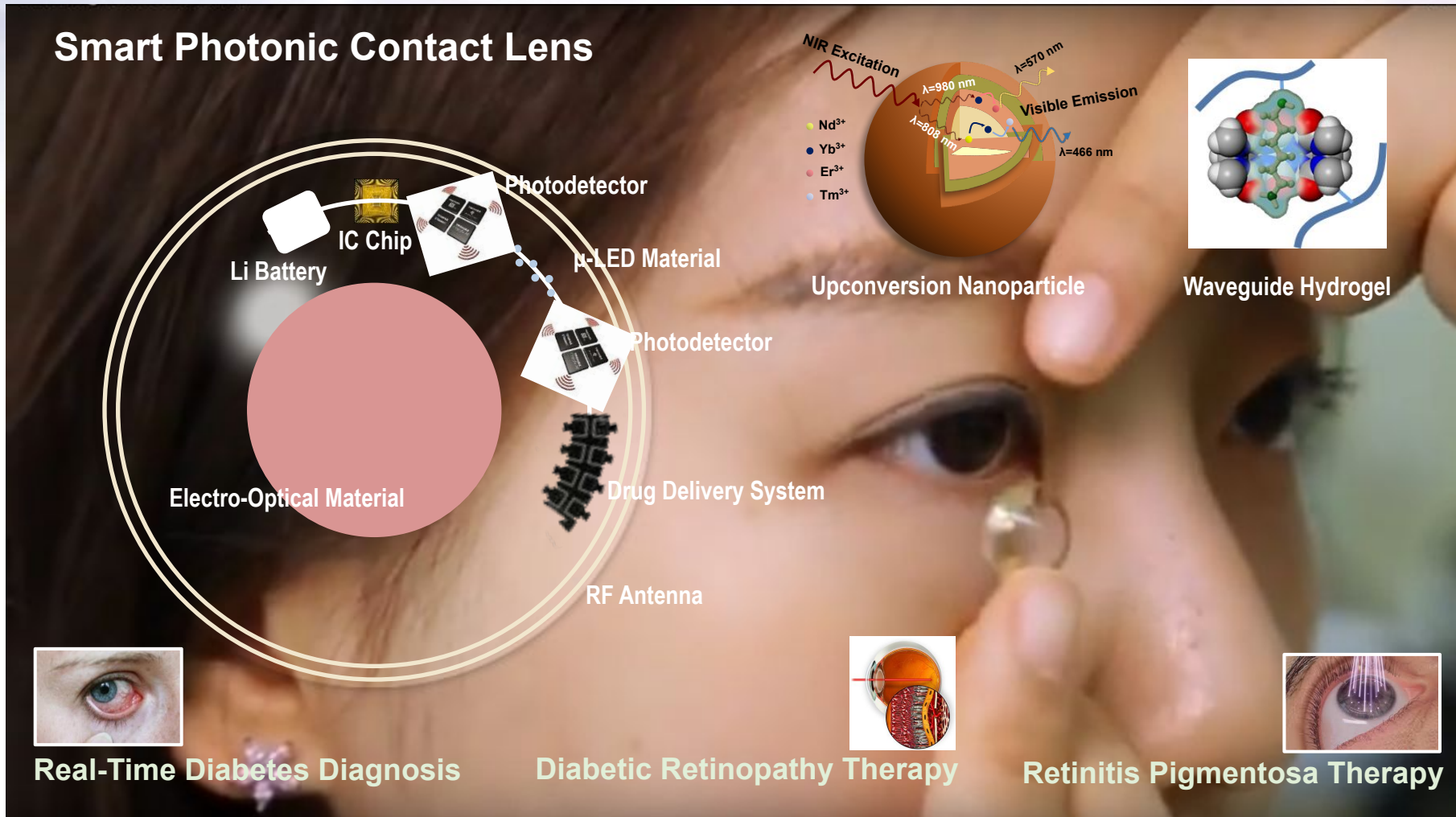
Pulse oximetry



Purpose: To measure oxygen concentration in blood using light absorption change

3. Smart Photonic Contact Lens

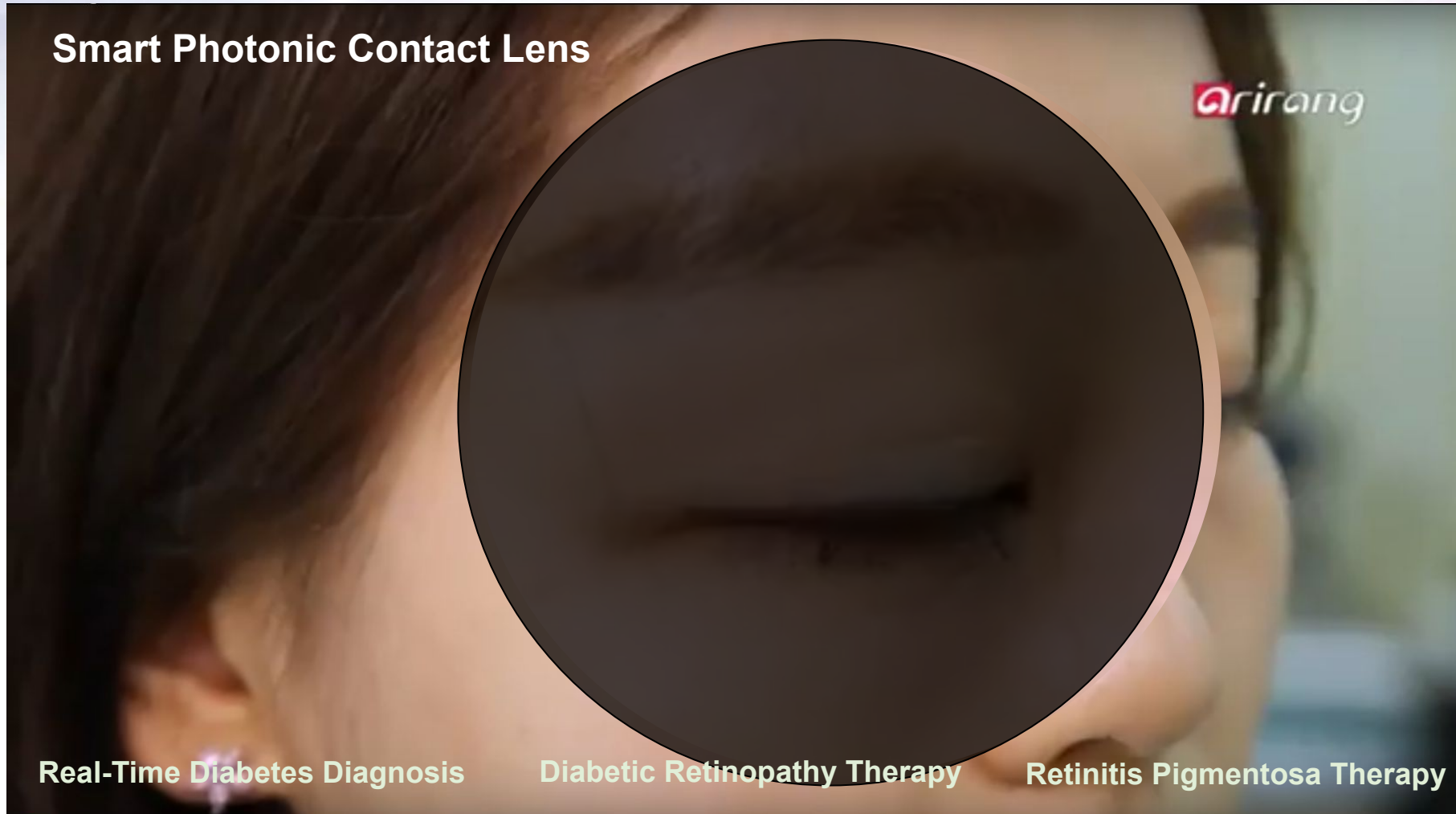
29



US Patent 15/522,816, EU Patent 16783461.3, PCT/KR2017/015243, Korean Patent 10-2017-0059225

3. Smart Photonic Contact Lens

30



US Patent 15/522,816, EU Patent 16783461.3, PCT/KR2017/015243, Korean Patent 10-2017-0059225

3. Smart Photonic Contact Lens

31



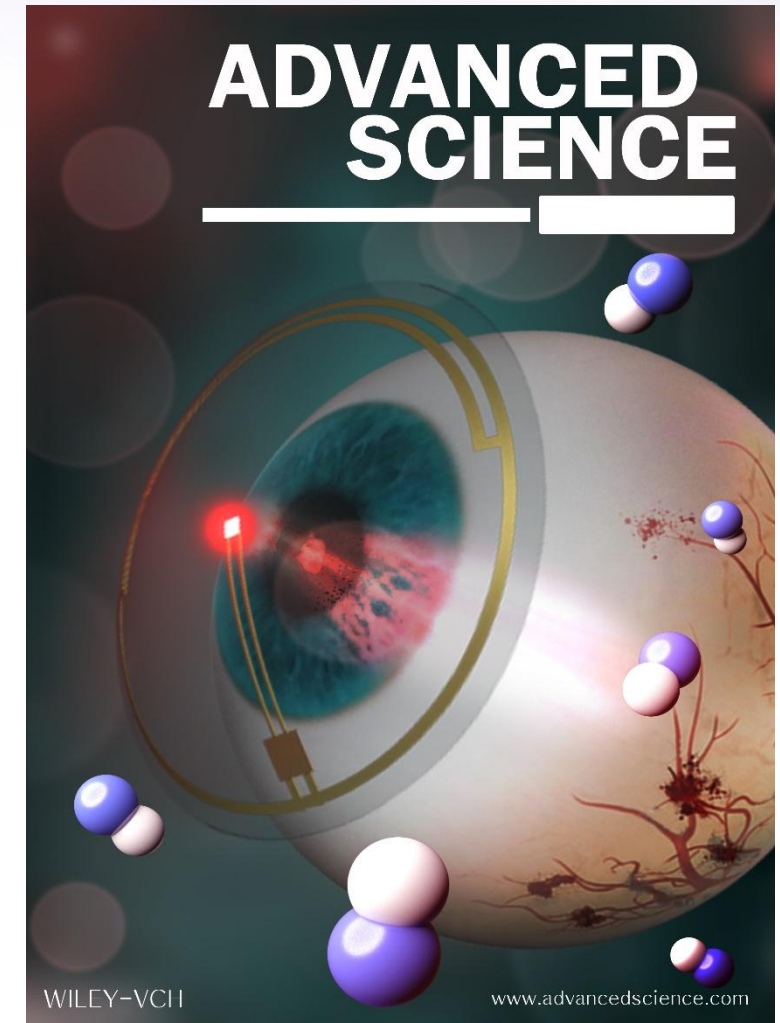
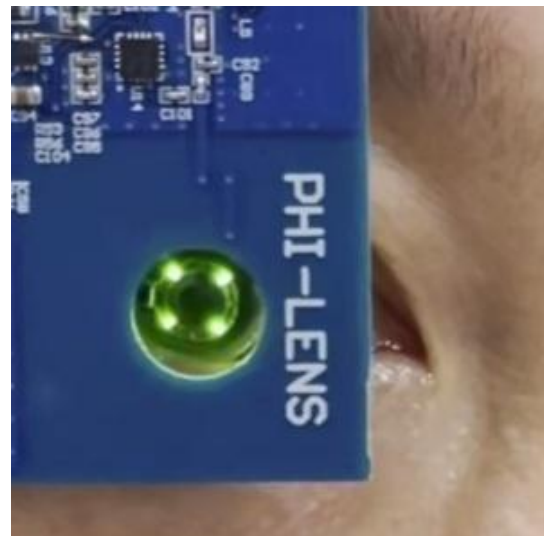
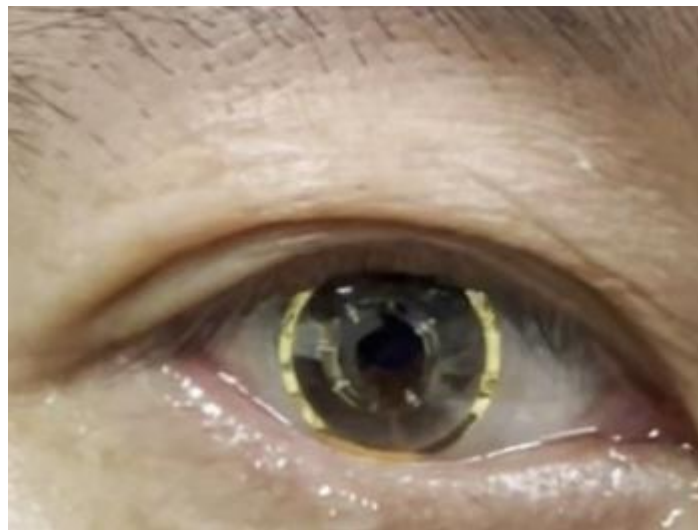
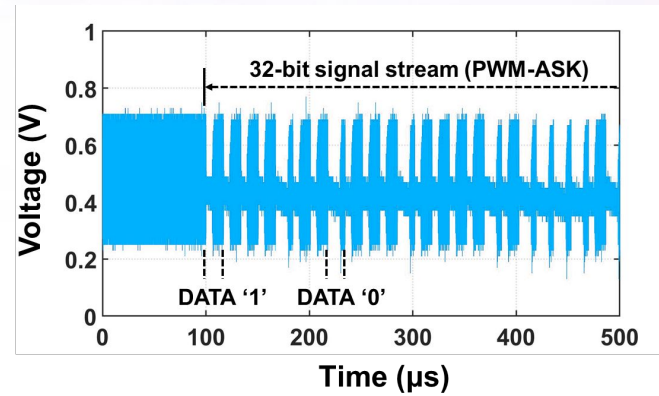
US Patent 15/522,816, EU Patent 16783461.3, PCT/KR2017/015243, Korean Patent 10-2017-0059225

Summary Smart photonic contact lens for diabetic retinopathy phototherapy



Diabetic retinopathy

Normal



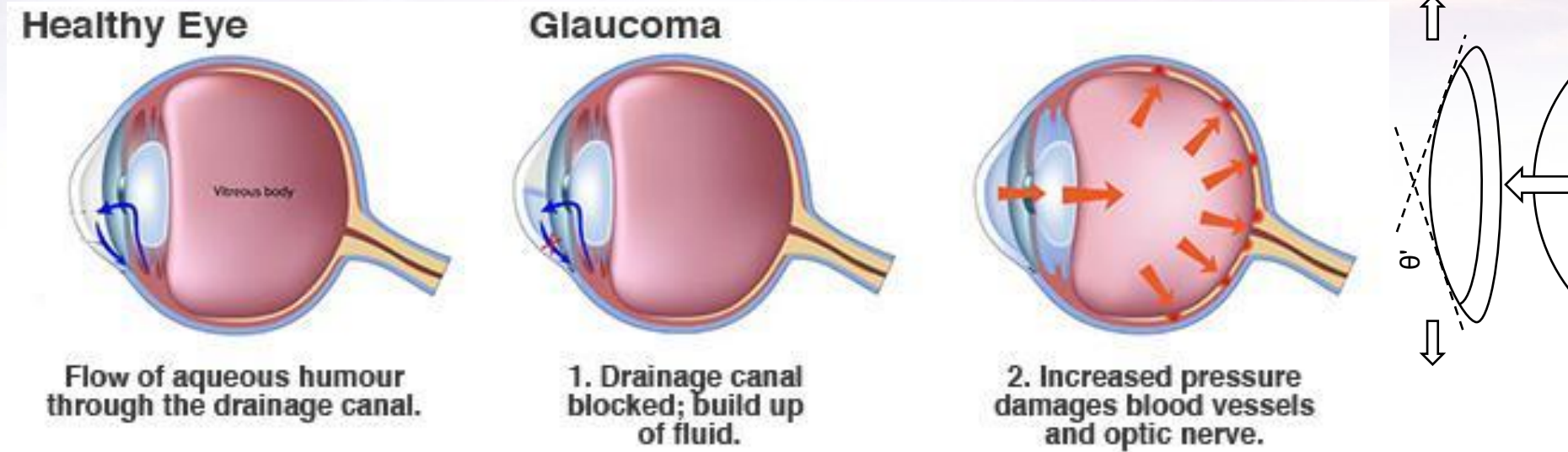
4. Smart Piezoelectric Contact Lens

- Smart Electrochemical Contact Lens
- Smart Photonic Contact Lens
- Smart Piezoelectric Contact Lens

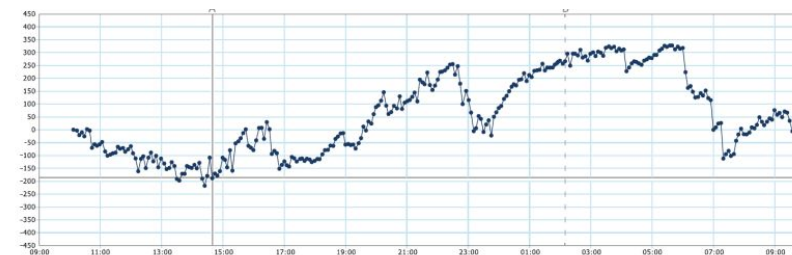
4. Smart Piezoelectric Contact Lens

34

◆ Development and symptoms of glaucoma



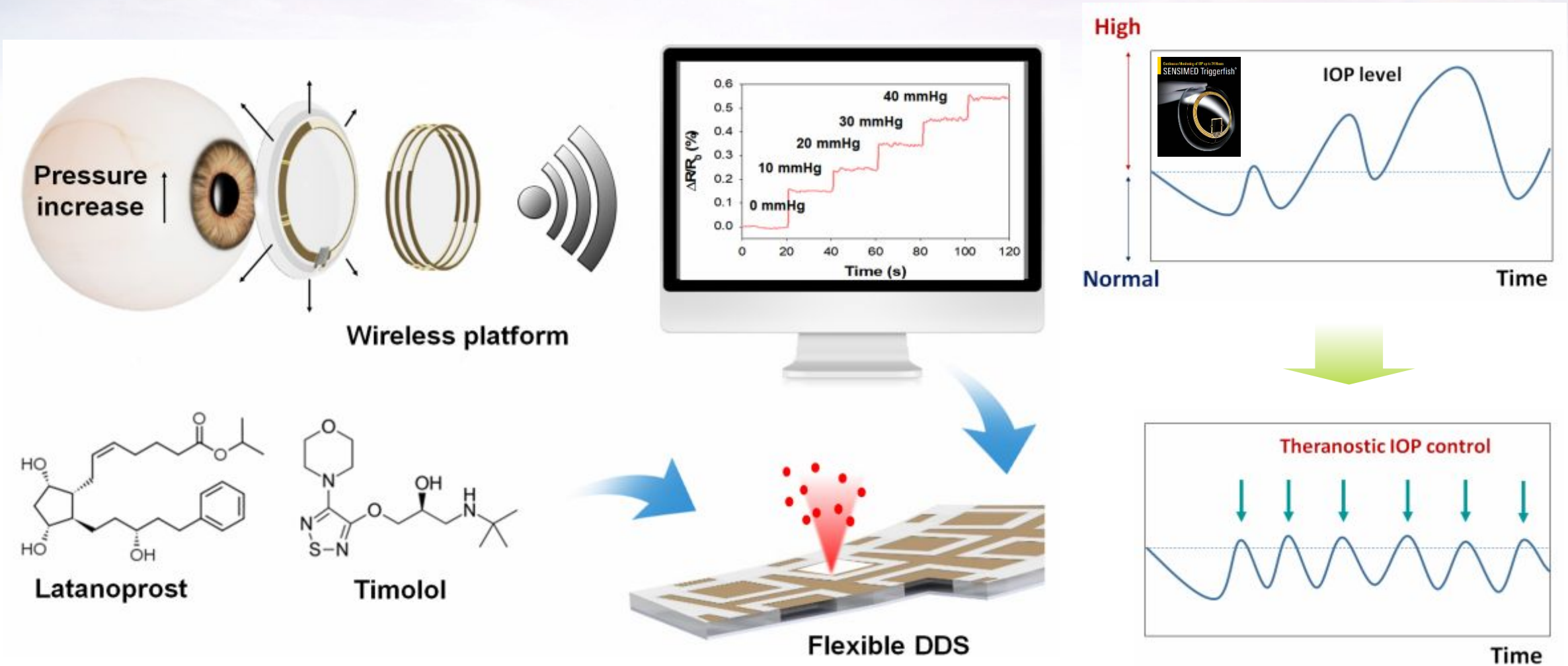
"Sensimed has developed a paradigm shift in glaucoma to continuously and non-invasively monitor individual intraocular pressure."

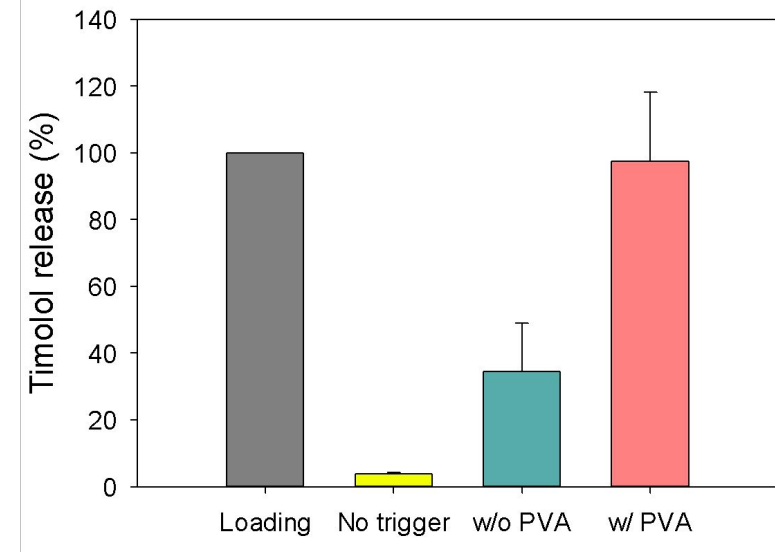


4. Smart Piezoelectric Contact Lens

35

◆ Design of transparent AuHNW IOP sensor and DDS on smart contact lens

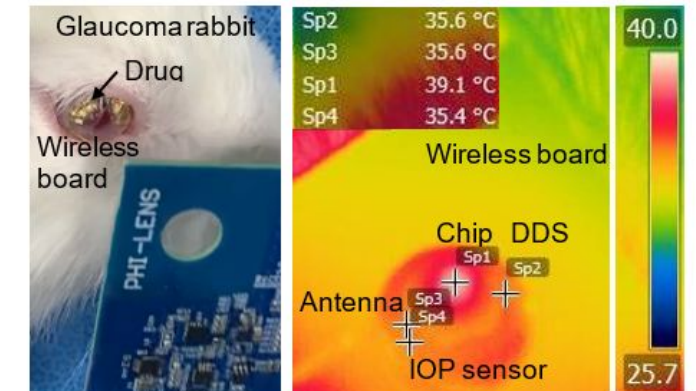
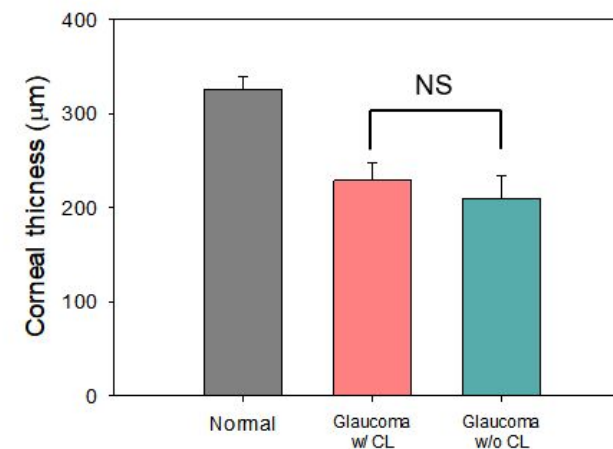
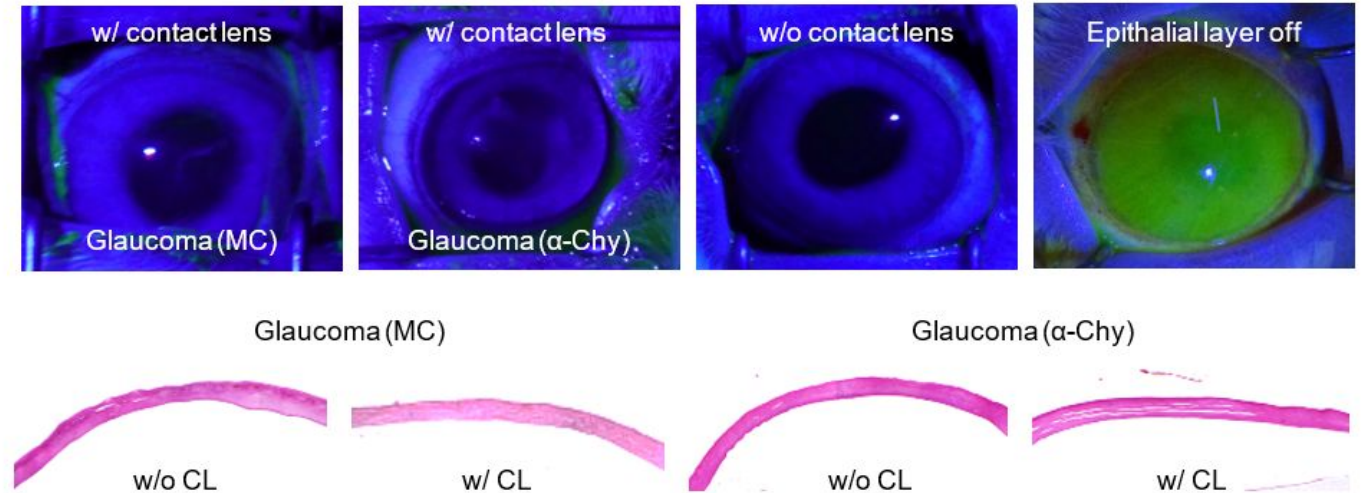
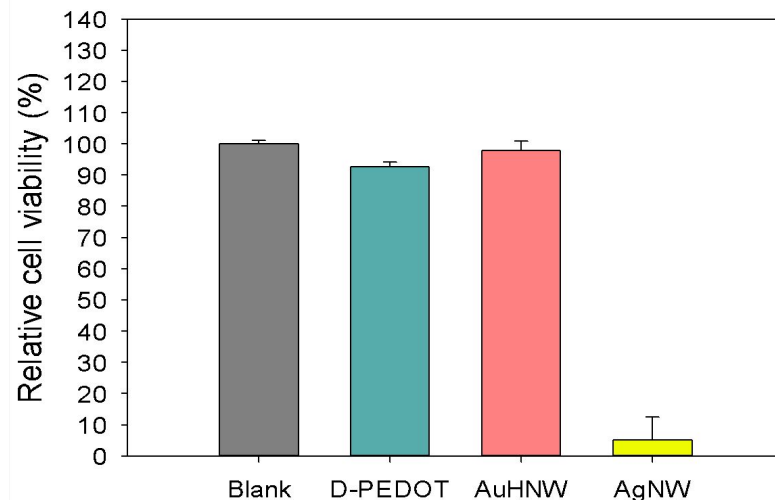
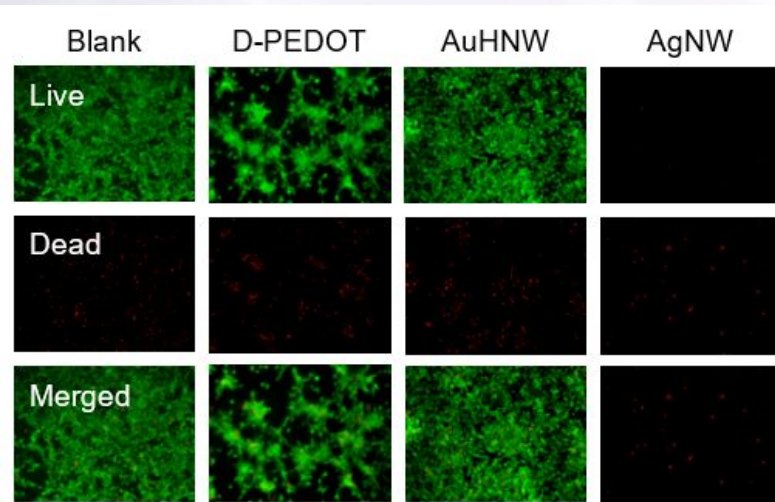


Hahn *et al.* Nature Communication, 13:6801 (2022)

4. Smart Piezoelectric Contact Lens

37

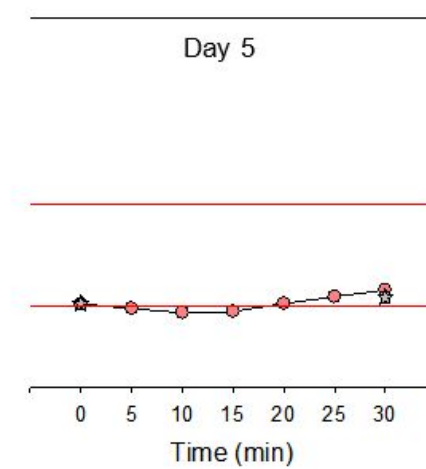
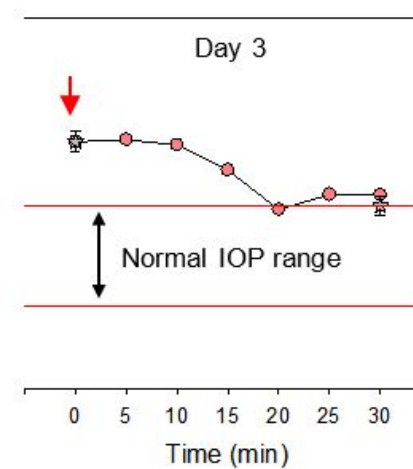
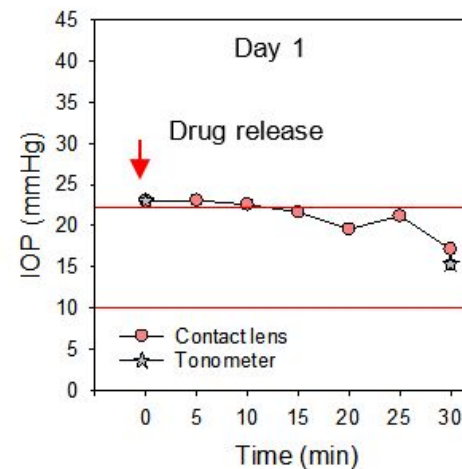
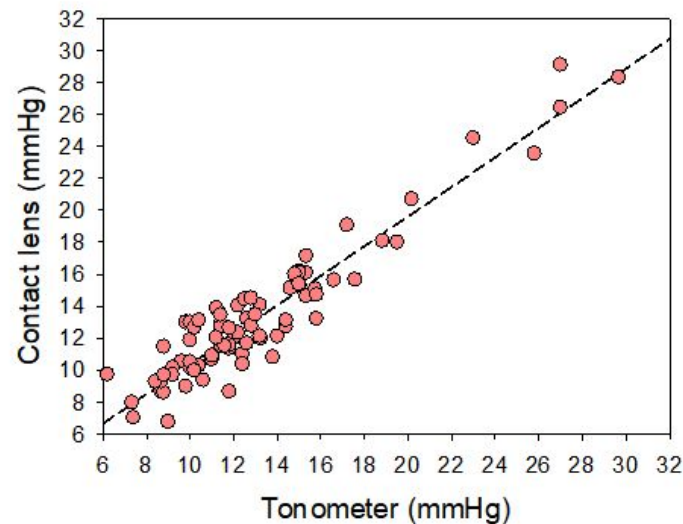
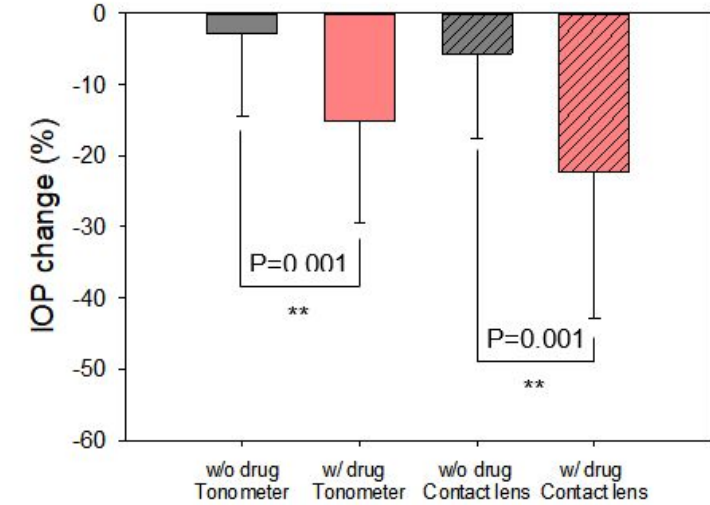
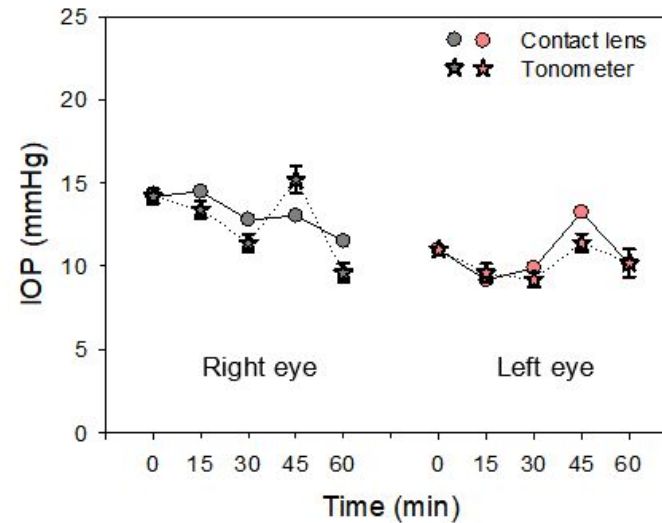
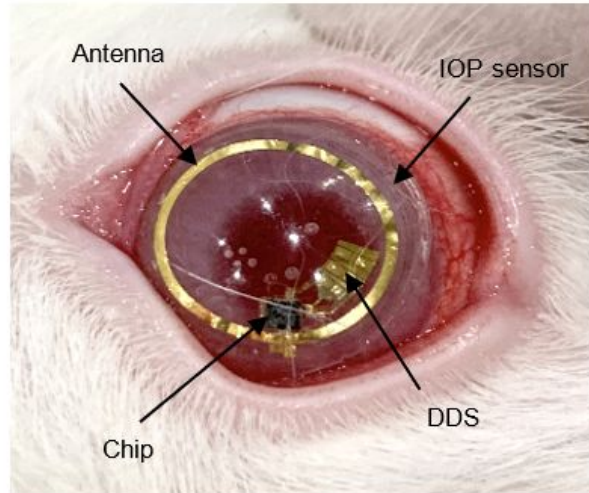
❖ Biological and electrical safety of smart contact lens for glaucoma IOP theranosis



4. Smart Piezoelectric Contact Lens

38

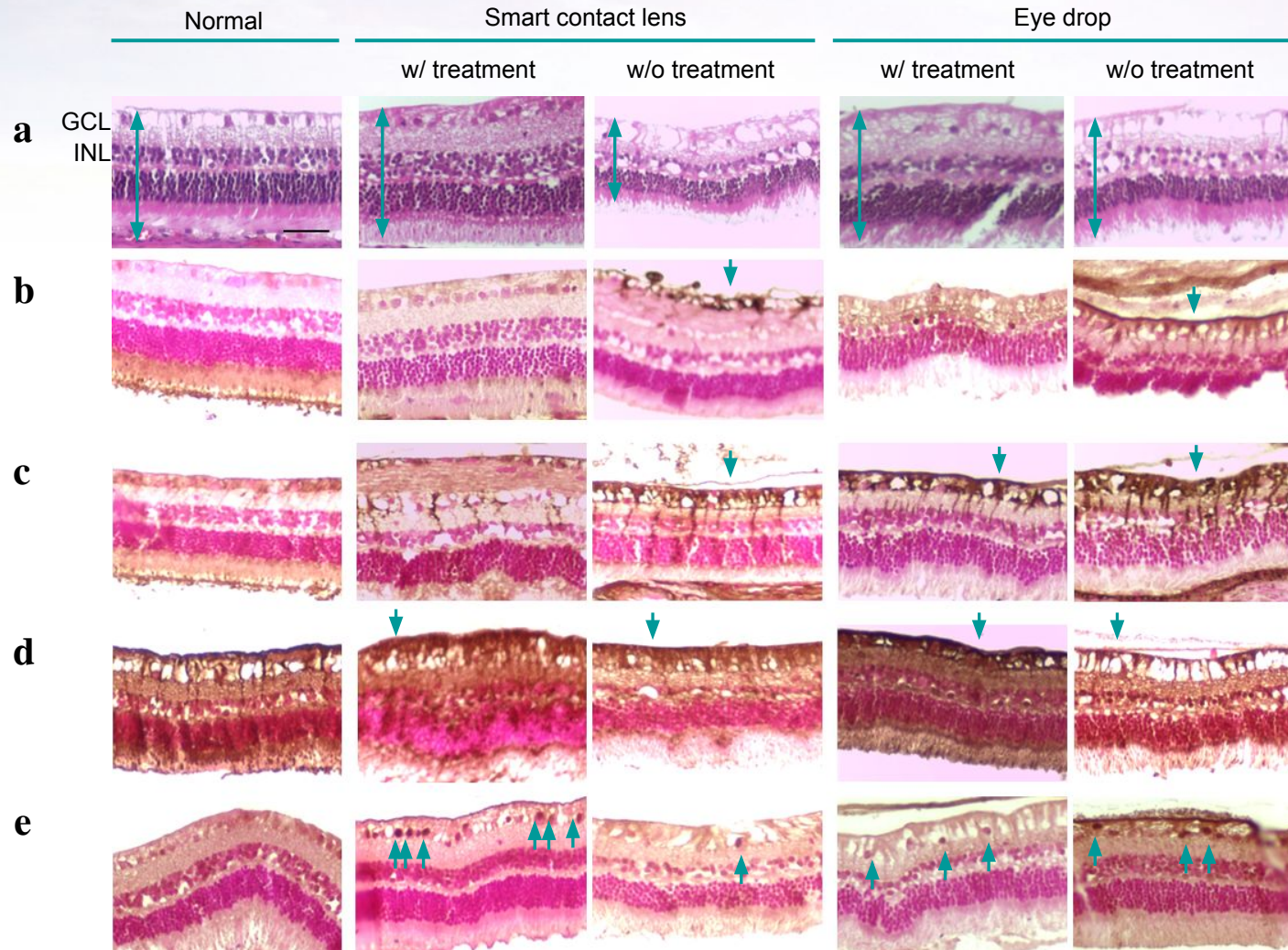
◆ *In vivo* monitoring and control of IOP by wireless smart contact lens



4. Smart Piezoelectric Contact Lens

39

◆ *In vivo* monitoring and control of IOP by wireless smart contact lens



***In vivo* therapeutic effect by
theranostic smart contact lens and eye
drop in glaucoma rabbits induced by
injecting methylcellulose. a, OM
images for retinal histology. OM images
for immunohistochemical analyses for b,
GFAP, c, CD11b, d, BDNF and e, Brn3a.
Arrows indicate the expression of each
marker (scale bar, 100 μ m).**

Summary Smart piezoelectric contact lens for theranostic IOP management in glaucoma

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Article <https://doi.org/10.1038/s41467-022-34597-8>

Wireless theranostic smart contact lens for monitoring and control of intraocular pressure in glaucoma

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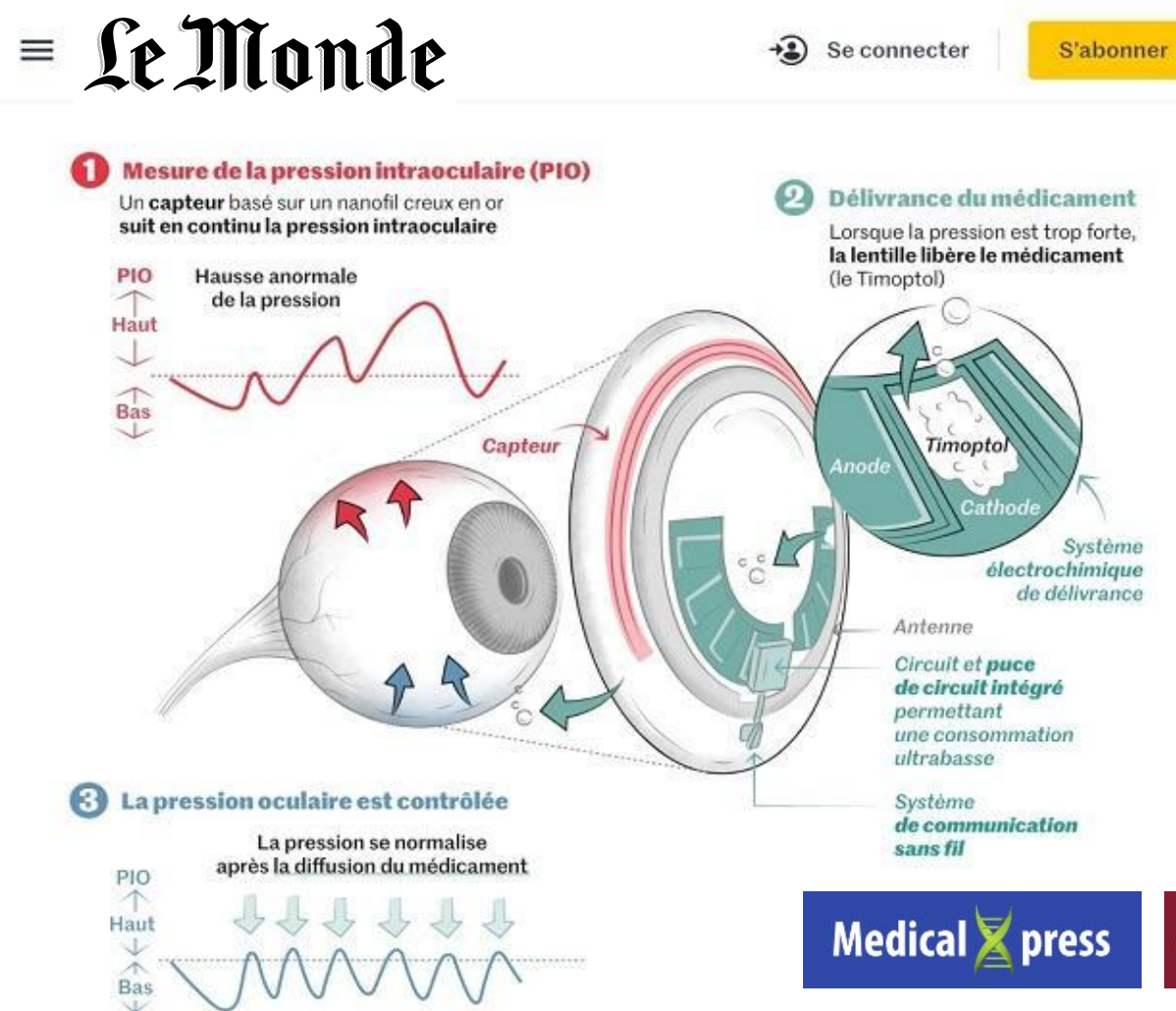
Tae Yeon Kim¹, Jee Won Mok², Sang Hoon Hong¹, Sang Hoon Jeong¹, Hyunsik Choi³, Sangbaek Shin³, Choun-Ki Joo² & Sei Kwang Hahn^{1,2}✉

Glaucoma is one of the irreversible ocular diseases that can cause vision loss in some serious cases. Although Triggerfish has been commercialized for monitoring intraocular pressure in glaucoma, there is no smart contact lens to monitor intraocular pressure and take appropriate drug treatment in response to the intraocular pressure levels. Here, we report a precisely integrated theranostic smart contact lens with a sensitive gold hollow nanowire based intraocular pressure sensor, a flexible drug delivery system, wireless power and communication systems and an application specific integrated circuit chip for both monitoring and control of intraocular pressure in glaucoma. The gold hollow nanowire based intraocular pressure sensor shows high ocular strain sensitivity, chemical stability and biocompatibility. Furthermore, the flexible drug delivery system can be used for on-demand delivery of timolol for intraocular pressure control. Taken together, the intraocular pressure levels can be successfully monitored and controlled by the theranostic smart contact lens in glaucoma induced rabbits. This theranostic smart contact lens would be harnessed as a futuristic personal healthcare platform for glaucoma and other ocular diseases.

Glaucoma is a chronic eye disease requiring continuous medical care for patients' life time. Intraocular pressure (IOP) is one of the most important indicators of glaucoma^{1,2}. Glaucoma patients are generally recommended for monitoring IOP and reducing IOP to a lower range. Accordingly, the appropriate IOP control is currently the only available first medical care for glaucoma patients. Commercial tonometers such as a rebound tonometer and a Goldmann applanation tonometer (GAT) have been used for the static IOP measurements in the clinic³. However, these measurements have some challenges. GAT can be inconvenient due to time and space constraints. Although home tonometry is portable, patients need to carefully follow the manual for accurate detection. These can significantly interrupt the daily life of patients. Furthermore, it is difficult to collect many data from the conventional static IOP measurements in a single day and to monitor the IOP fluctuation of patients. This may cause inappropriate treatment to patients, because the IOP can change time to time^{4,5}. Recently, eye drop solutions are the important first medical treatment for the IOP control of glaucoma patients⁶⁻⁸. However, it is highly challenging to achieve the high adherence of glaucoma patients. The method and time of drug treatments as instructed have not been followed by many glaucoma patients⁹. Furthermore, each patient can have a different therapeutic effect of drugs, which necessitate a different drug dose for each person¹⁰. Accordingly, it is important to monitor continuous IOP changes in real-time and delivers drugs in response to the IOP profiles. Smart contact lenses can provide a new paradigm in glaucoma as a promising alternative to conventional management methods with non-invasive, continuous IOP monitoring and on-demand drug delivery¹¹⁻¹³. In particular, recent smart contact lenses based on strain

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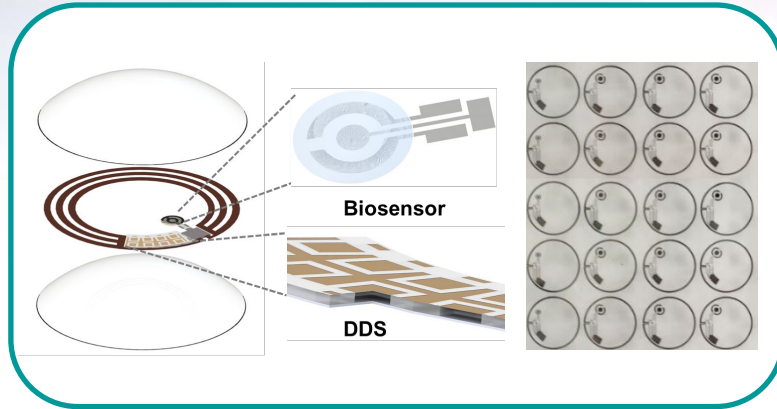
Nature Communications | (2022)13:6801



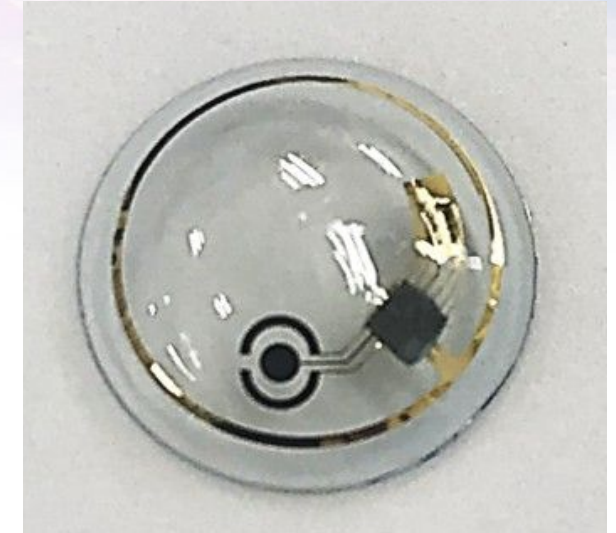
5. Summary for Smart Theranostic Contact Lens

41

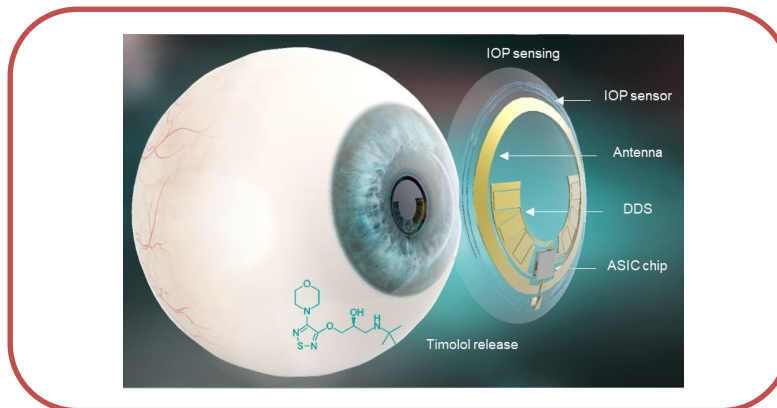
Smart Electrochemical Contact Lens



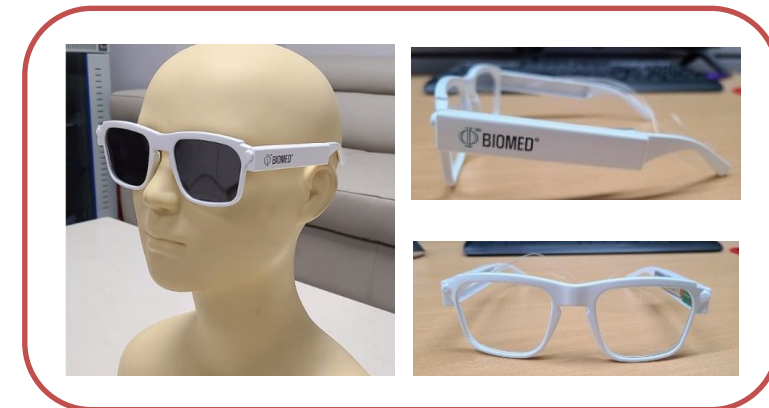
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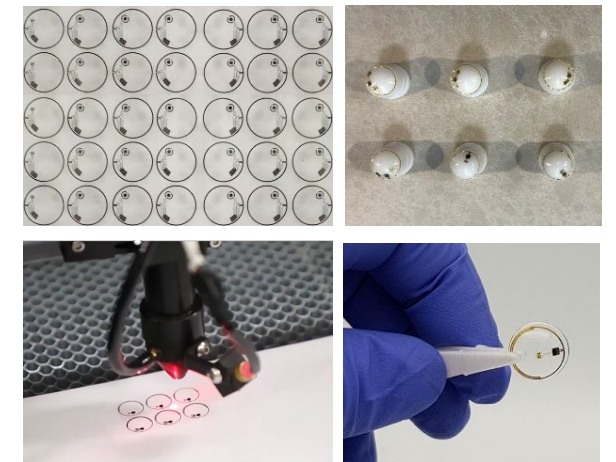
Smart Theranostic Contact Lenses for Diabetes and Ocular Diseases



Smart Piezoelectric Contact Lens



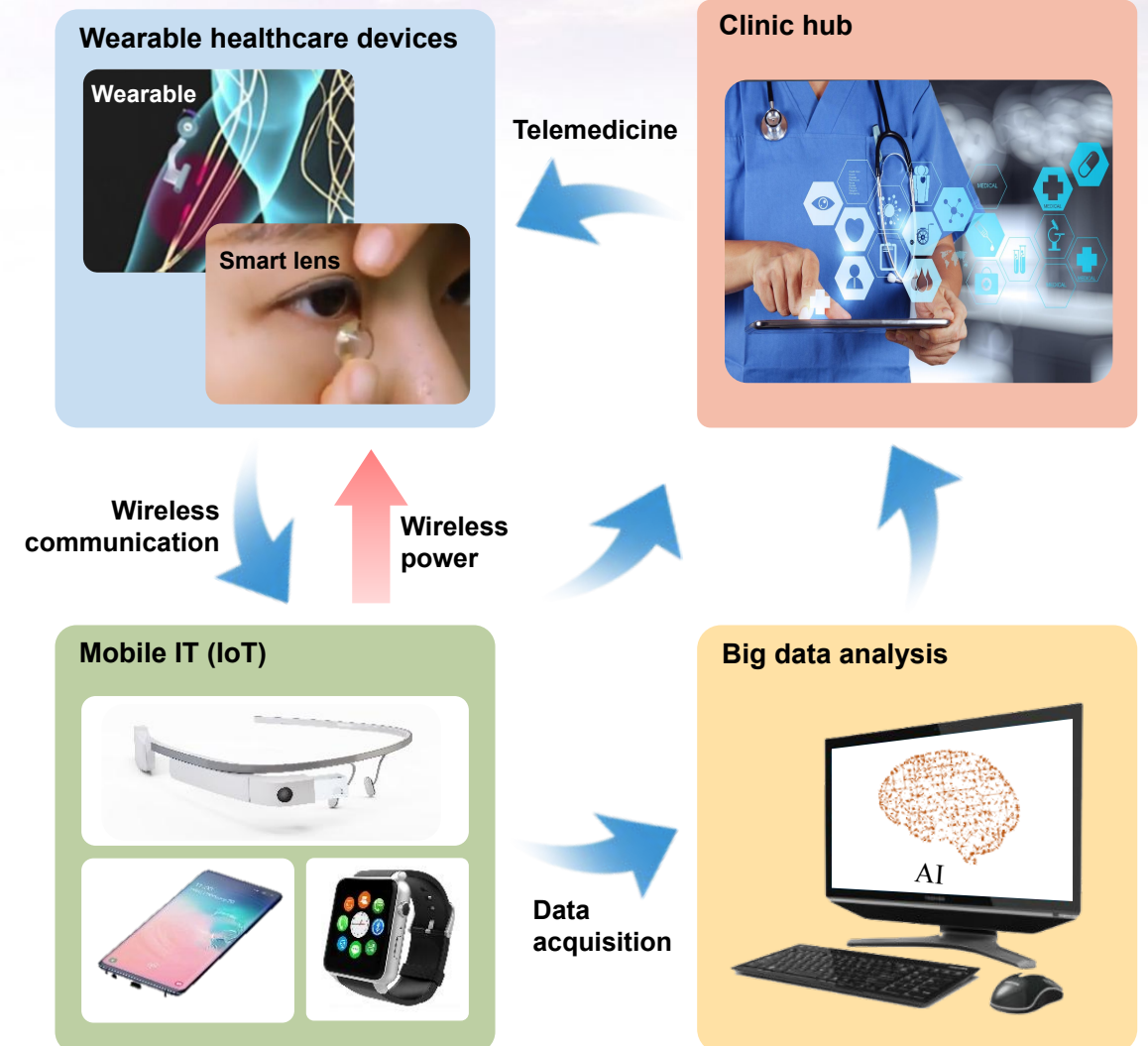
Smart Glasses for Ubiquitous Healthcare



5. Smart Healthcare Contact Lens and Glasses

42

❖ Wireless smart contact lens and glasses for ubiquitous healthcare in Industry 4.0



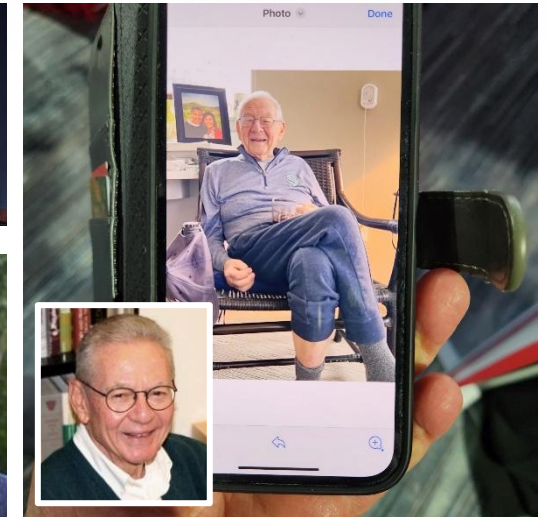
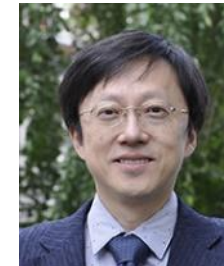
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Thank You for Your Kind Attention !!!

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Seok Cheon Endowed Chair Professor Sei Kwang Hahn

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