Technische Universität Dresden

DRESDEN concept

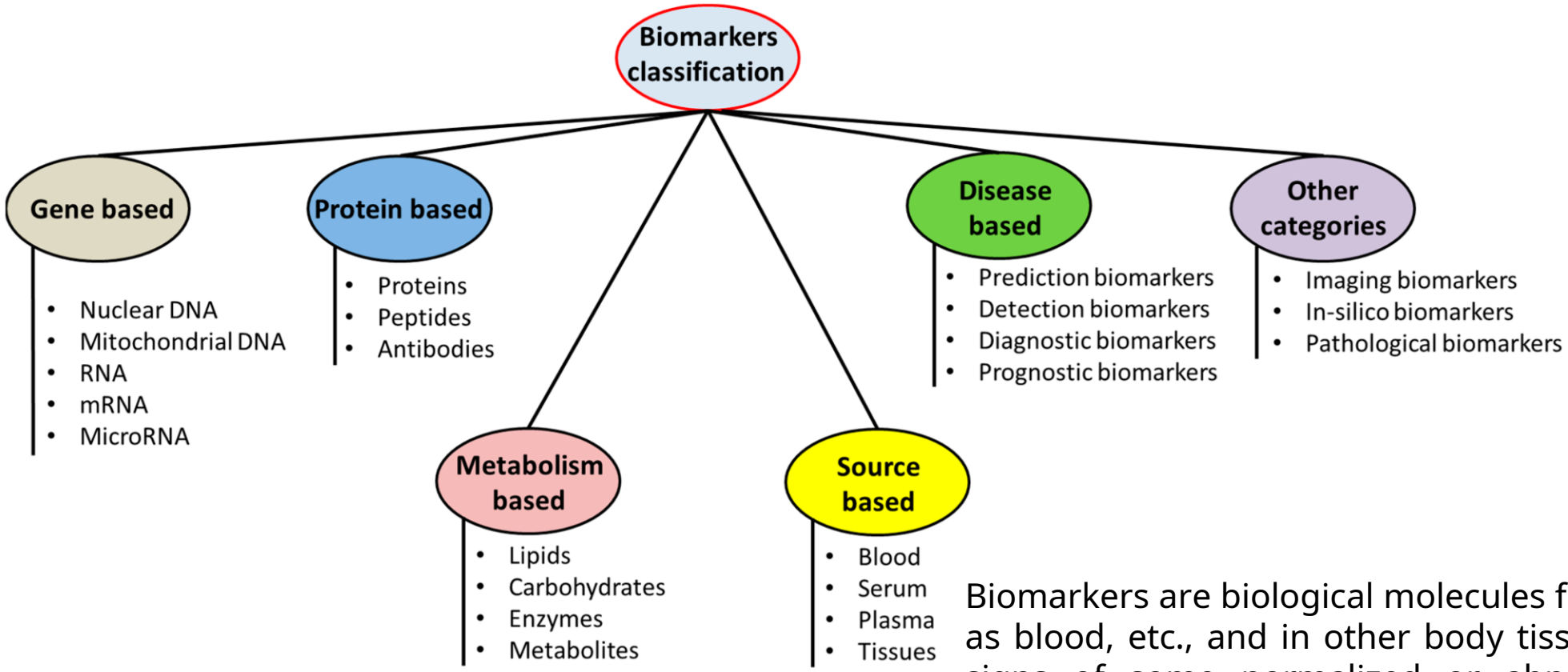
Bioelectronics and Neuromorphic Computing with Organic Electrochemical Transistors

Lecture Summer Term 2026

Hans Kleemann, Peiyun Li
(Dresden Integrated Center for Applied Physics and Photonic Materials)

7. Bioelectronic Application

7.1 Biochemical Sensing

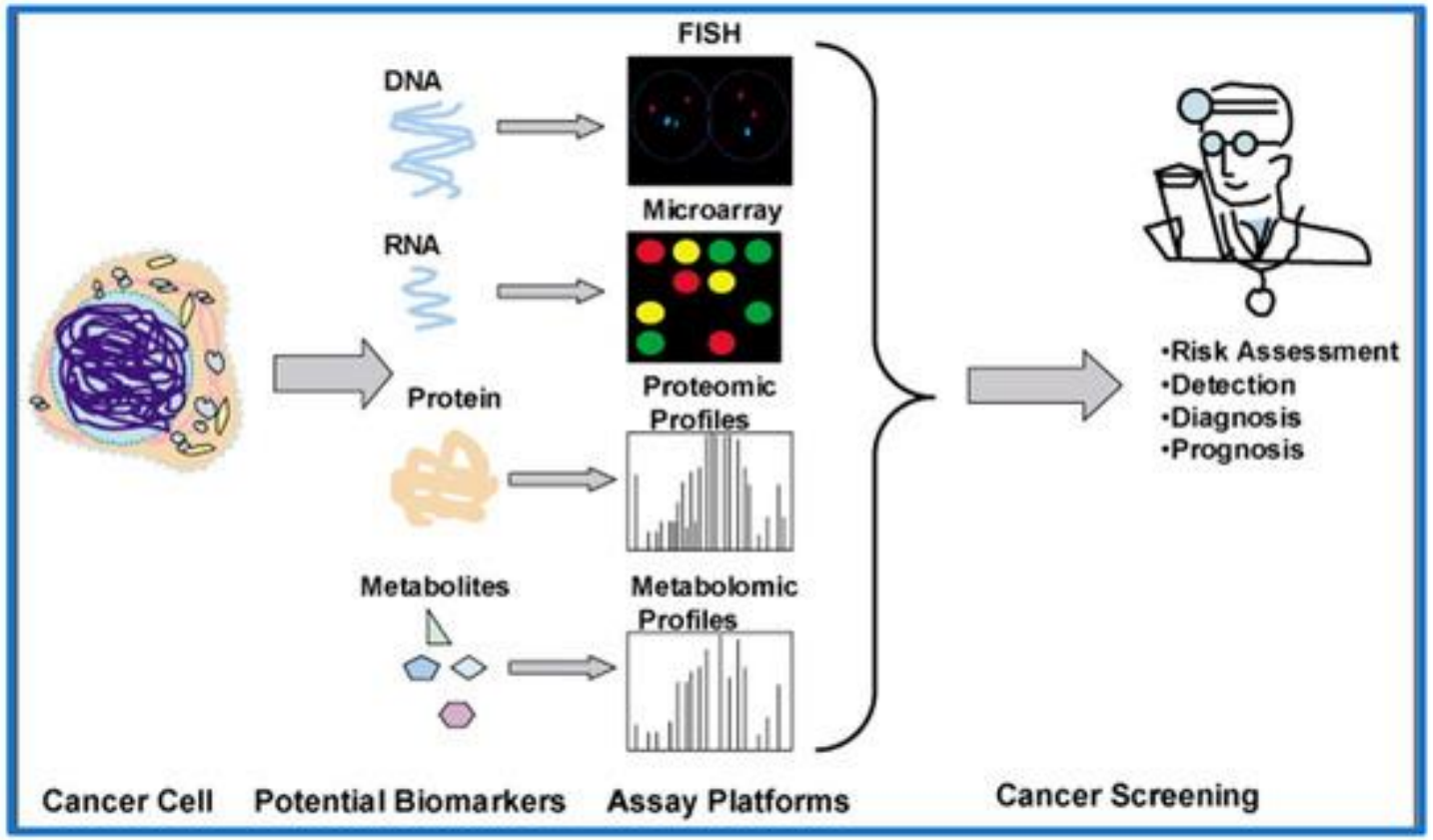


Biomarkers are biological molecules found in body fluids such as blood, etc., and in other body tissues which can offer the signs of some normalized or abnormal pathophysiologic conditions, or a disease.

Pharmaceutics 2023, 15(6), 1630

7. Bioelectronic Application

7.1 Biochemical Sensing



Fluorescence In Situ Hybridization
PCR: Polymerase Chain Reaction

MS: Mass Spectrometry

LC-MS: Liquid Chromatography-Mass Spectrometry

GC-MS: Gas Chromatography-Mass Spectrometry

2-DE: Two-dimensional gel electrophoresis

NMR: Nuclear Magnetic Resonance

Pharmaceutics 2023, 15(6), 1630

7. Bioelectronic Application

7.1 Biochemical Sensing

Urine test strips
enzymatic colorimetric dipstick

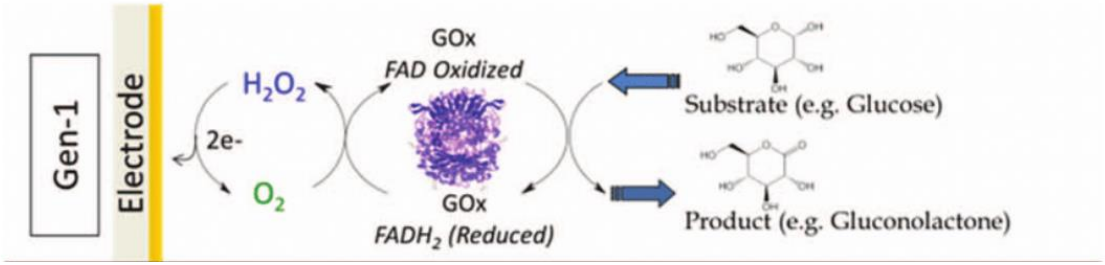
Serum, plasma, whole blood
Hexokinase-based photometric assay

Finger-prick capillary blood
Electrochemical enzymatic strips with a handheld meter

Interstitial fluid
Continuous glucose monitoring (CGM)
Subcutaneous electrochemical sensor for continuous readout

7. Bioelectronic Application

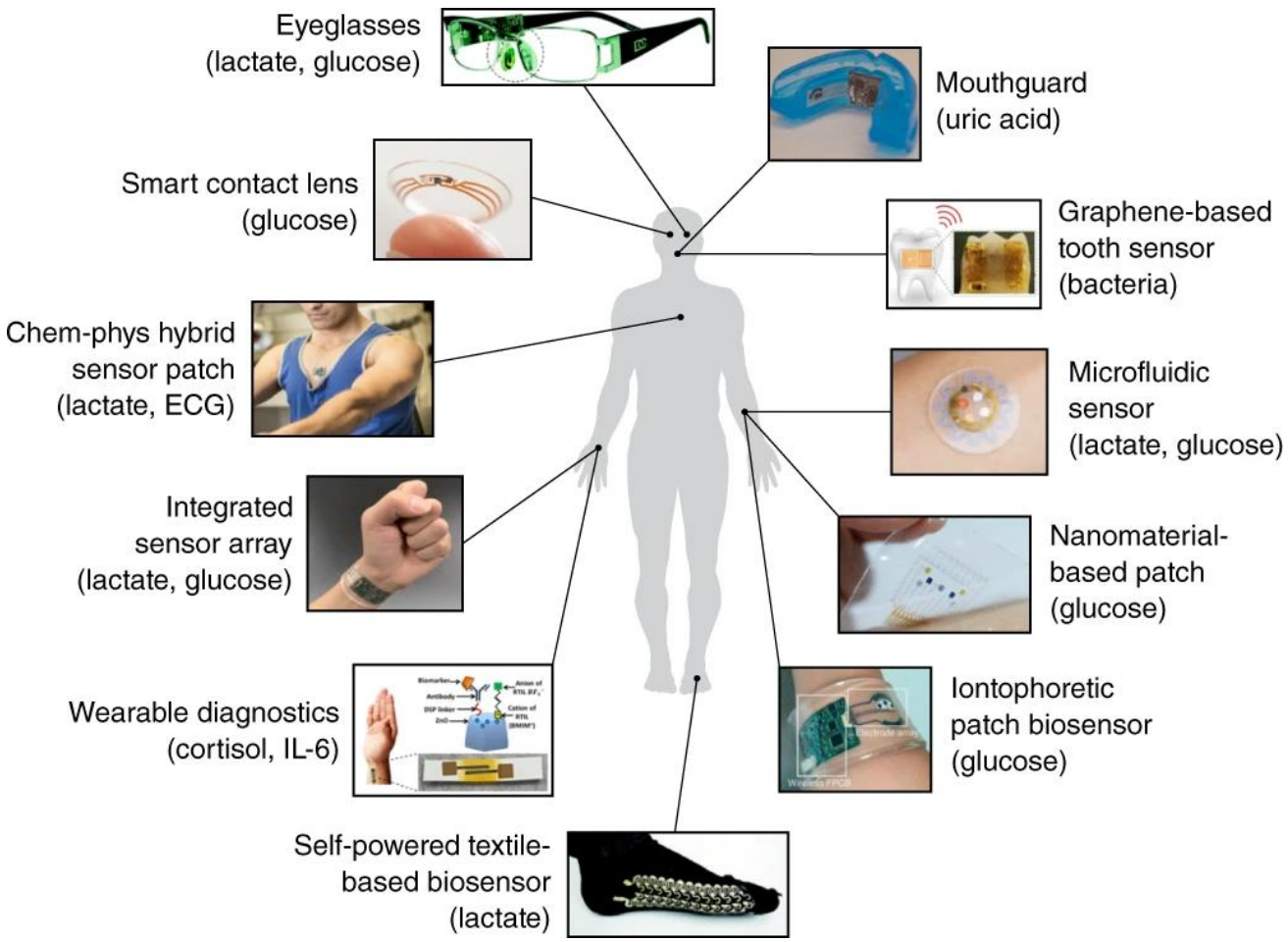
7.1 Biochemical Sensing

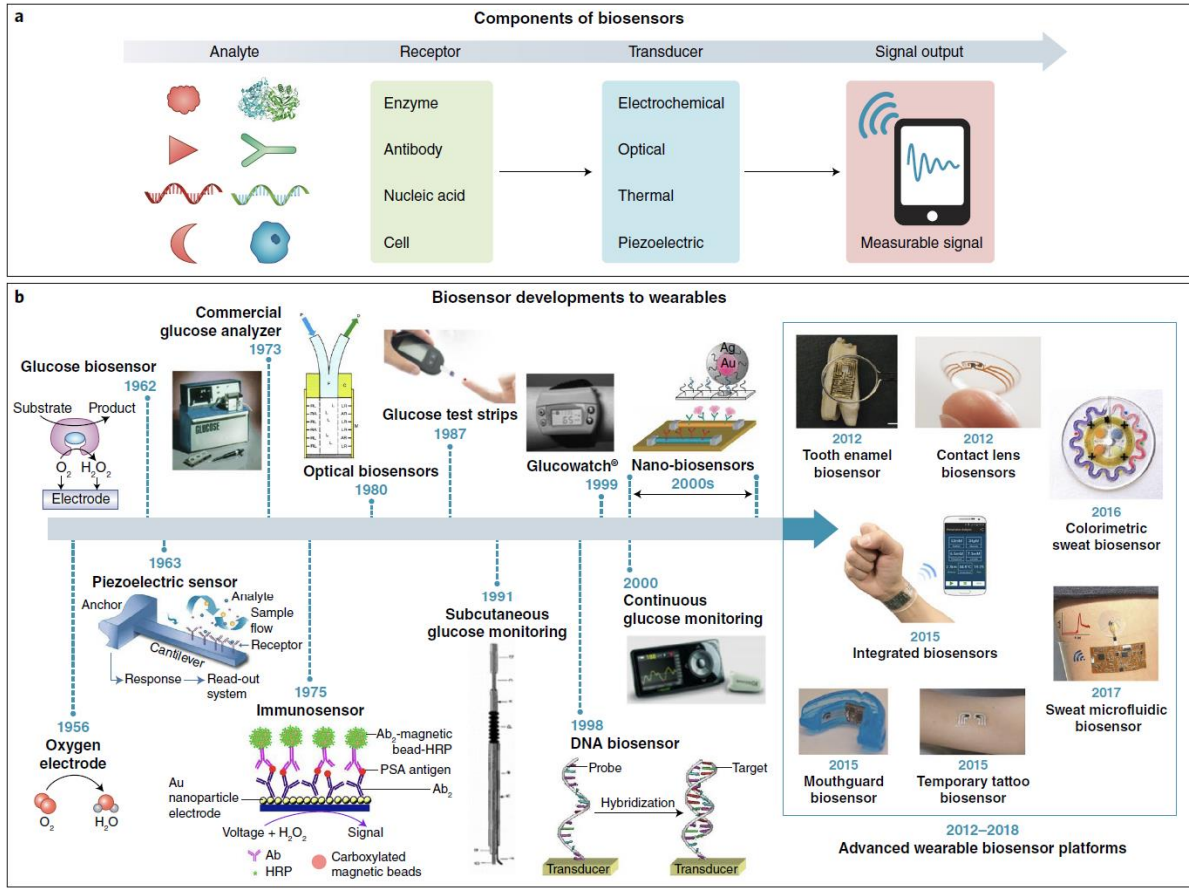


- Invasive———non-invasive/semi-invasive
- Color change (qualitative)——Electrochemical readout (quantitative)
- Single use——long time use
- Fast response
- High resolution
- Integration

7. Bioelectronic Application

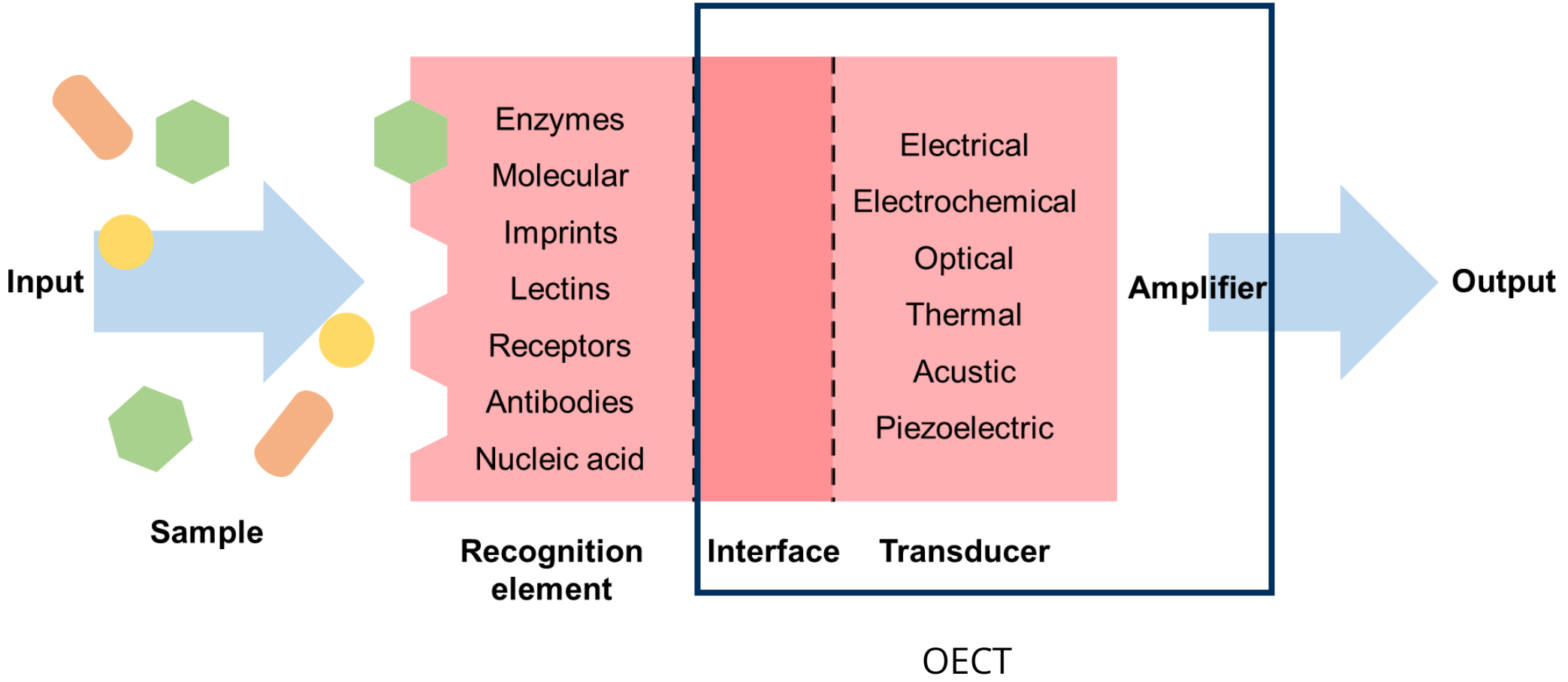
7.1 Biochemical Sensing





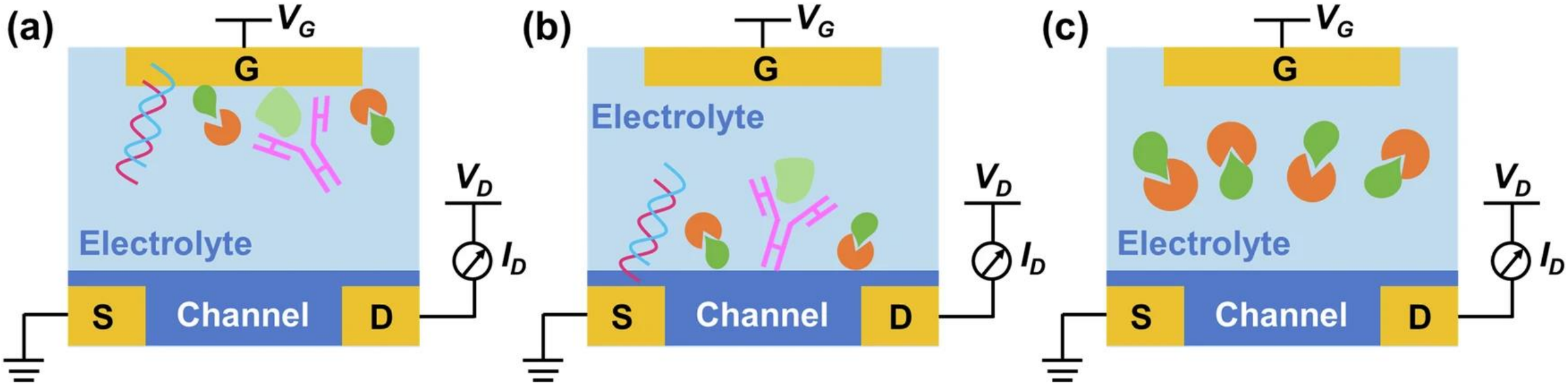
7. Bioelectronic Application

7.1 Biochemical Sensing



7. Bioelectronic Application

7.1 Biochemical Sensing



Gate

- Ions
  H^+, K^+, Na^+, NH^{4+}

Channel

- Small molecular
  Glucose, Lactate, Dopamine, Cortisol

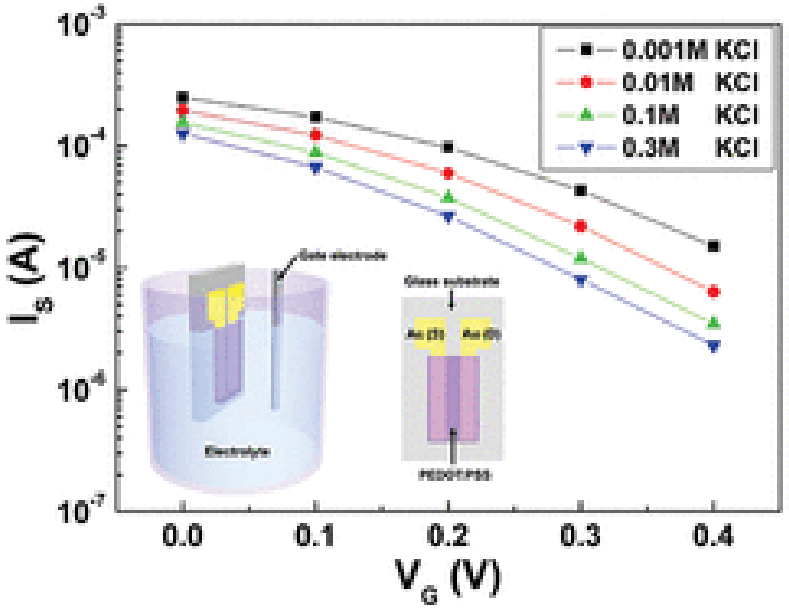
Electrolyte

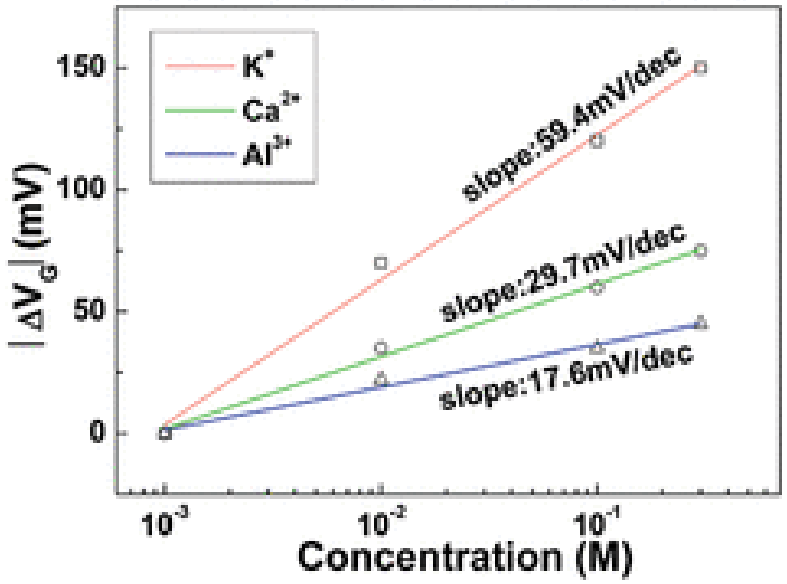
- Macromolecule
  DNA, RNA, proteins
- Cell, bacteria, Viruse

7. Bioelectronic Application

7.1 Biochemical Sensing

Intrinsic Ion Sensibility

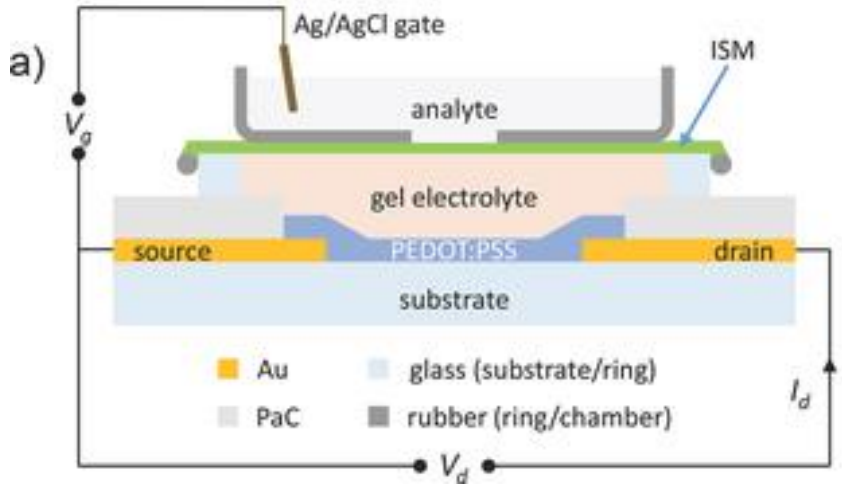




ACS Appl. Mater. Interfaces 2010, 2, 6, 1637–1641

$$E = E^0 + \frac{RT}{nF}\ln a_i = E^0 + \frac{2.303RT}{nF}\log a_i \qquad 59.2 \text{ mV dec}^{-1}$$

Ion-Selective Membrane

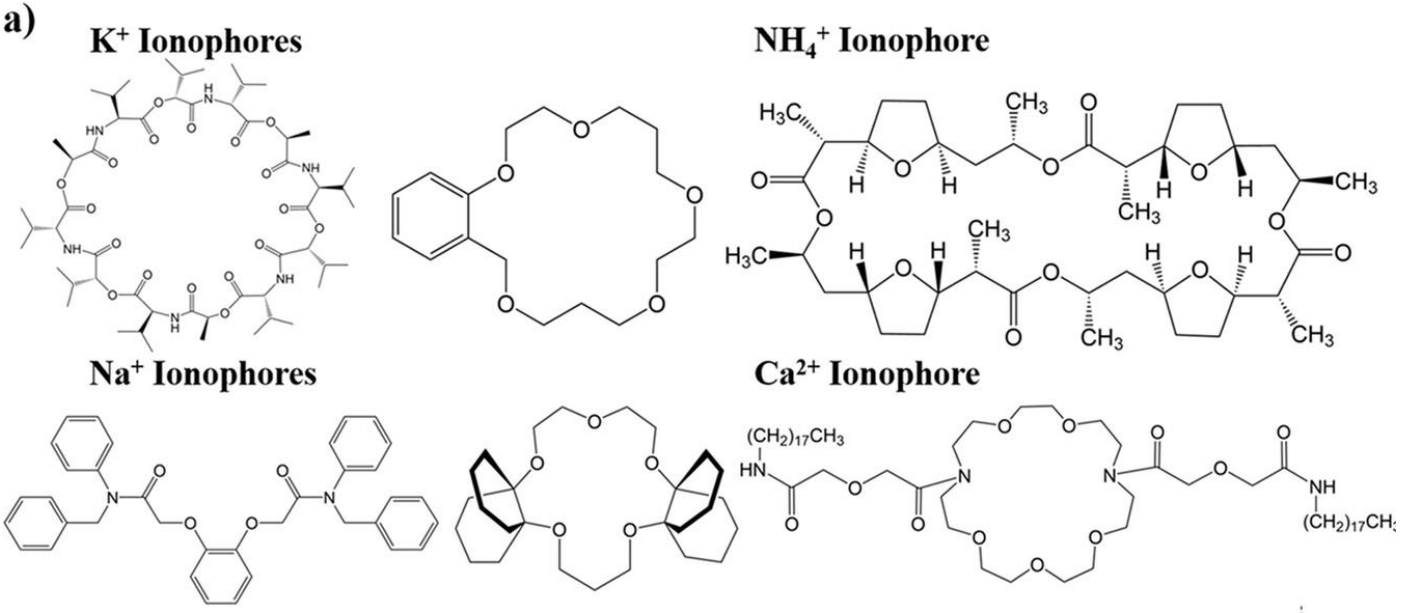


Adv. Mater. 2014, 26 (28), 4803-4807

7. Bioelectronic Application

7.1 Biochemical Sensing

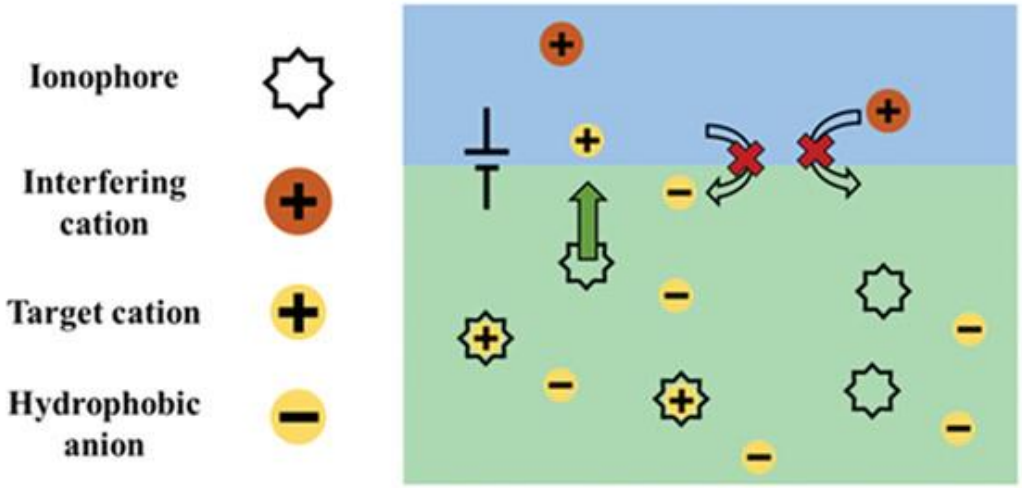
ISM



ion-binding receptors crown ethers

- matrix supporting material, PVC
- Plasticizer
- ionic sites

$$E = E^0 + \frac{2.303RT}{nF} log\ a_i$$

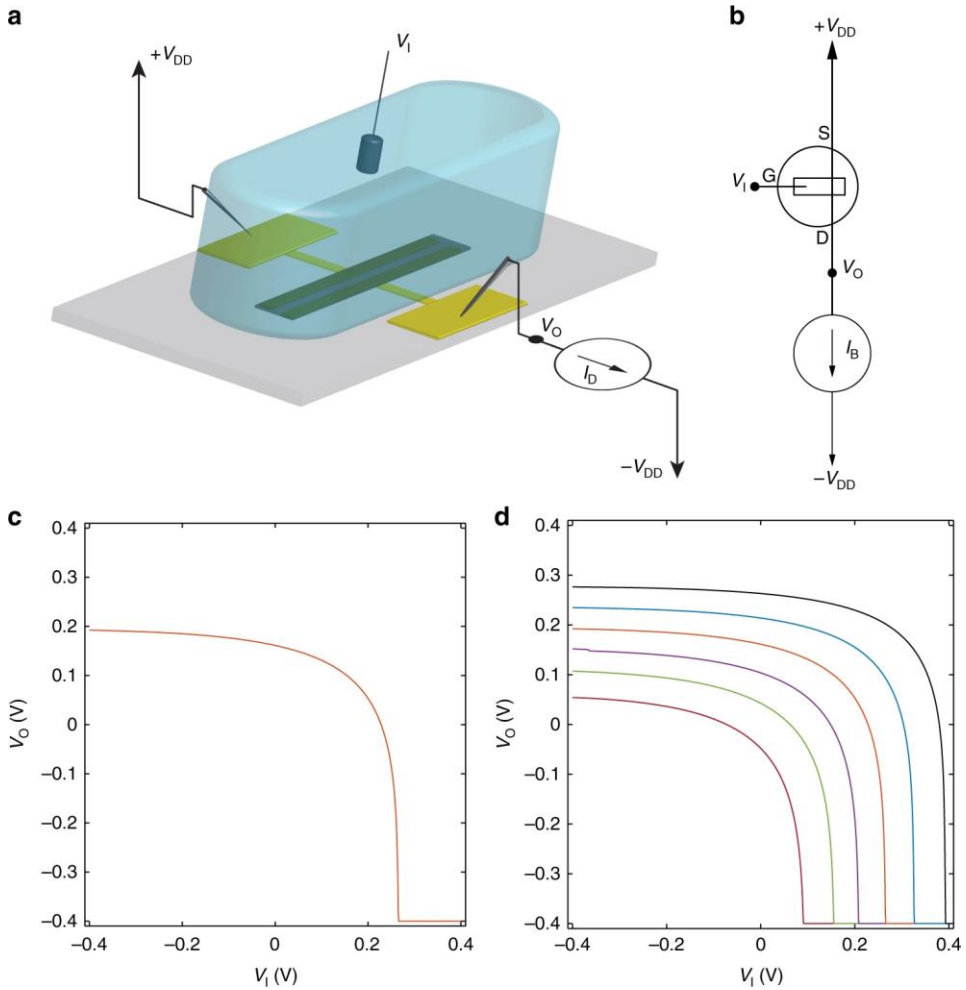


Preparation of the ISM: the membranes were prepared by drop-casting a THF mixture containing high molecular weight PVC (36.5 wt.%), diisodecyl adipate (60.5 wt.%), potassium tetrakis(4-chlorophenyl)-borate (0.5 wt.%) and potassium ionophore III (2.5 wt.%) onto a glass slide. The size of the membrane was defined by confining the liquid with a rubber ring. The mixture was allowed to dry at ambient conditions and peeled-off with the rubber ring.

Small 2022, 18, 2107413

7. Bioelectronic Application

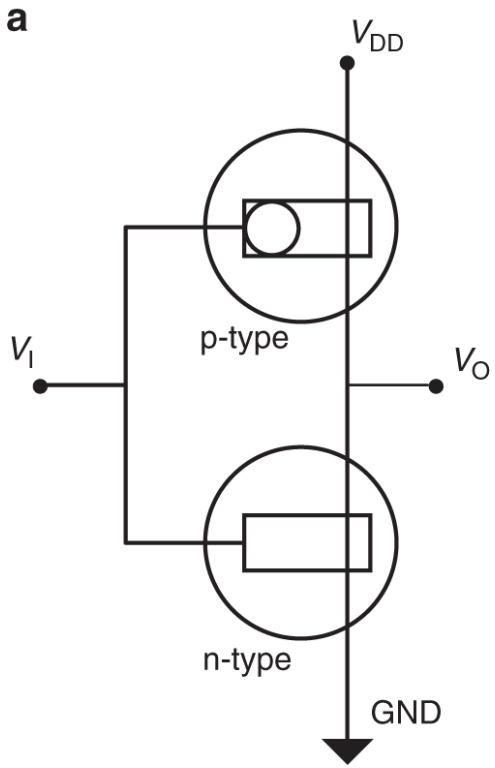
7.1 Biochemical Sensing

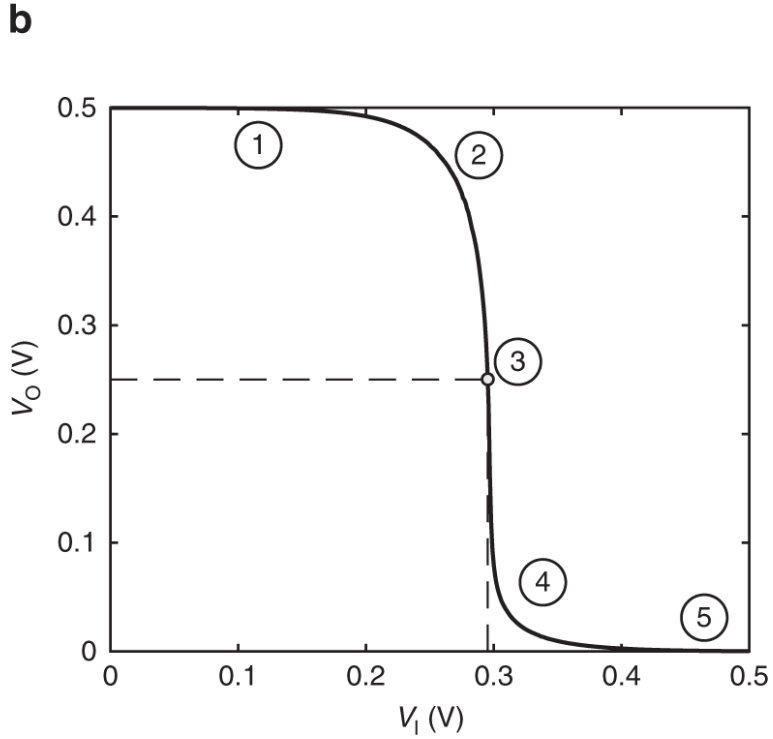


- Current driven

Nat Commun 9, 1441 (2018).

Circuit Design





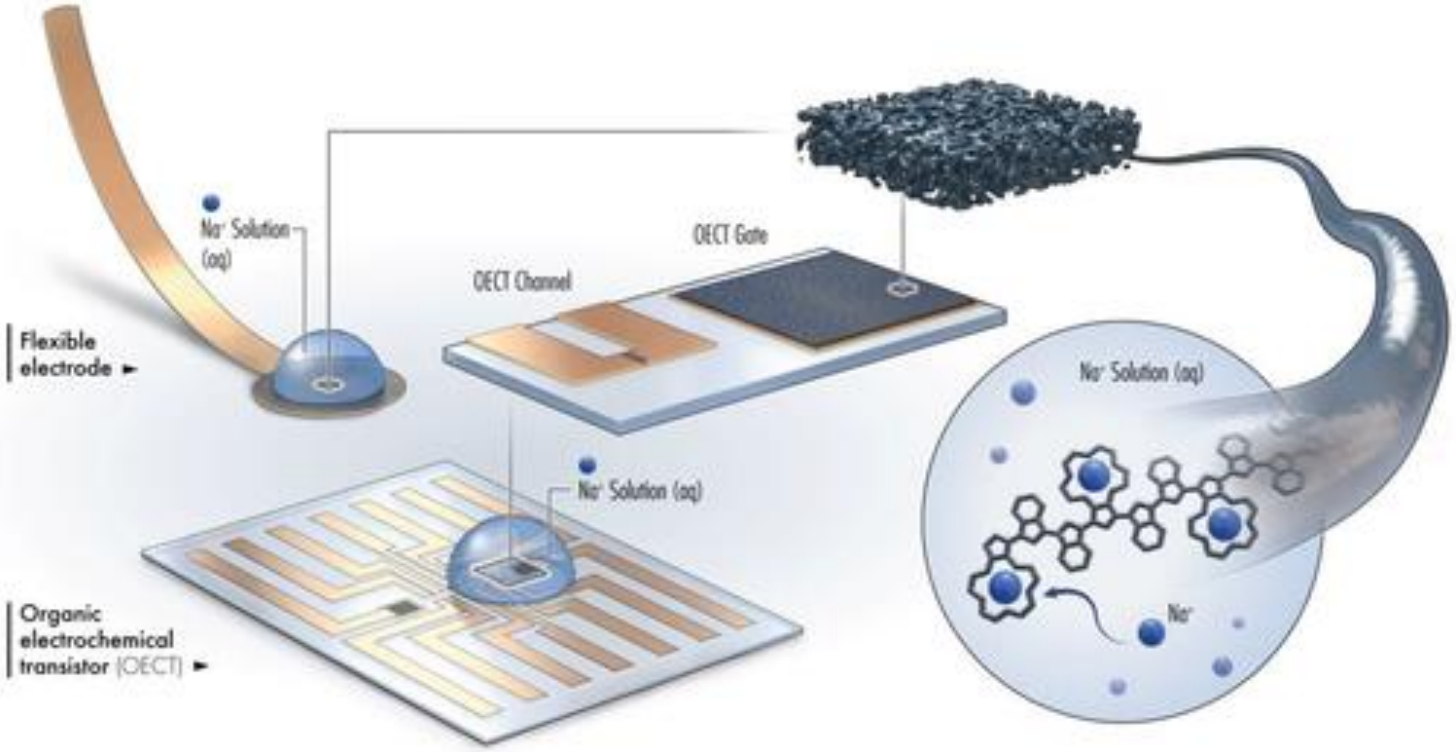
- Complementary amplifier

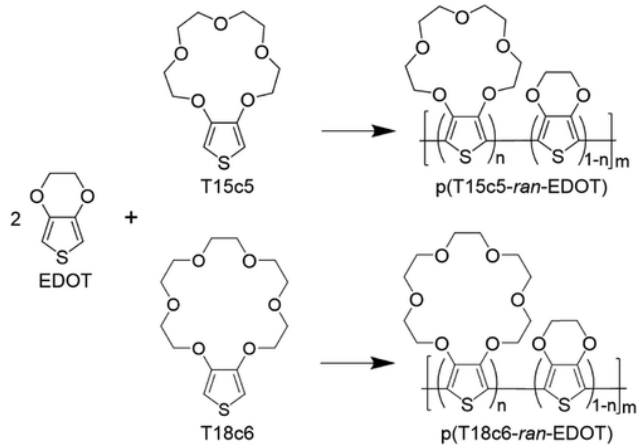
Nat Commun 11, 3743 (2020).

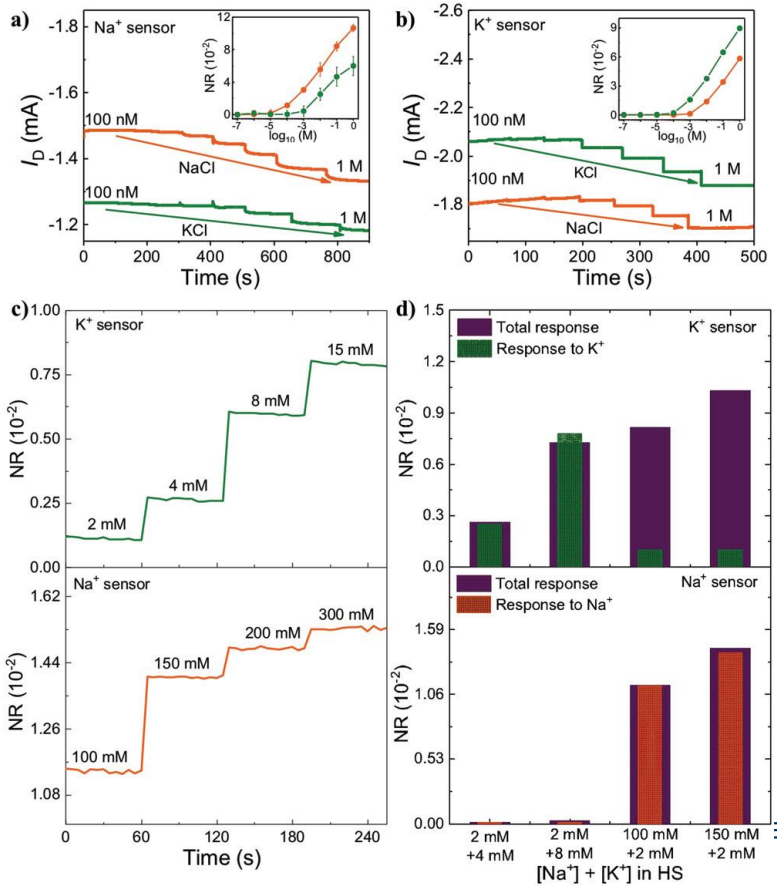
7. Bioelectronic Application

7.1 Biochemical Sensing

Functionalized OMIEC







Adv. Funct. Mater.2019, 29, 1904403.

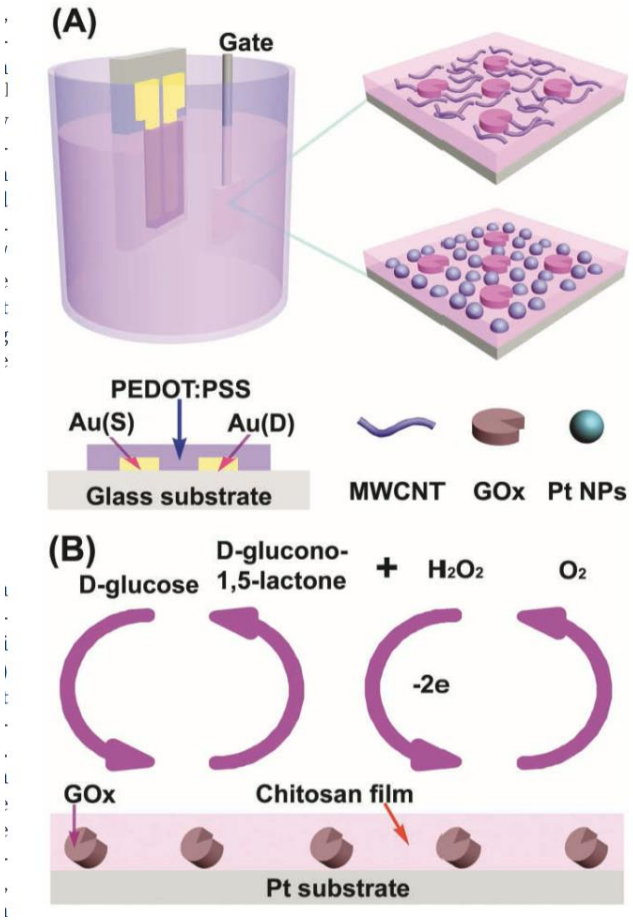
7. Bioelectronic Application

7.1 Biochemical Sensing

$$Glucose + O_2 \overset{GOx}{\rightarrow} Gluconolactone + H_2O_2$$

$$H_2O_2 \rightarrow O_2 + 2H^+ + 2e^-$$

Glucose/Lactate



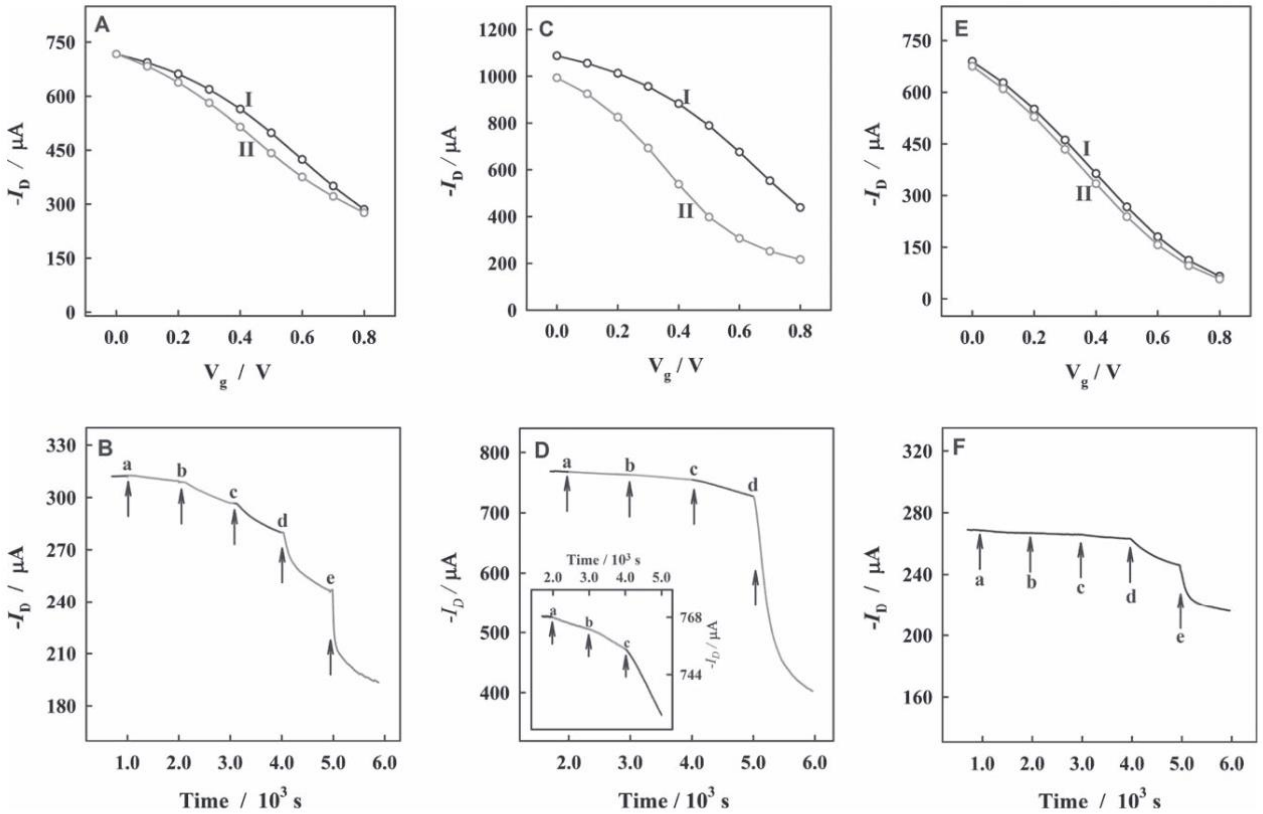


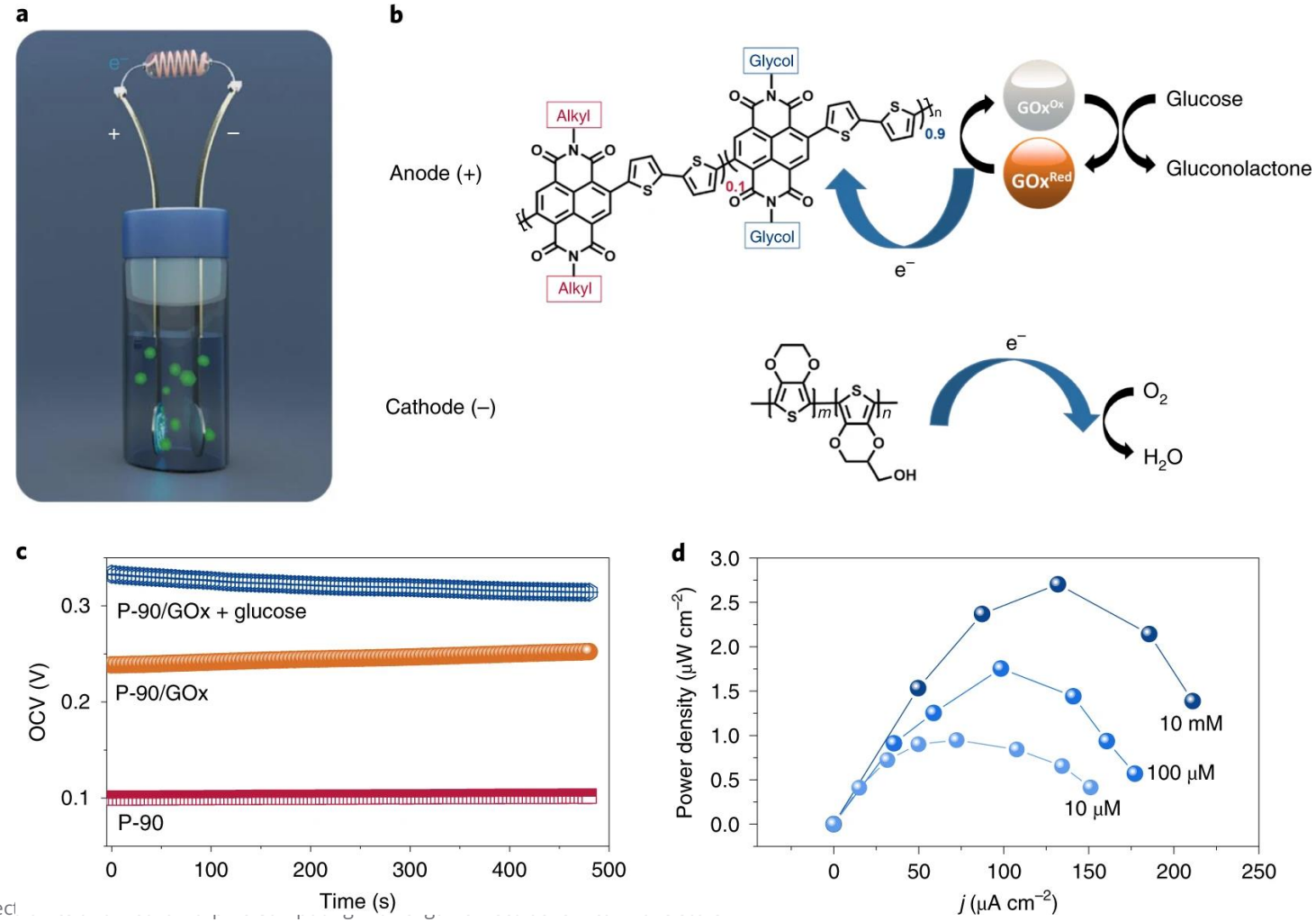
Figure 7. A,C,E) Typical I_D vs. V_G and B,D,E) typical I_D vs. time curves of the OECT devices using MWCNT-CHIT/GOx/Pt (A, B), CHIT/GOx/Pt-NPs/Pt (C, D), and CHIT/GOx/Pt (E, F) gate electrodes. In (A, C, E) the devices are characterized in blank (I) and 100 μM glucose (II) PBS (pH 7.2) solutions. For I_D vs. time curves, V_G is fixed at 0.4 V; Glucose additions: in B and F, a–e: 0.5, 1, 10, 100 μM and 1 mM; in D, a–d: 0.005, 0.05, 0.5, and 5 μM.

7. Bioelectronic Application

7.1 Biochemical Sensing

Glucose/Lactate

Biofuel powered glucose detection

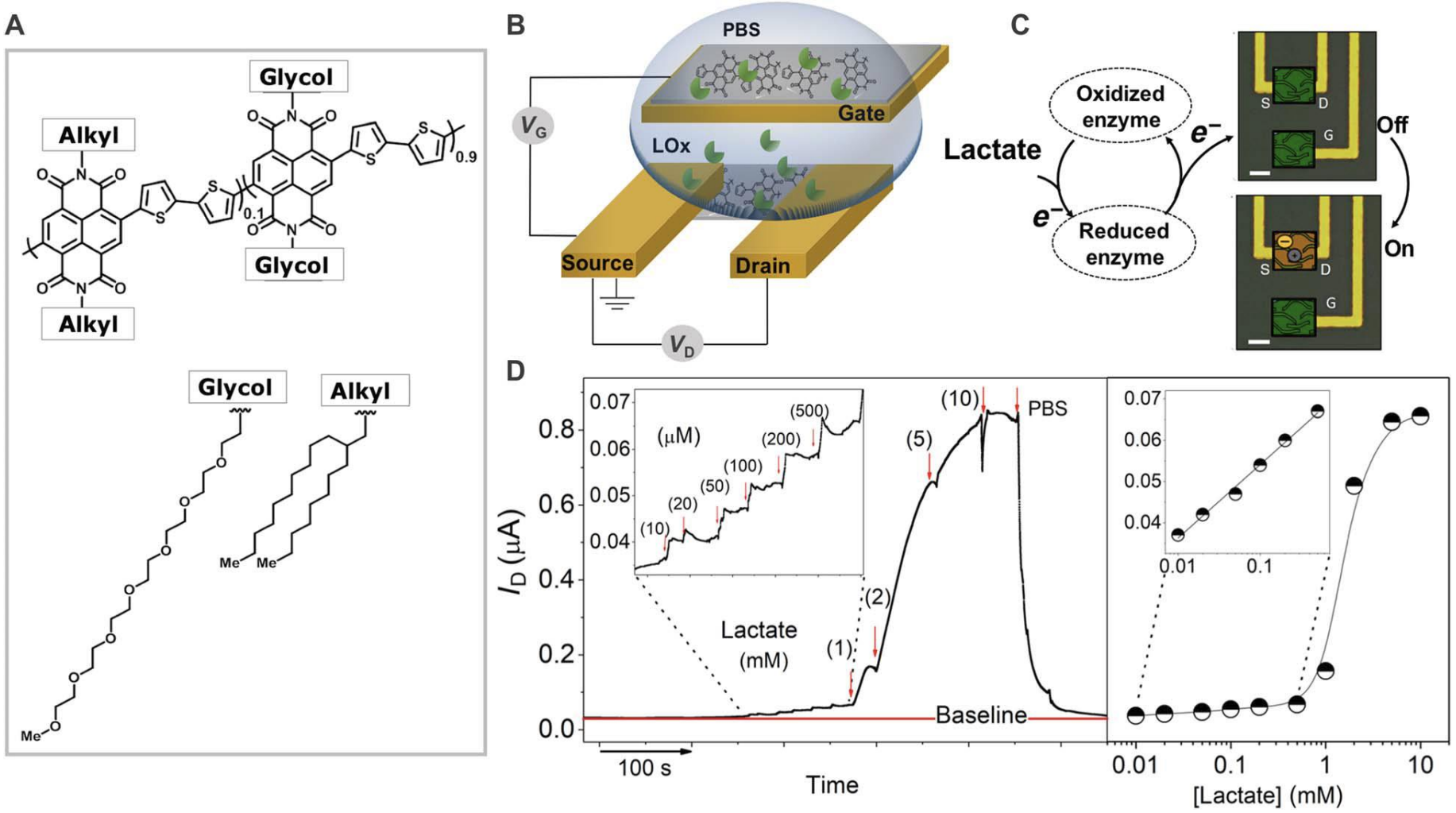


Nat. Mater. 19, 456–463 (2020).

7. Bioelectronic Application

7.1 Biochemical Sensing

Glucose/Lactate

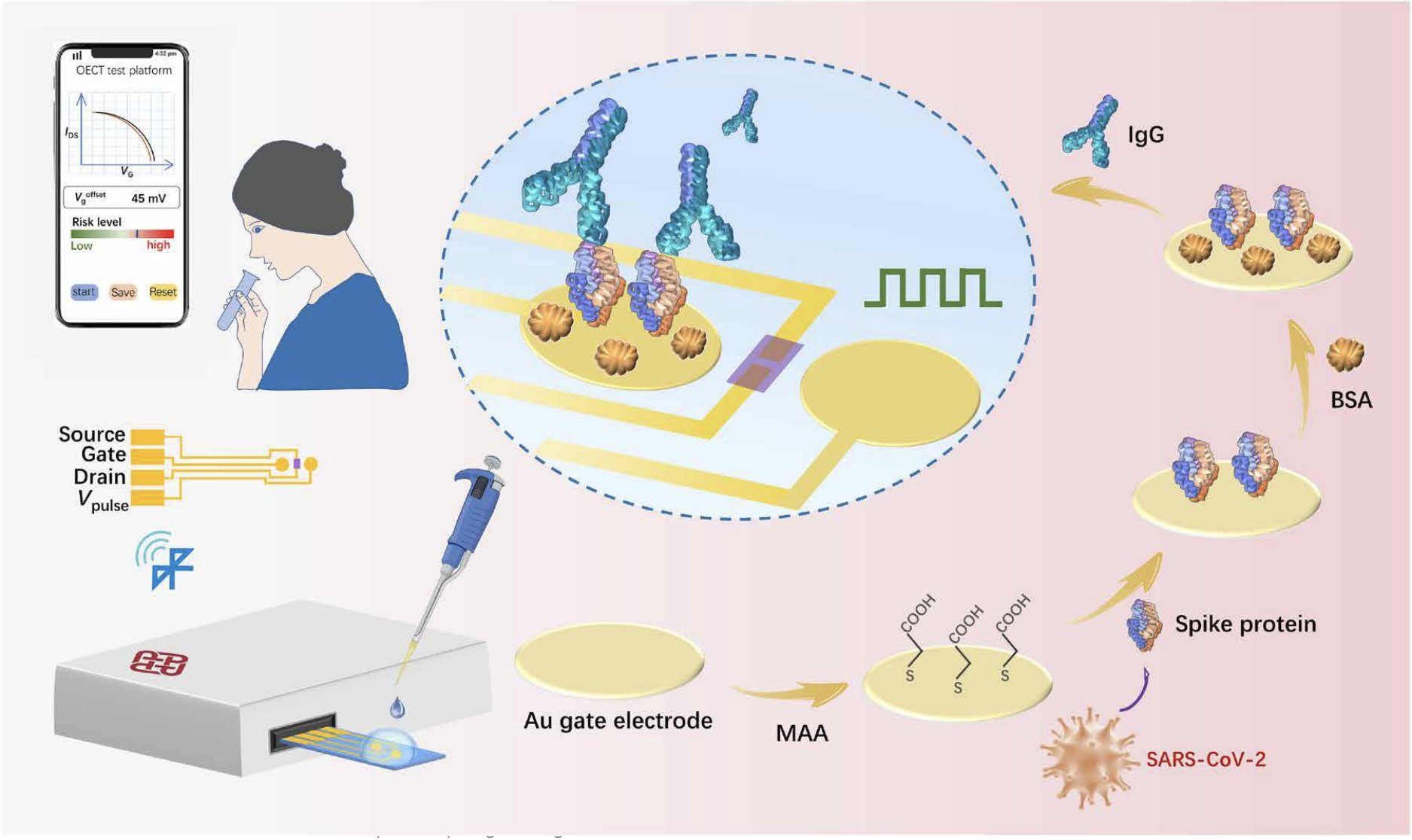


Sci. Adv. 2018;4: eaat0911

7. Bioelectronic Application

7.1 Biochemical Sensing

Protein



10 fM to 100 nM

SARS-CoV-2 immunoglobulin G (IgG)

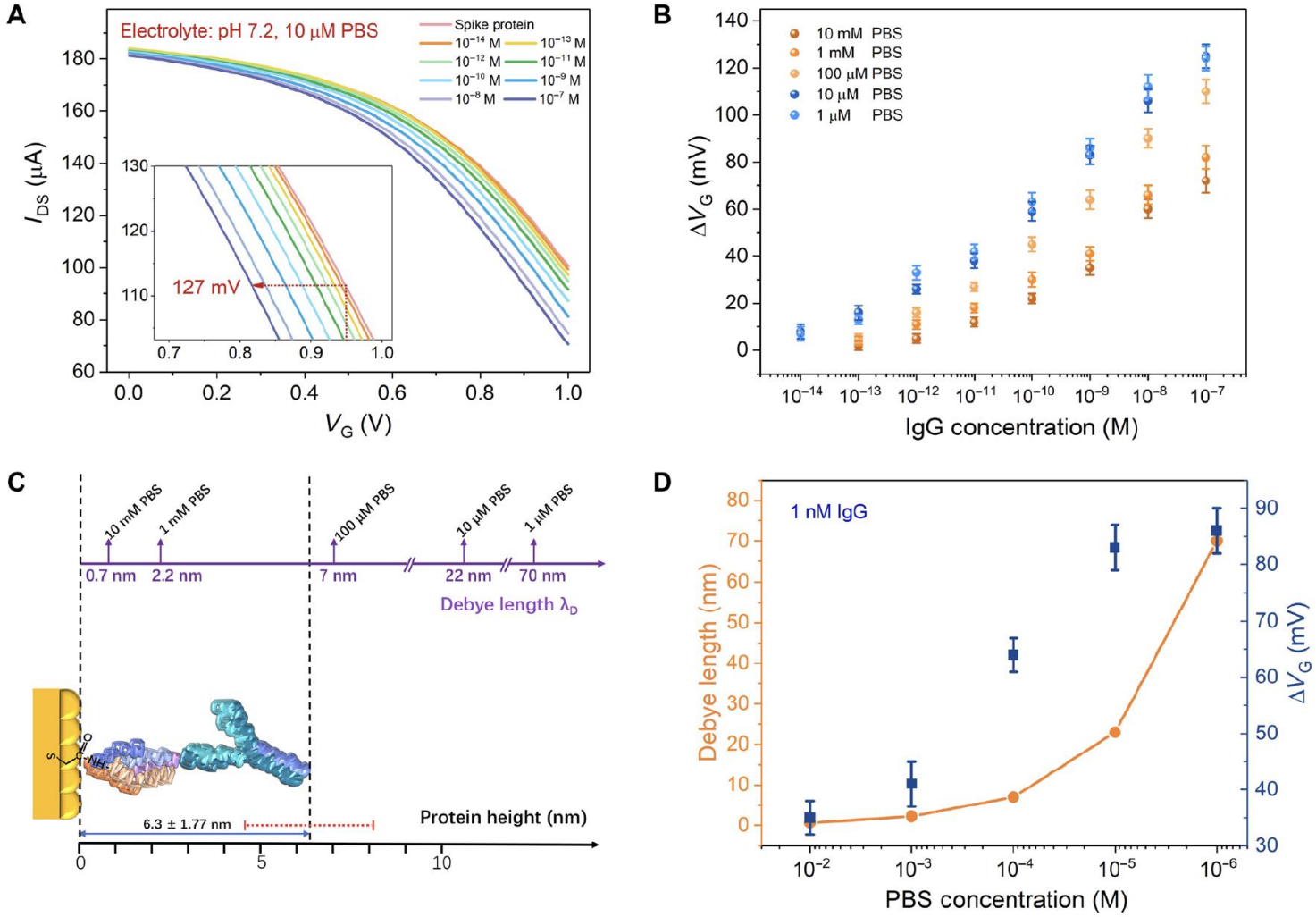
7. Bioelectronic Application

7.1 Biochemical Sensing

Protein

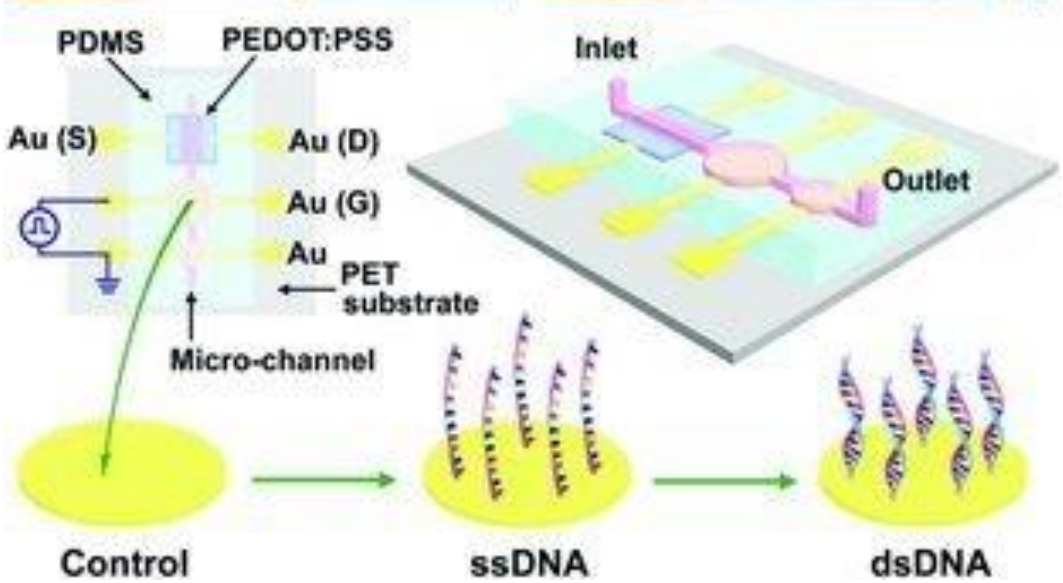
$$\lambda_D = \sqrt{\frac{\varepsilon kT}{2N_A q^2 I}}$$

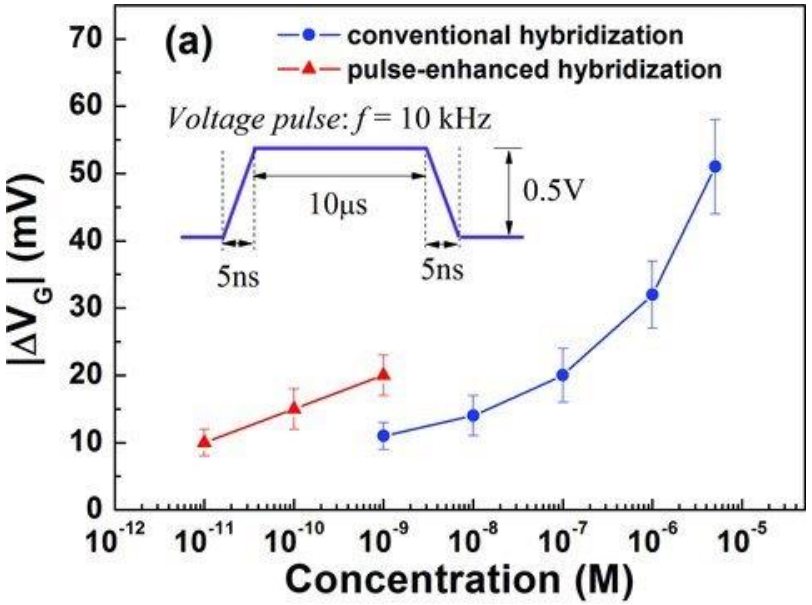
Sensitivity enhancement by increasing Debye length

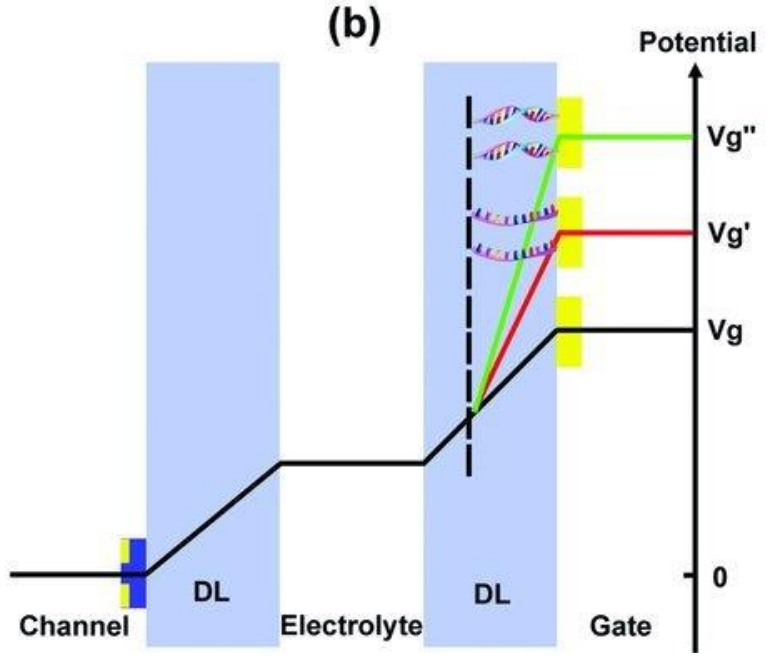


7. Bioelectronic Application

7.1 Biochemical Sensing DNA/RNA





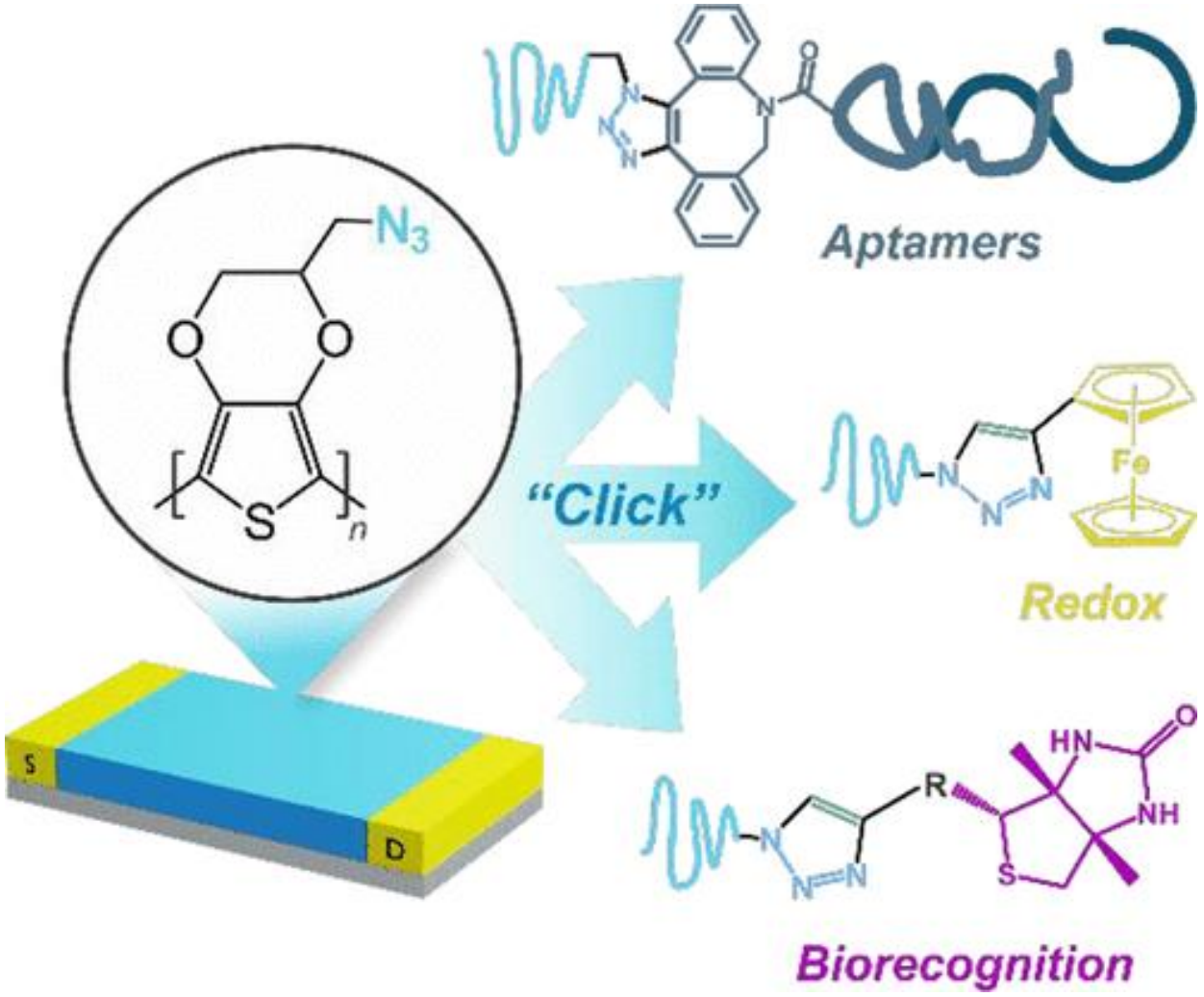


Adv. Mater. 2011, 23: 4035-4040.

7. Bioelectronic Application

7.1 Biochemical Sensing

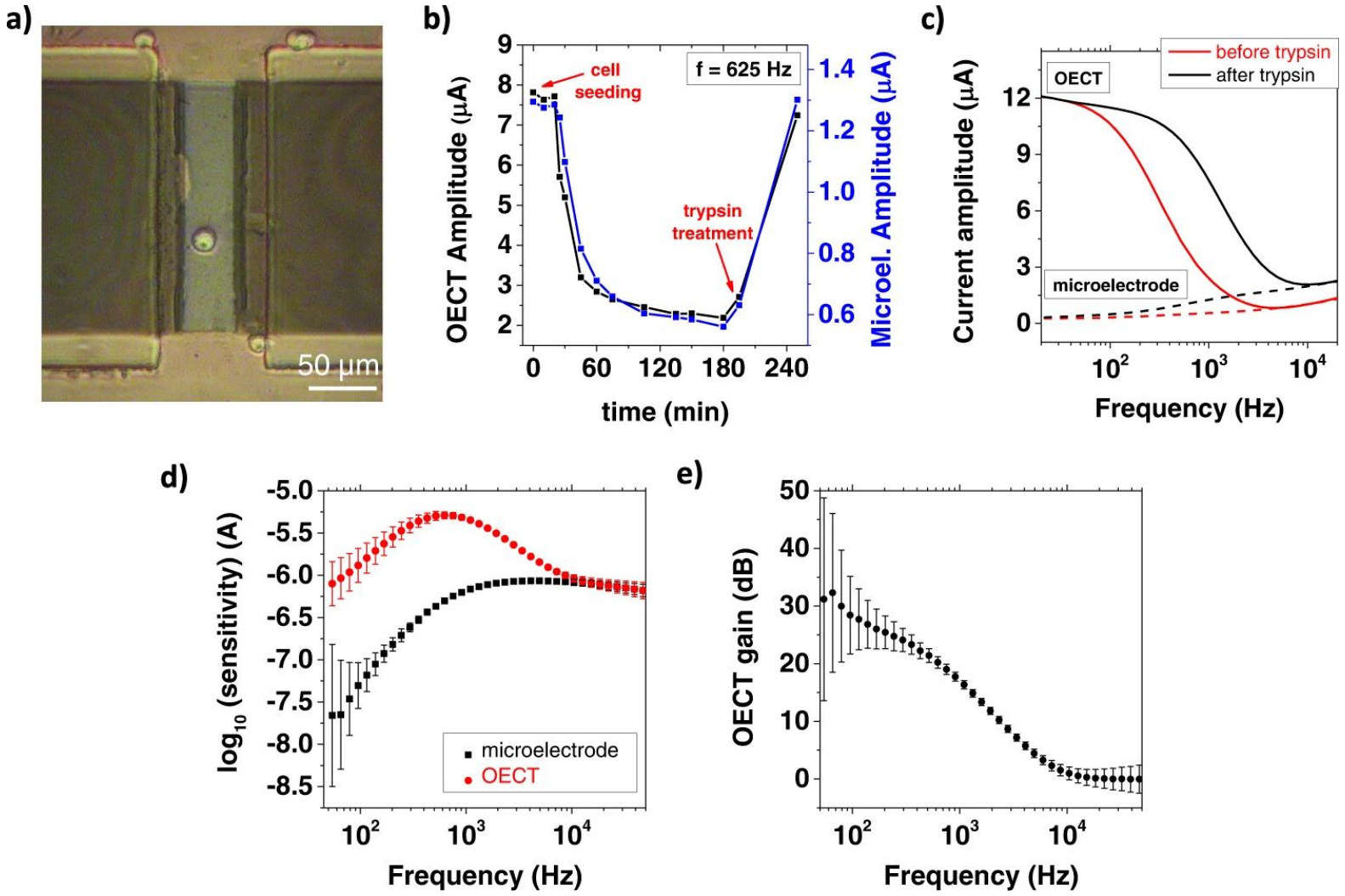
Clickable OECT



7. Bioelectronic Application

7.1 Biochemical Sensing

Cell

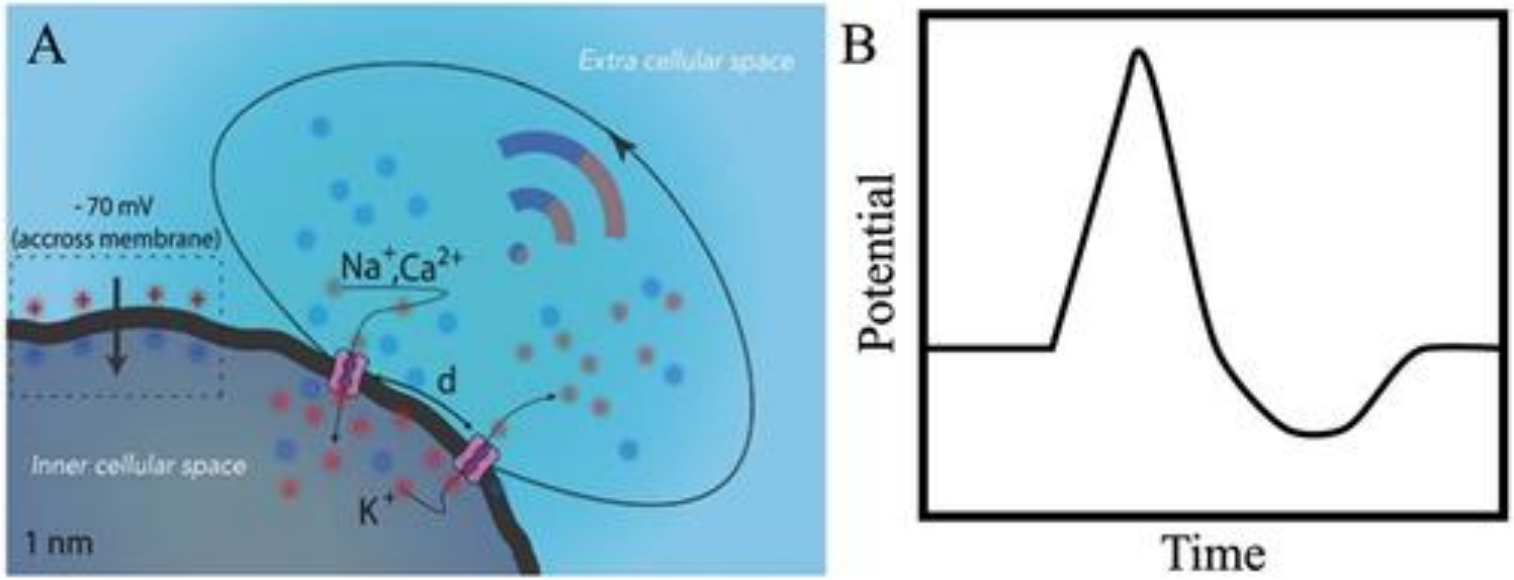


Nat Commun 13, 5423 (2022)

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

Electrophysiology Signal

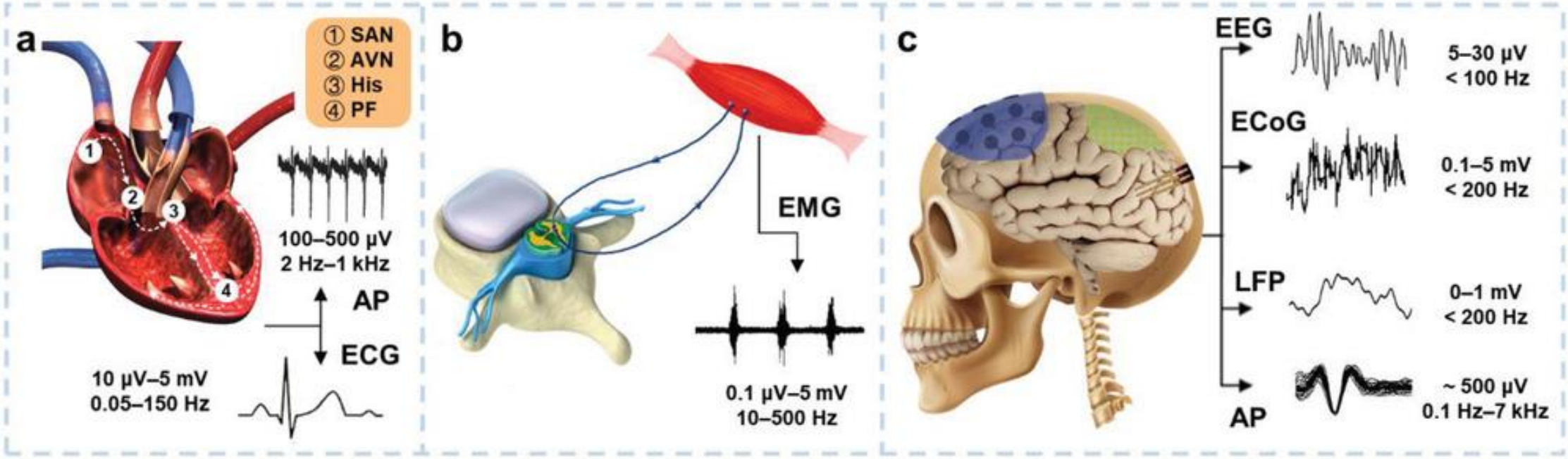


Adv. Healthcare Mater.2021, 10, 2100646.

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

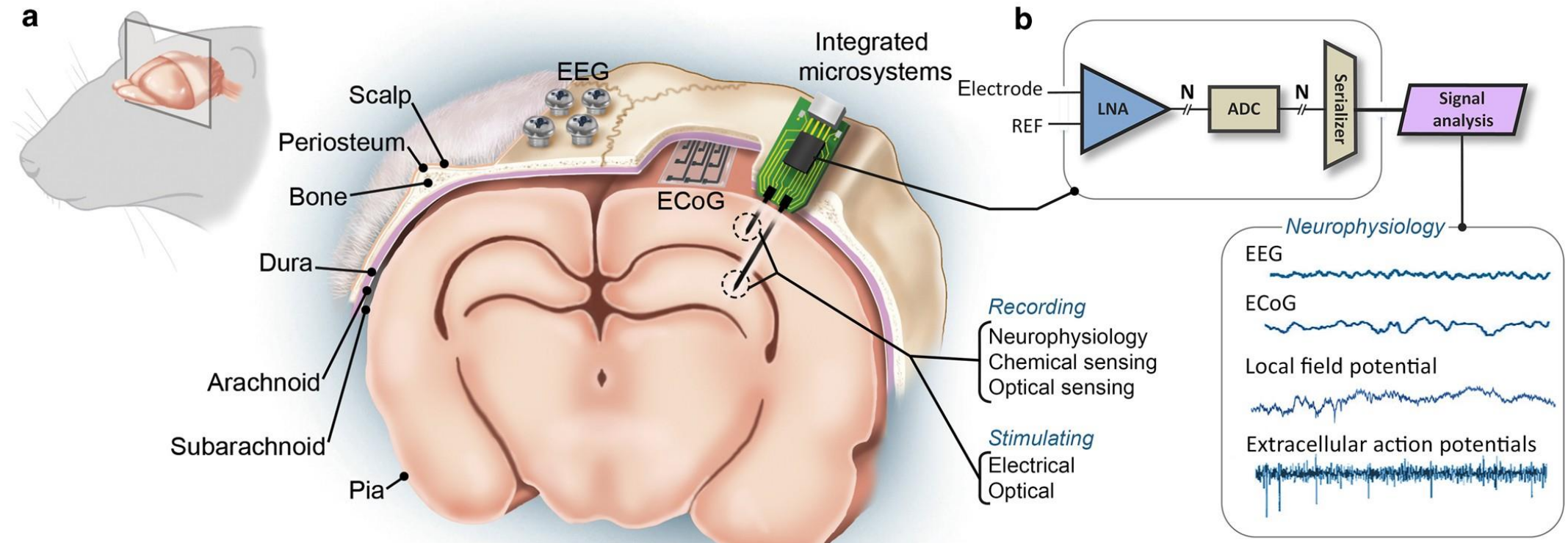
Electrophysiology Signal



Adv. Healthcare Mater.2021, 10, 2100646.

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

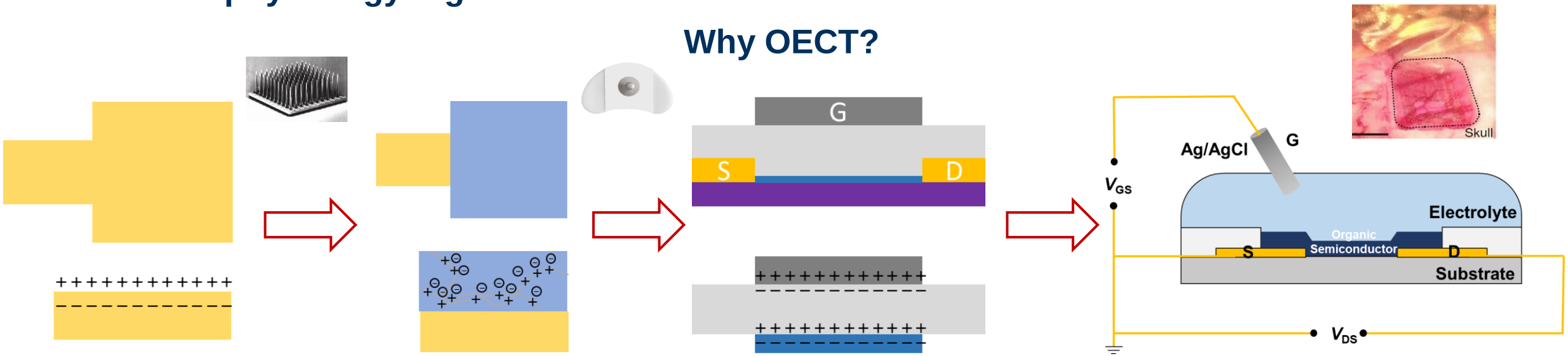


Microsyst Nanoeng, 3, 16066 (2017)

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

Why OECT?



Metal Electrode

- Simple
- Hard
- High ionic impedance

Modified Electrode

- Soft
- Large effective size
- Low impedance
- Limited sensibility

TFT

- Enhanced sensibility
- Hard
- Large voltage
- Instability in water

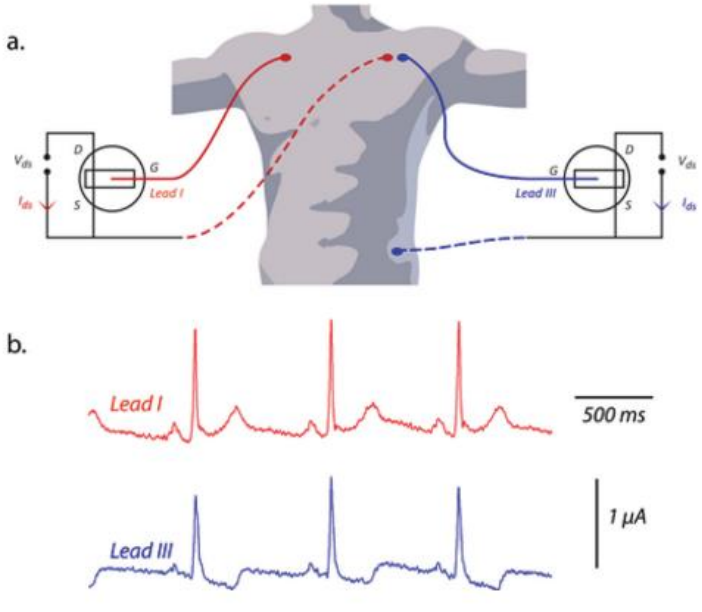
OECT

- Aqueous environment
- Large sensibility
- Low voltage (<1 V)
- Good bio-interface
- Biocompatibility

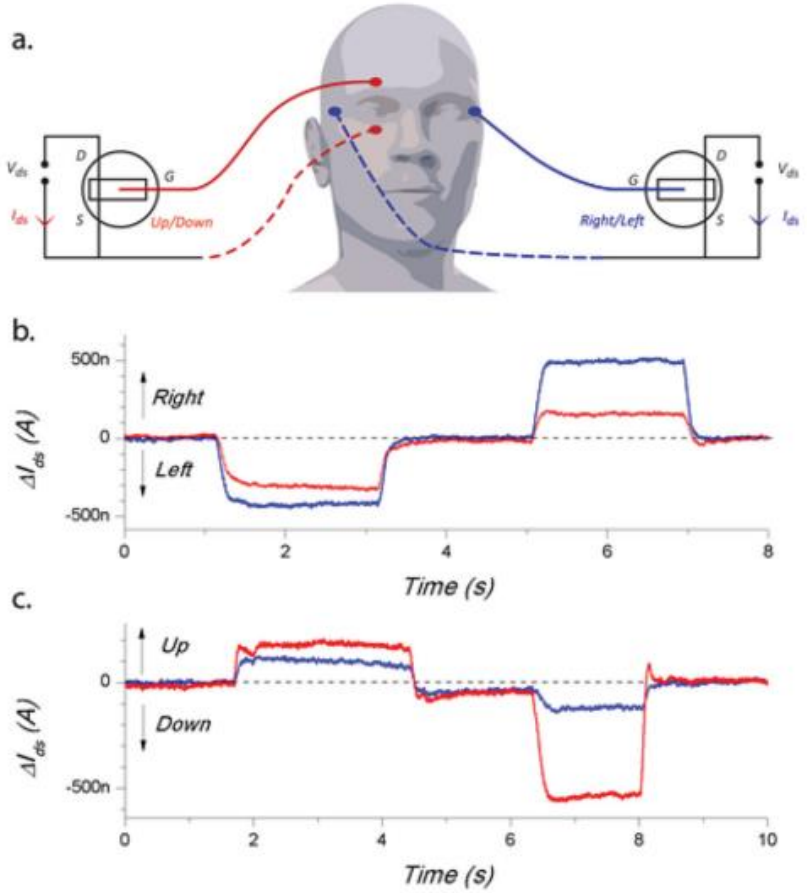
7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

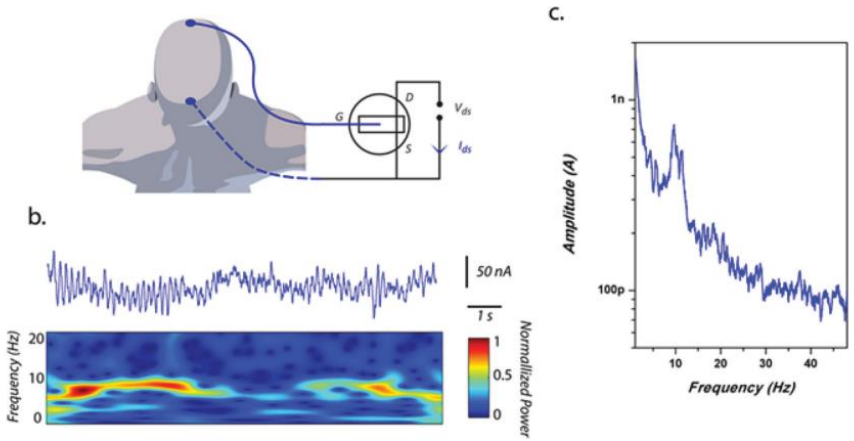
In vitro



ECG



EOG



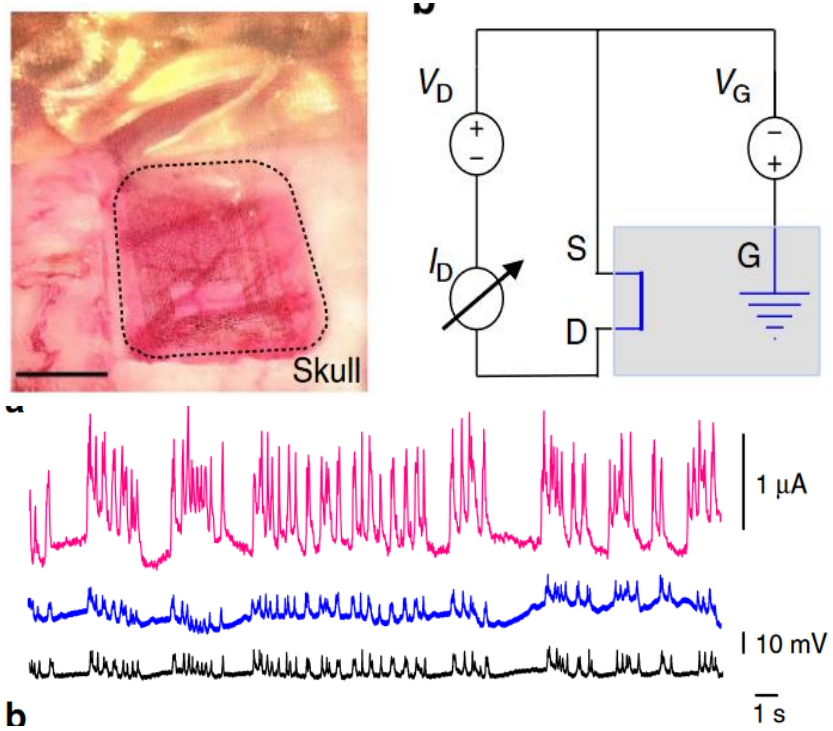
EEG

Adv. Healthcare Mater. 2015, 4, 142–147

7. Bioelectronic Application

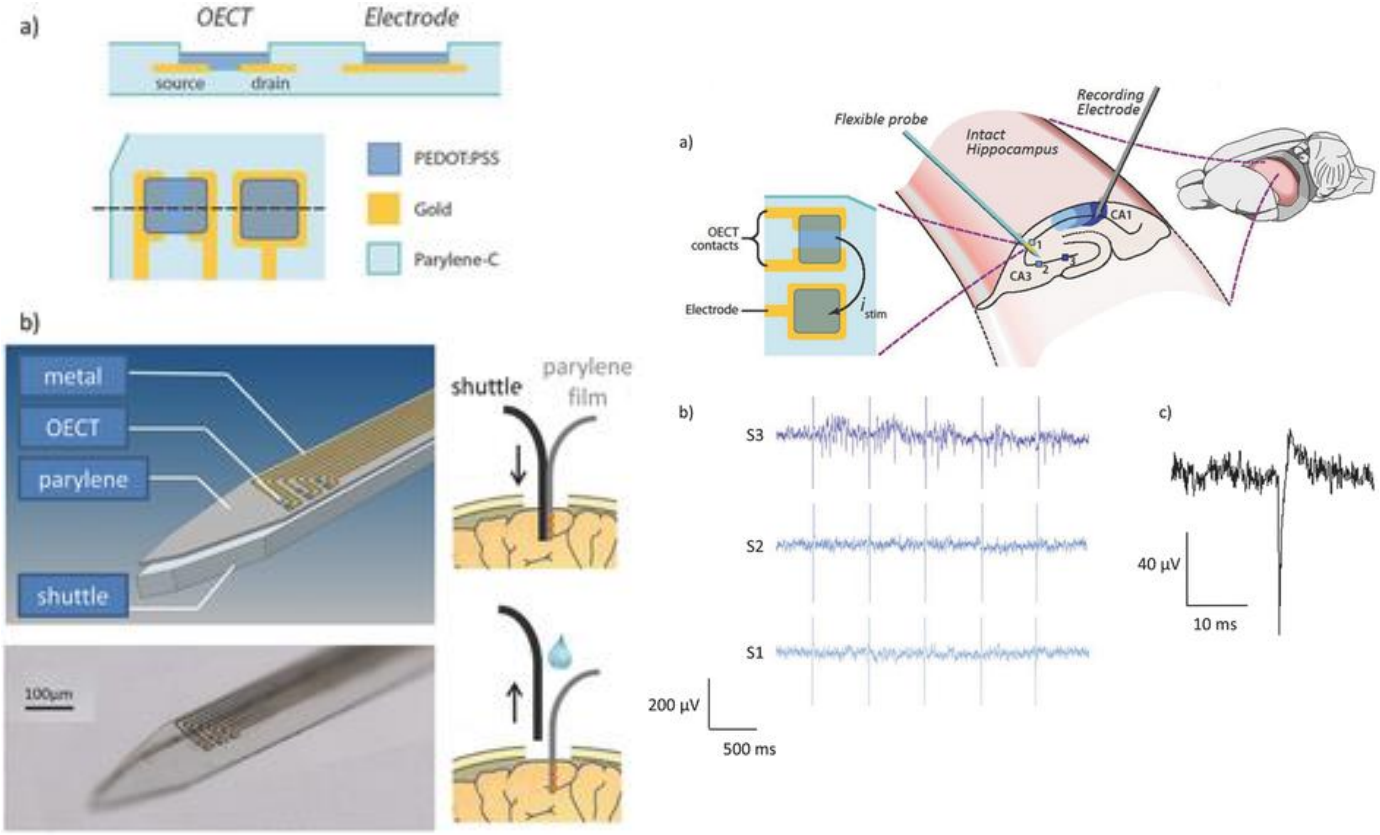
7.2 Electrophysiology Signal Detection

In vivo ECoG



Nat. Commun. **4**, 1575(2013)

In vivo Stimulate



Adv. Mater. 2015, 27, 4405–4410

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

Inverter Amplifier

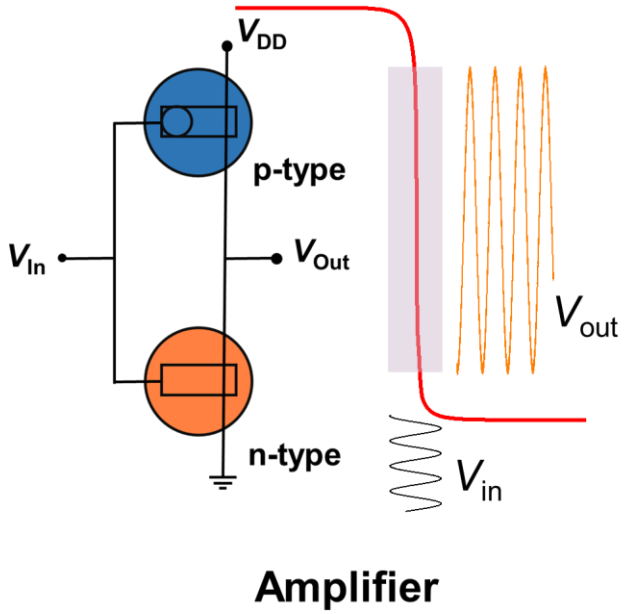
single transistor

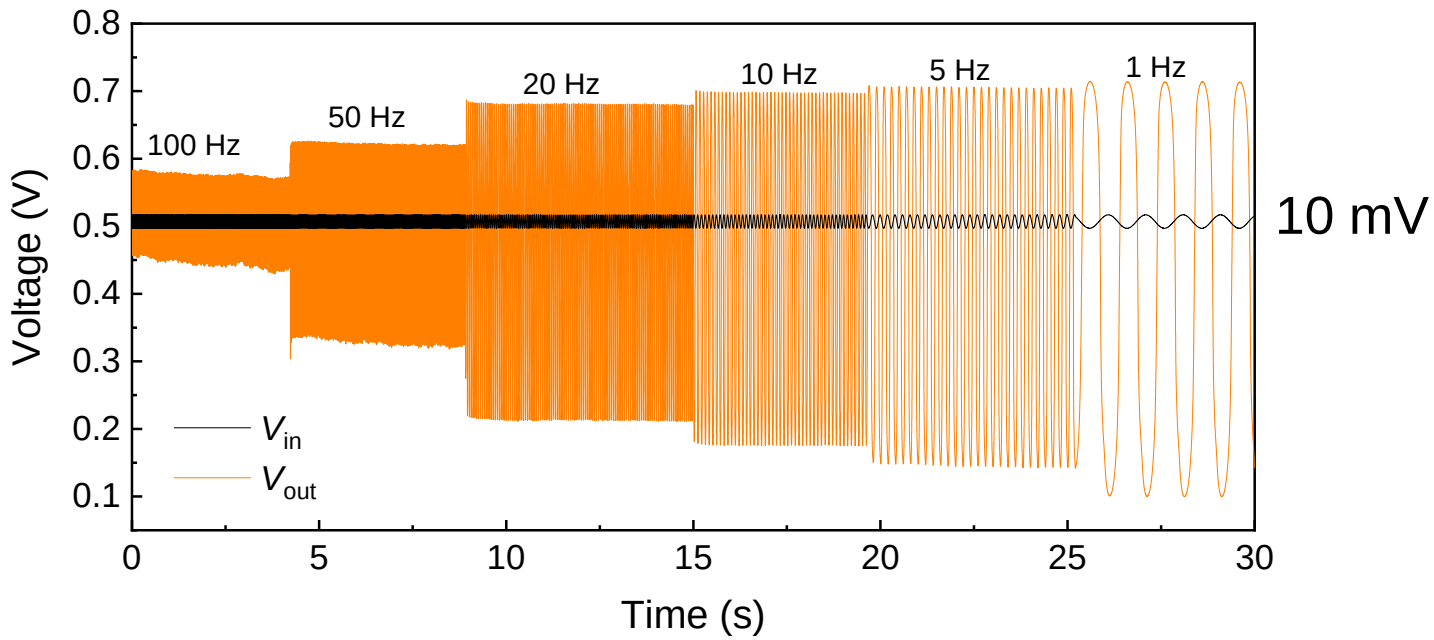
current signal

⇒

complementary logic circuits

voltage signal



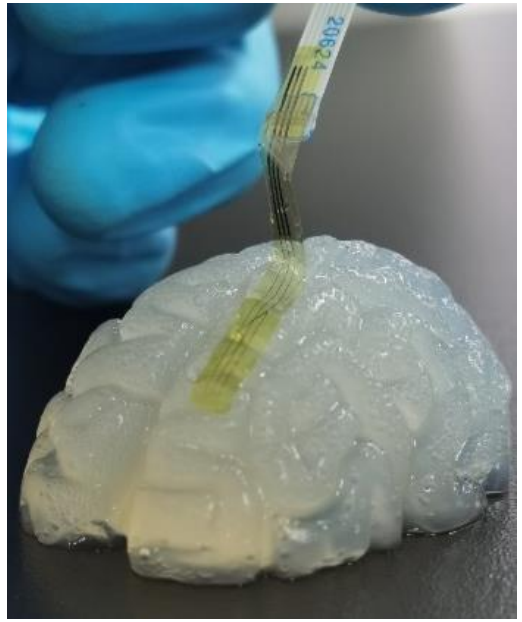


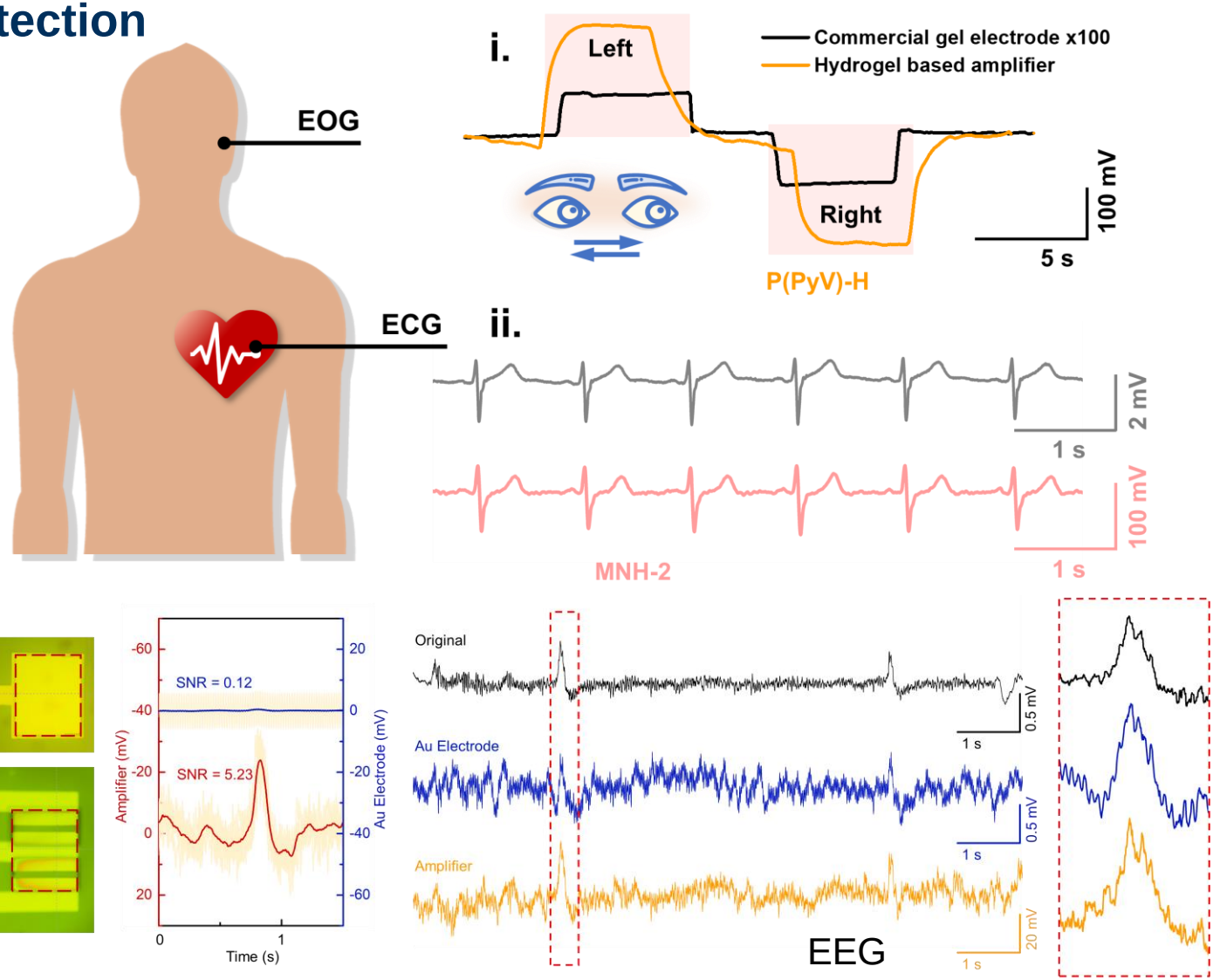
Nat. Commun. **4**, 1575(2013)

P. Li[#], W. Sun[#], T. Lei*, et al. *Science*, 384, 557-563 (2024).

7. Bioelectronic Application

7.2 Electrophysiology Signal Detection





Nat. Commun. **4**, 1575(2013)

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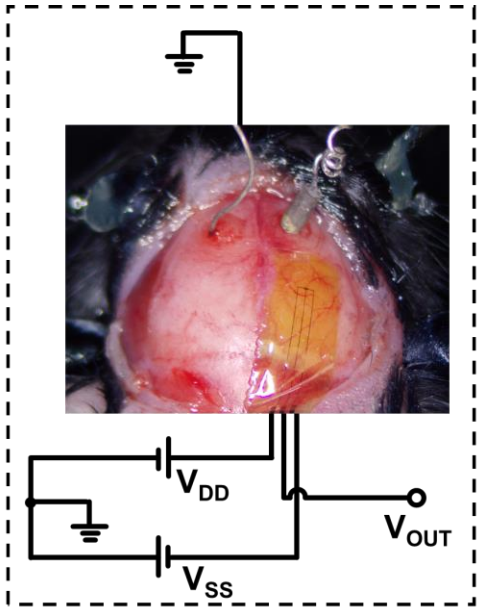
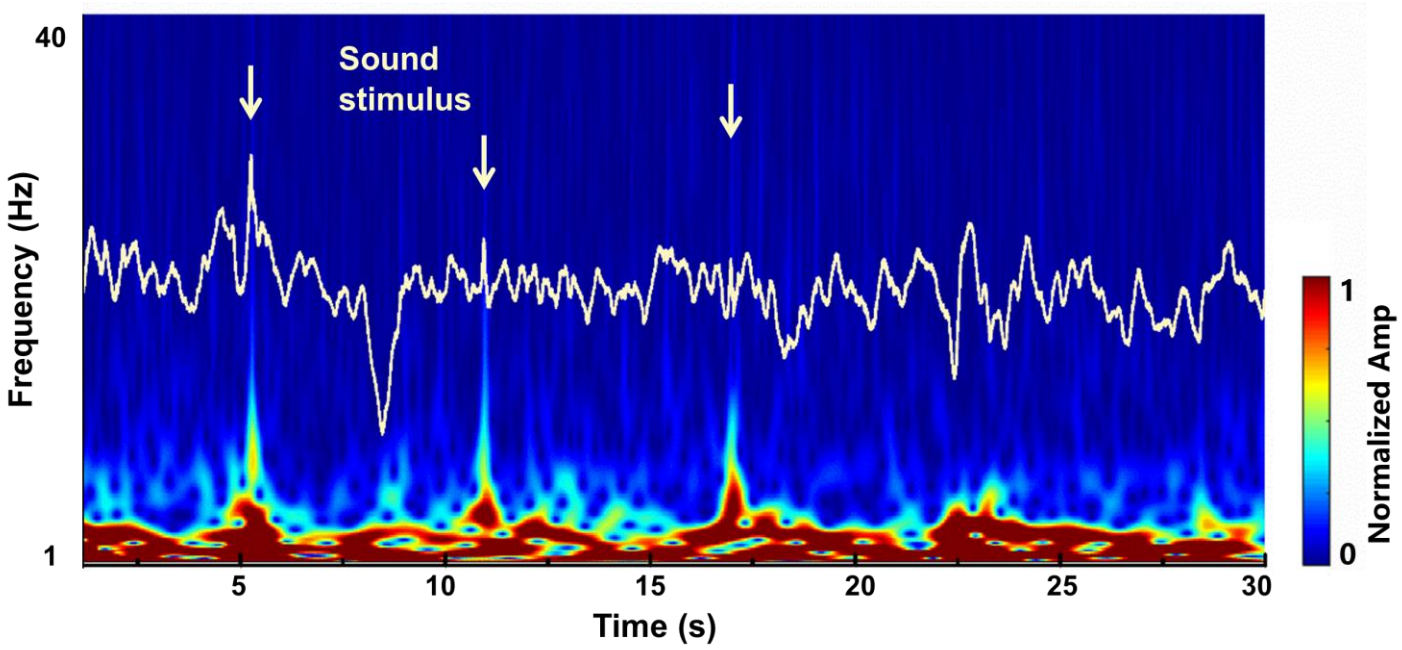
7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

Inverter Amplifier



ECoG



Nat. Commun. **4**, 1575(2013)

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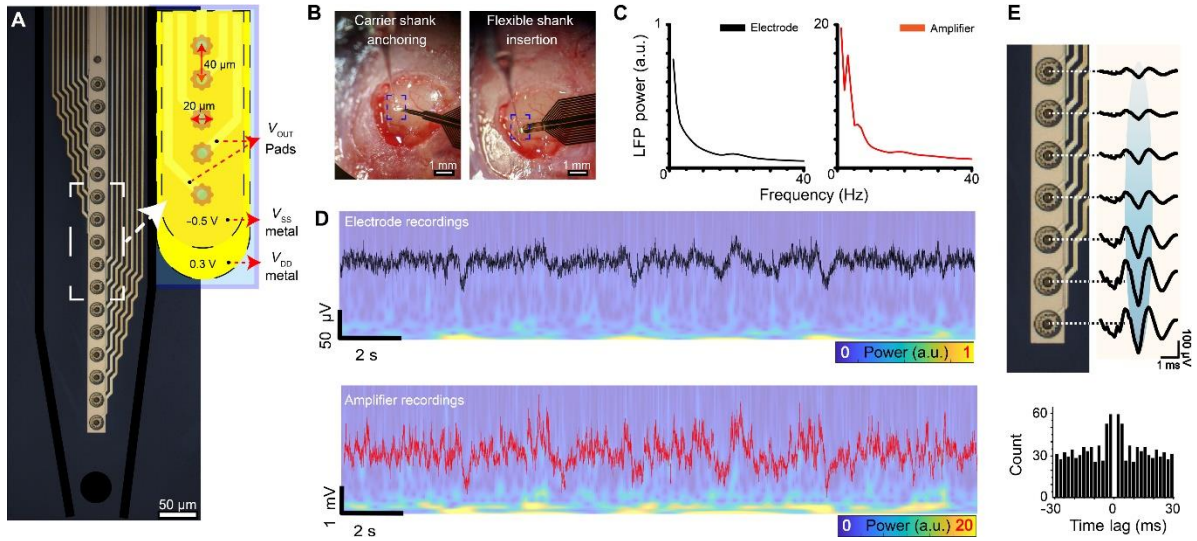
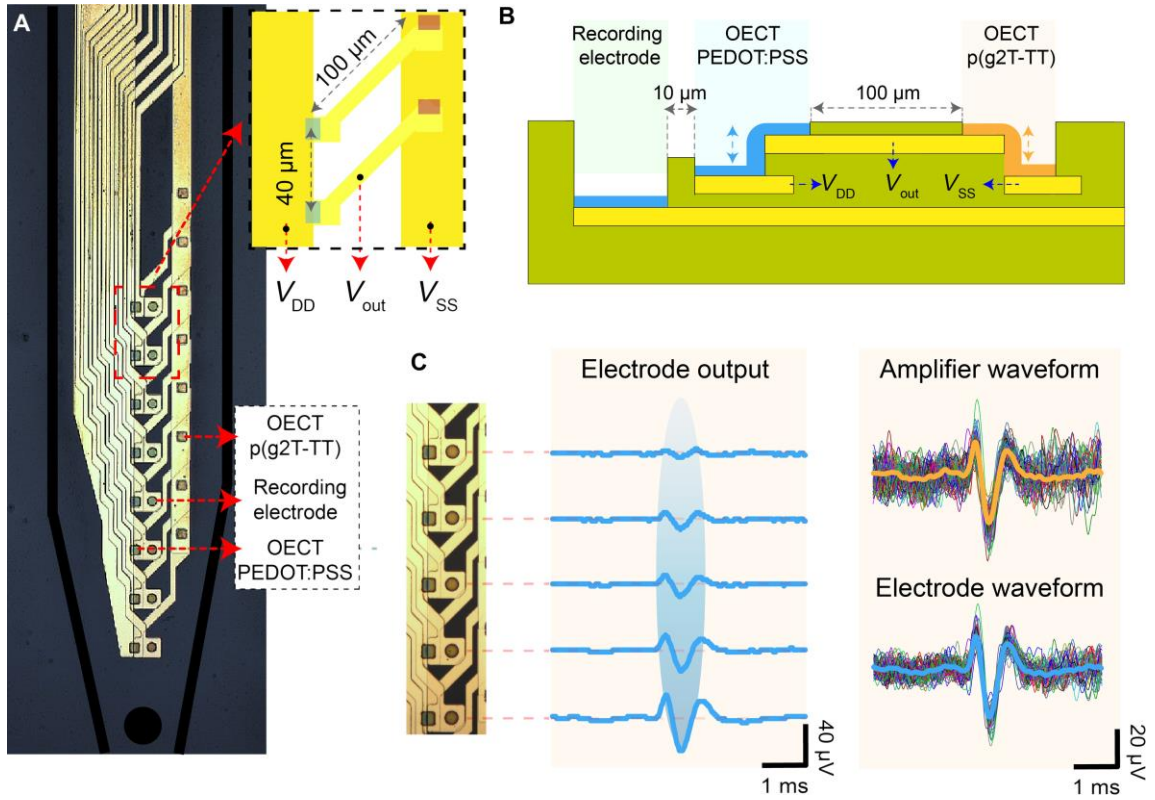
7. Bioelectronic Application

7.2 Electrophysiology Signal Detection

Inverter Amplifier



push-pull amplifiers



Differential amplifier

Nat. Commun. **4**, 1575(2013)

Sci. Adv.10,eadi9710(2024)

7. Bioelectronic Application

Summary

Wearable

- Stretchable
- Adhesion
- Humidity/Sweat
- Integrated with wireless chips & energy supply

Implantable

- Immune response
- Array uniformity
- Signal processing&classification

Nat. Commun. **4**, 1575(2013)