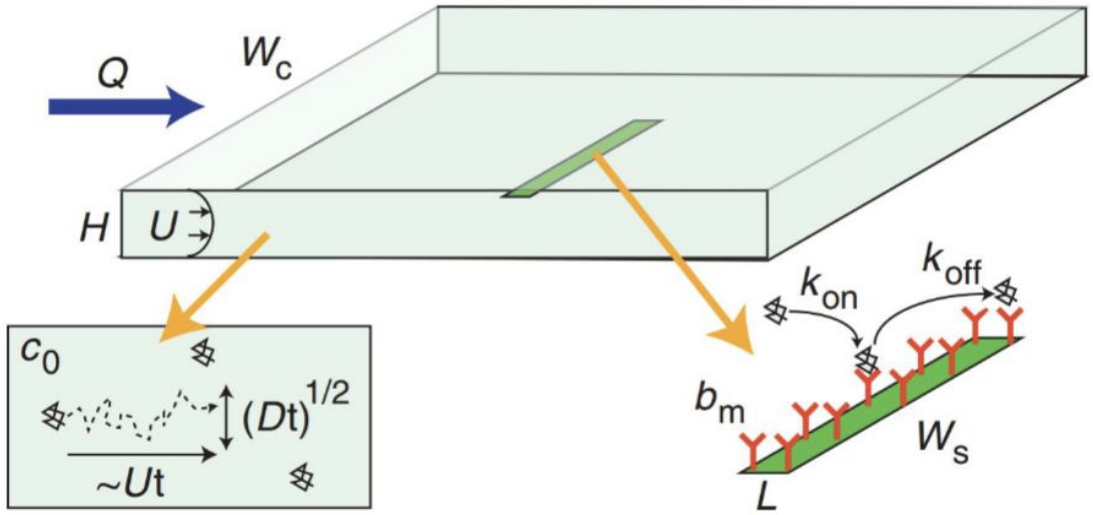
Case Study: Nanowire Biosensing

Ben Yang & Kamila Kunes

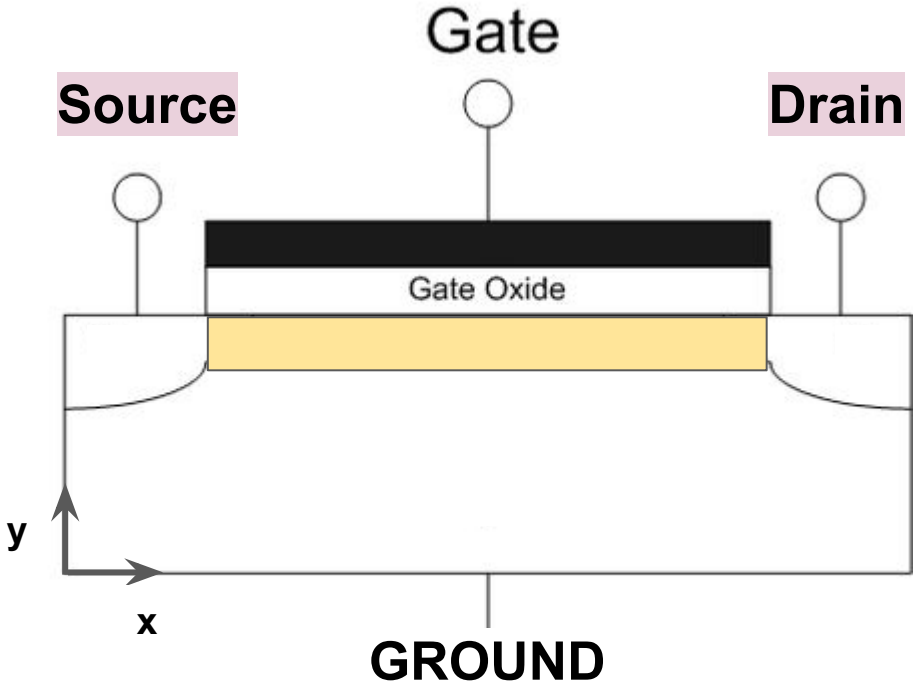
Analyte Transport to Sensor Surface: Model System



Solution with target concentration c_0 flows with velocity U and volumetric flow rate $Q \sim HW_cU$ through a channel of height H and width W_c over a sensor of length L and width W_s that is functionalized with b_m receptors per unit area. The kinetic rate constants for the binding reaction are k_{on} and k_{off}, and the diffusivity of the target molecules is D.

T. M. Squires *et al.*, Nature Biotechnology 2008

Field Effect Transistors

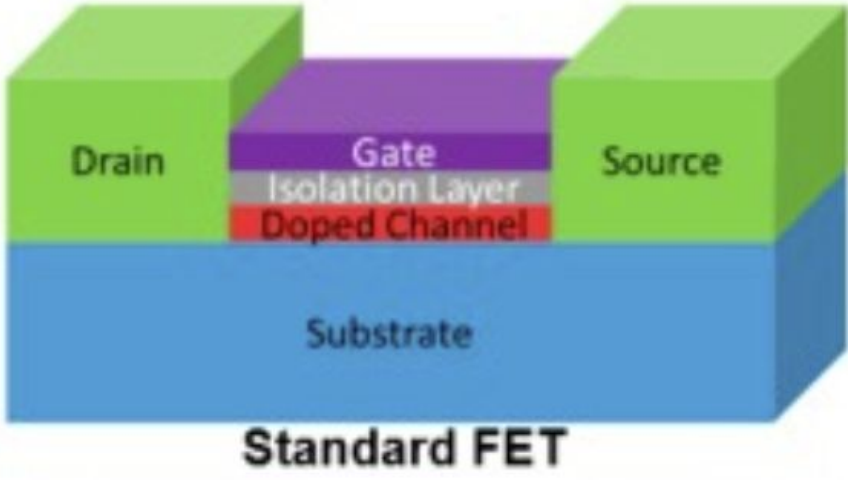


3 Channel Device:

1. Apply constant V_{SD}
2. Apply V_G (field)
3. Yellow region's conductance changed
4. Current between source & drain changes

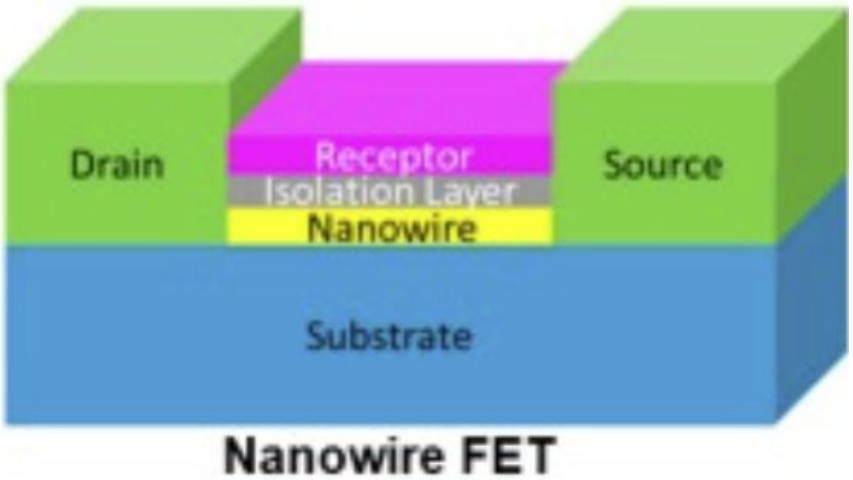
Think of gate & ground as a capacitor

Nanowire FET



Standard FET

vs.



Nanowire FET

Replace doped channels & gates w/ nanowires & receptors, dielectric layer stays

Why Nanowires – A new realm of biomarker diagnostics

Amplifies Signal & Robust

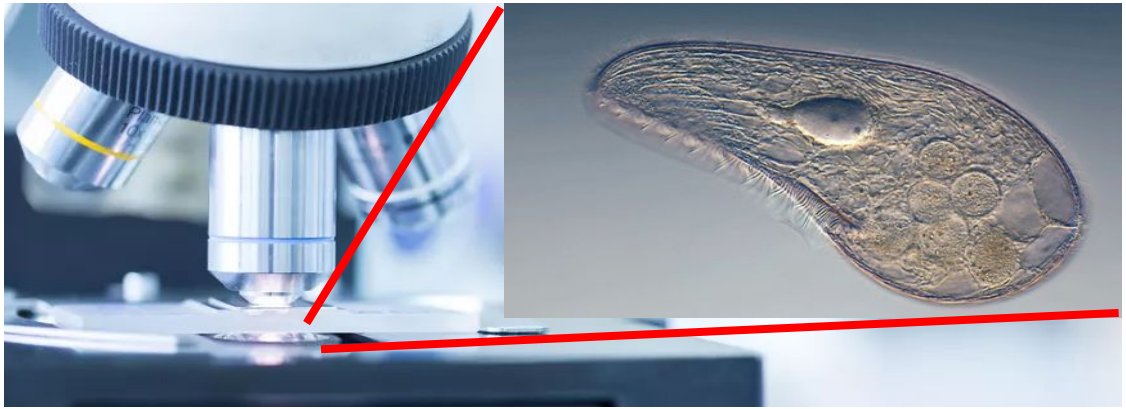
→ Sensitivity much higher

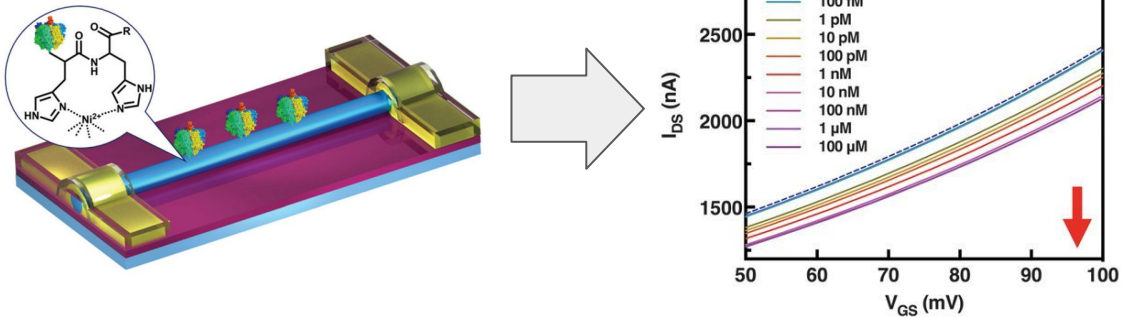
high dynamic range

→ Easily integrated

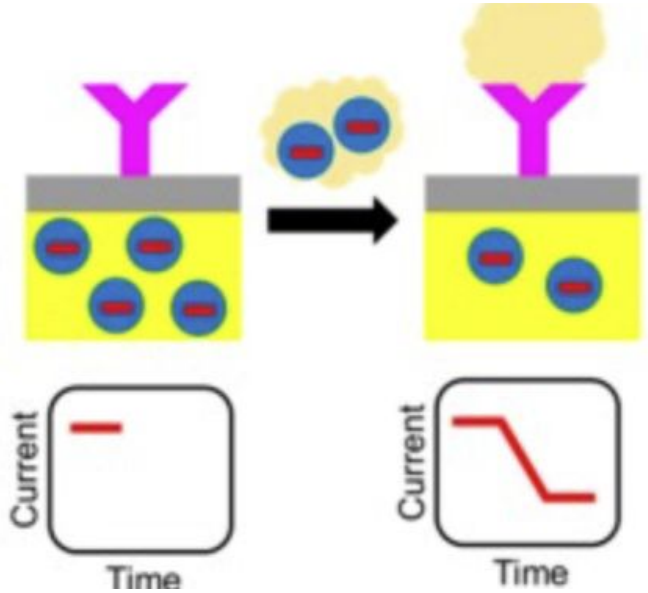
→ Robust

real time monitoring

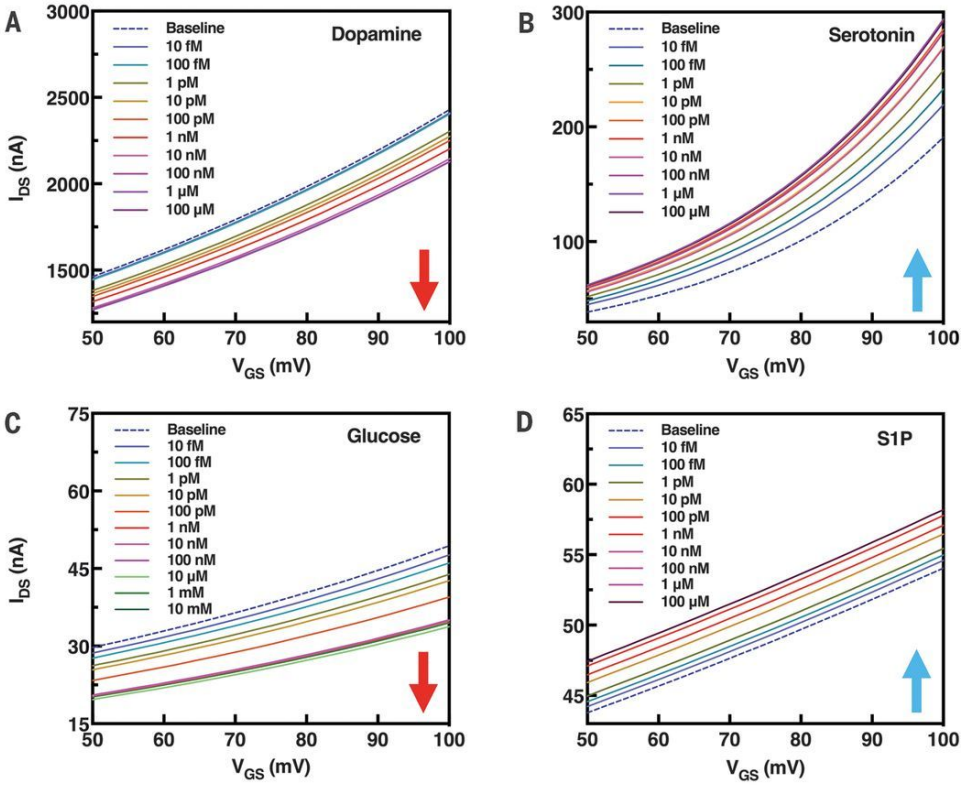




Operating Principle



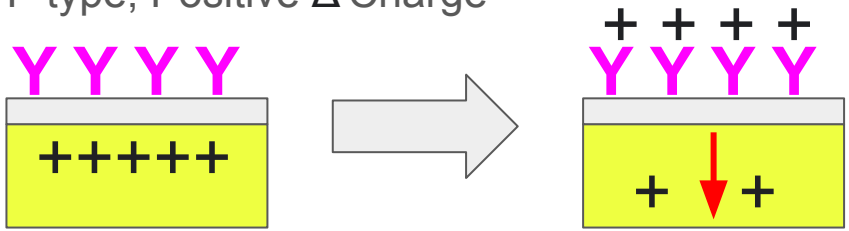
IV Curves at different concentrations



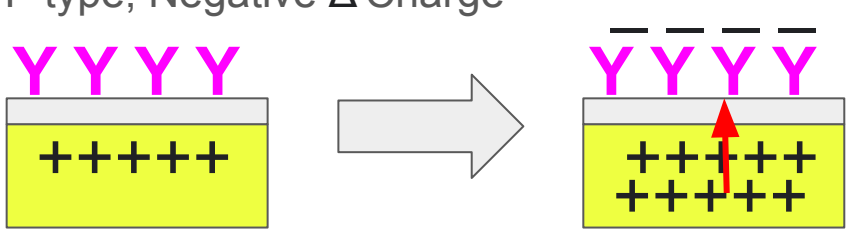
Operating Principle

Nanowire Type	**Δ Charge (Q_i - Q_f)**	
	Positive	Negative
N type (- dominant)	Attracts e-, σ up, R down → current <u>UP</u>	e- away, σ down, R up → current <u>DOWN</u>
P type (+ dominant)	How does current change?	

P type, Positive Δ Charge

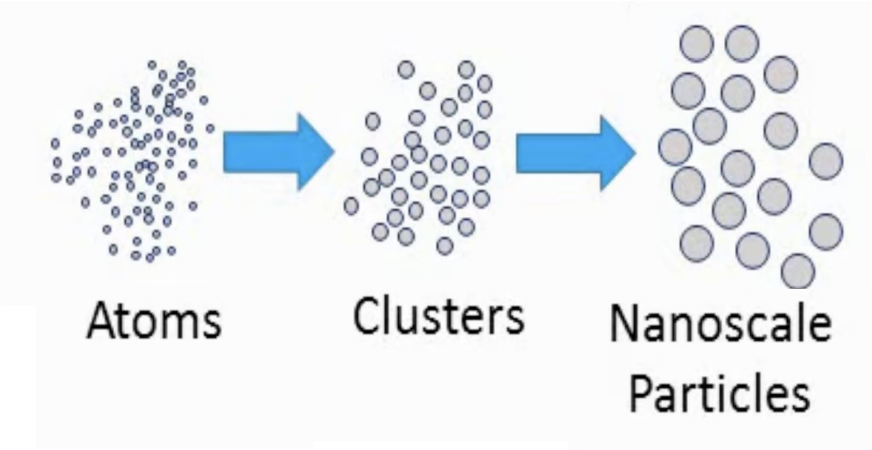


P type, Negative Δ Charge

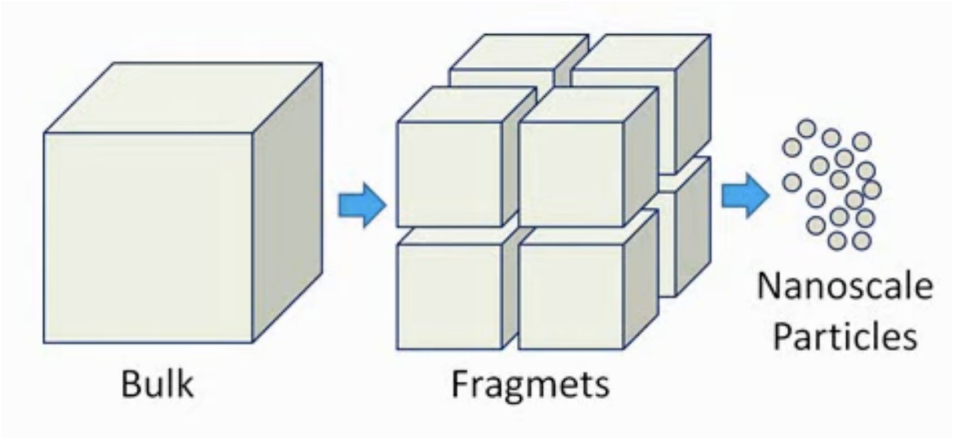


Fabrication → 2 approaches

Bottom Up



Top Down



Bottom Up

1. Grow Si nanowires w/ CVD
2. Suspension → deposit on Si

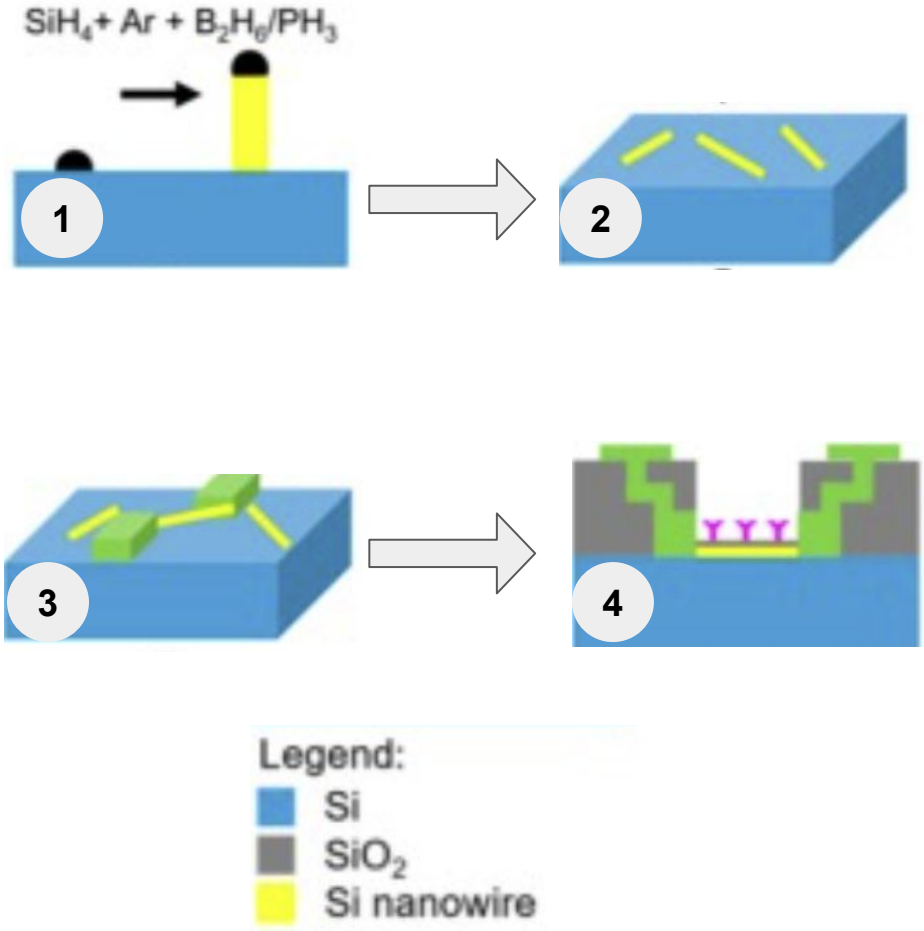
2.5 Photoresist spin coating

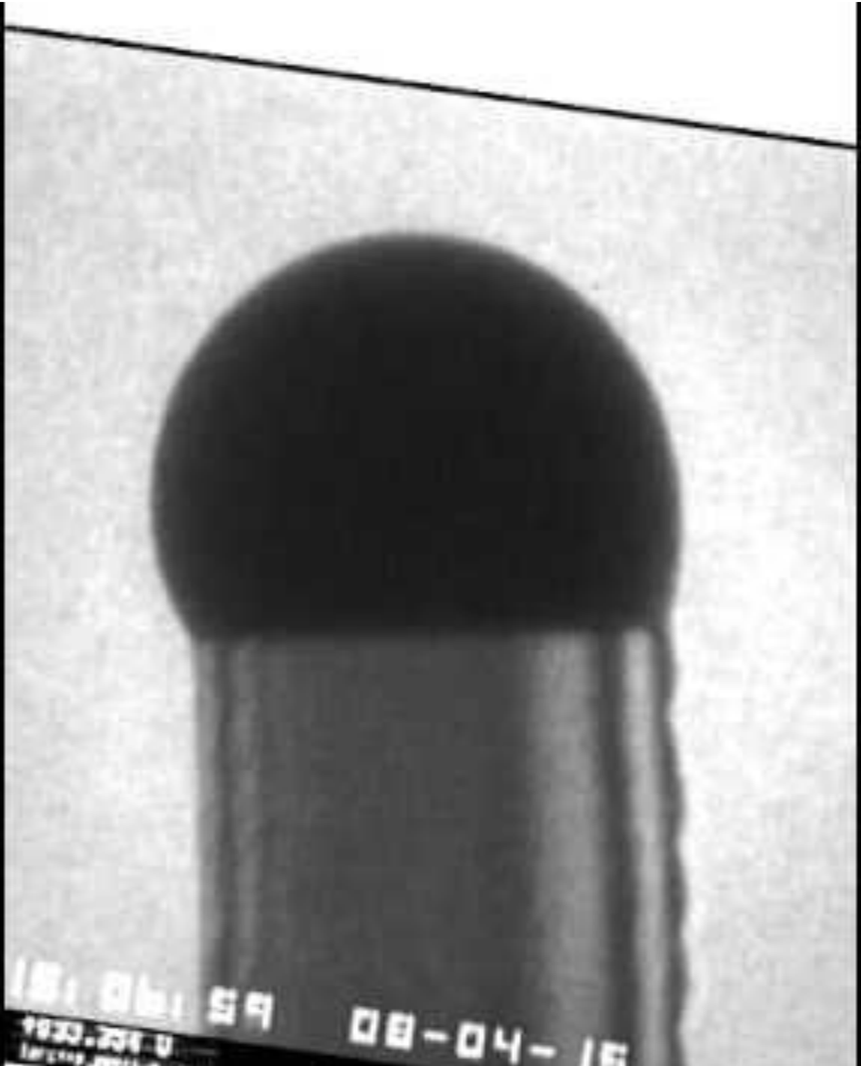
3. Metal electrodes patterned w/ lift-off
   a. stay or not stay
4. Passivation & surface modification

High quality BUT

Random nanowire orientation so

Low Yield



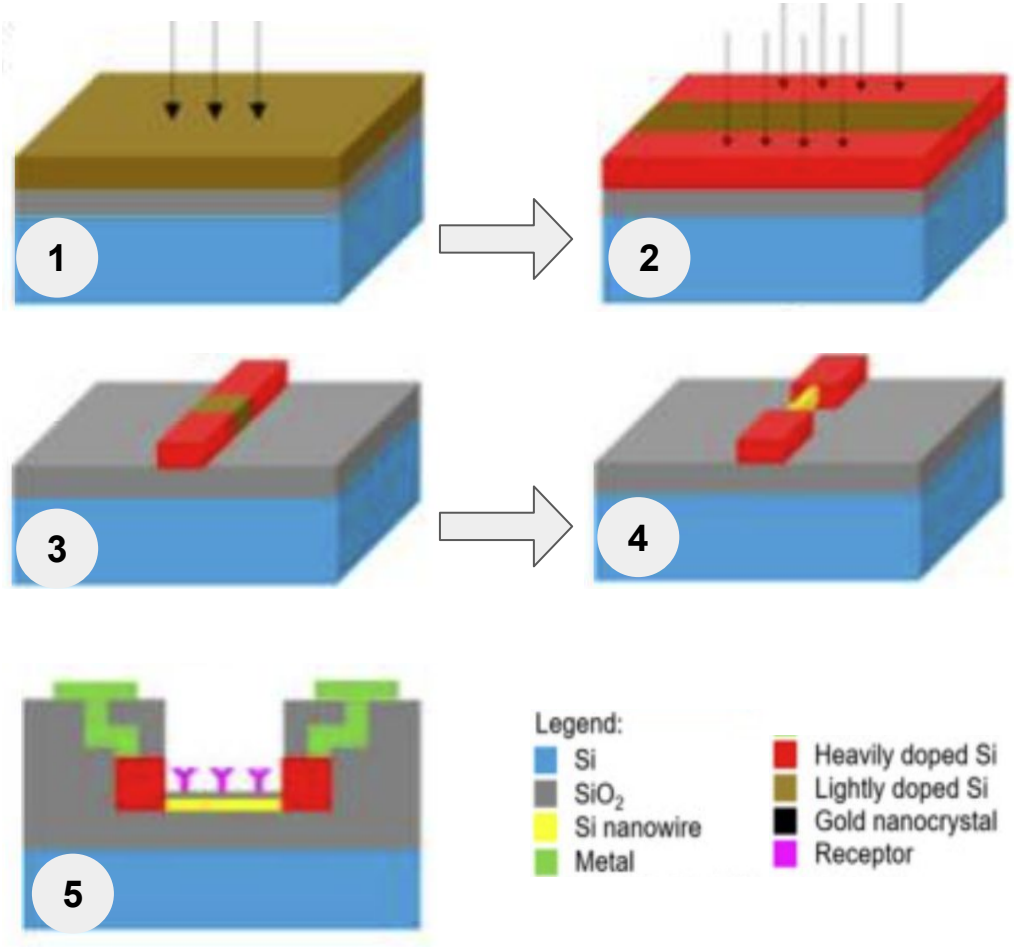

18:06:59 08-04-15

Top Down

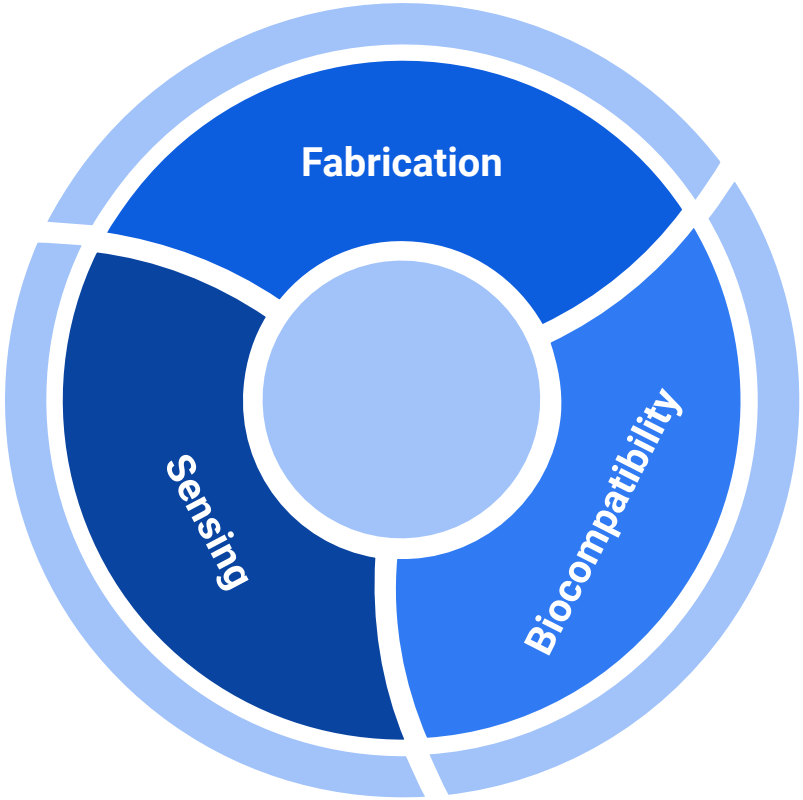
1. Dope low density boron/phosphorus on insulator layer (SOI)
2. Heavy doping for source & drain
3. Reactive Ion Etching → μm bar
4. Electron beam lithography for Si nanowires
5. Thermal Evaporation for metal contact leads
6. Passivation & surface modification

Compatible w/ CMOS techniques BUT

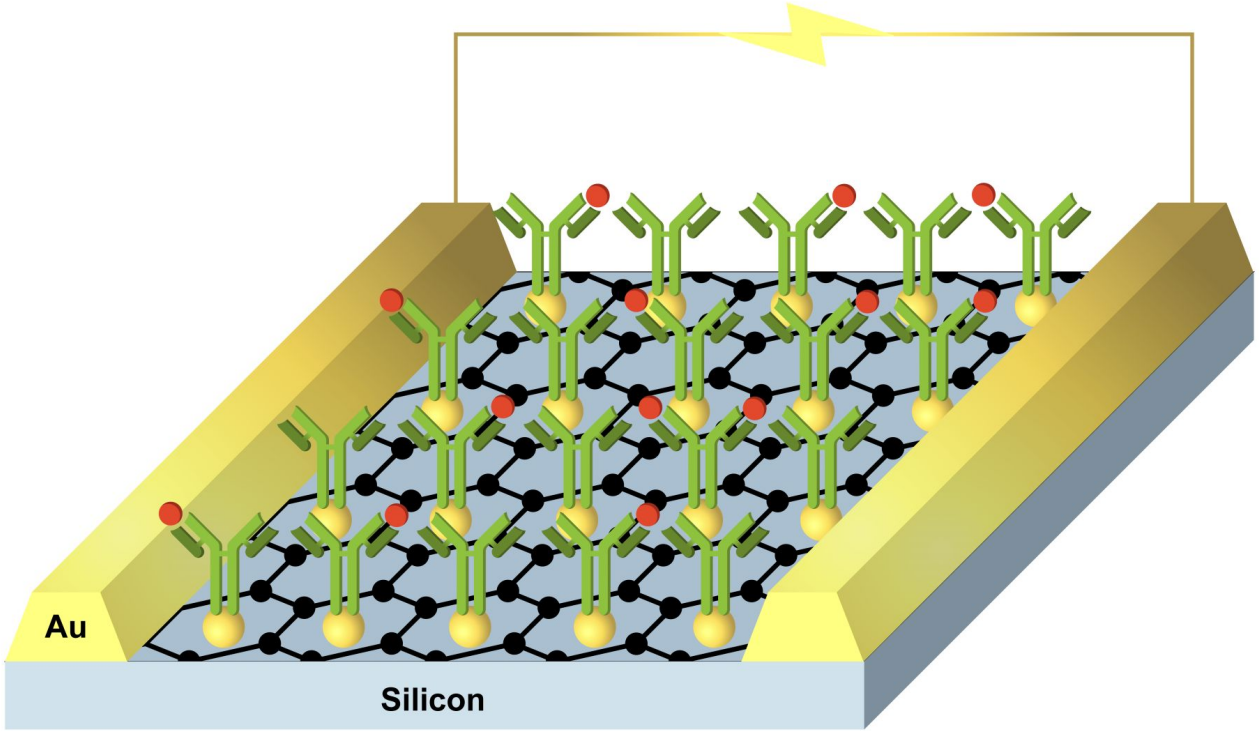
Larger nanowires than bottom up



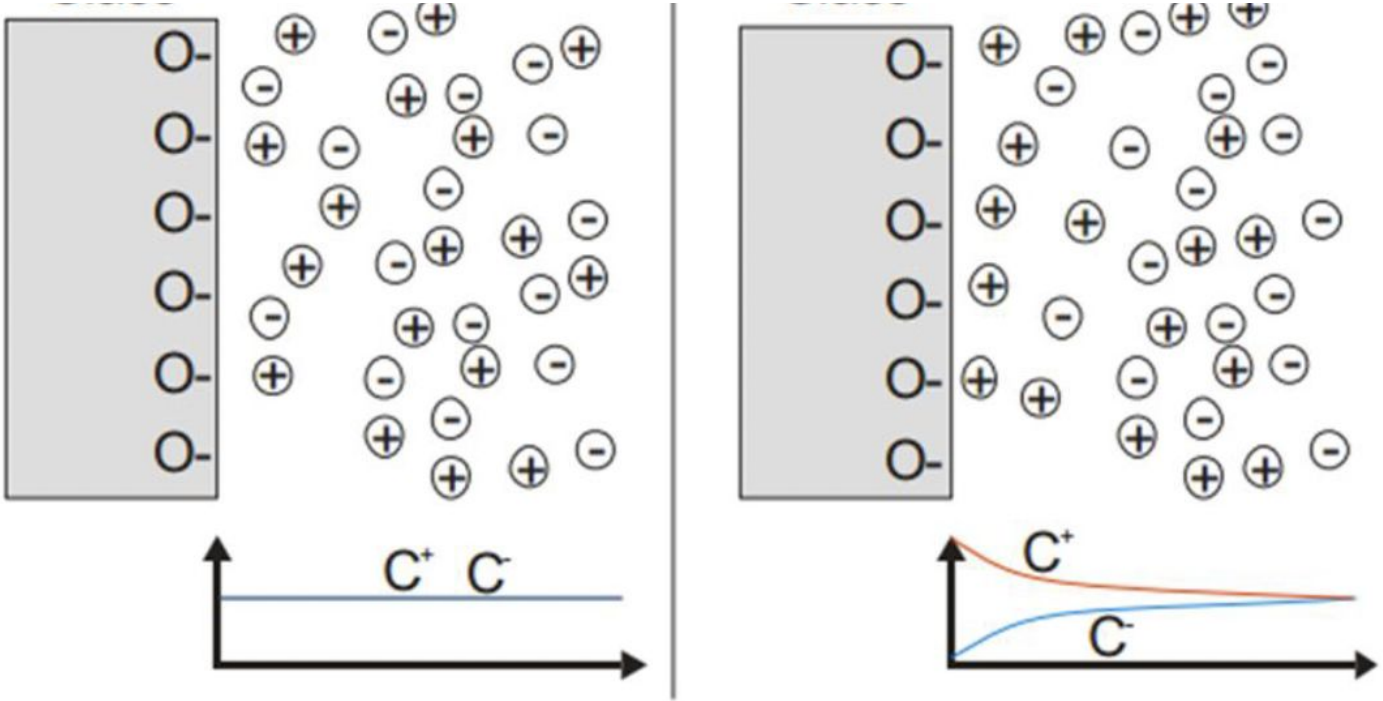
Challenges & Problems



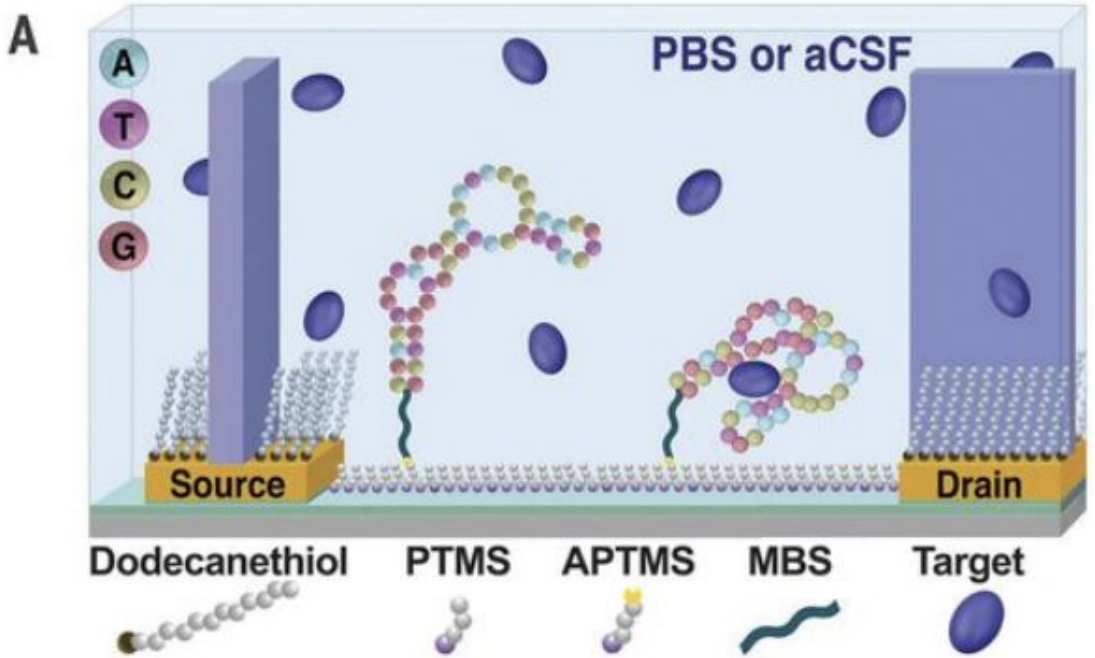
Analyte Problem



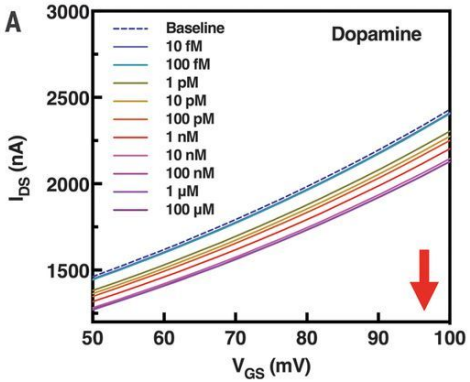
Debye Problem

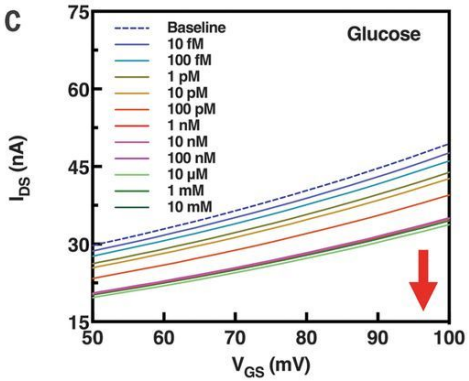


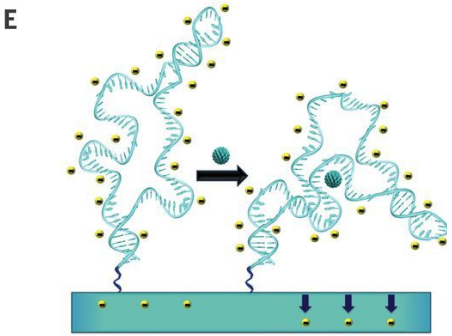
Aptamers and potential solution…

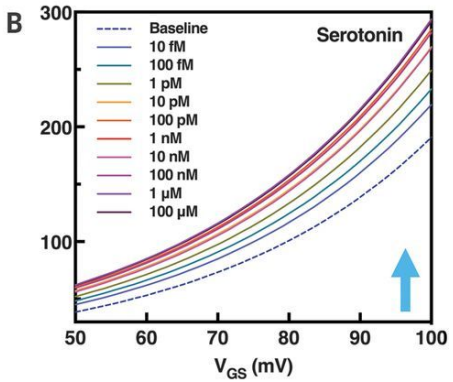


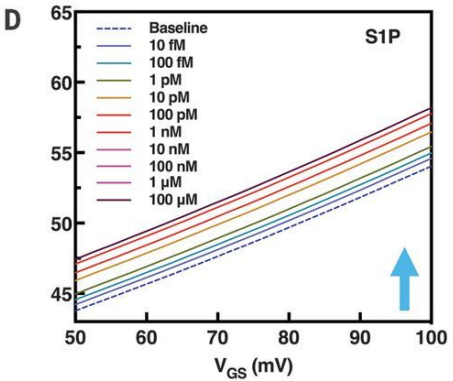
Aptamers and potential solution…

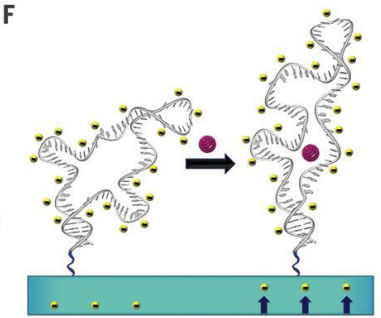




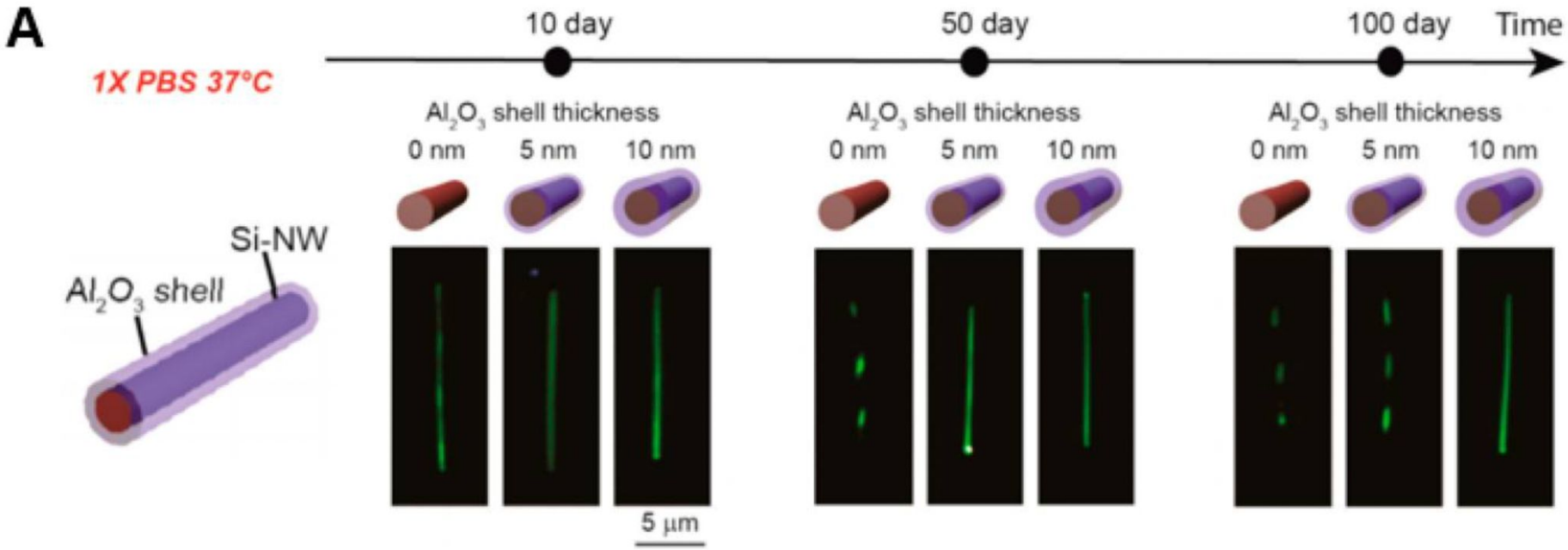




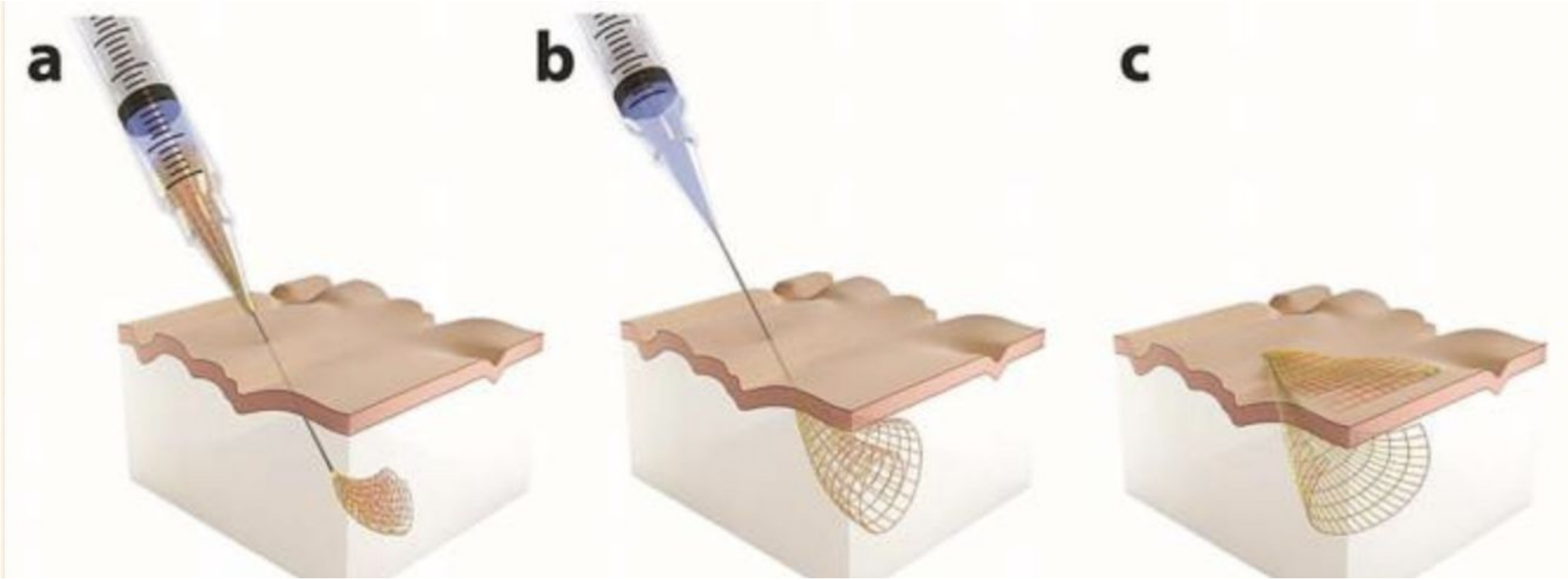


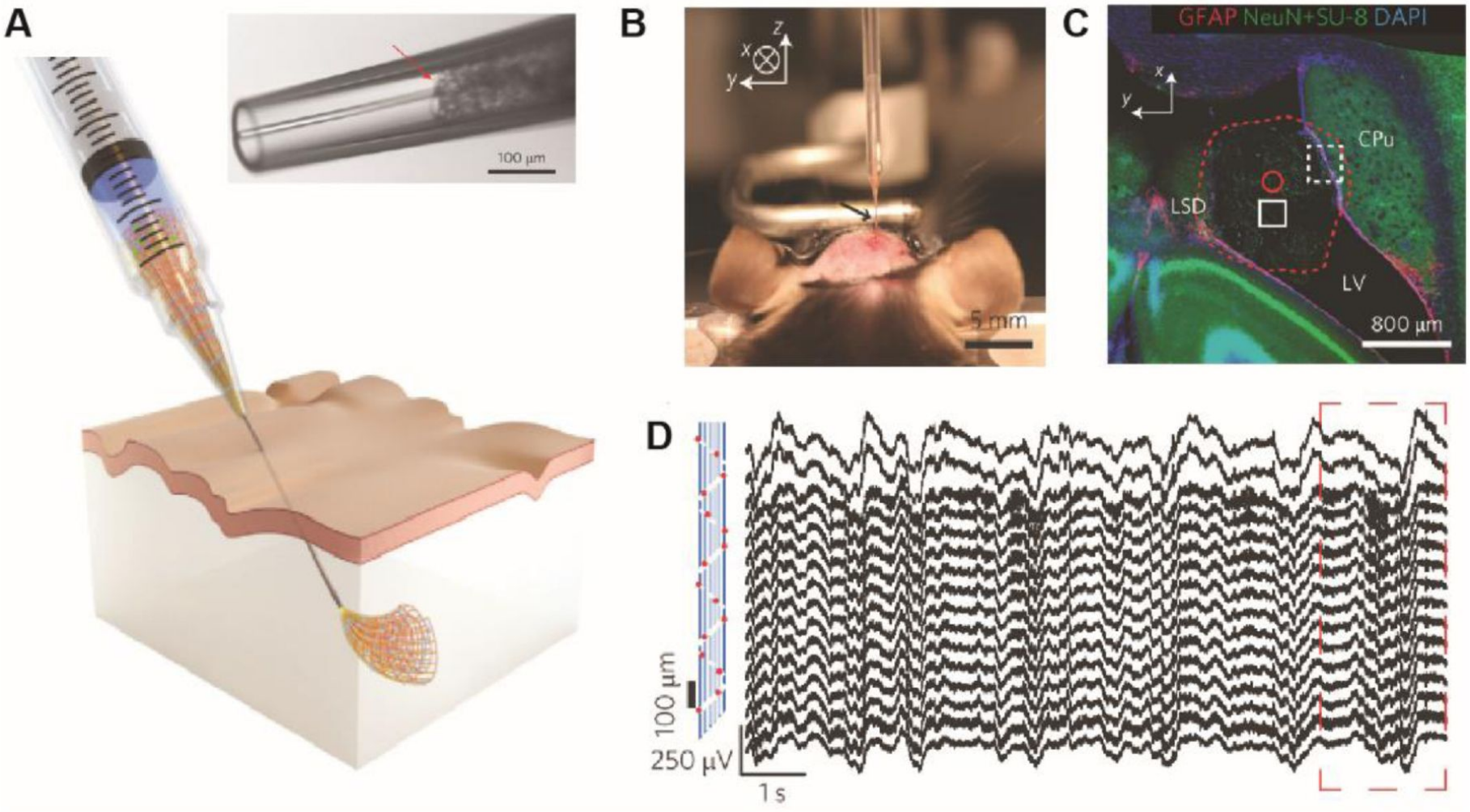


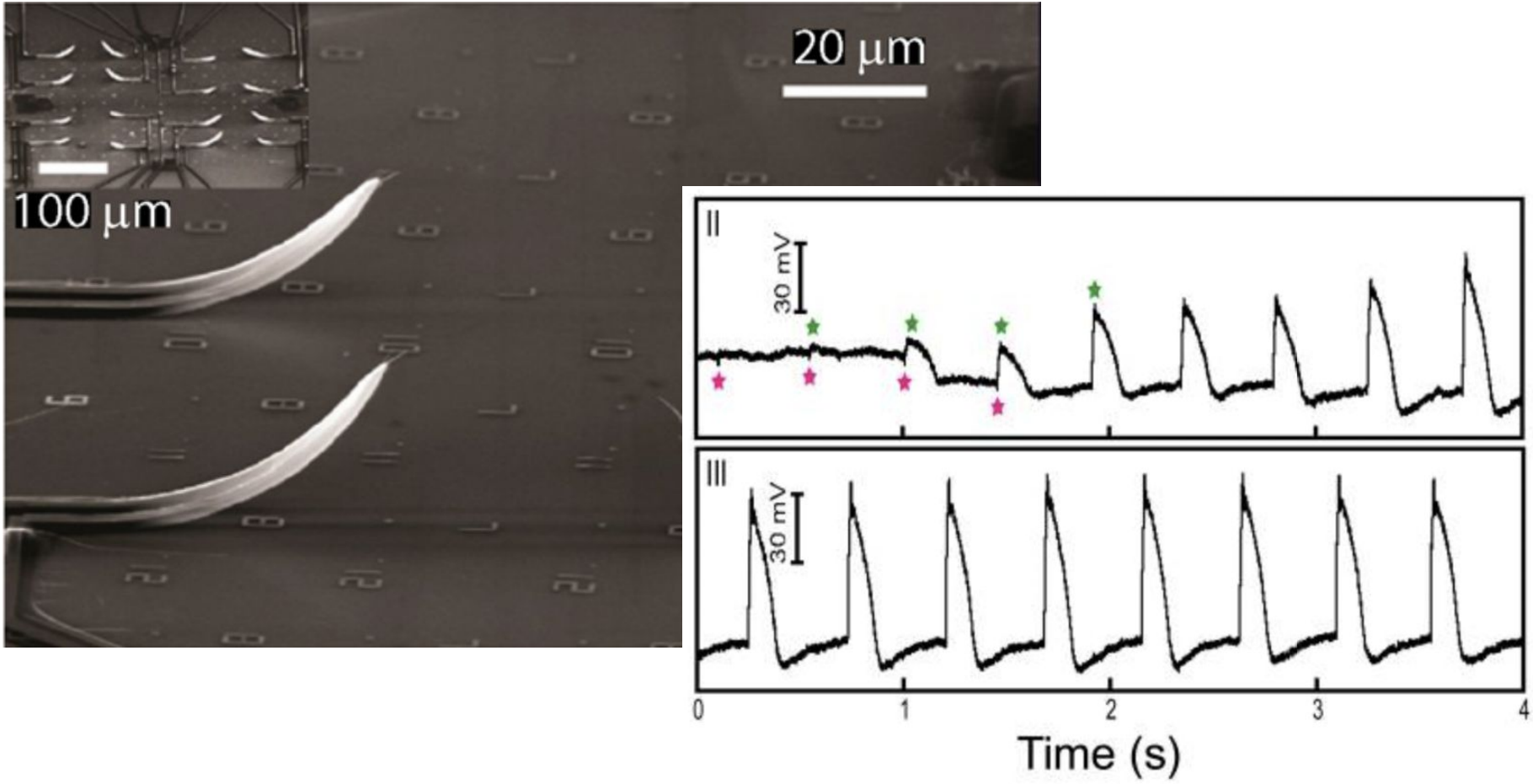
In-Vivo Potential

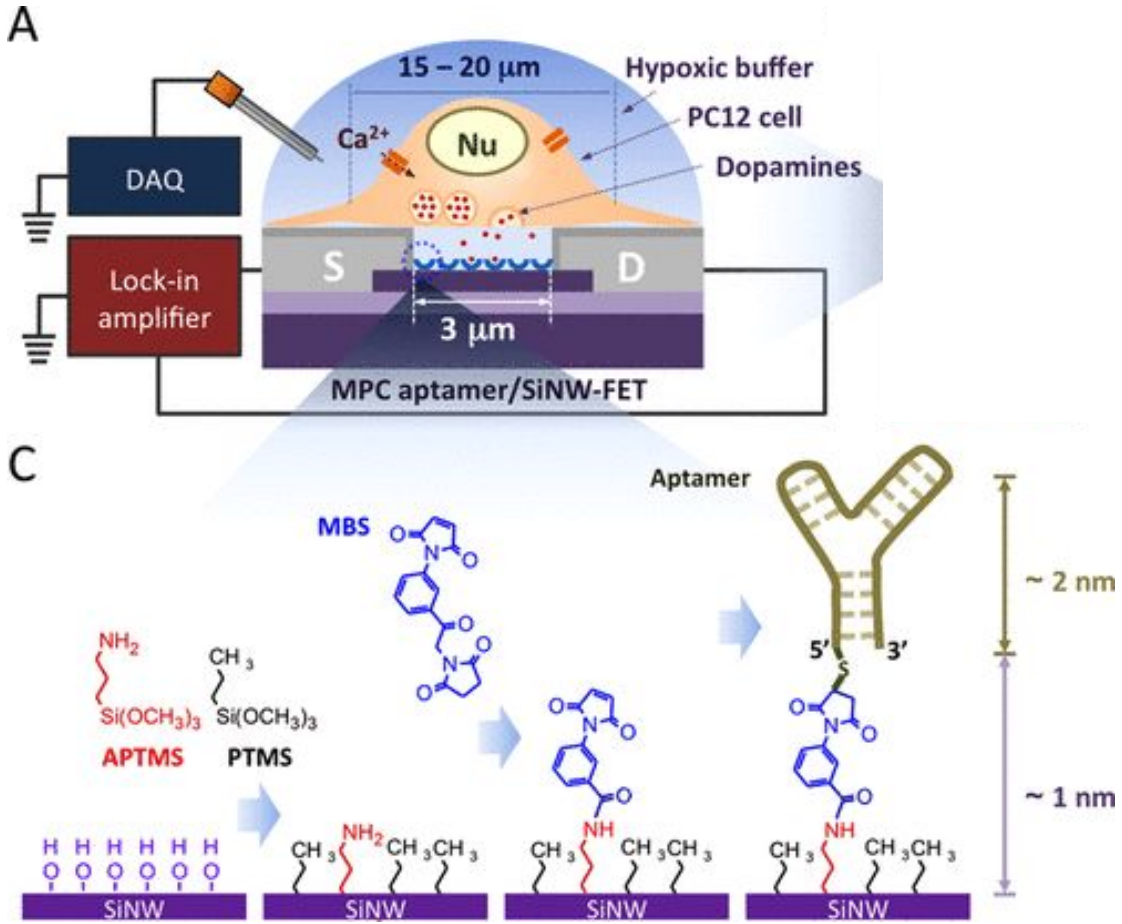


Injectable Electronics




A
100 µm
B
z
x
y
5 mm
C
GFAP NeuN+SU-8 DAPI
x
y
CPu
LSD
LV
800 µm
D
100 µm
250 µV
1 s


20 µm
100 µm
II
30 mV
III
30 mV
0
1
2
3
4
Time (s)


A
15 – 20 μm
Hypoxic buffer
PC12 cell
Dopamines
Ca2+
Nu
DAQ
Lock-in amplifier
S
D
3 μm
MPC aptamer/SiNW-FET
C
Aptamer
MBS
~ 2 nm
~ 1 nm
5′
3′
APTMS
PTMS
SiNW
SiNW
SiNW
SiNW

Questions?

SOURCES

- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3771379/
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4591029/
- https://www.science.org/doi/10.1126/science.aao6750
- https://www.science.org/doi/10.1126/sciadv.abk0967