

CMOS electronics see inside biological cellular networks (1st generation device)

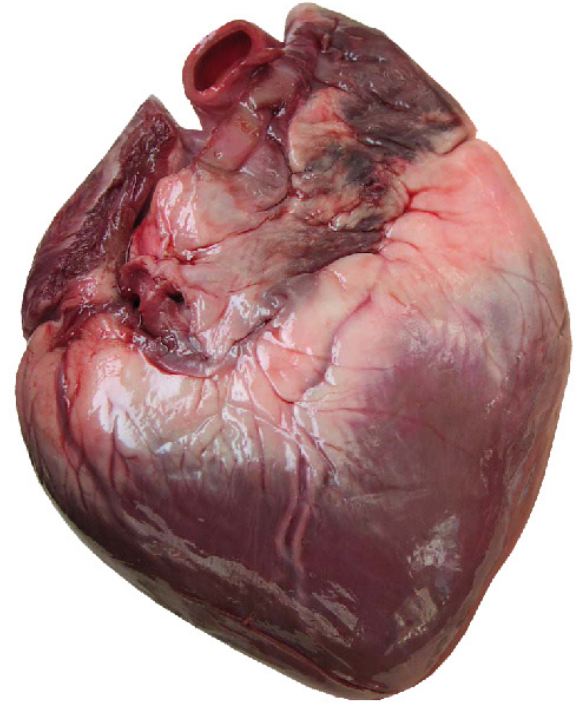
Donhee Ham, Harvard University



Electrogenic cellular networks



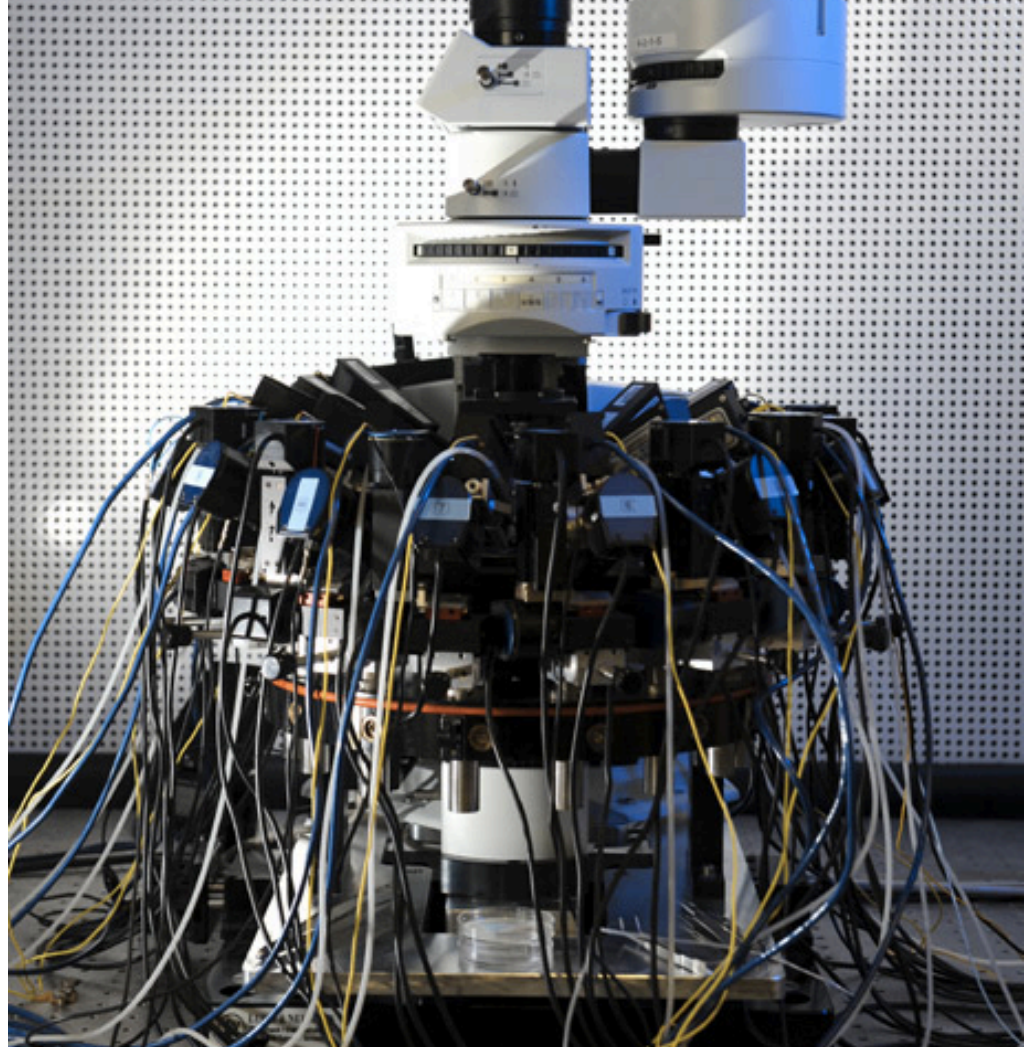
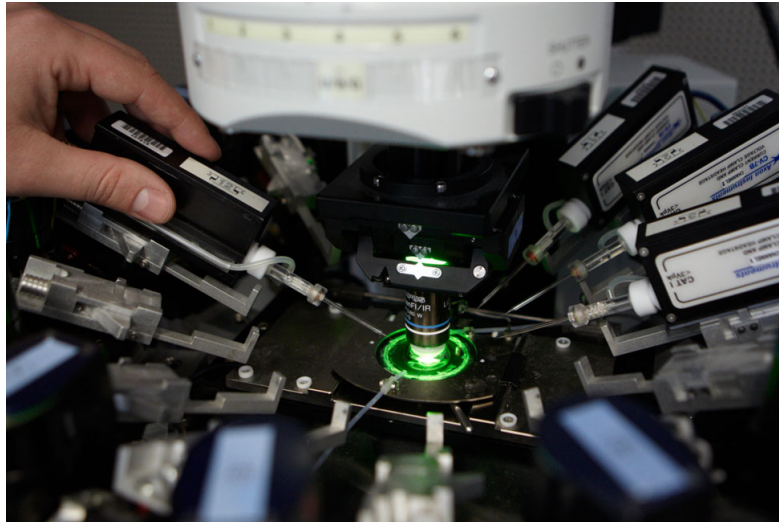
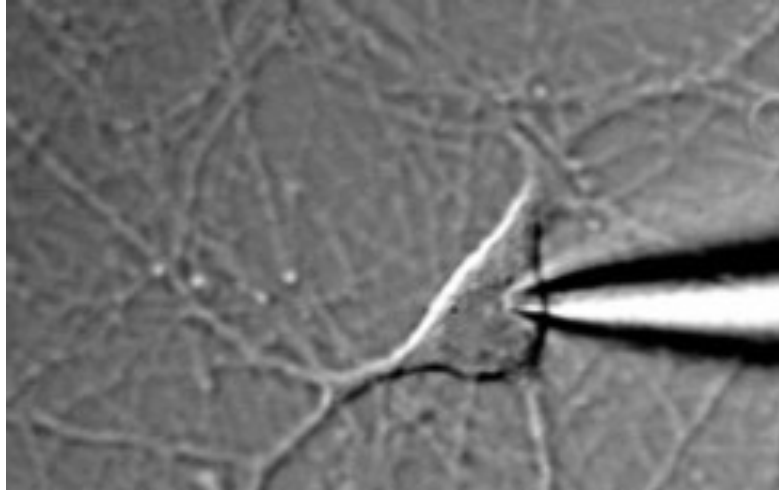
$\sim 10^{11}$ neurons
 $\sim 10^{15}$ synapses



$\sim 10^9$ cardiomyocytes
 $\sim 10^{10}$ cell-cell connections

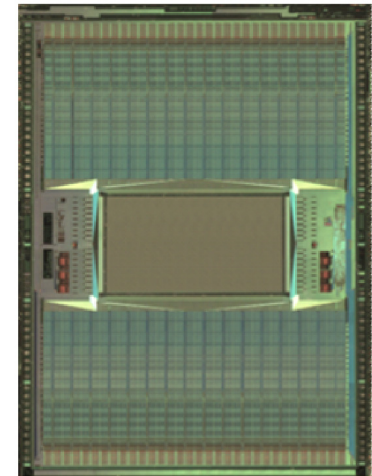
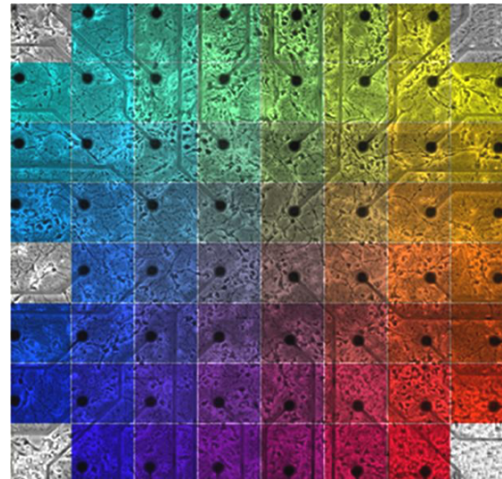
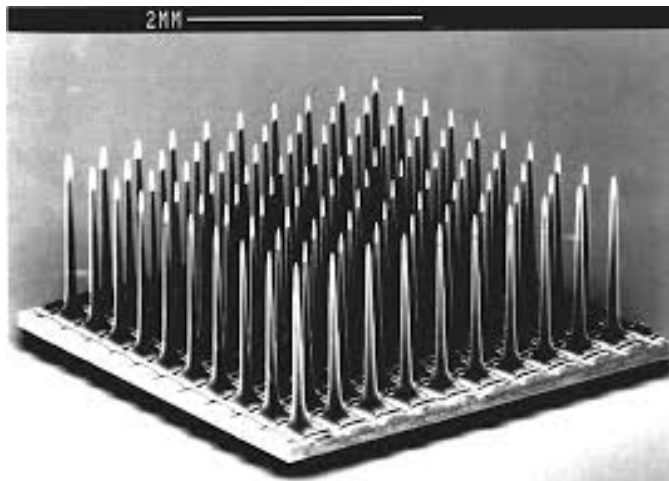
Dichotomy — intracellular vs. parallel

Patch pipette — Intracellular, but not parallel



Dichotomy — intracellular vs. parallel

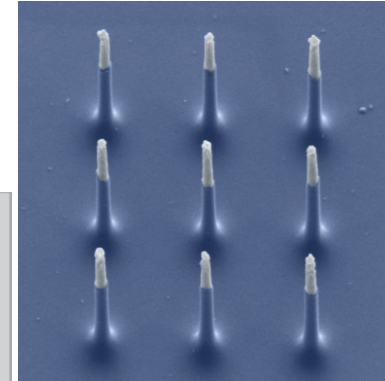
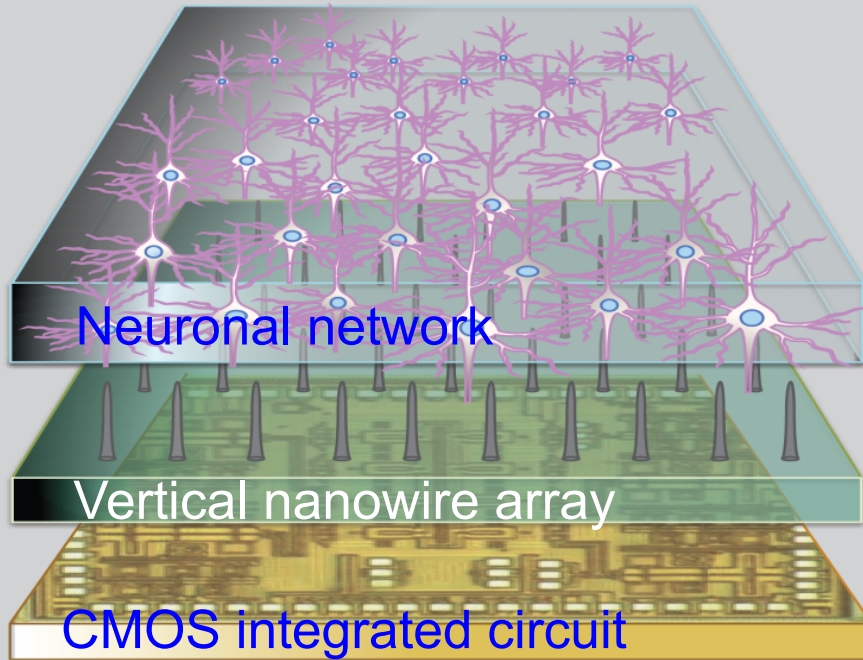
Microelectrode array — parallel, but not intracellular



26,400 electrodes
1,024 channels

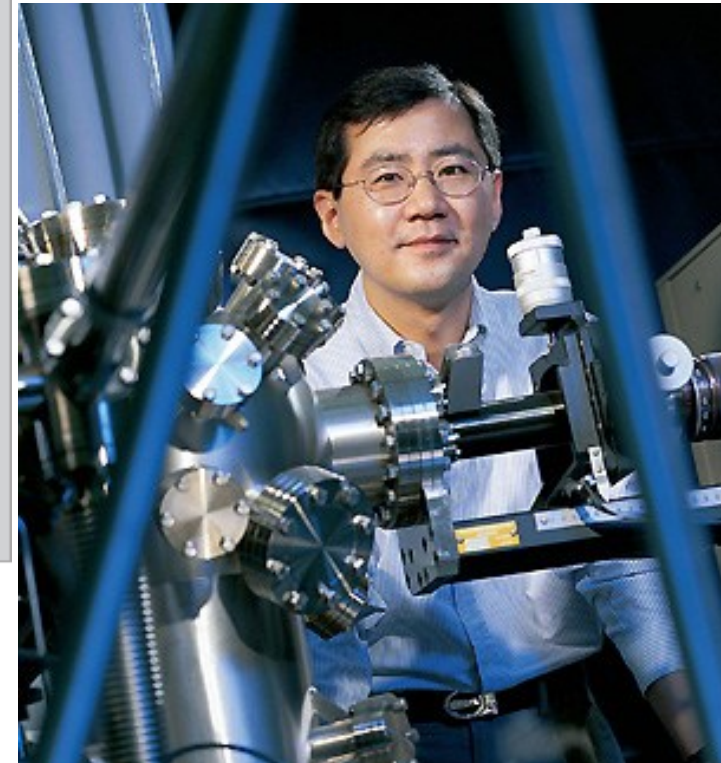
M. Ballini et al.,
IEEE JSSC (2014)

CMOS nanoelectrode array — Intracellular + parallel



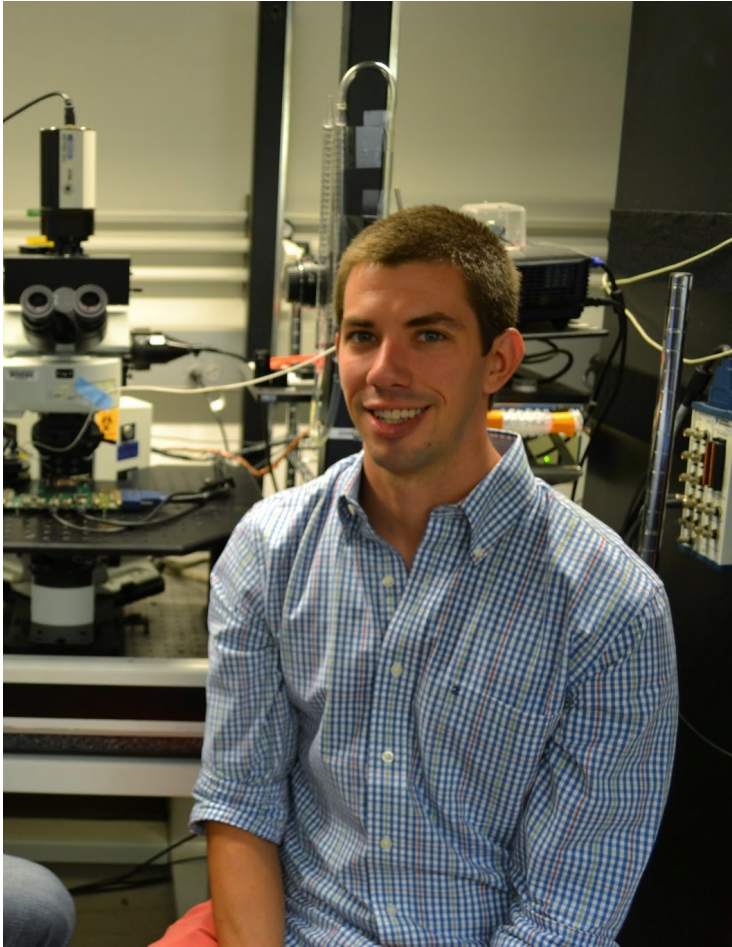
Vertical
Nanowires

Park lab,
Nature Nano.
7, 180 (2012).

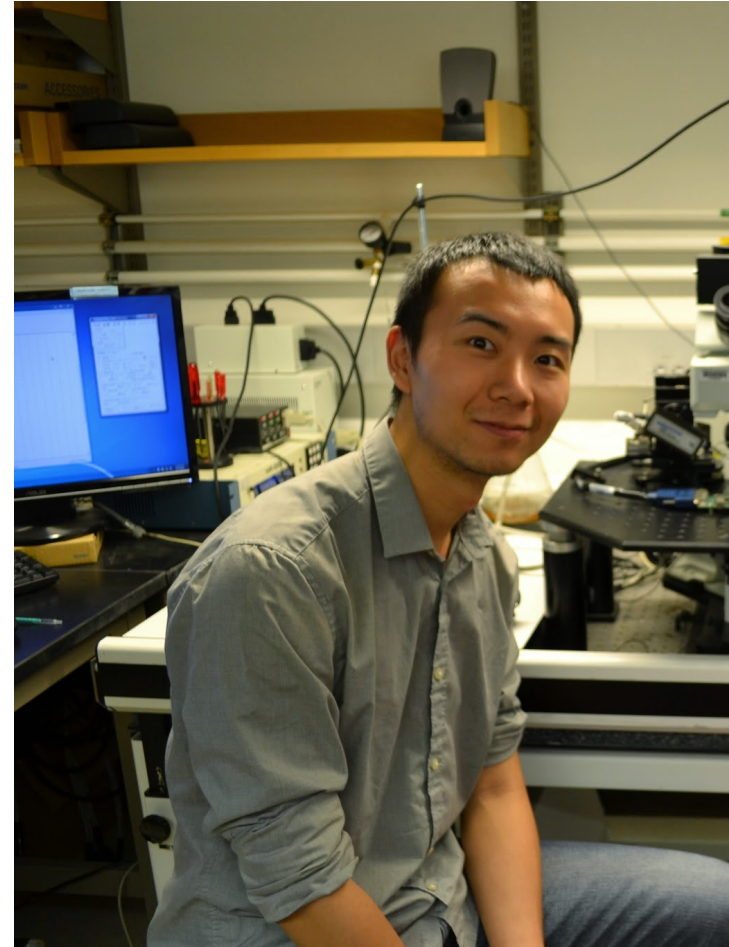


Prof. Hongkun Park
(Harvard Chemistry & Physics)

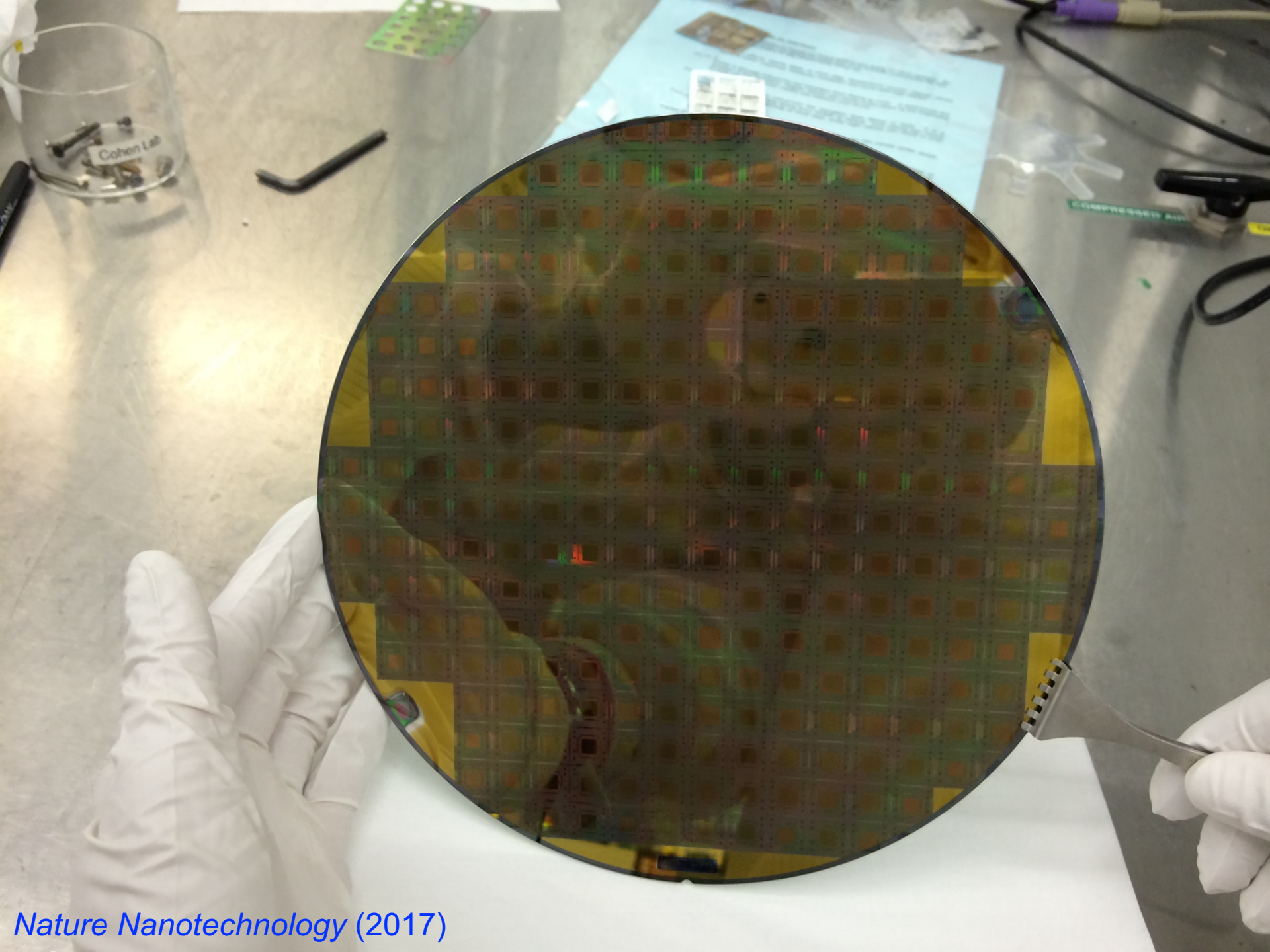
CMOS nanoelectrode array — Intracellular + parallel



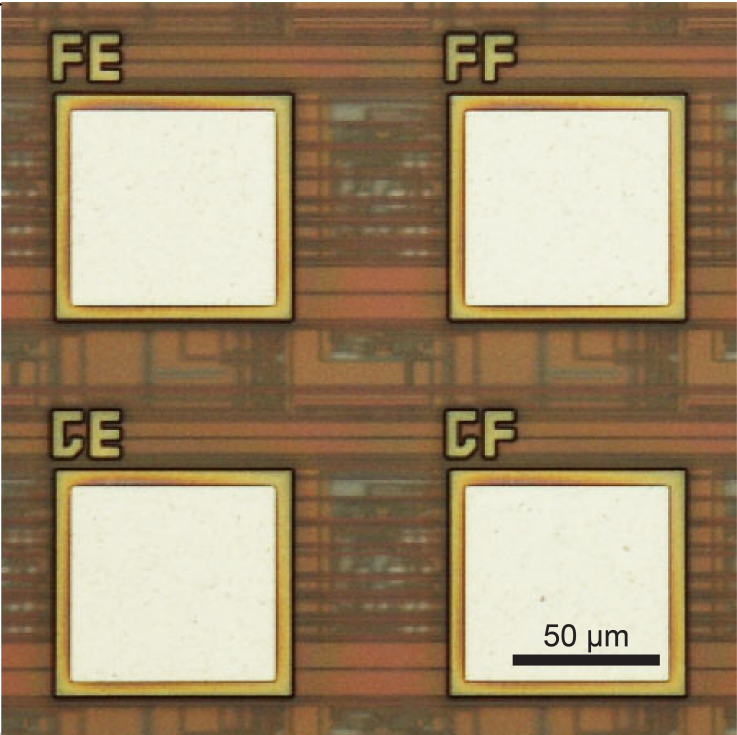
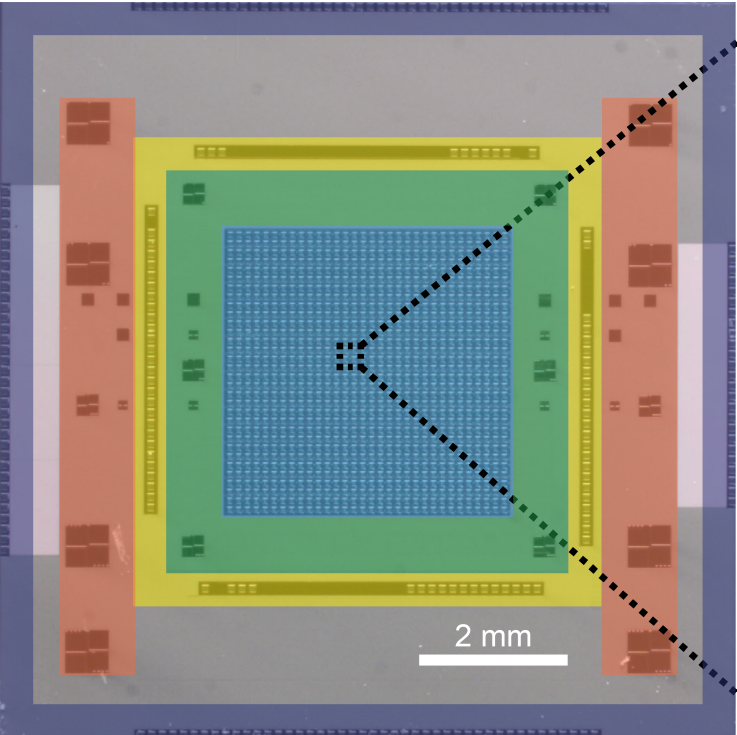
Jeffrey Abbott



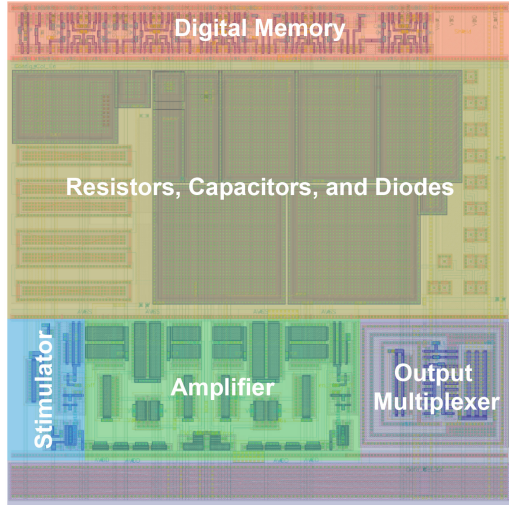
Tianyang Ye (Park lab)



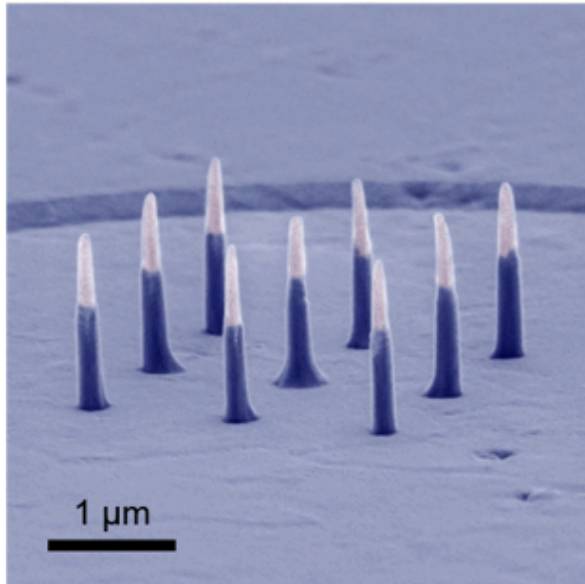
CMOS IC chip (1024 active site array)



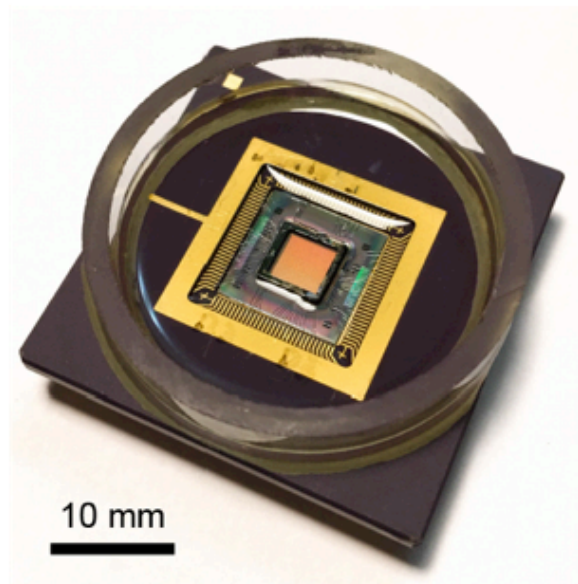
- Array of pixels
- Control Circuitry
- I/O Pads
- Alignment Marks
- Test Structures



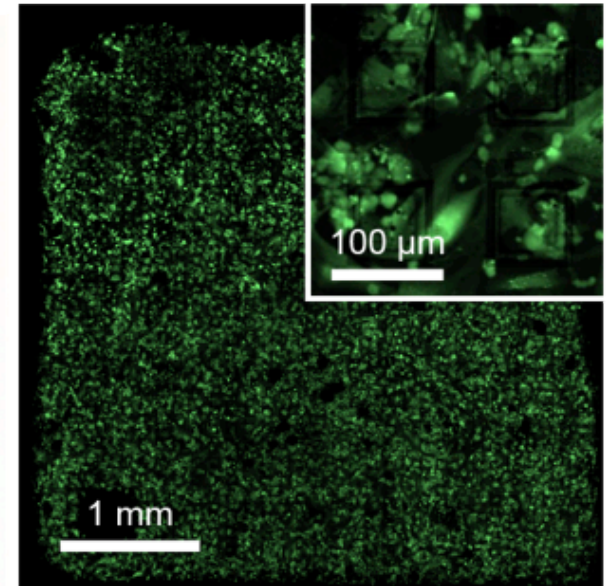
Vertical nanoelectrodes on the surface + packaging



9 nanoelectrodes
per pixel

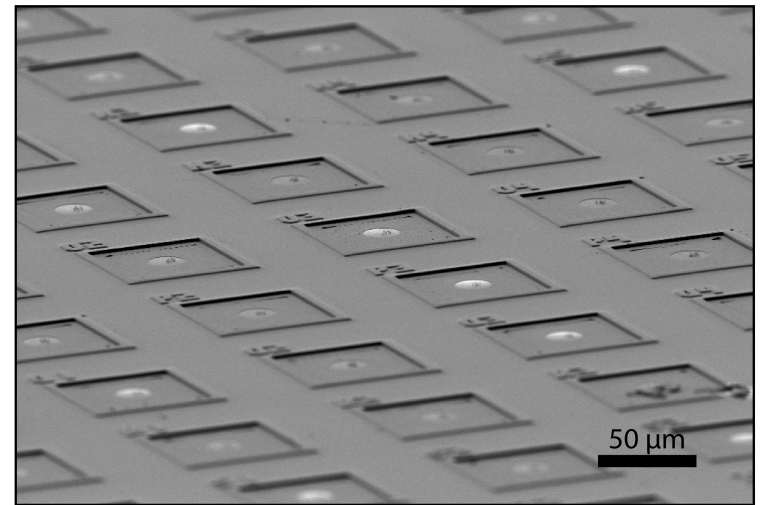
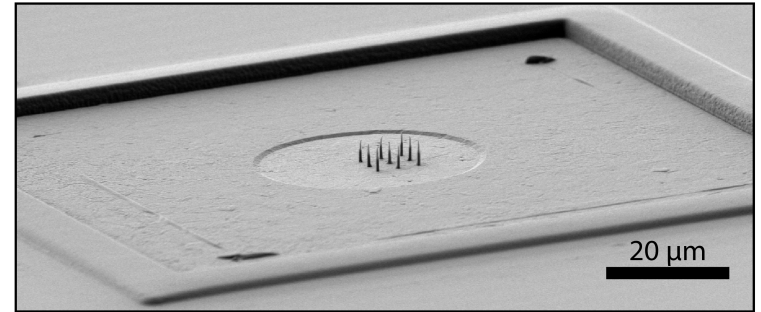
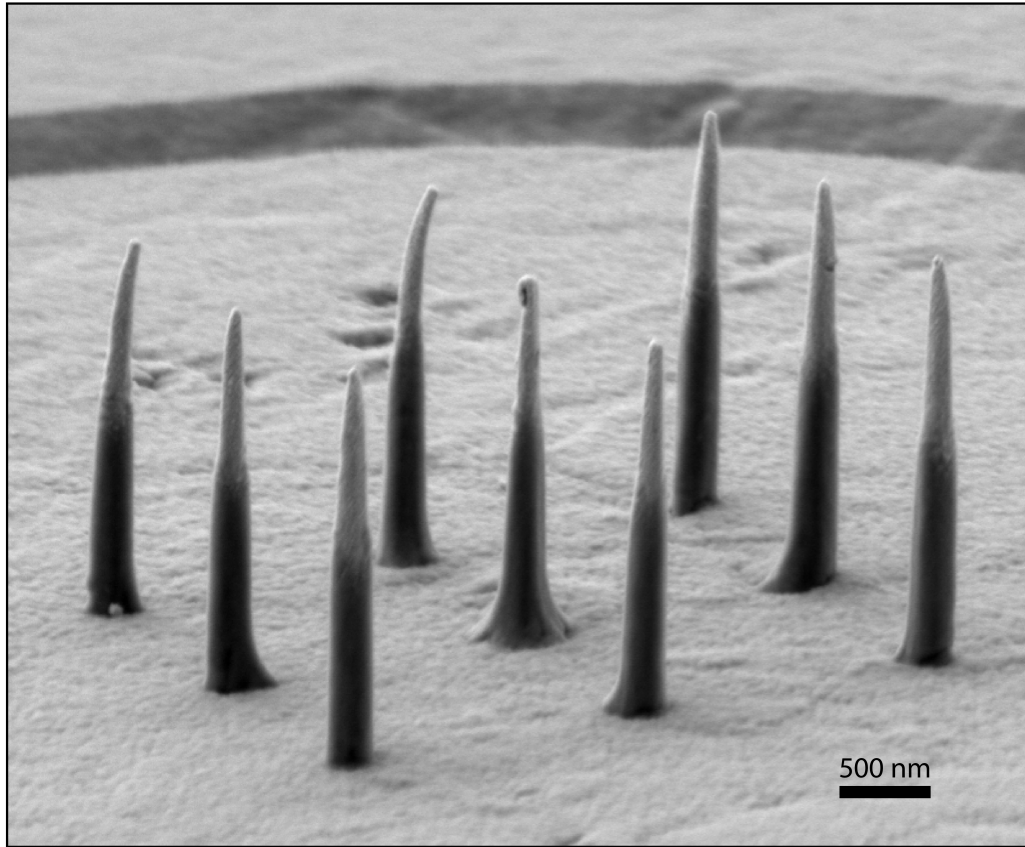


Packaged device



Cardiomyocyte tissue
in vitro cultured on top

Vertical nanoelectrodes



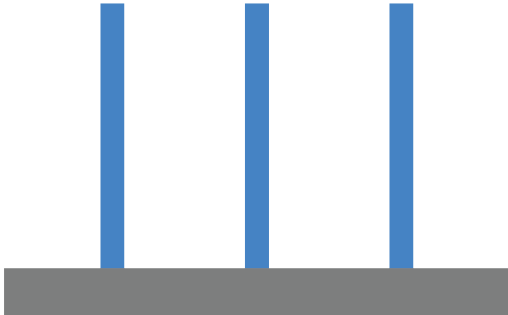
Post fabrication steps



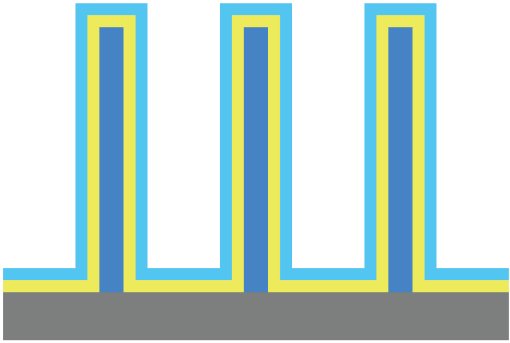
PECVD SiO₂ on Al pad



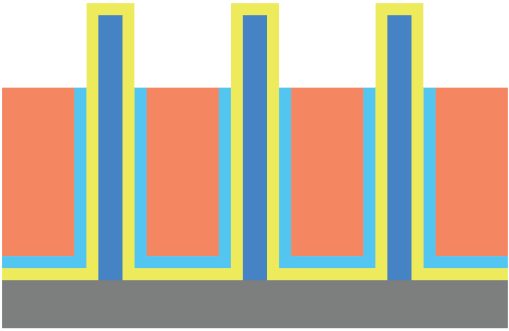
Stepper lithography and dry etch to form SiO₂ pillar



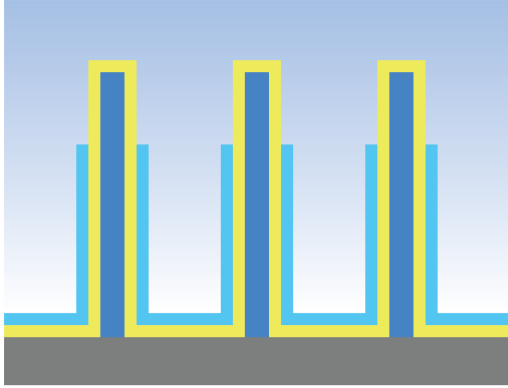
Wet etch pillar into SiO₂ wires



Sputter metal coating; insulate with ALD SiO₂

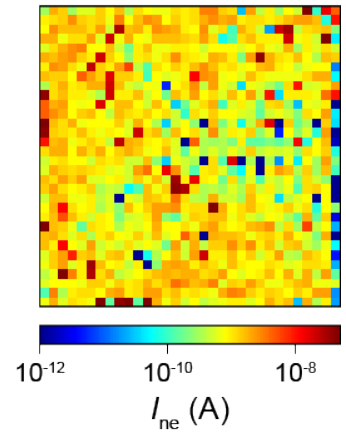
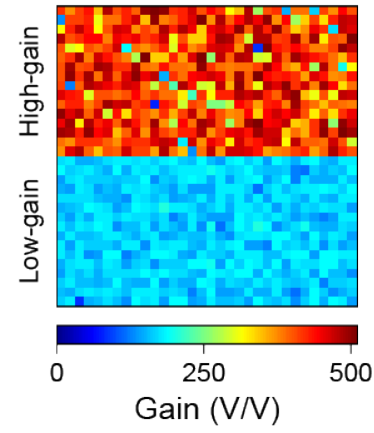
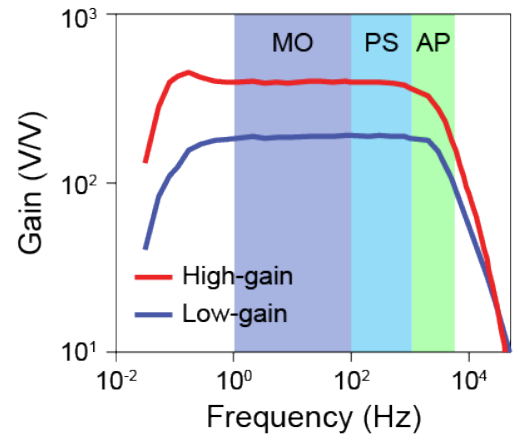
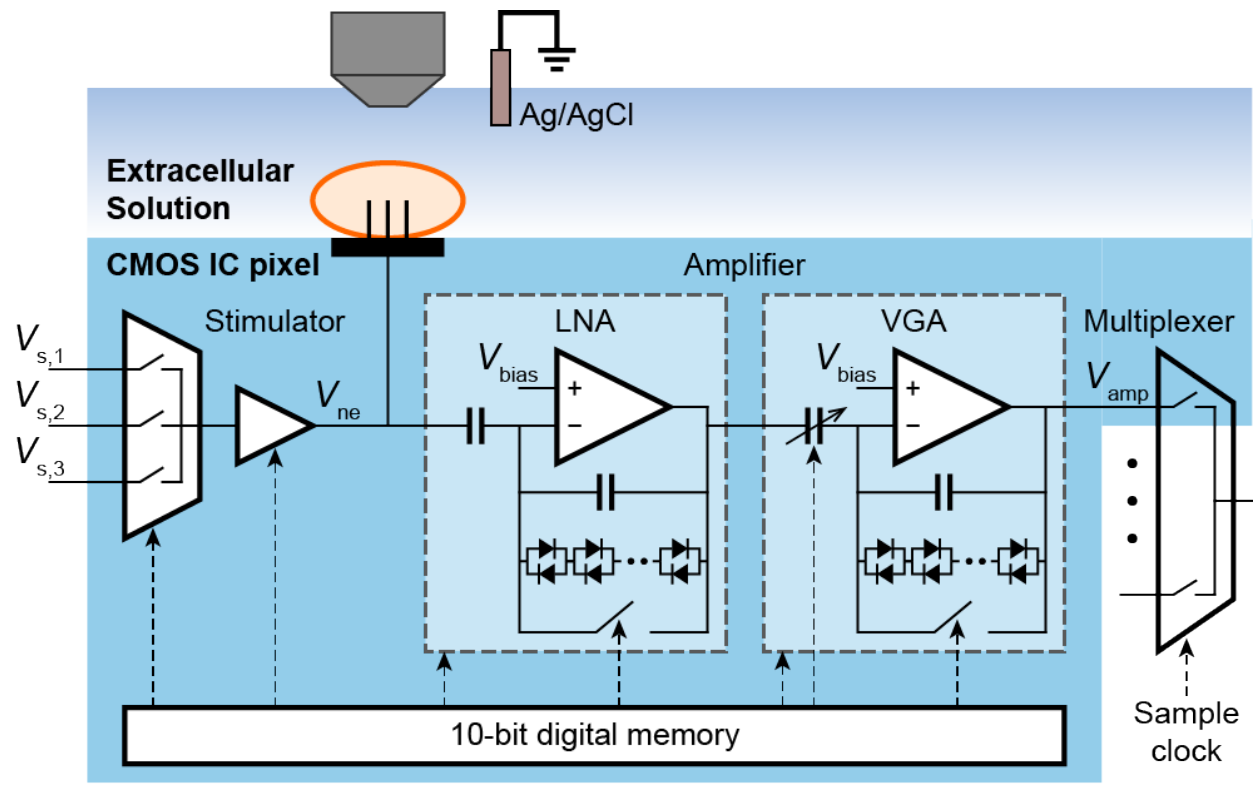


Spincoat resist; wet etch nanowire tip

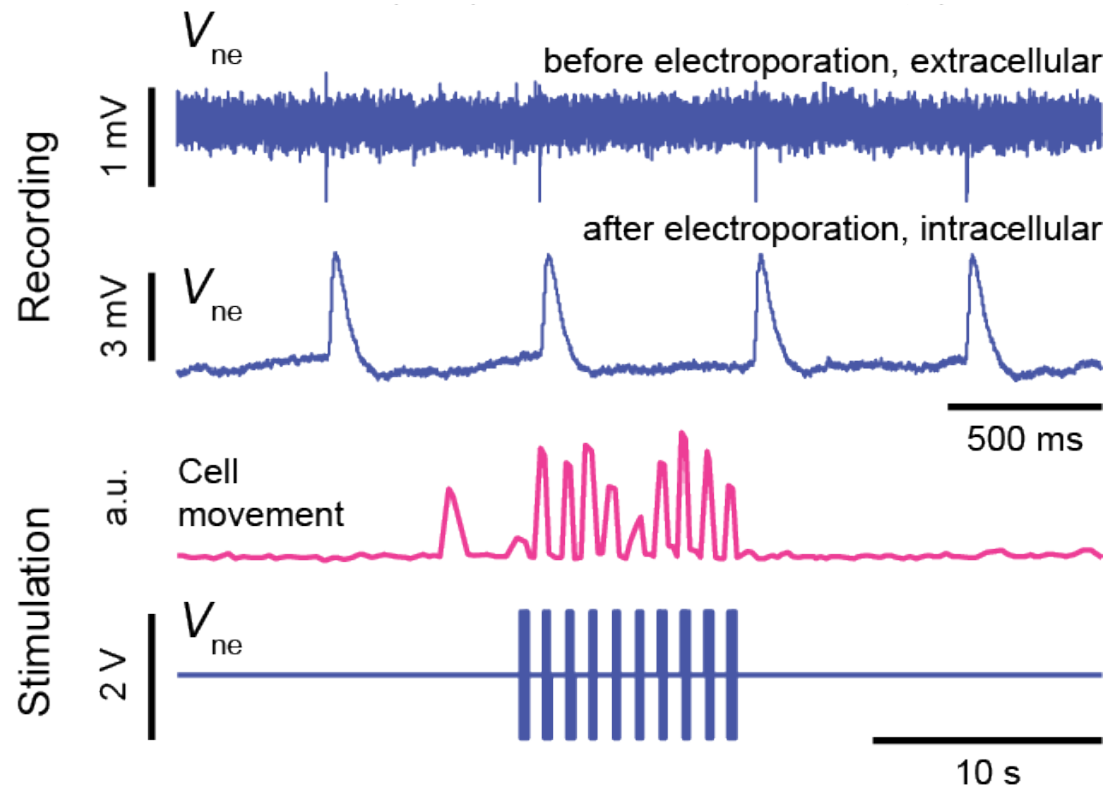
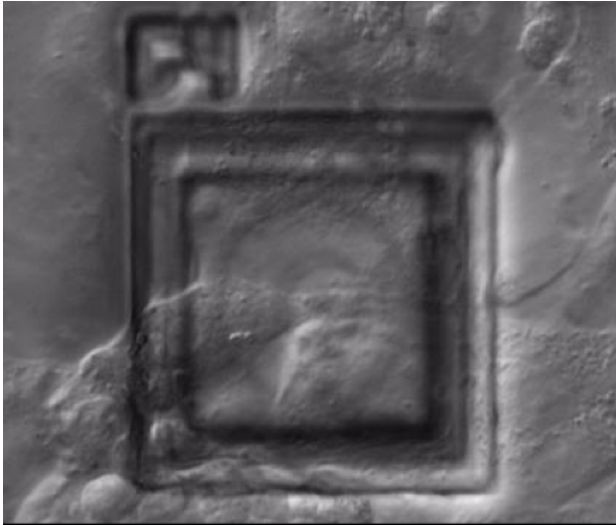


Ready for cell experiment in solution

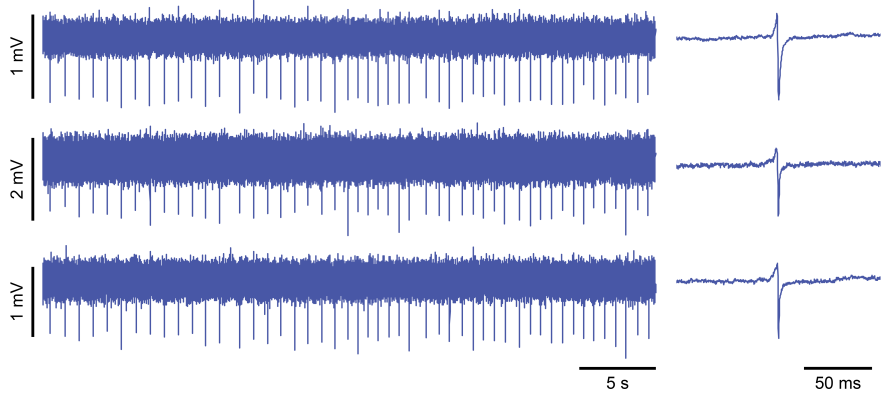
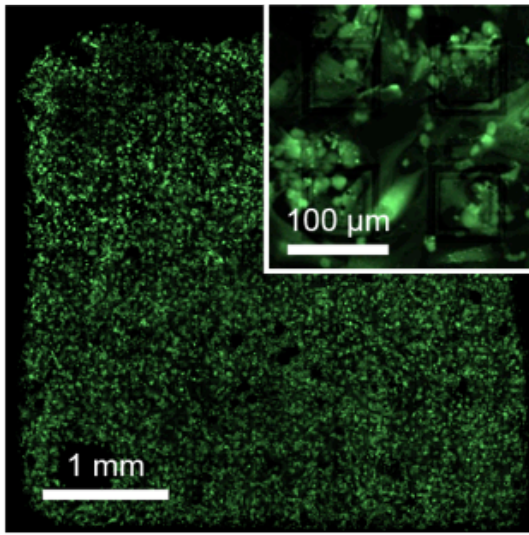
Pixel circuit & electrode characterization



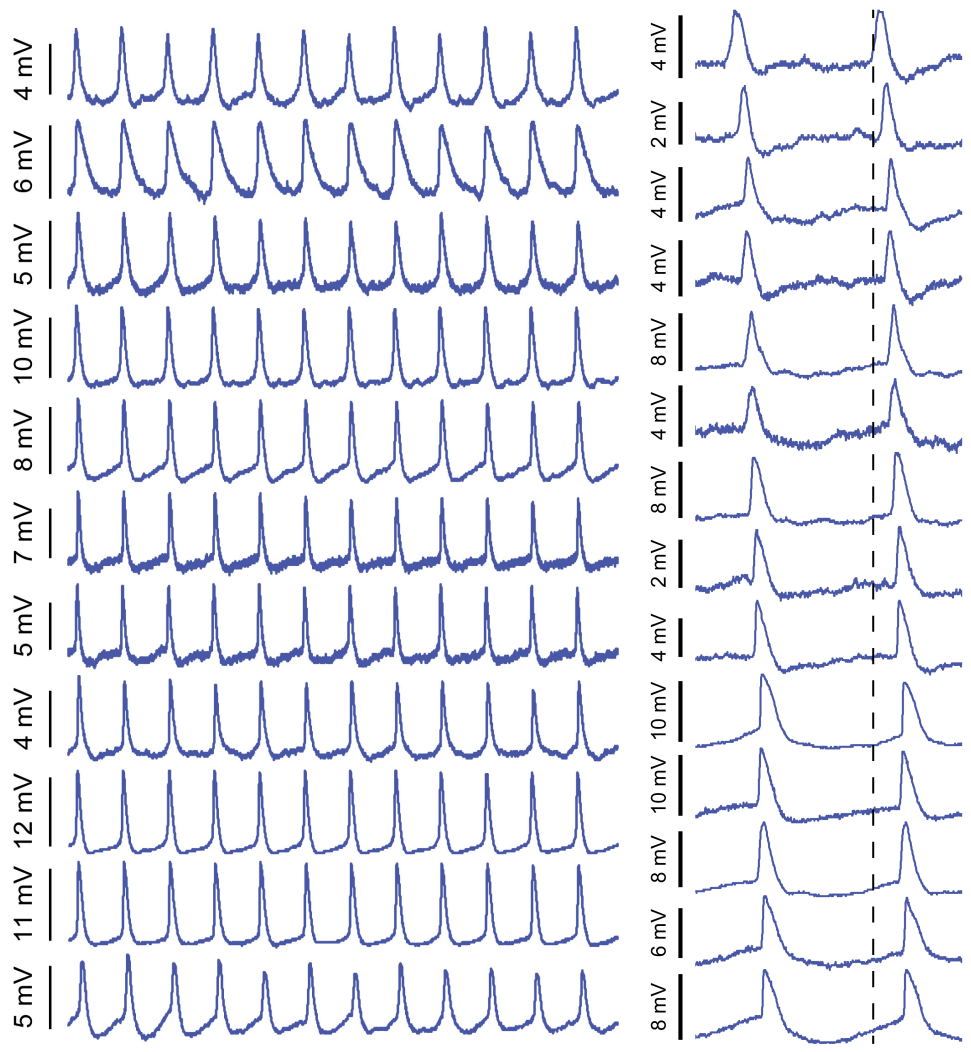
Single myocyte intracellular recording & stimulation



Parallel + intracellular recording from 235 cardiomyocytes

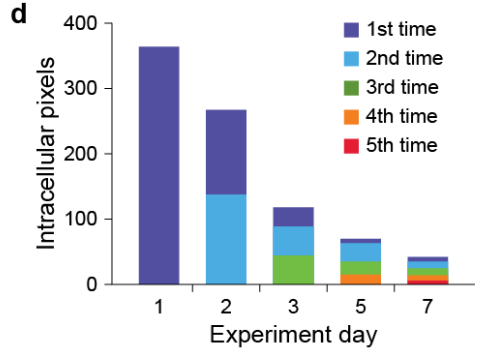
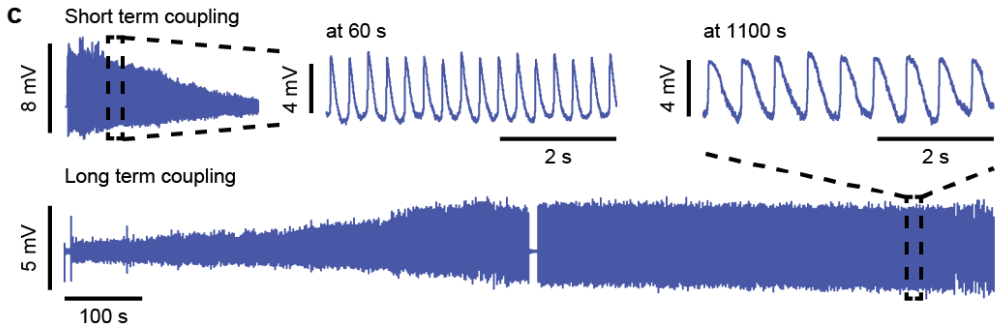
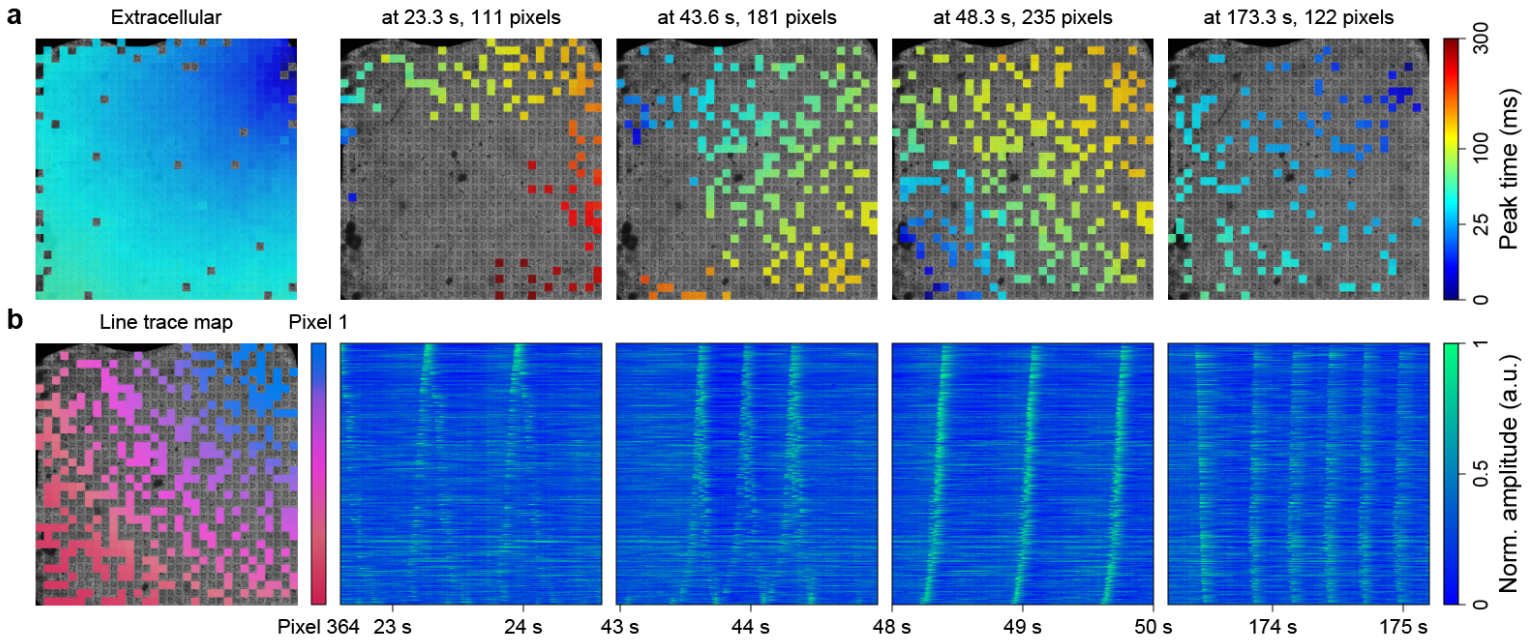


Extracellular recording

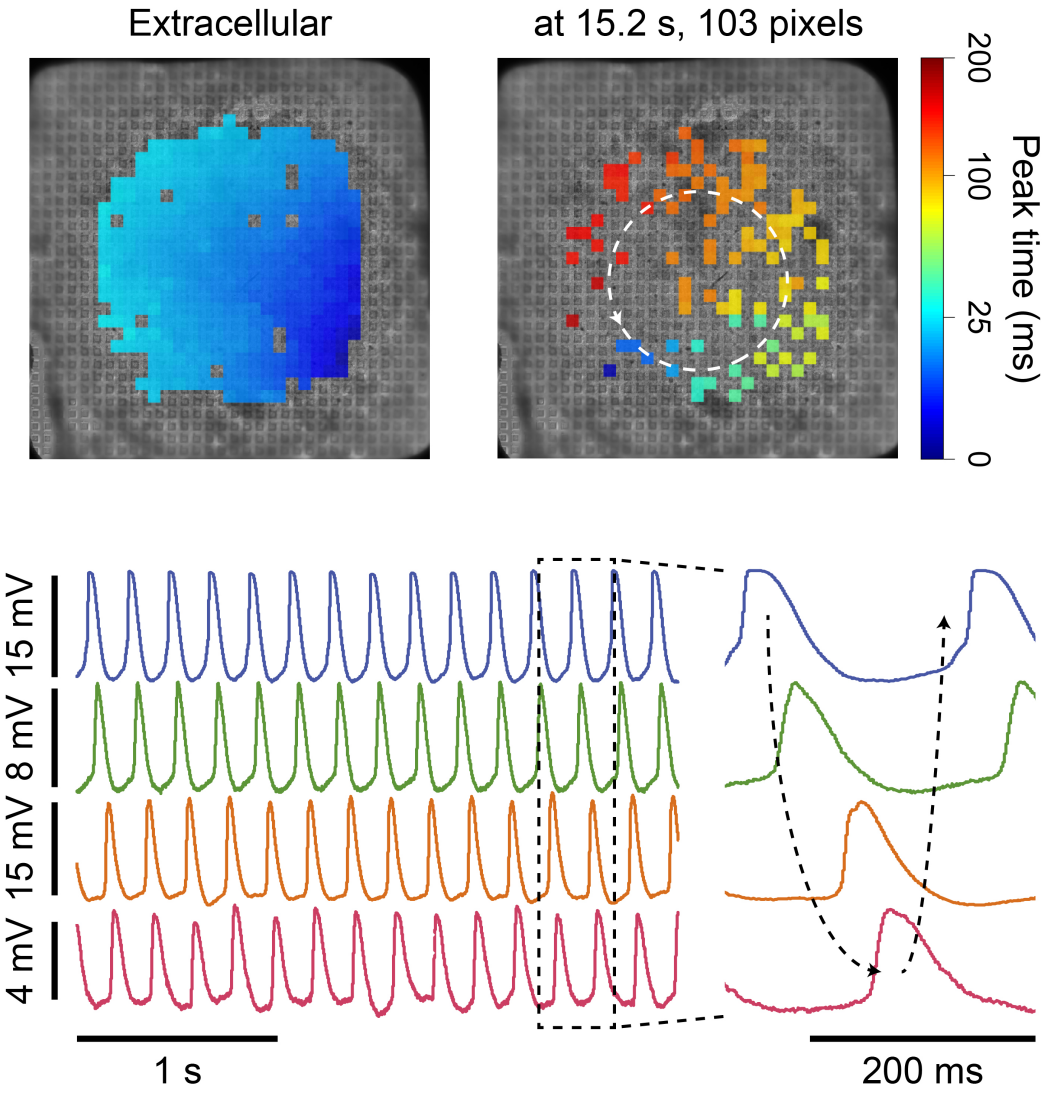


Intracellular recording

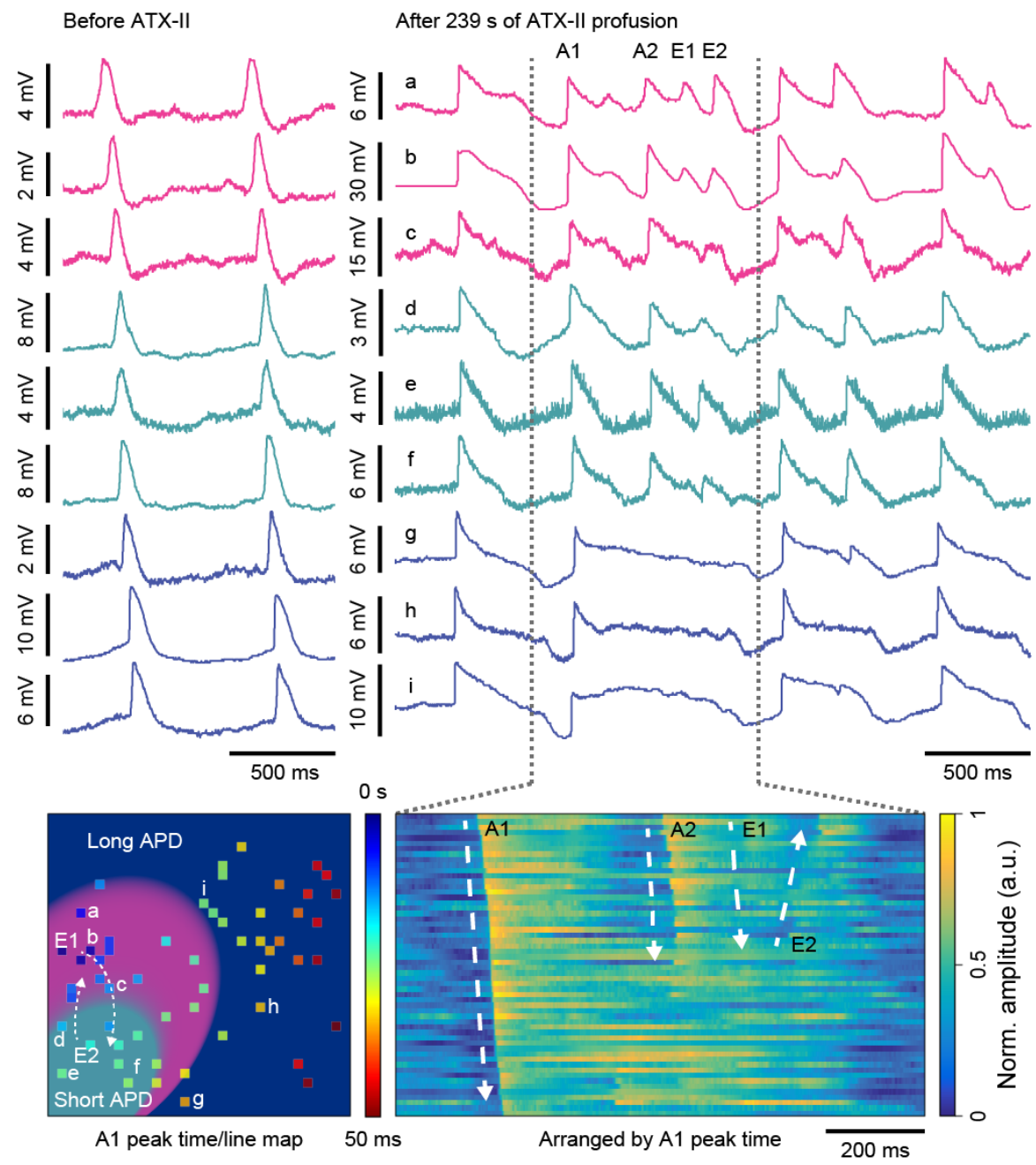
Parallel + intracellular recording from 235 cardiomyocytes



Parallel + intracellular recording – another example



Drug-screening — Network-level intracellular investigation



CMOS nanoelectrode array for all-electrical intracellular electrophysiological imaging

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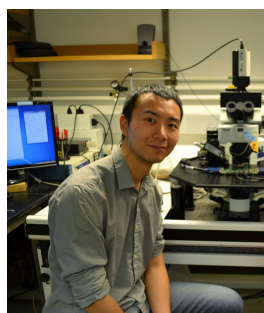


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Catalyst Foundation



Jeffrey
Abbott



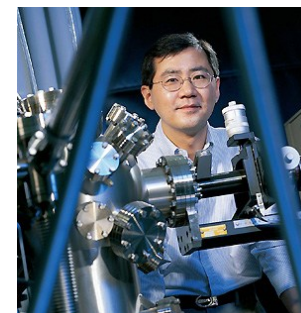
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(Park)



Ling Qin



Marsela Jorgolli
(Park)



Prof. Hongkun
Park