Zero-Energy Devices: *Technology and Applications of Ubiquitous 6G Systems*

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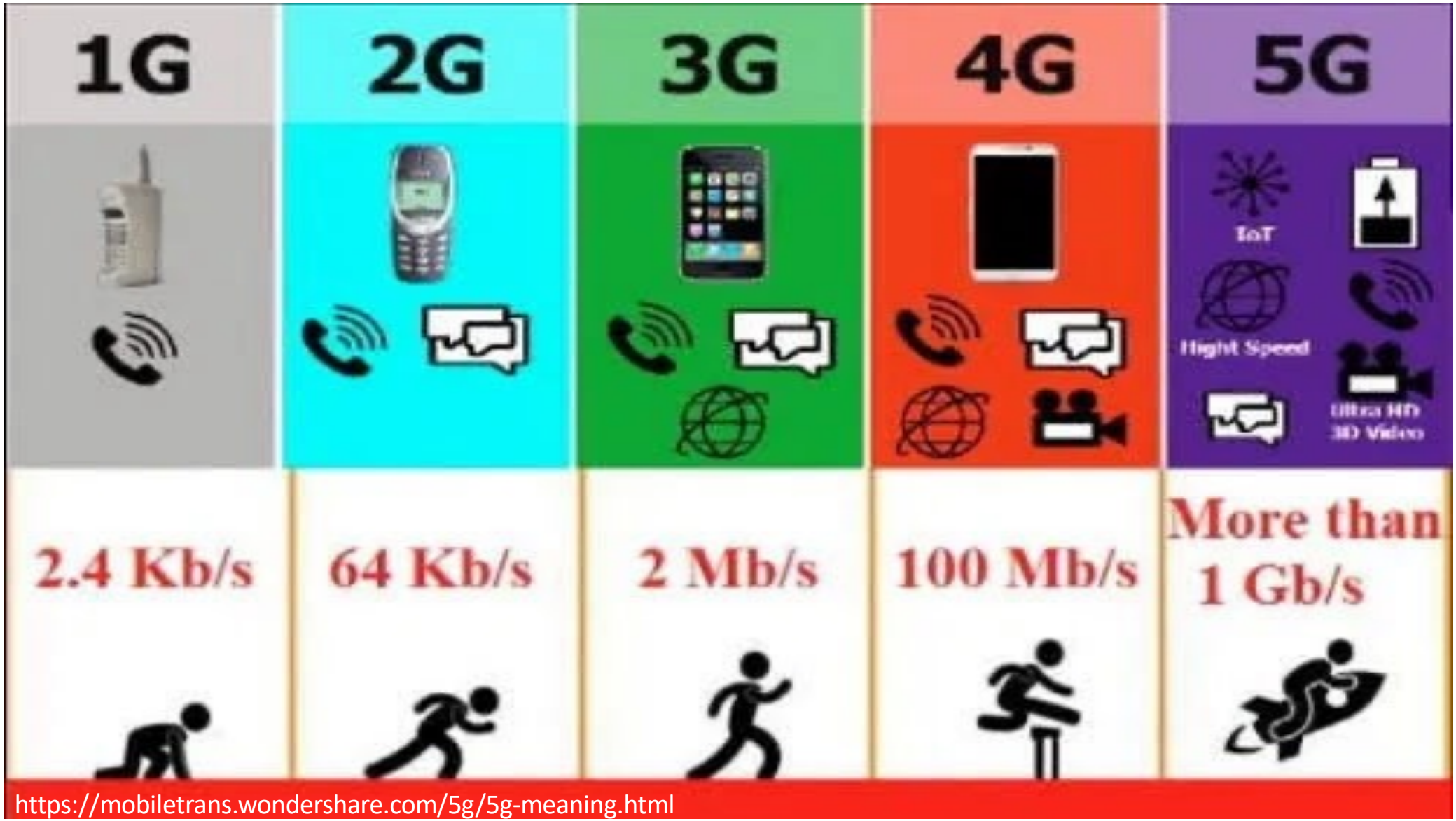
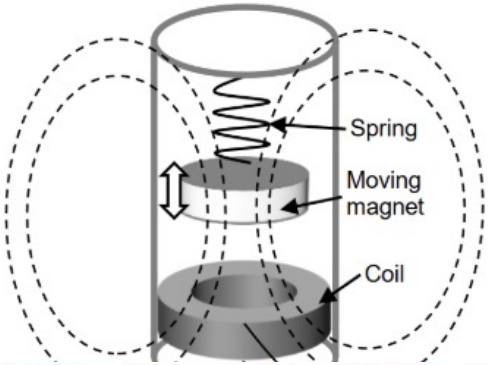
November 15th, 2022

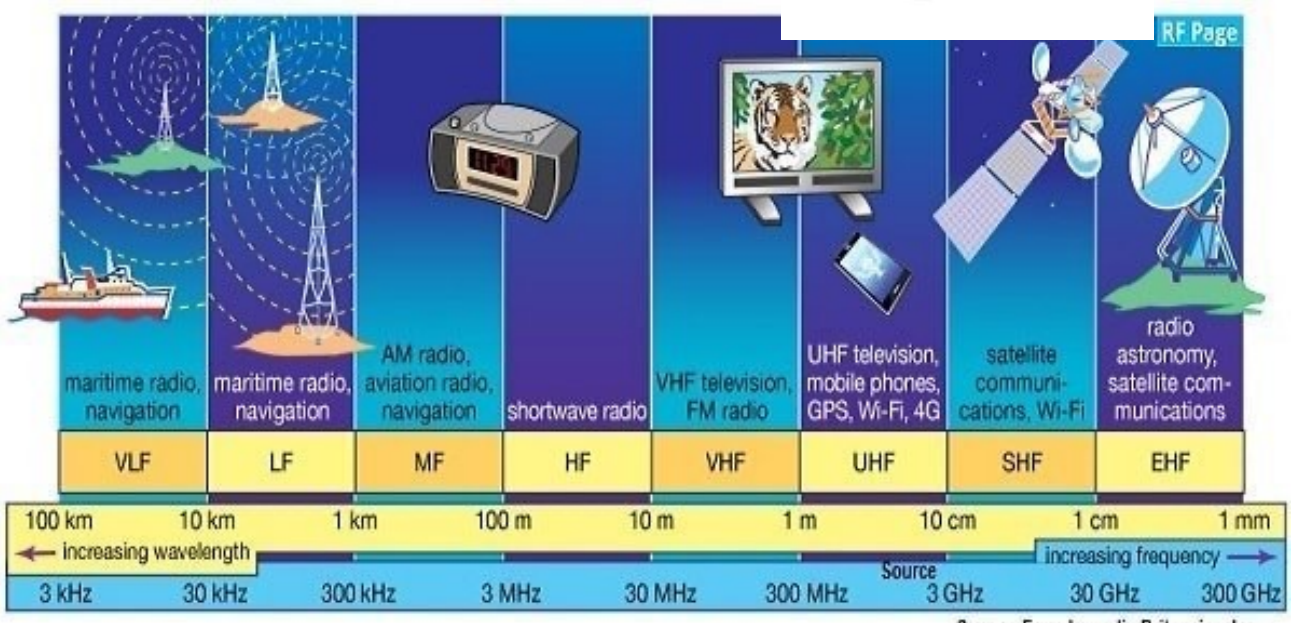


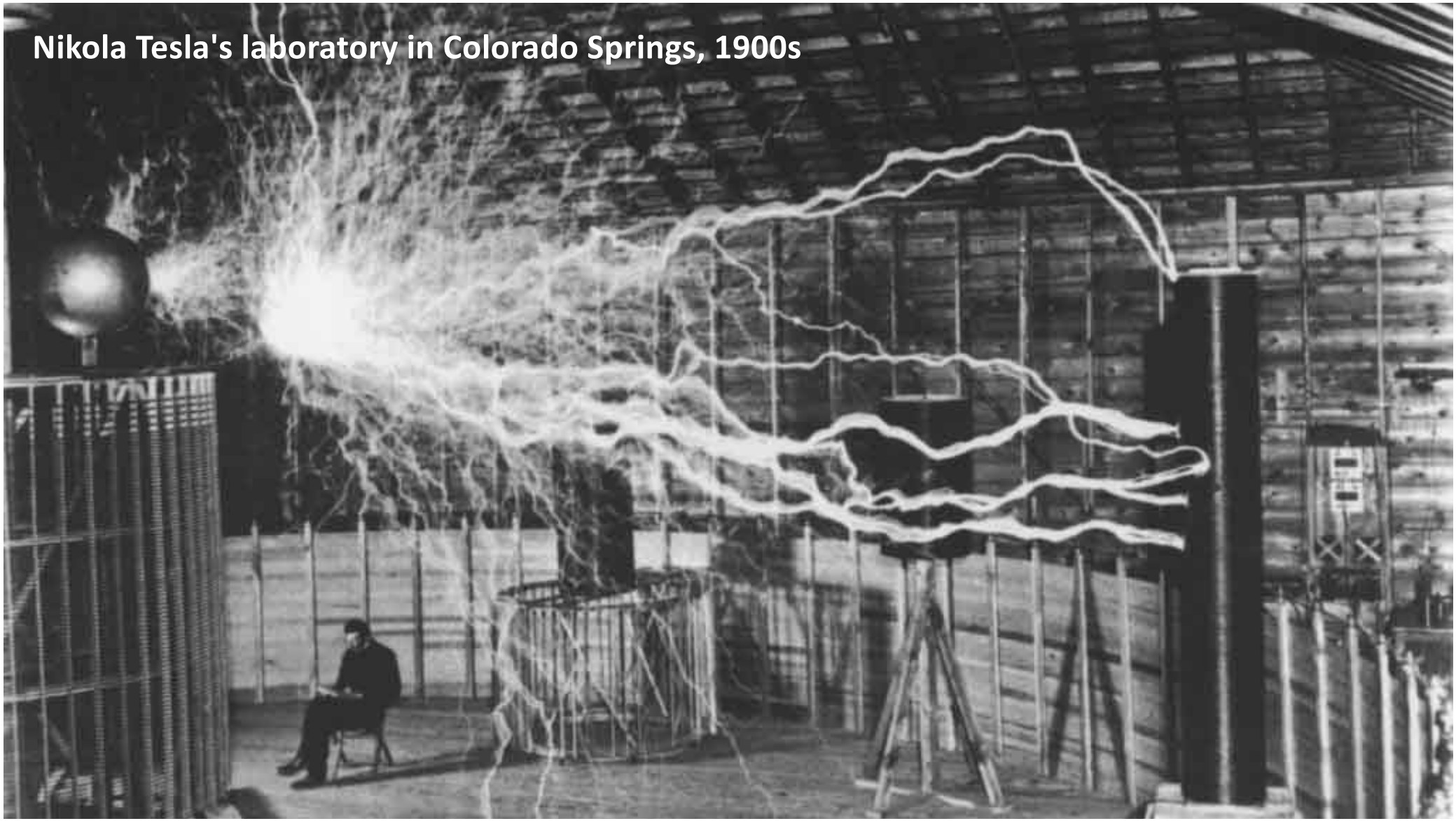
https://mobiletrans.wondershare.com/5g/5g-meaning.html


6G: Trillions of Connected Devices
"Zero" Energy Systems are Key
Ultra Low Power Electronics
Energy Harvesting
https://carto.com/blog/chicago-array-of-things/

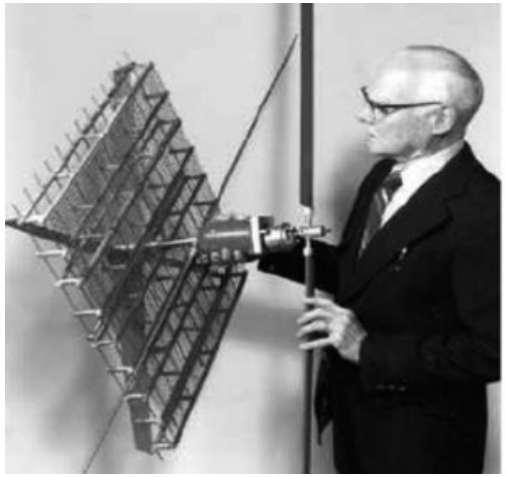
Some Options for Energy Harvesting in 6G Systems

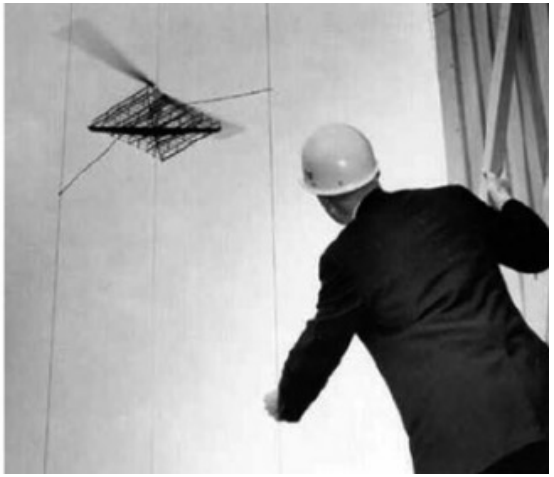





Nikola Tesla's laboratory in Colorado Springs, 1900s

Previous demonstrations…



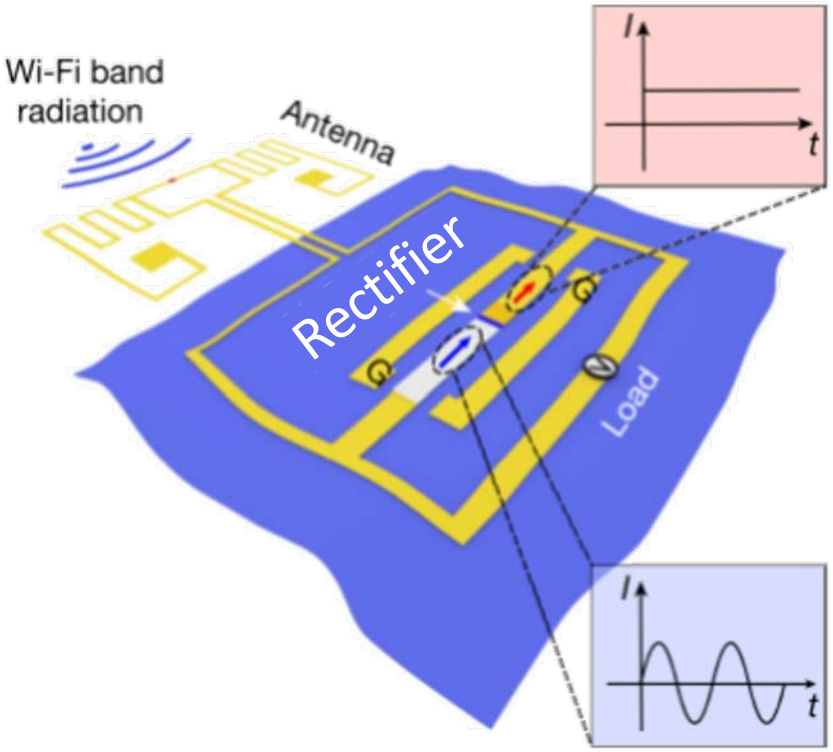


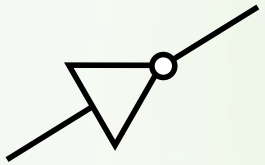
A helicopter powered by 2.45 GHz microwaves, 1964

However, 6G devices require a completely different approach

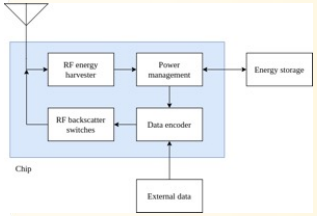
Form factor
Power density
Future “6G network” compatibility

Zero-energy systems





Energy harvesting



System designs/constrains

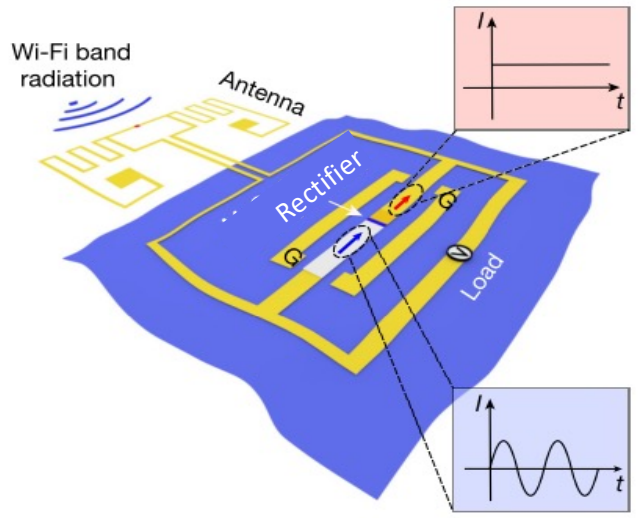
Heterogenous integration

Rectifier + input voltage boost

- Harvest RF energy
- Increase the voltage to power electronics

Image from the Internet

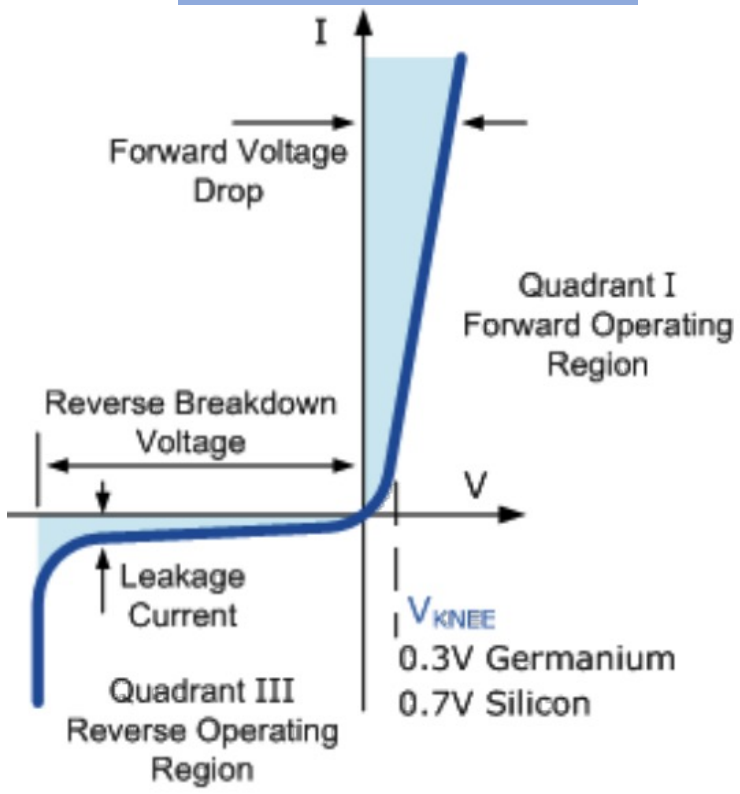
Limits of rectifier technology

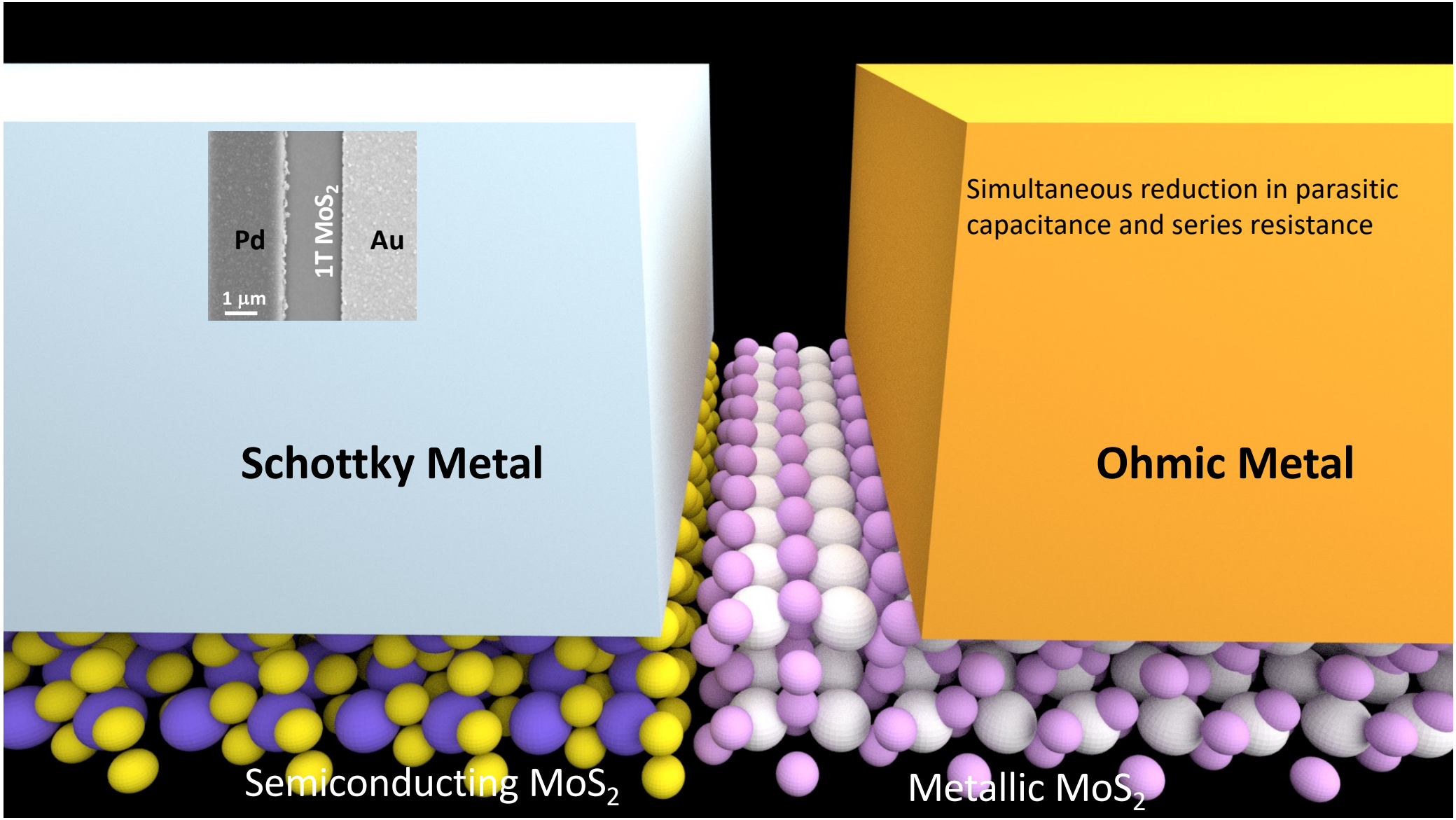


Goal :

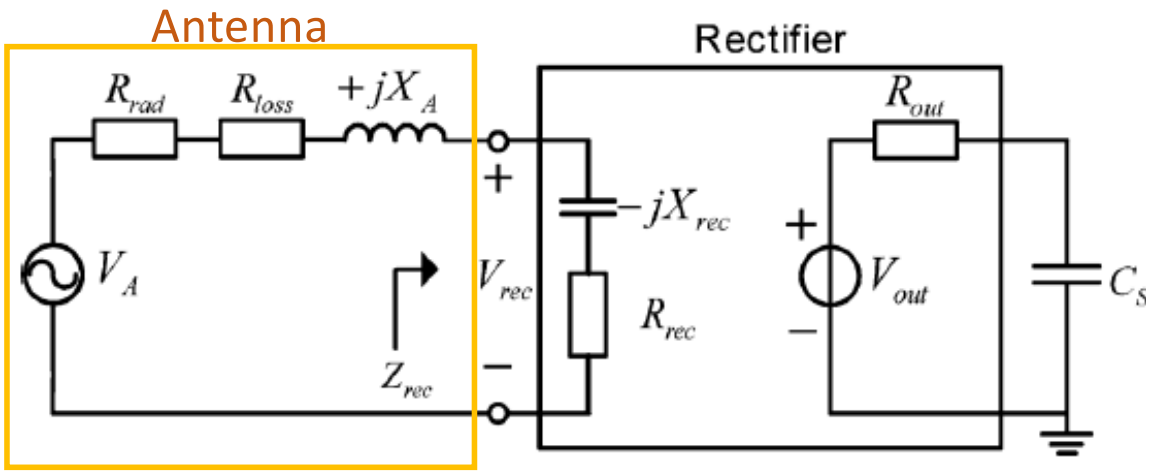
- Minimize the turn-on voltage
- Maximize current responsivity
- Ultra-low leakage current
- High frequency operation
- Compatible with CMOS Si

Bulk material diode

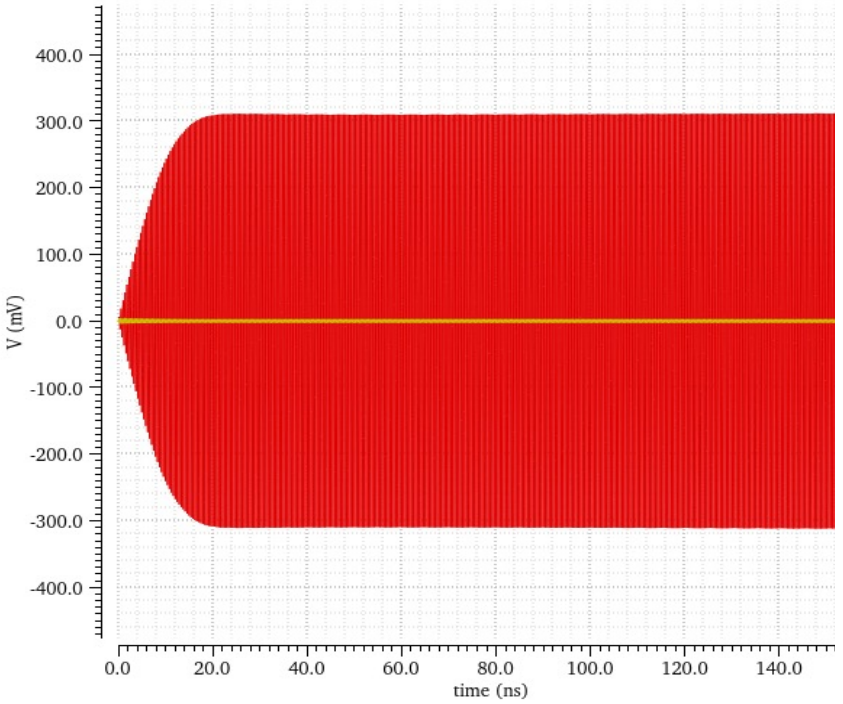



Pd
1T MoS2
Au
1 μm
Schottky Metal
Simultaneous reduction in parasitic capacitance and series resistance
Ohmic Metal
Semiconducting MoS2
Metallic MoS2

Antenna – Rectifier: *RLC resonance to boost signal output*

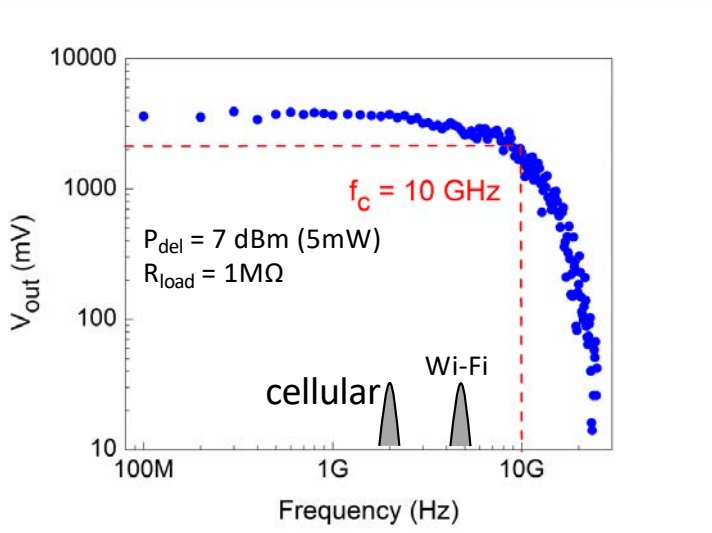


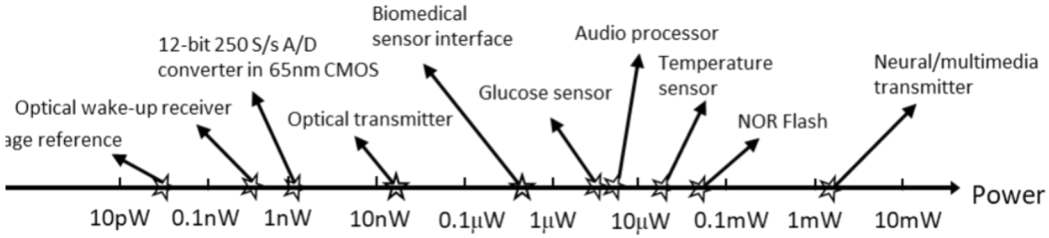
$$G_{V,boost} = \left| \frac{V_{\text{rec}}}{V_A} \right| \approx \frac{X_{\text{rec}}}{R_A + R_{\text{rec}}}.$$



A few mVs of antenna voltage swing can be boosted a few hundreds.

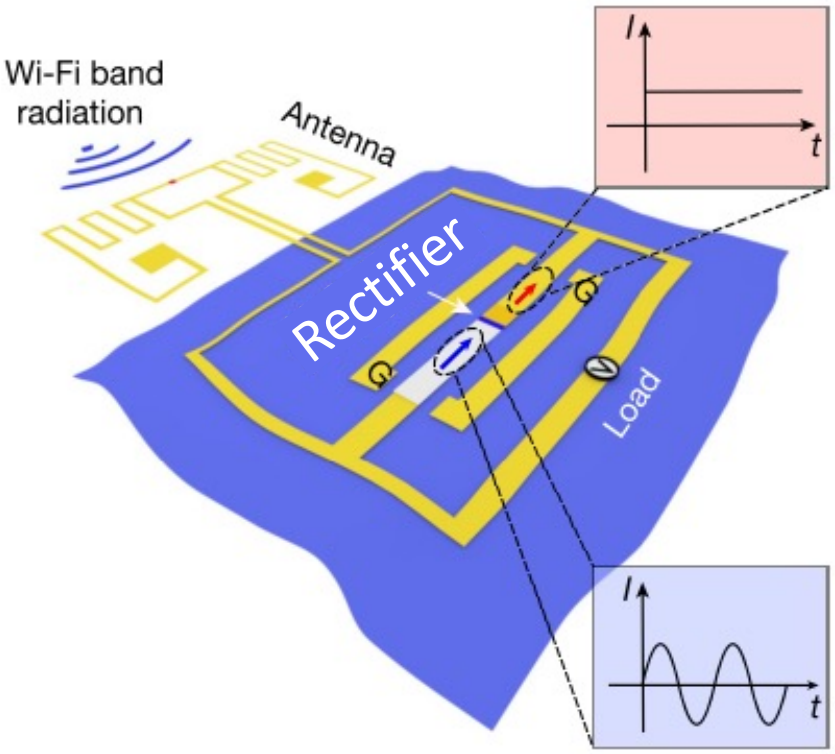
WiFi/5G RF Energy Harvester

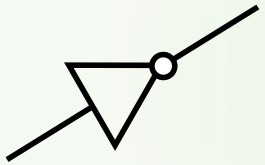




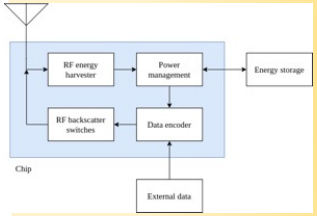
X. Zhang et al., Nature 2019

Zero-energy system





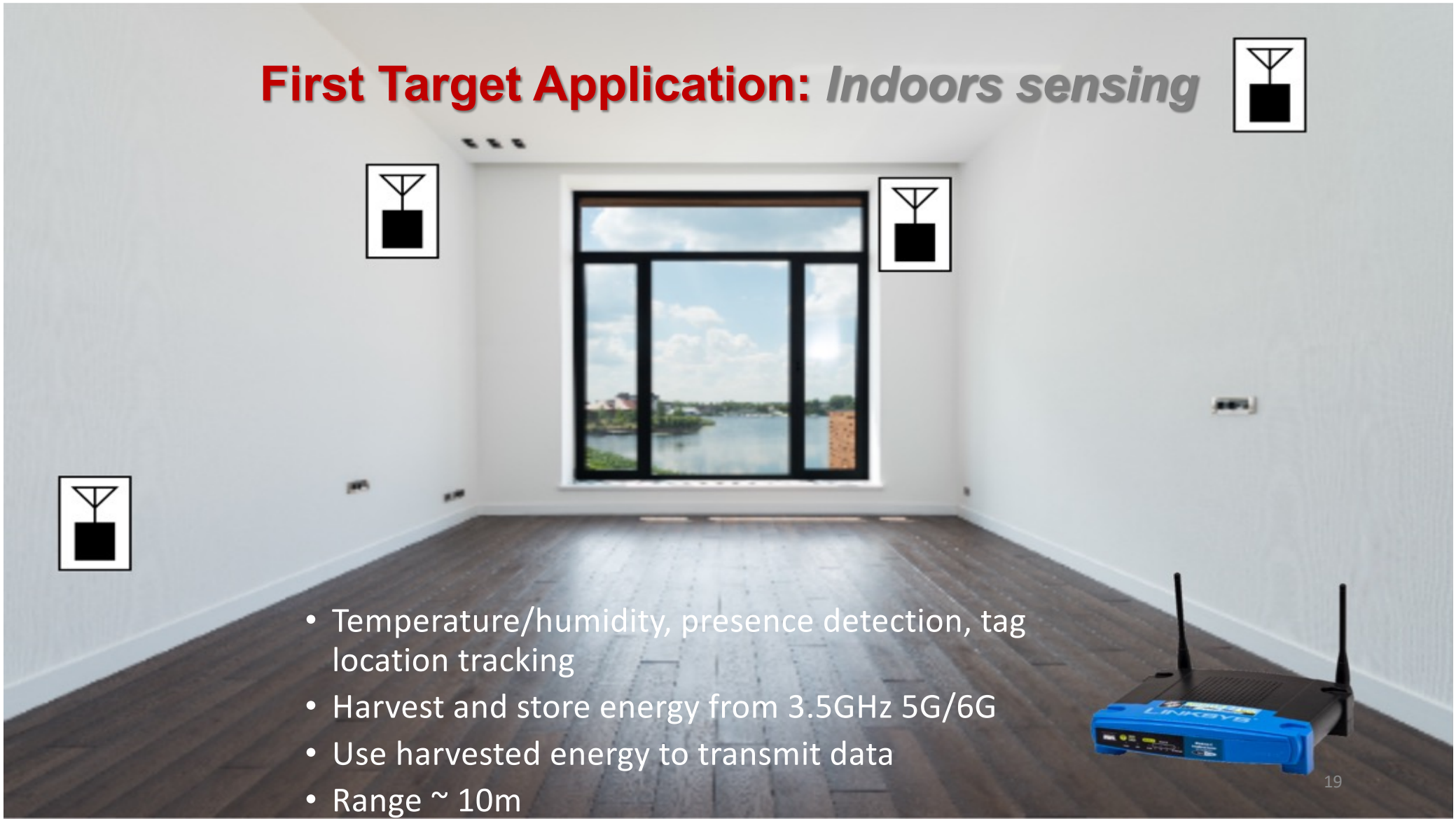
Energy harvesting blocks



System designs/constrains

Heterogenous integration

First Target Application: *Indoors sensing*



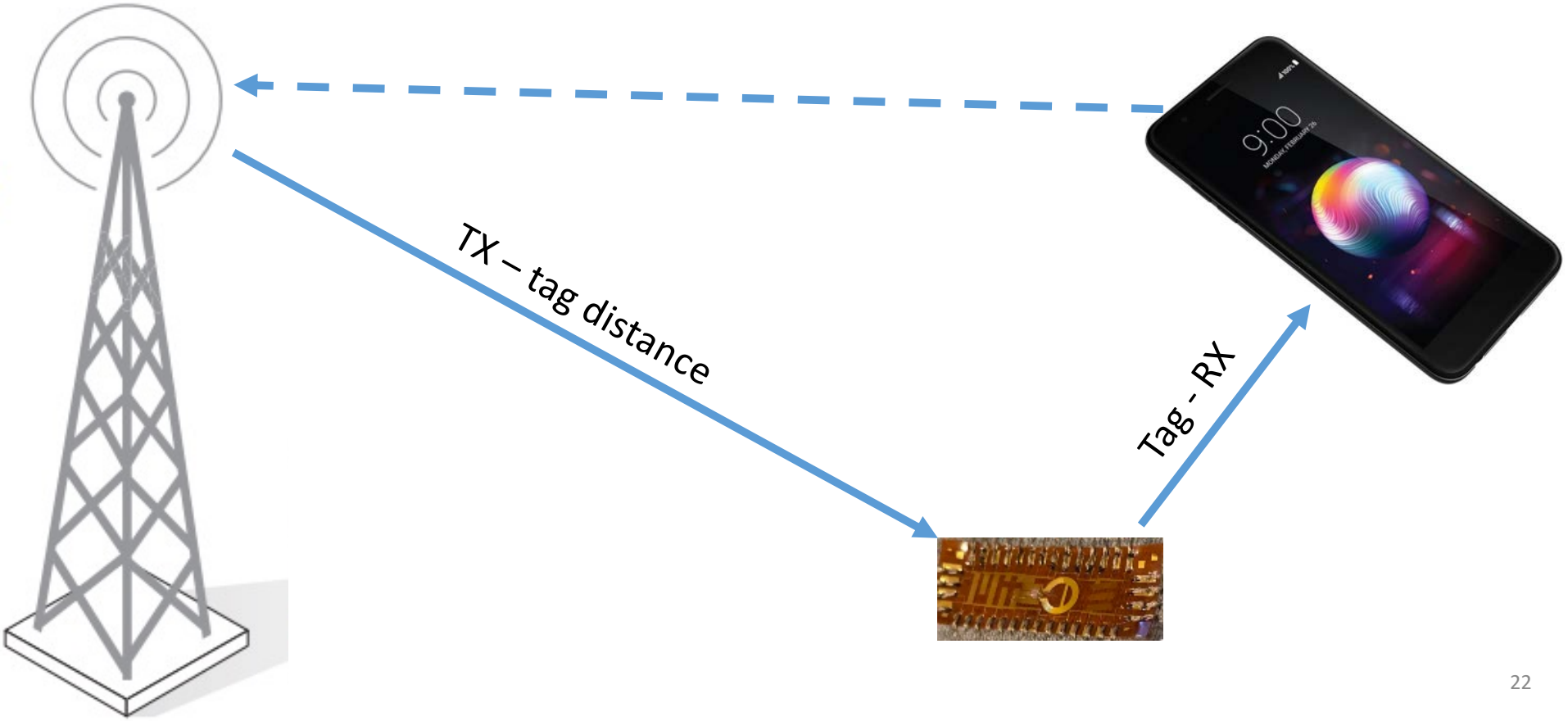
- Temperature/humidity, presence detection, tag location tracking
- Harvest and store energy from 3.5GHz 5G/6G
- Use harvested energy to transmit data
- Range ~ 10m

Comparison of communication methods

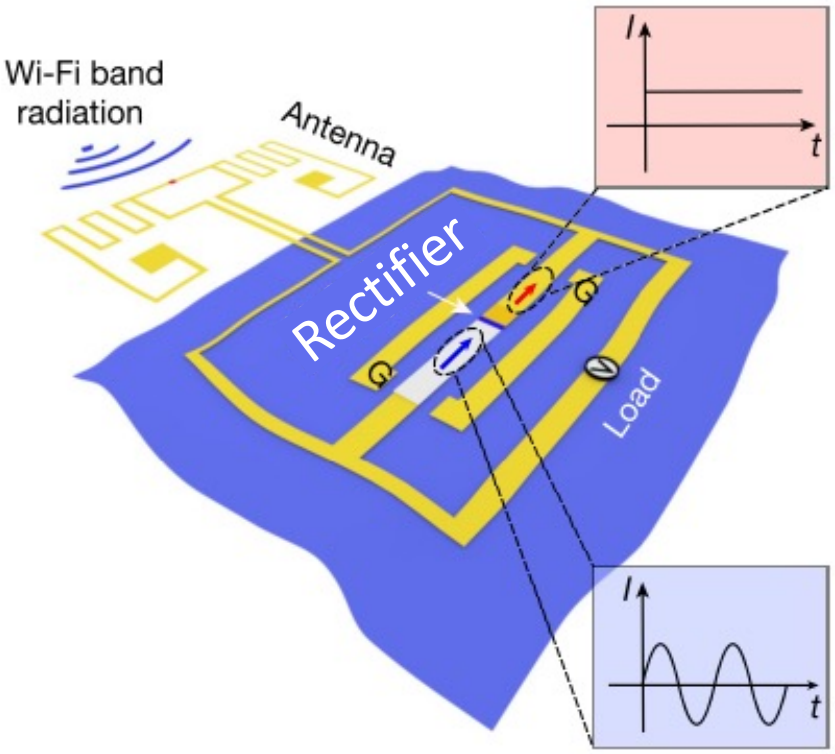
Backscattering	Active transmission

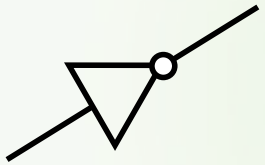
• Lower power consumption
  • No power amplifier
  • Oscillator needs to run at only ~kHz (vs. GHz for active transmission)
	• Higher potential transmit power
	  • Instantaneous transmit power can be higher than received power
	• Transmit frequency is independent of received frequency

Backscattering link budget



Zero-Energy Systems





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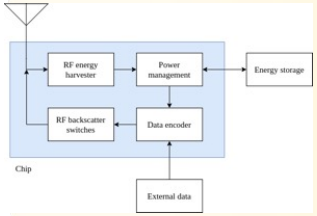
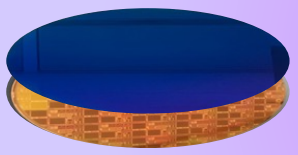
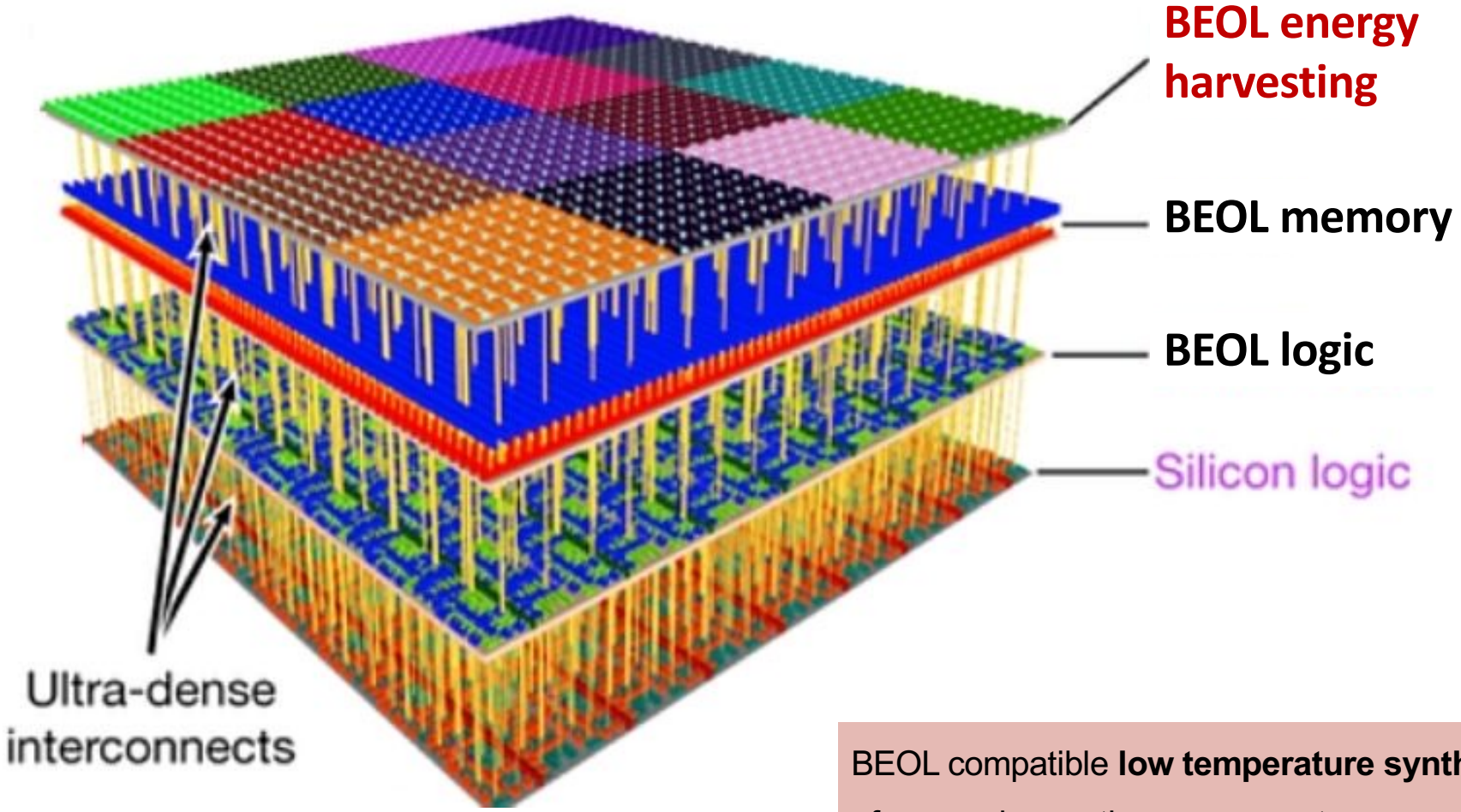


System designs/constrains



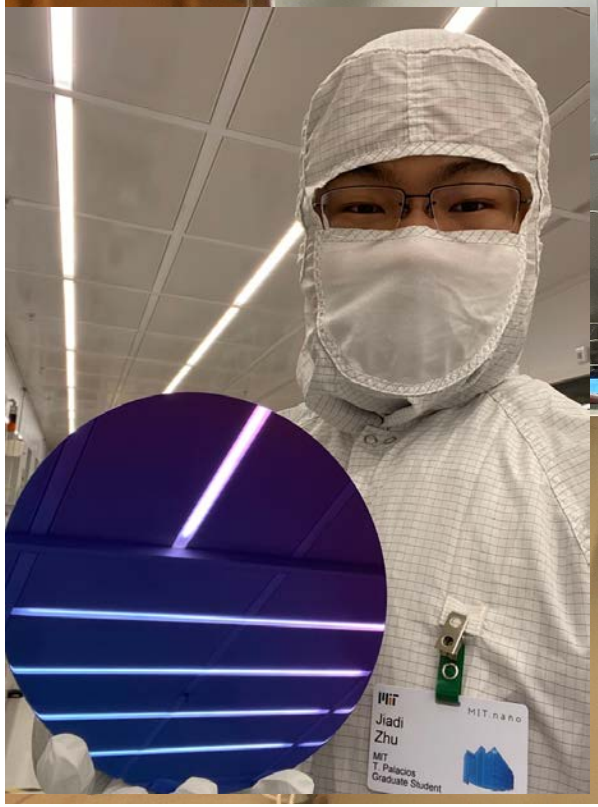
Heterogenous integration

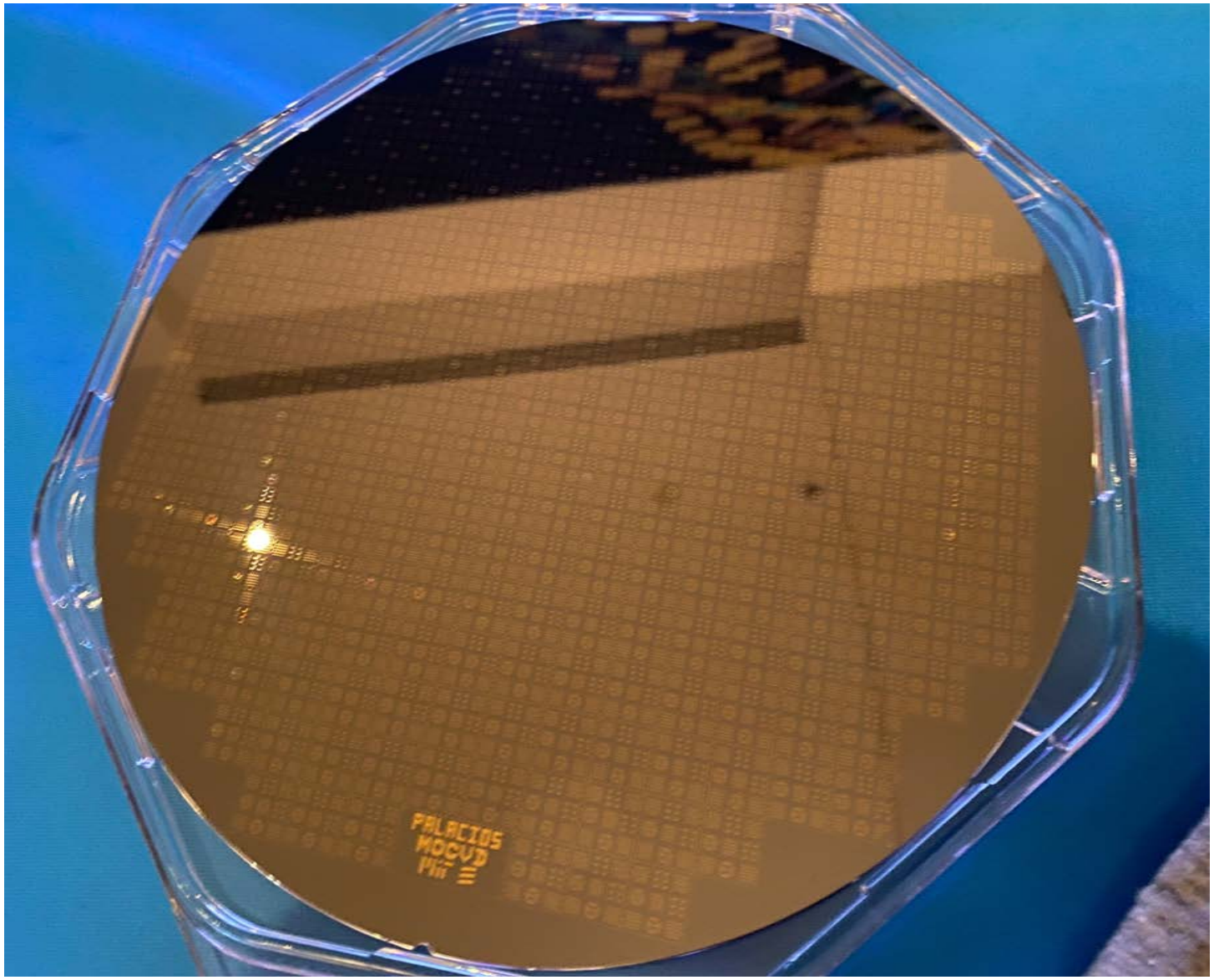


BEOL compatible **low temperature synthesis**/fabrication of energy harvesting components

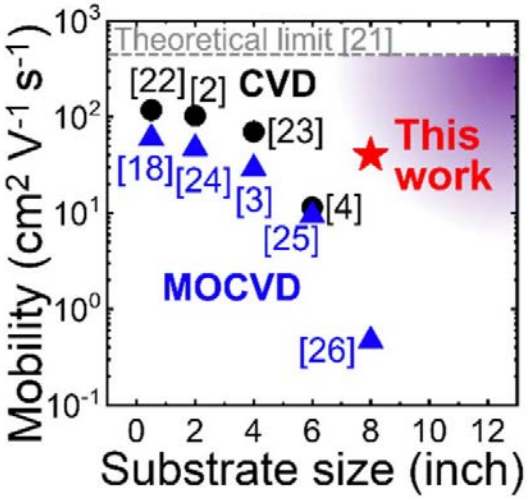
Adapted from Prof. Max Schulaker (MIT)

8-inch MOCVD system for 2D materials



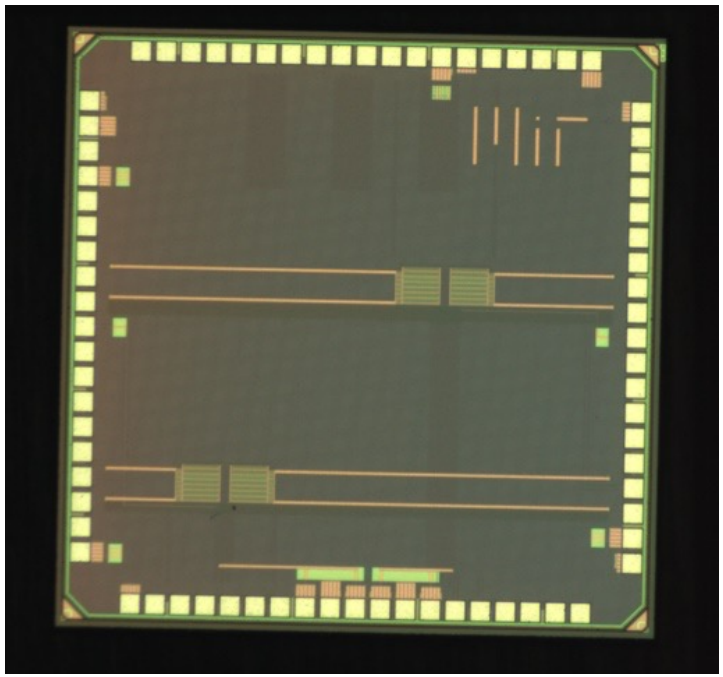


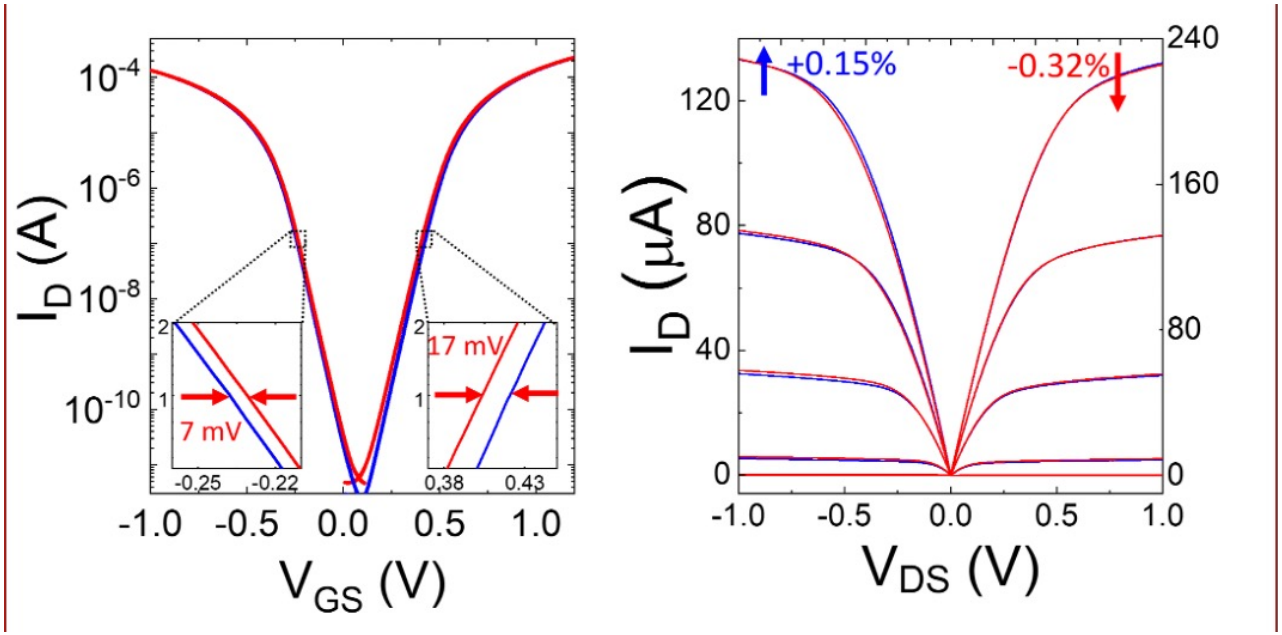
8-inch MOCVD system for 2D materials



No damage to Si technology underneath

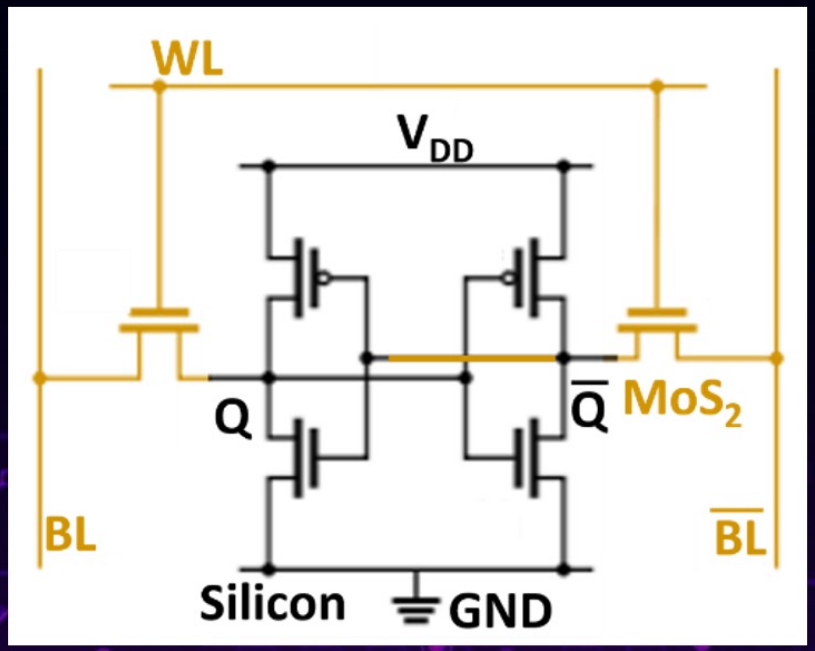
- Growth @ 275°C for 60 mins
- No degradation to silicon transistors

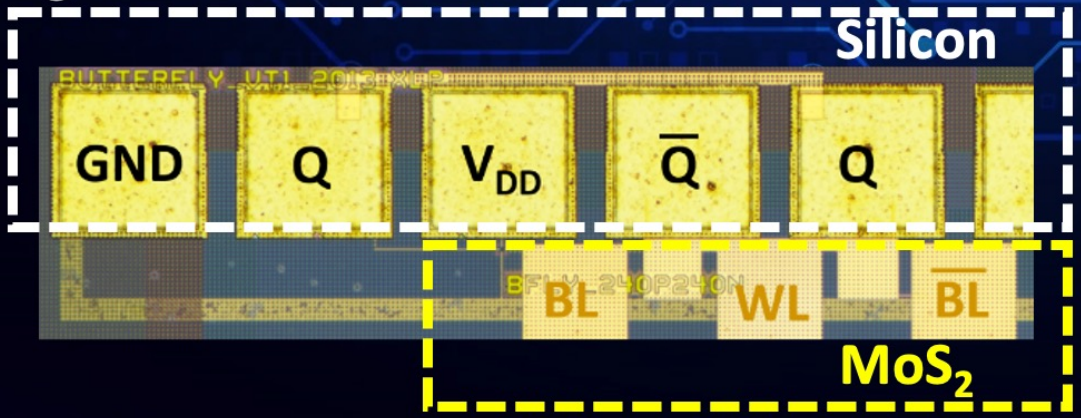


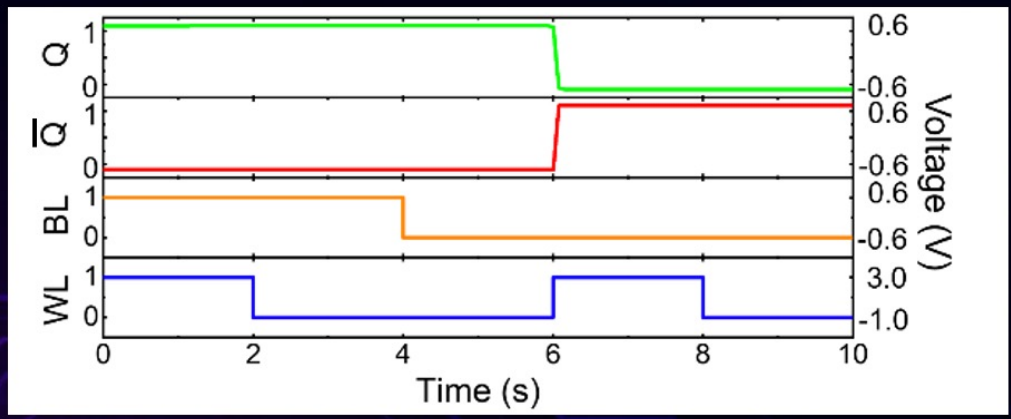


Silicon BEOL integration

- MoS_2-Silicon heterogeneous-integrated SRAM cell

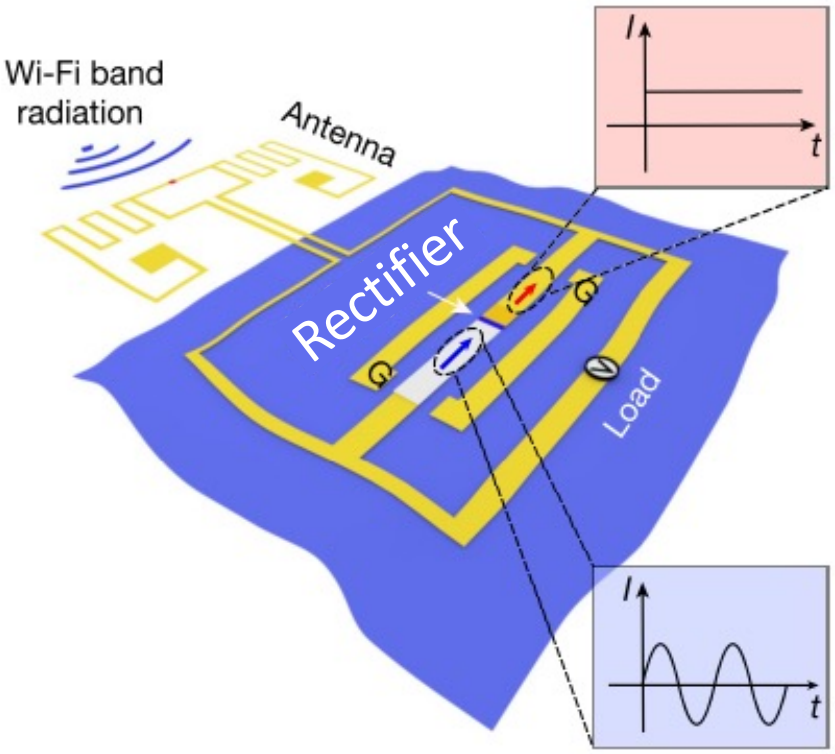


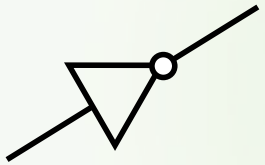




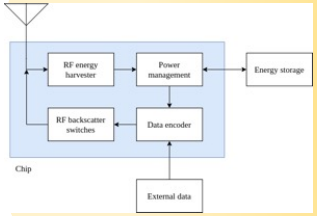
J. Zhu†, J.-H. Park†, *et al*, in review

Zero-Energy Systems





Energy harvesting

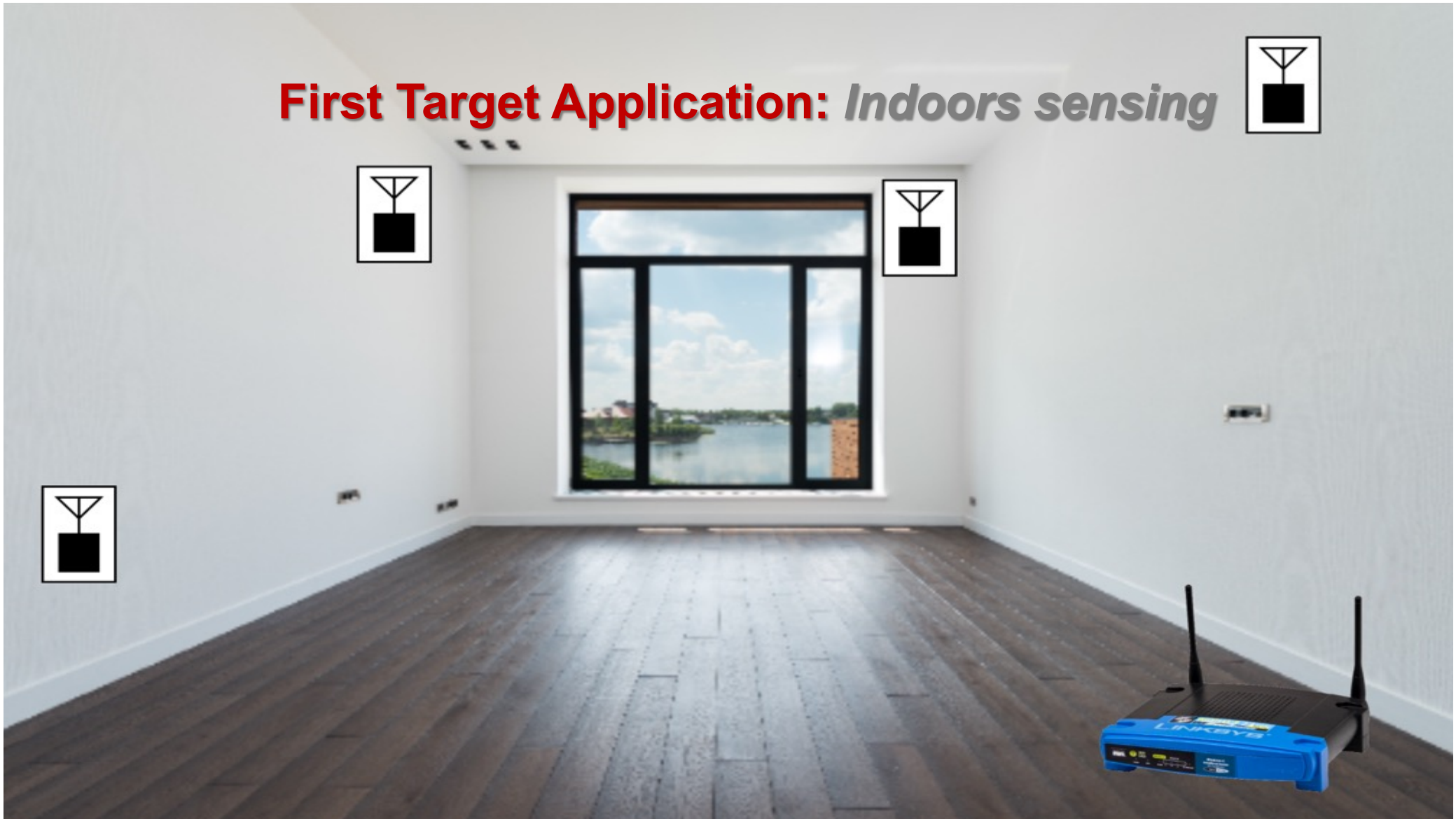


System designs/constrains

Heterogenous integration

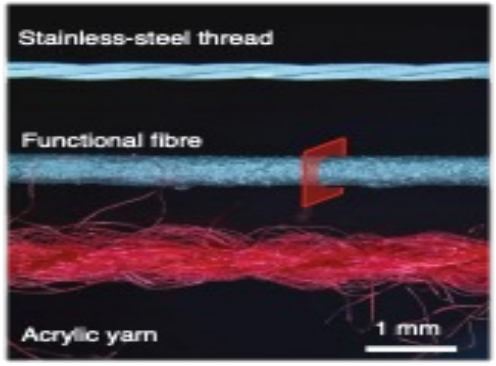
Some potential applications….

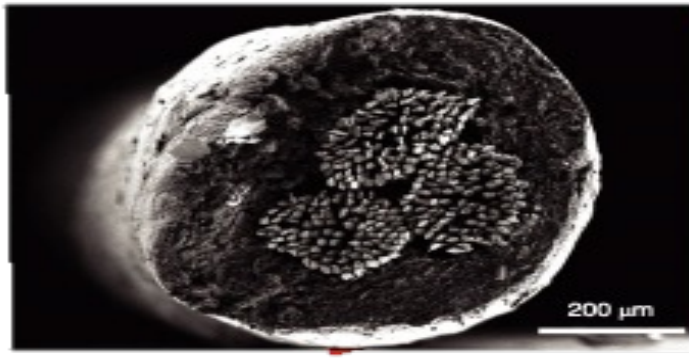
First Target Application: *Indoors sensing*

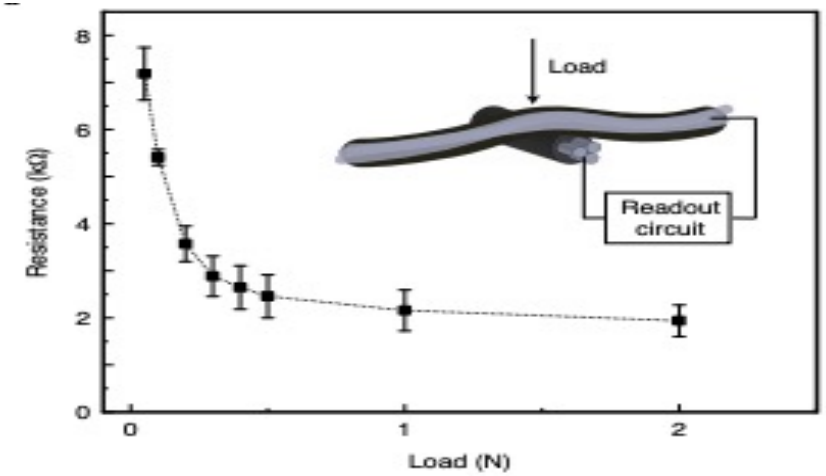


https://nationalpost.com/travel/get-guatemalan-textiles-straight-from-weavers-hands-in-indigenous-community-san-juan-la-laguna

First, we need functional fibers…





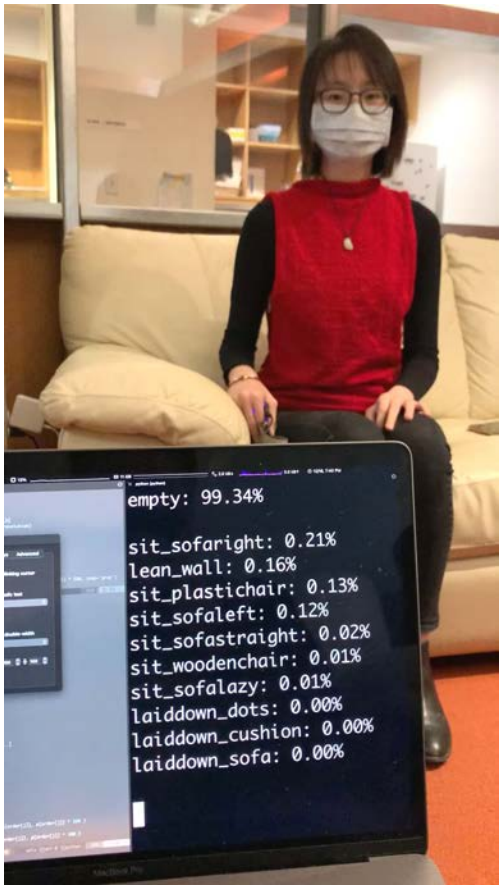


Nature Electronics 4, 193

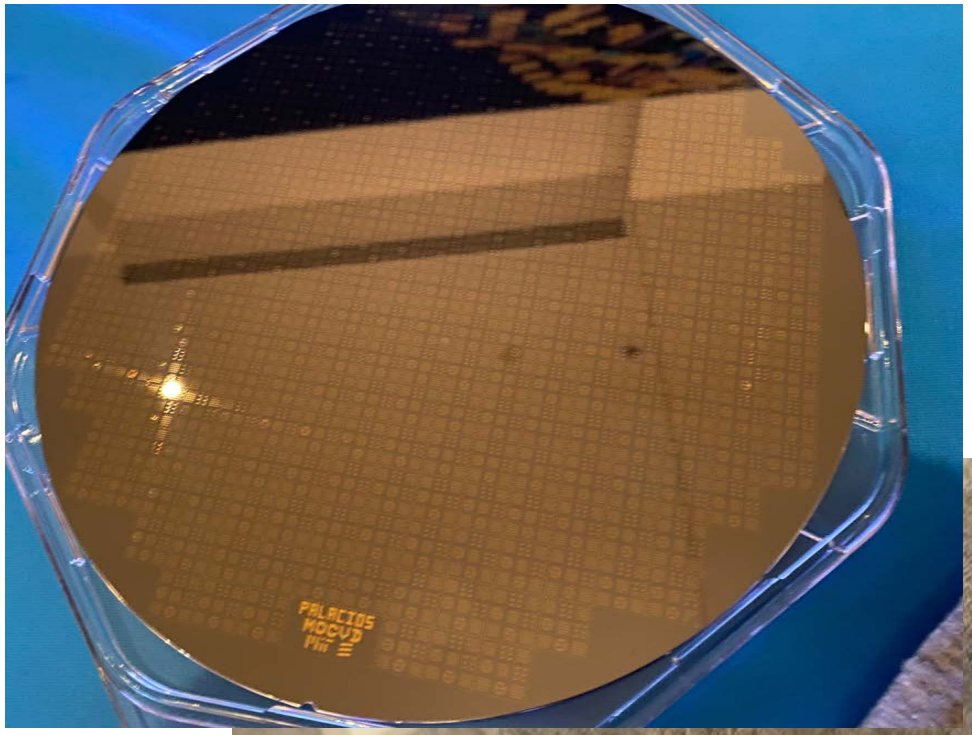
And then, we start knitting…

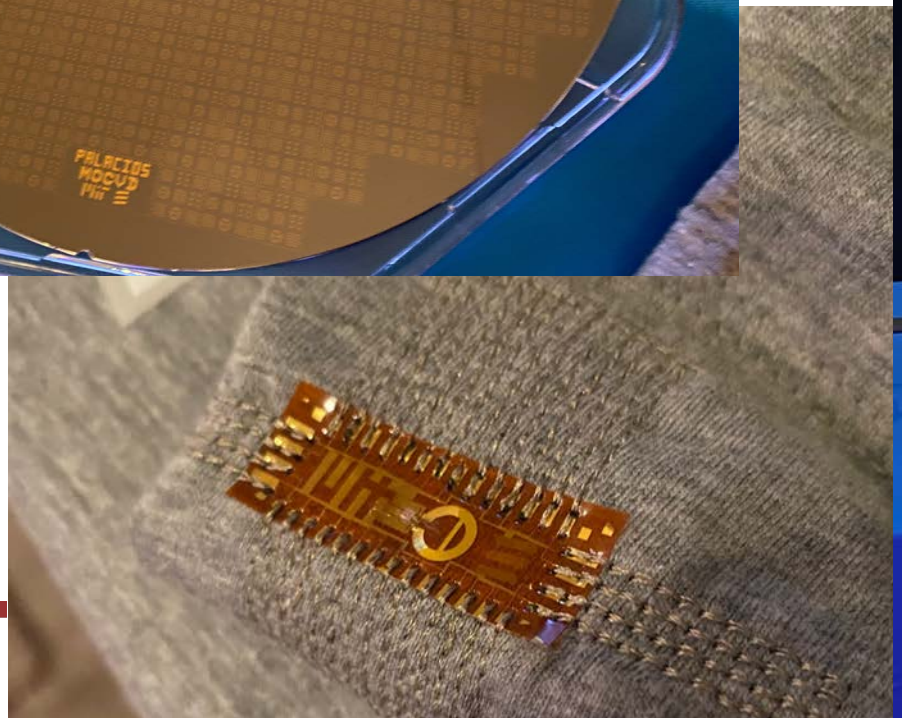
https://www.technologyreview.com/2017/04/06/152728/3-d-knitting-brings-tech-to-your-sweaters-for-a-price/

To get some new “devices”…



Nature Electronics 4, 193


PALACIOS
MOCVD
MIT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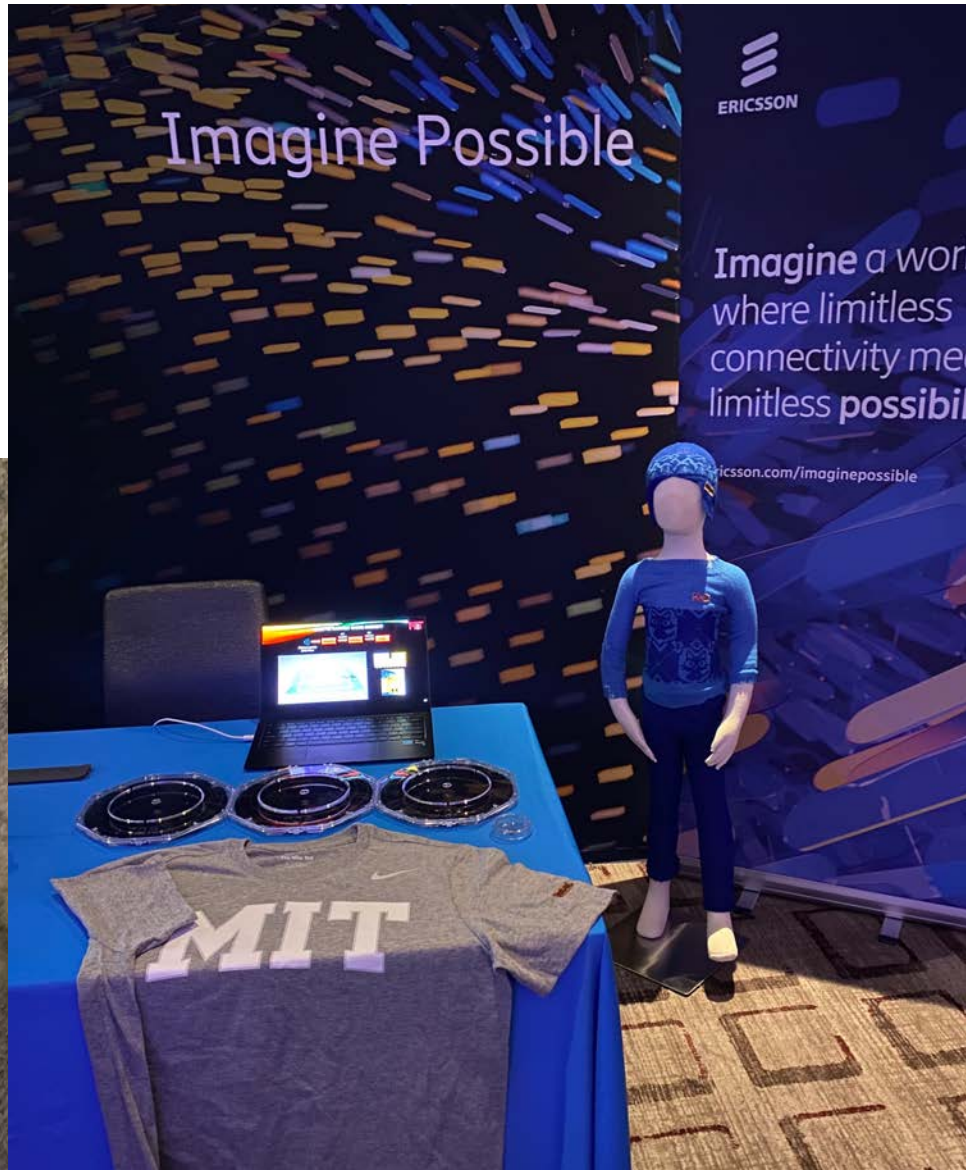
Imagine Possible
ERICSSON
Imagine a wor
where limitless
connectivity me
limitless possibi
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Zero-Energy Systems will enable
the era of Ubiquitous Intelligence
tpalacios@mit.edu