Zero-Power Sensors for Border Protection

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So What? Who Cares?

- <u>Space</u>: *Human, vehicle & fire detection*
- <u>Problem</u>: *Limited assess to electrical power prevents high granularity detection*
- <u>Solution</u>: *Eliminate standby power consumption*
- <u>Results</u>: Detect human ~1 m away, *detect hydrocarbon fire ~50 m away, standby power consumption < 10 nW*
- <u>TRL</u>: *3 for people & vehicle detection, 4 for fire detection*
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      Prof. Matteo Rinaldi <u>rinaldi@ece.neu.edu</u>

Border Protection Relies on Sensors

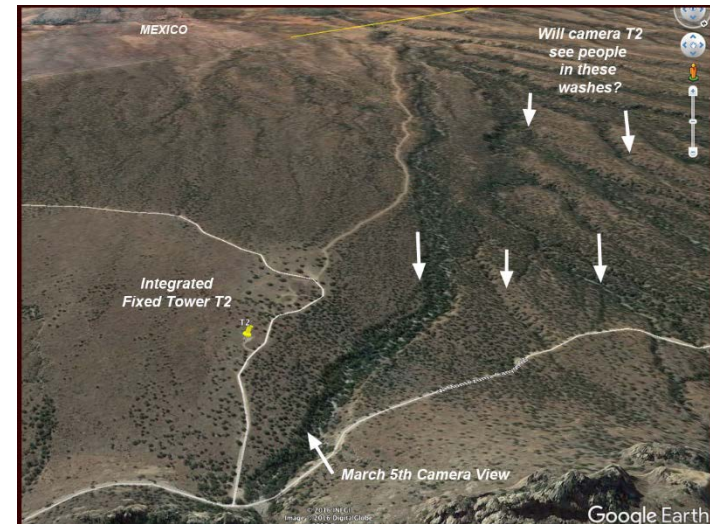### Arizona Border
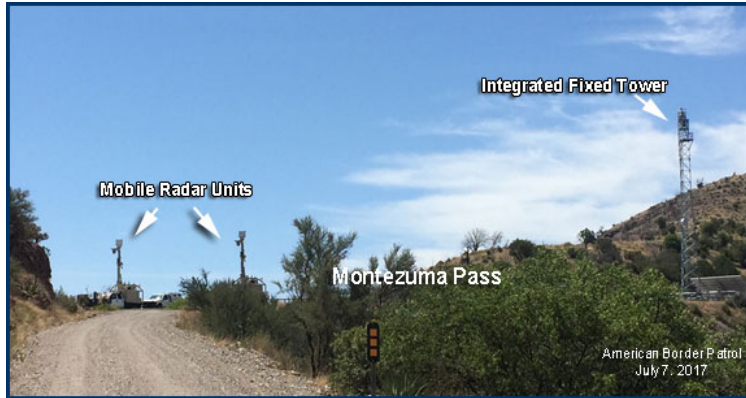
Fixed Tower

Mobile Surveillance Truck

- 80 feet tall (~24 m)
- Radar
- Visible-light cameras
- Infrared cameras
- Wireless communication
- Solar-powered w/ generator backup

- 52 Towers
- 49 Trucks
- >600 Unattended Ground Sensors

Rugged terrain and dense ground cover create blind spots

Source: CBP

Demands and Dilemma on Sensors

- Detect all entering threats **without being affected by blind spots** created by man-made and natural occurring obstacles

- Discriminate between **human, animal, and vehicle** targets in all terrains, landscapes, and weather conditions present where USBP conducts operations.

- **Scalable and deployable** across all environments throughout the Southwest Border and Northern Border
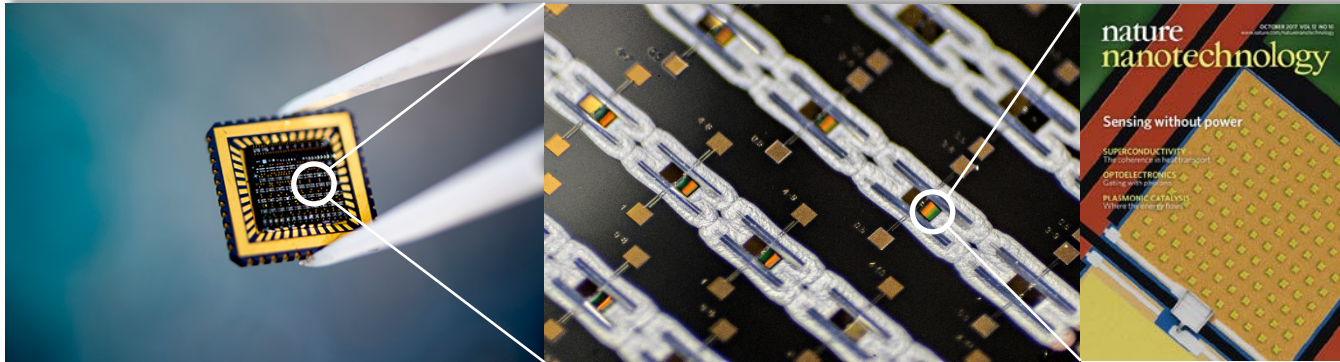
Battery replacement costs are unsustainable for many sensors in challenging environments!
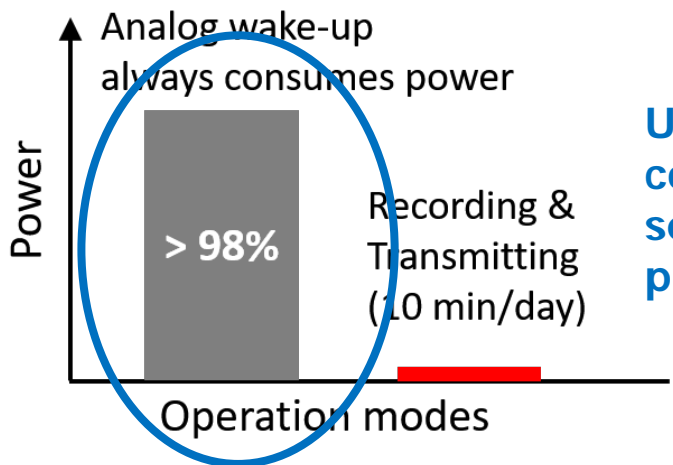
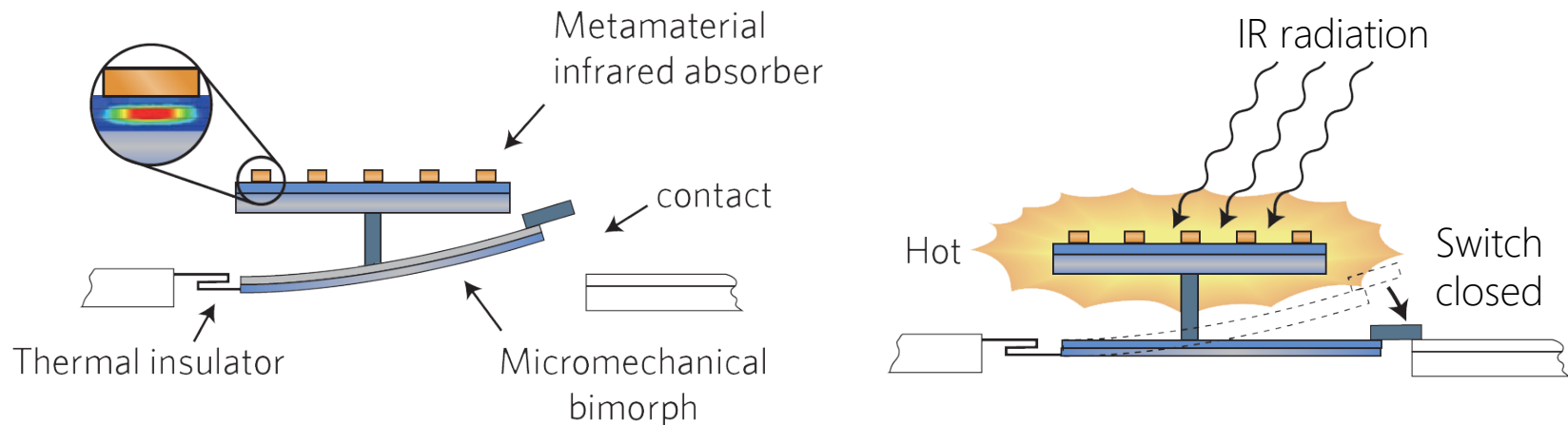**Used for continuous sensing & signal processing**

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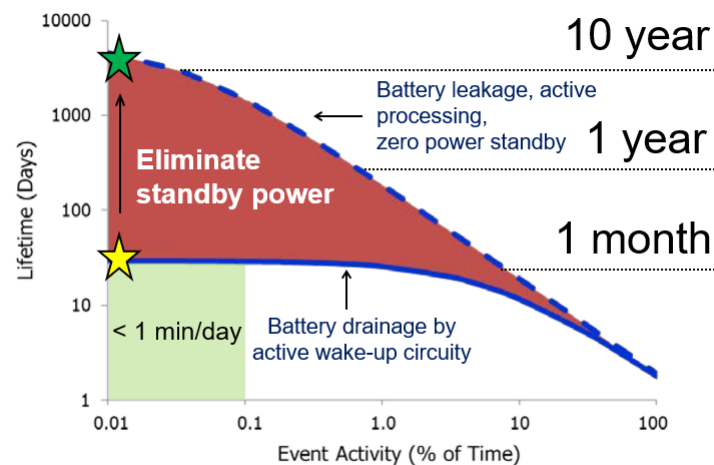
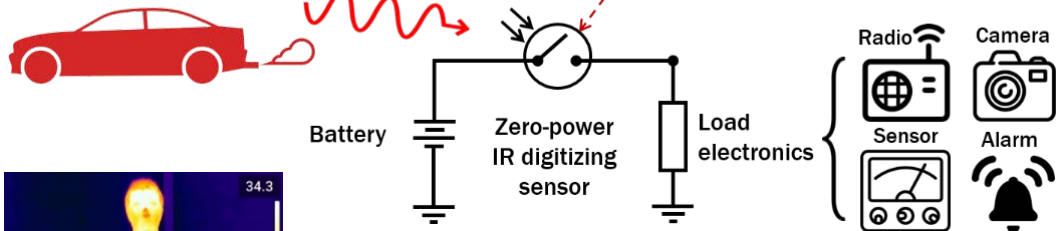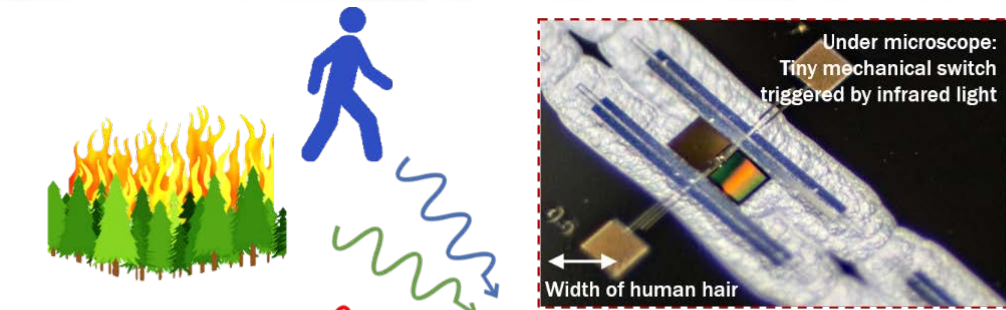# Sensing Without Using Power

A micromechanical photoswitch that can harvest energy from specific infrared radiations to implement abrupt ON/OFF switching without using any electrical power
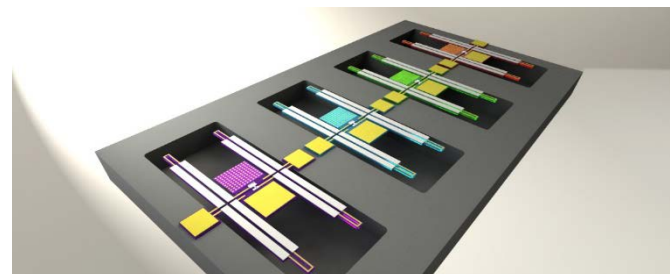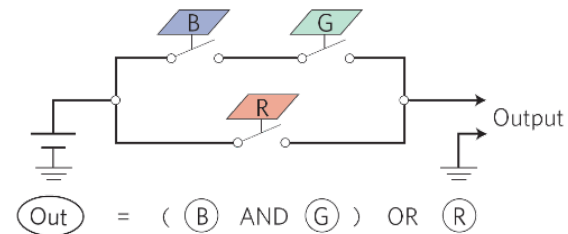
Why Infrared?

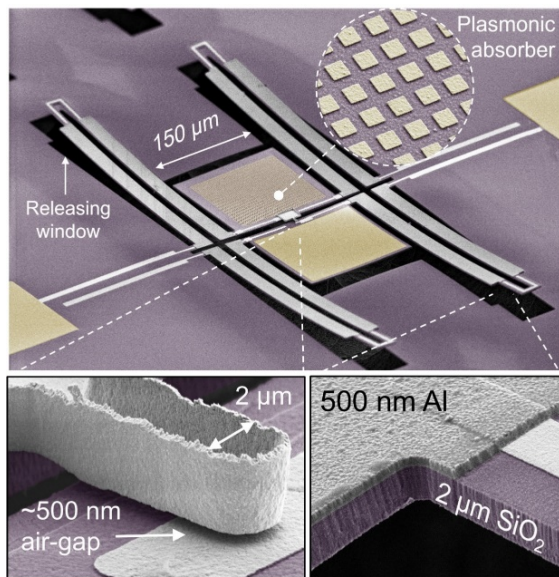Warm objects radiate infrared in different spectral bands ("colors")

- Human body — Blackbody at 37 °C
- Hydrocarbon flame — $H_2O + CO_2$
- Exhaust plume — Nitrogen oxides, Carbon oxides

Normalized Emission vs. Wavelength (μm)
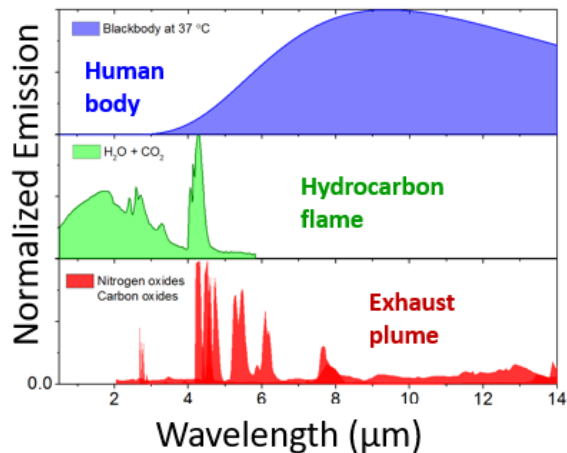
Achieve high selectivity through passive spectrum analysis:

Under microscope: Tiny mechanical switch triggered by infrared light

Width of human hair

Battery — Zero-power IR digitizing sensor — Load electronics

Radio, Camera, Sensor, Alarm

$Out = (B \ AND \ G) \ OR \ R$

Exhaust plume

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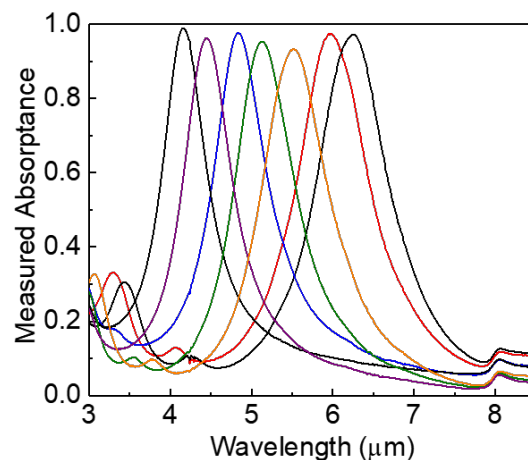# Experimental Results

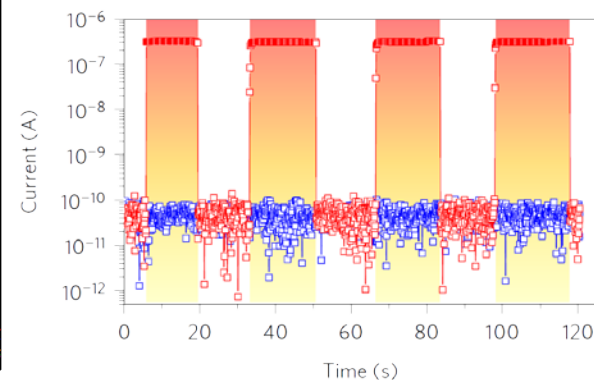**Dual folded-beams for compensation**

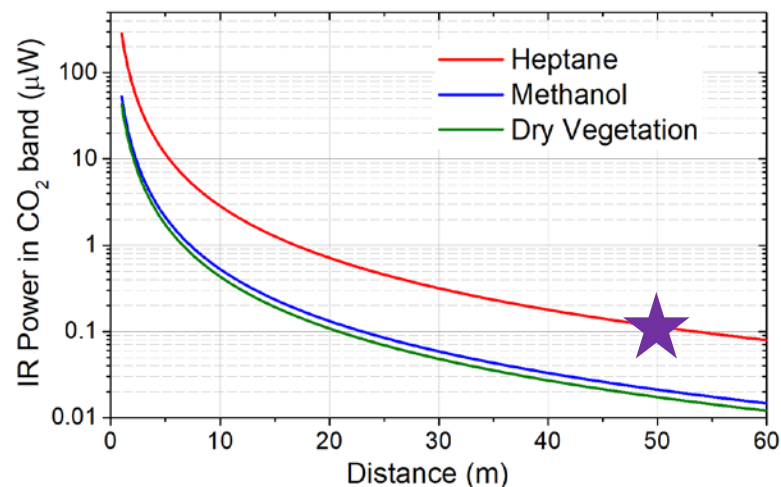### Spectral selectivity

Switch Response
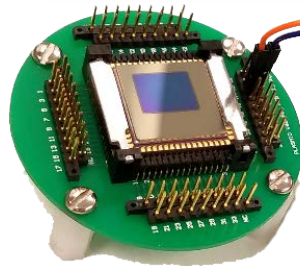

- ❖ Zero leakage (< 5 fA at 20 V bias)
- ❖ ON/OFF conductance ratio **>1×10^{12}**
- ❖ Ultra-low detection threshold: **~100 nW**
- ❖ High reliability: **>8000** consecutive cycles without failure
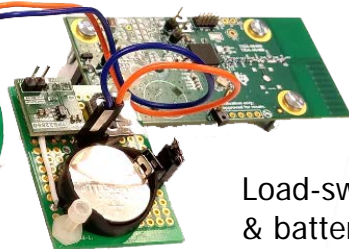- ❖ Wide spectral tuning range: **3-8 µm & LWIR**

Experimental Results

Vacuum-packaged sensor
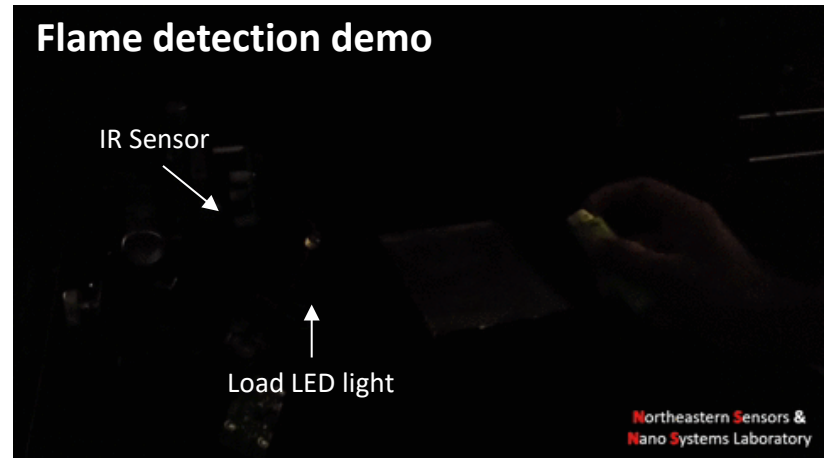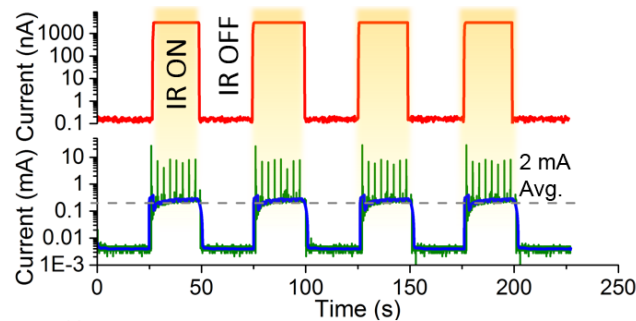
TI Sub-1GHz wireless module

Load-switch & battery unit

Flame detection demo

IR Sensor

Load LED light

Northeastern Sensors & Nano Systems Laboratory

Current in Photoswitch

Current drawn by the entire sensor node

- **Standby power consumption: ~2.6 nW**

- **>3 order of magnitude better than state-of-the-art motion sensors**

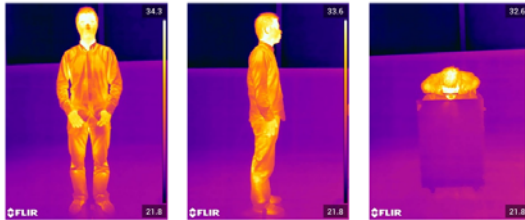- **>6 order of magnitude better than state-of-the-art flame detectors**

Towards Border Protection

- **Focus on human detection**

Case study: available IR power from human body to drive the ZIR sensors

Tool:
Commercial thermal detector with active area of Φ 10 mm **(3489x larger than our sensor)**

Measurement	Front Facing	Side Facing	Top Facing
Power @ 0.5m (1.6 ft)	~ 440 µW	~ 330 µW	~ 203 µW
Power @ 1m (3.3 ft)	~ 220 µW	~ 158 µW	~ 50 µW
Power @ 2m (6.6 ft)	~ 65 µW	~ 45 µW	~ 22 µW
Power density @ 1m	2.8 W/m^2	2.0 W/m^2	0.64 W/m^2
Power delivered to 150x150 µm^2 device	63 nW	45 nW	14 nW

Solar Radiation Spectrum
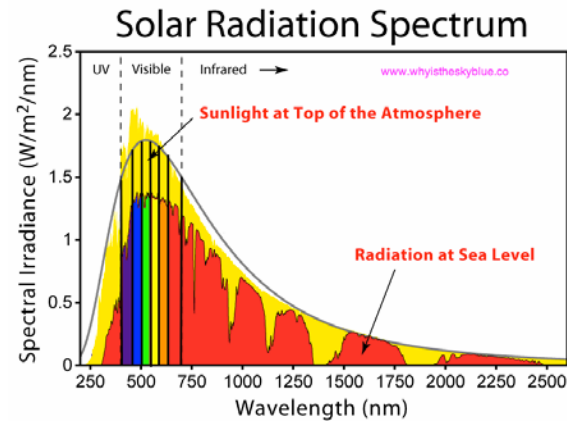
- **Study the effect from sunlight**

- **Extend detection range by using IR lens**

Perform R&D to reduce technical risks
- Design and fabricate optimized IR sensor with threshold < 50 nW
- Design and test IR Fresnel lens (**10 m detection range**)
- Reliability test and design optimization
- Demonstration of a working prototype in lab environment (**TRL 4**)
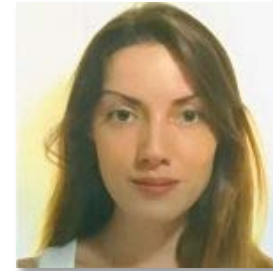
Acknowledgment

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