Multi-Spectral Infrared Sensing Microsystems

Prof. Matteo Rinaldi
rinaldi@ece.neu.edu
https://web.northeastern.edu/nemslab/

Department of Electrical and Computer Engineering
Northeastern University
Boston, MA 02115, USA

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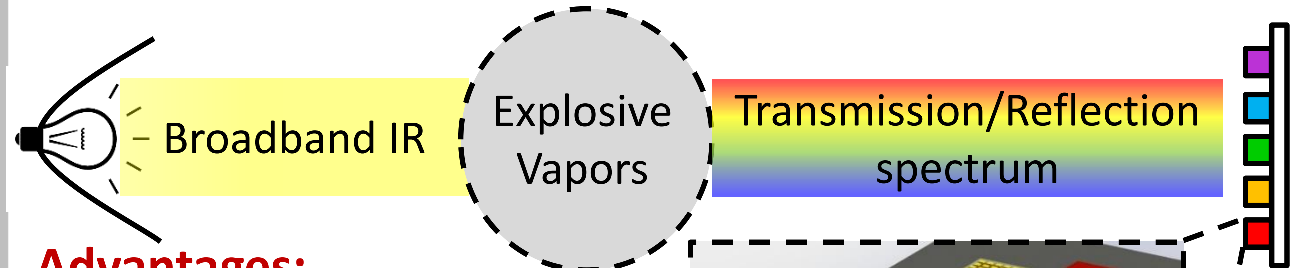
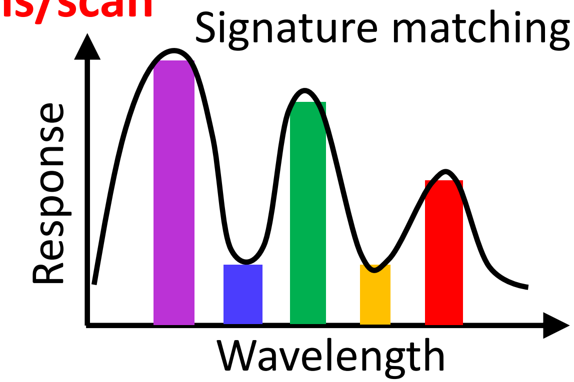
Uncooled Spectrally Selective IR Detectors for Fast Screening of Explosive Vapors

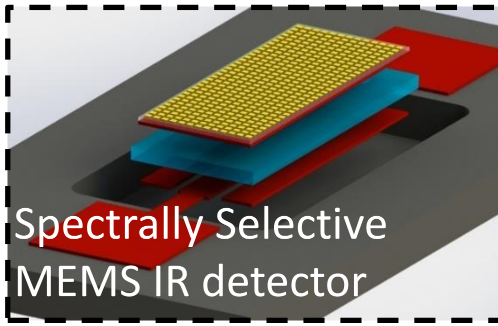
Multiple detectors acquiring data simultaneously: < 10 ms/scan





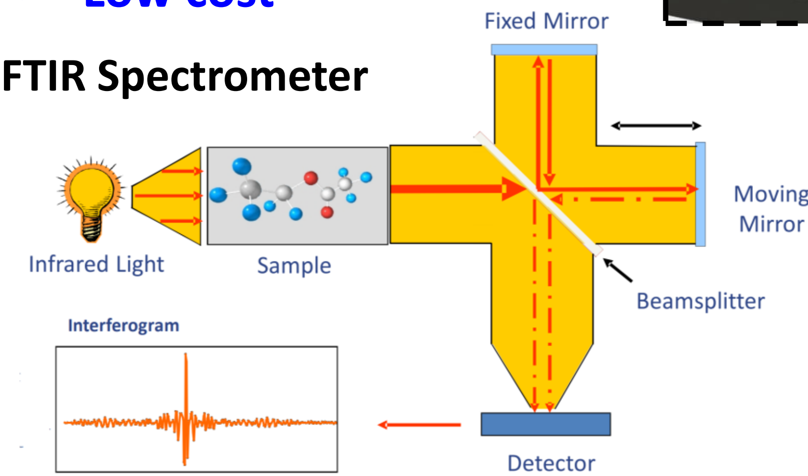
Advantages:

- ✓ Fast data acquisition
- ✓ Low power consumption
- ✓ Small form factor
- ✓ Low cost

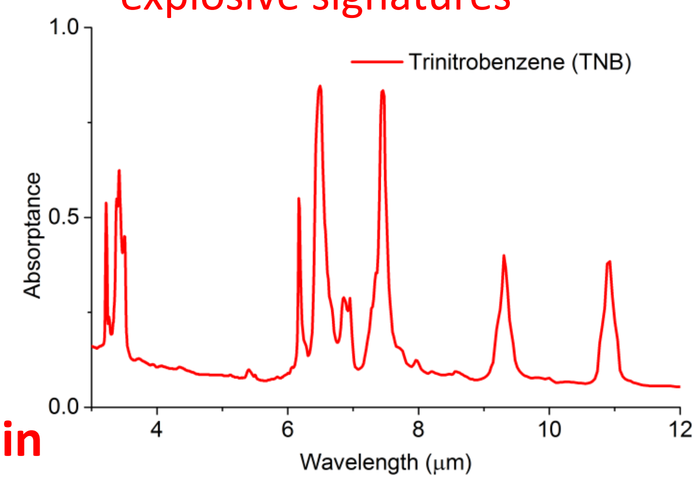


Further measurement with QCL to get high-resolution data if initial scan matches any explosive signatures

FTIR Spectrometer

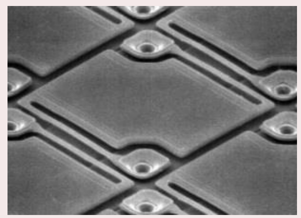
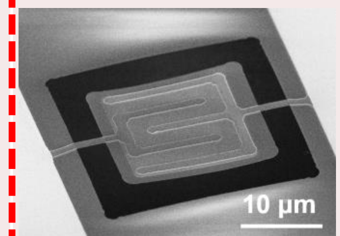


- high-spectral resolution
- wide spectral range
- slow speed
- hard to miniaturize



Time per scan: ~ few seconds to 1 min

State-of-the-art IR detector technologies

	Photon Detector	Thermal Detector (uncooled)			
	Cooled	Thermoresistive	Pyroelectric	Thermoelectric	MEMS resonant
Example	 HgCdTe(MCT) / Quantum well	 Microbolometer	 PIR sensor	 Thermopile	 AlN Nano Plate Resonator
NEP	< pW/Hz$^{1/2}$	~100s pW/Hz$^{1/2}$	~100s pW/Hz$^{1/2}$	~ nW/Hz$^{1/2}$	~ 10s pW/Hz$^{1/2}$
Speed	ps - μs	10s ms	10s ms	10s ms	~ 10s μs
Pixel Size	30 × 30 μm^2	25 × 25 μm^2	40 × 40 μm^2	200 × 200 μm^2	~ 30 × 30 μm^2
Selectivity	Broad/Narrow	Broadband	Broadband	Broadband	**Narrowband**

- **High sensitivity to external perturbations**
- **High *Q* guarantees ultra-low noise**
- **Lithographically defined absorption band**

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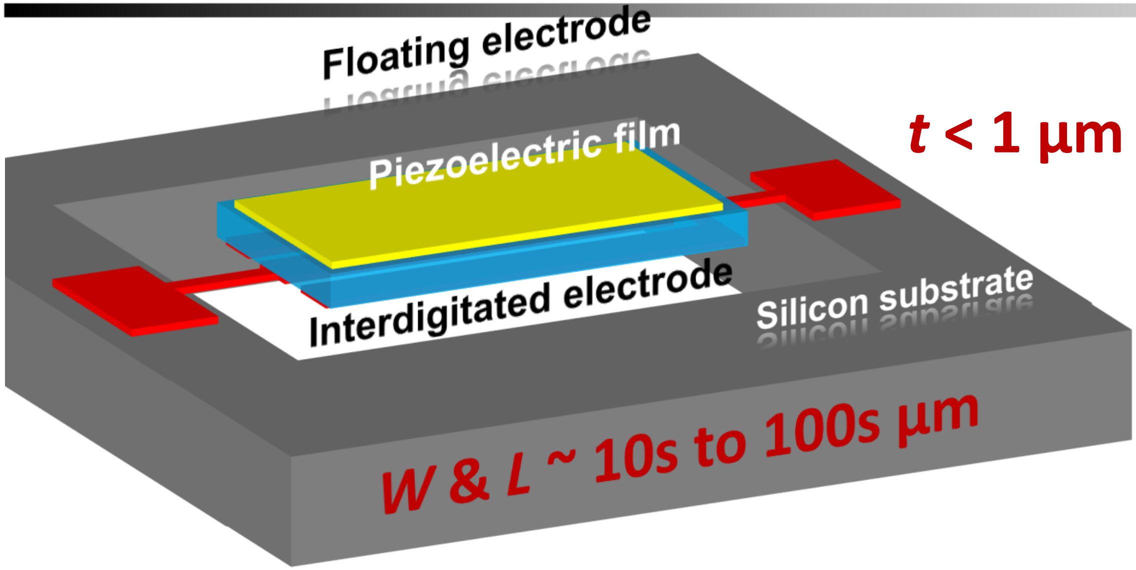
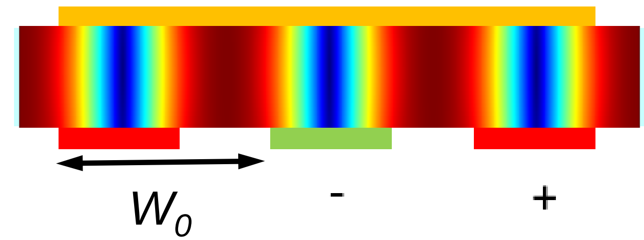
Piezoelectric Resonant Thermal Detector



t < 1 µm



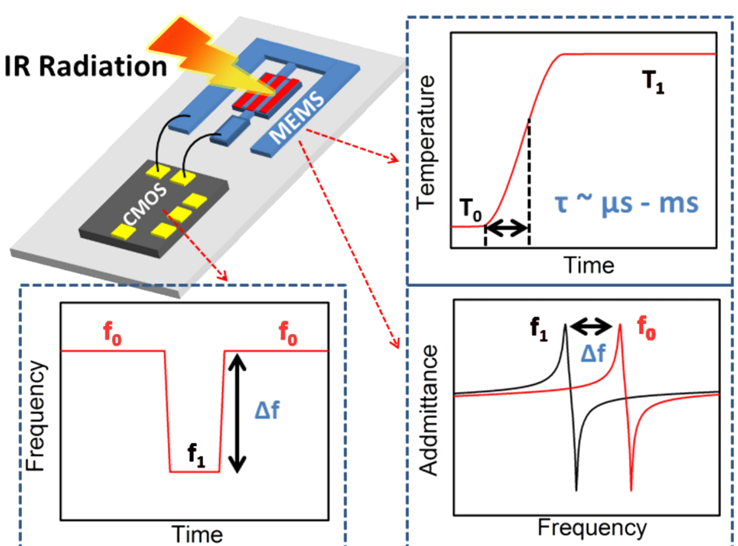
$$f_0 = \frac{1}{2W_0}\sqrt{\frac{E_{eq}}{\rho_{eq}}}$$

Temperature

$$\Delta f_{noise} = \sqrt{\frac{K_B T_0 (1+F_c) B}{4P_c}} \cdot \frac{f_0}{Q}$$

$$NEP = \frac{\Delta f_{noise}}{R_s}$$

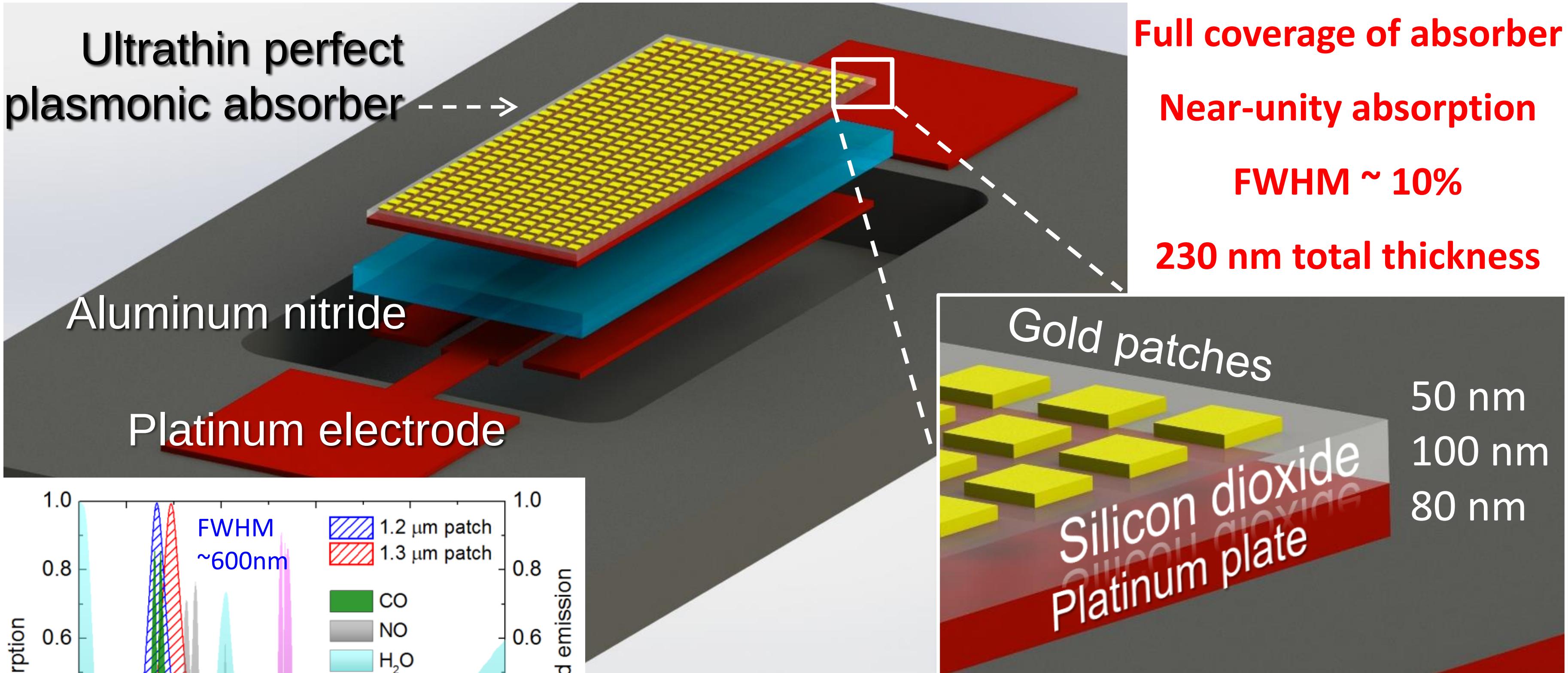
$$R_s = \frac{\Delta f_{IR}}{Q_p} = \eta \cdot R_{th} \cdot TCF \cdot f_0$$



$$\tau = R_{th} \cdot C_{th} \qquad C_{th} \propto A \cdot t \qquad C_0 \propto \frac{A}{t}$$

$$FoM = \frac{1}{NEP \cdot \tau} \propto \frac{\eta \cdot TCF \cdot Q}{C_0 \cdot t^2}$$

Integration of ultrathin narrowband absorber

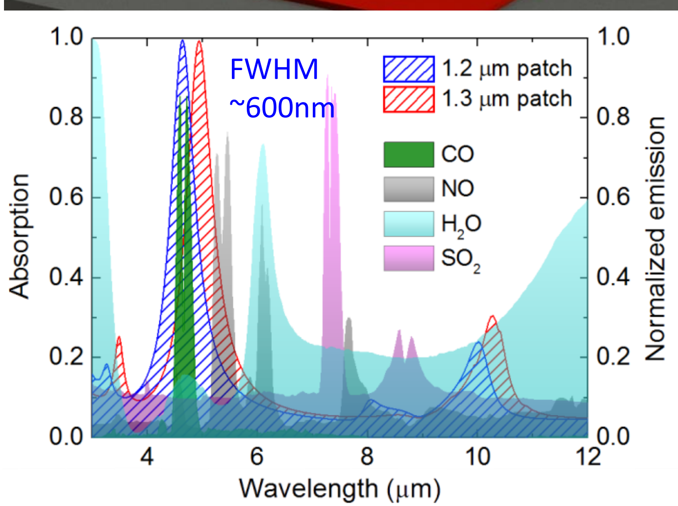


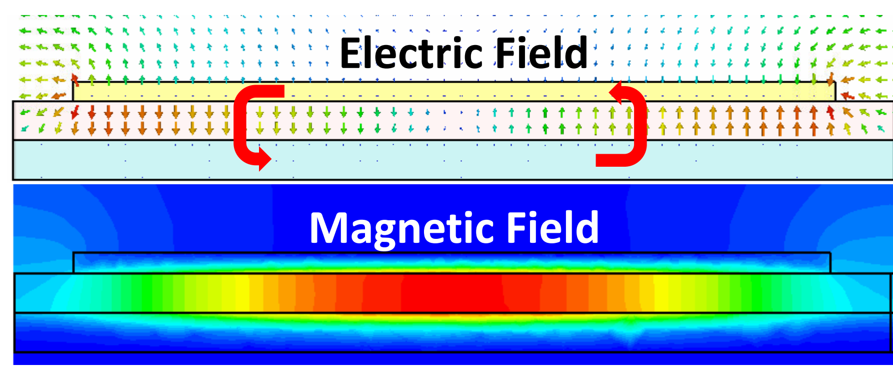
Full coverage of absorber

Near-unity absorption

FWHM ~ 10%

230 nm total thickness





Z. Qian, S. Kang, V. Rajaram and M. Rinaldi; Proceeding of the IEEE Sensors 2016 Conference (Sensors 2016), pp. 1-3, doi: 10.1109/ICSENS.2016.7808614

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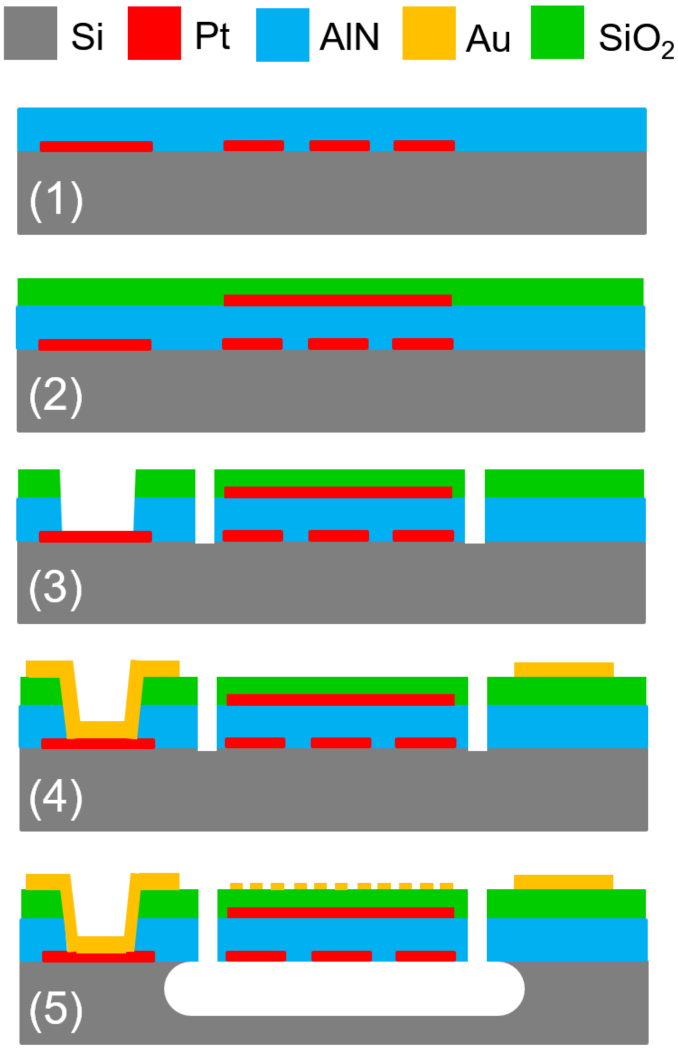
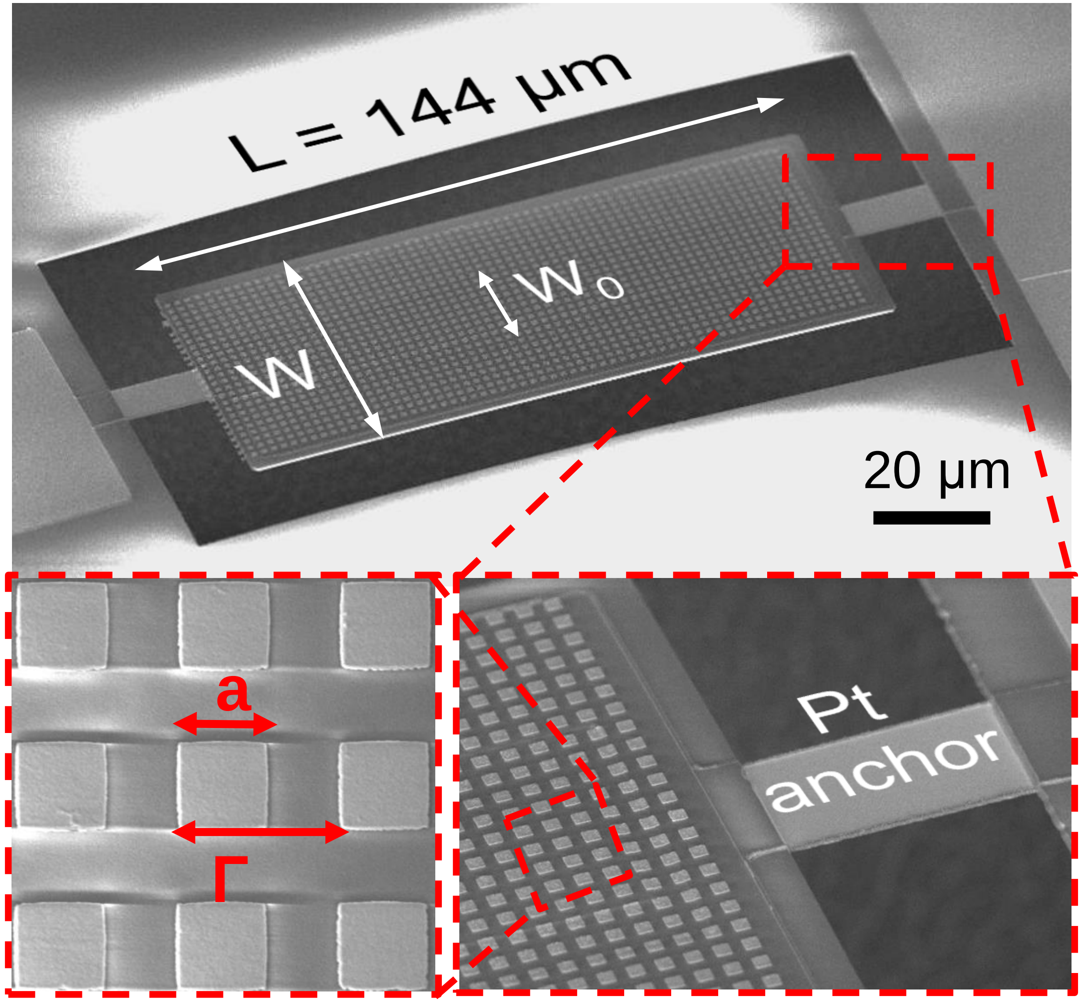
Microfabrication





a=1.2 or 1.3 µm, Γ=2.2 µm, W=60 µm, W_0=20 µm

Z. Qian, S. Kang, V. Rajaram and M. Rinaldi; Proceeding of the IEEE Sensors 2016 Conference (Sensors 2016), pp. 1-3, doi: 10.1109/ICSENS.2016.7808614

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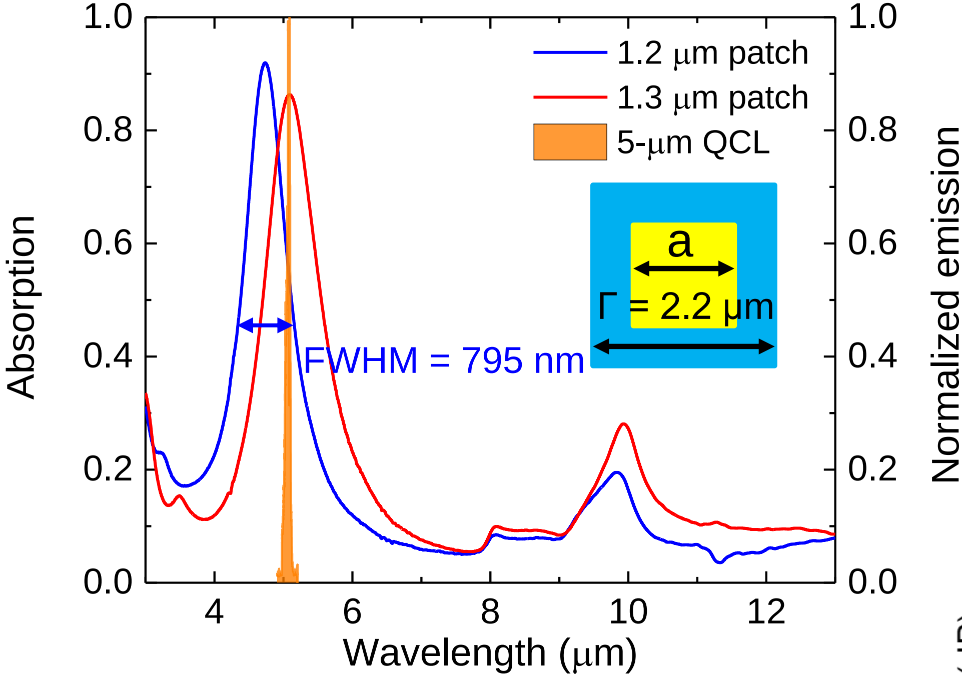
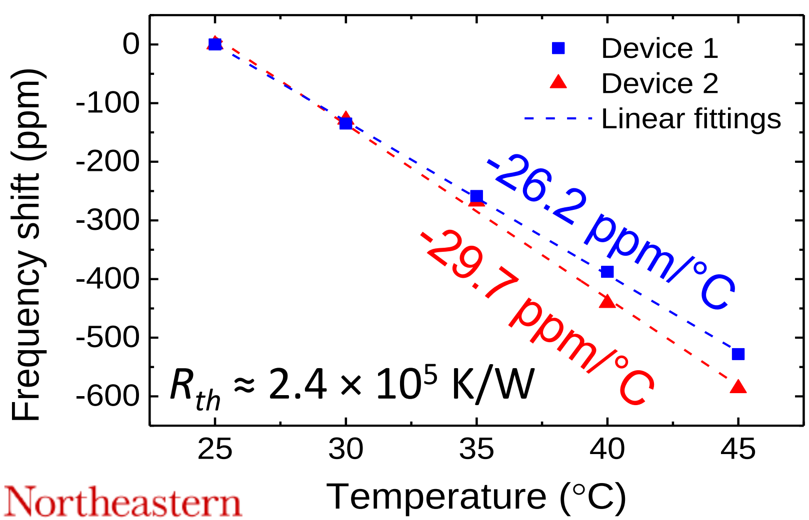
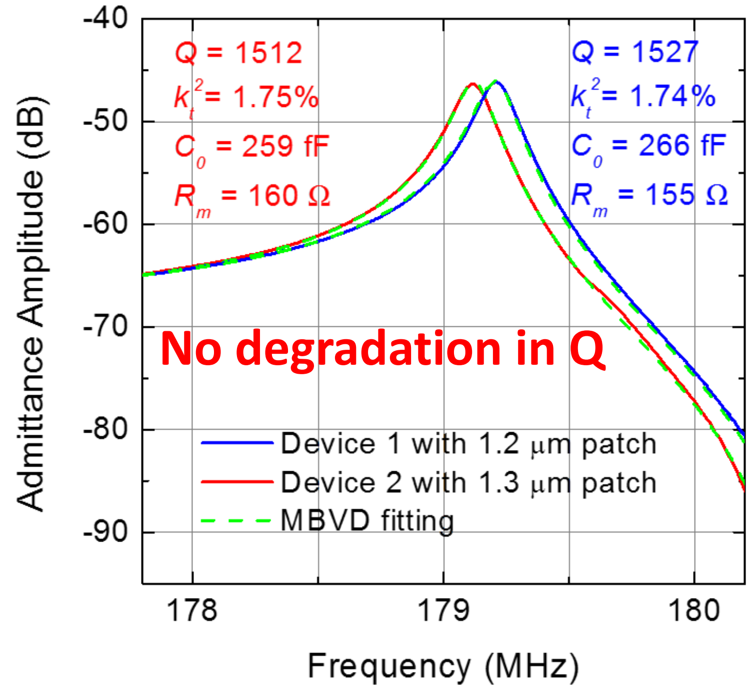
Experimental results



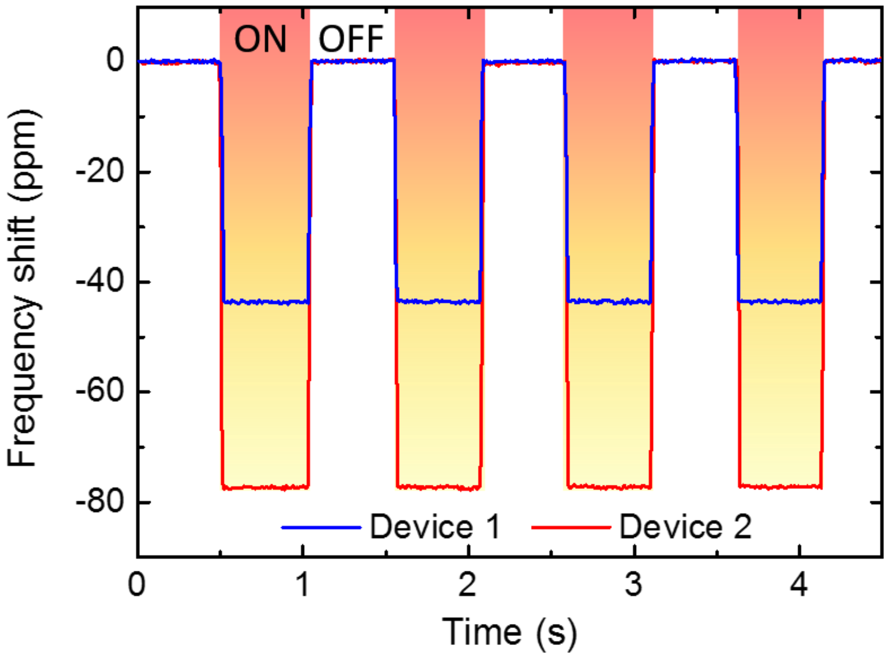
Z. Qian, S. Kang, V. Rajaram and M. Rinaldi; Proceeding of the IEEE Sensors 2016 Conference (Sensors 2016), pp. 1-3, doi: 10.1109/ICSENS.2016.7808614

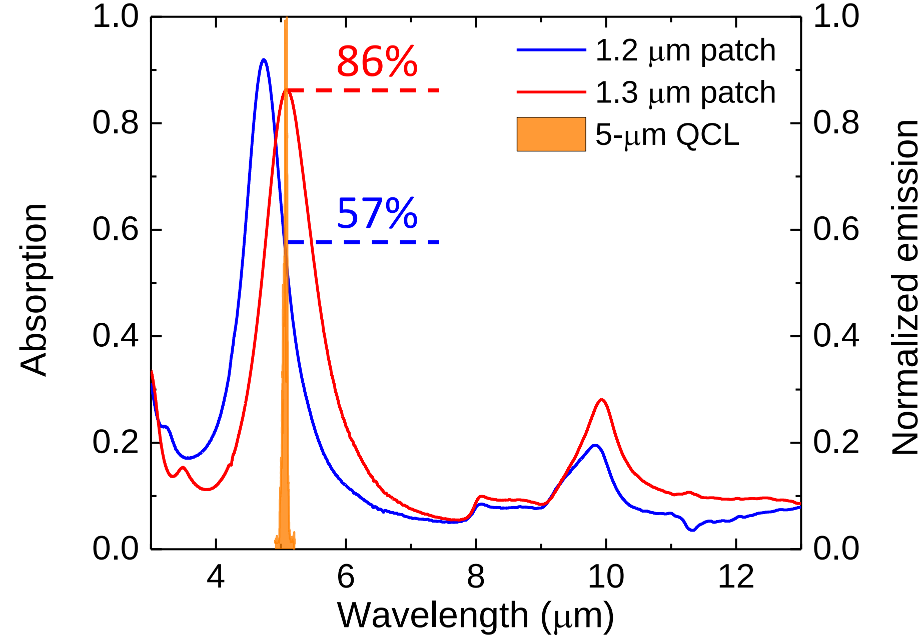
Absorptance ~92%, FWHM ~16%





Frequency response to IR radiation





$R_{th} \approx 2.4 \times 10^5$ K/W

$\tau \approx 3.5$ ms

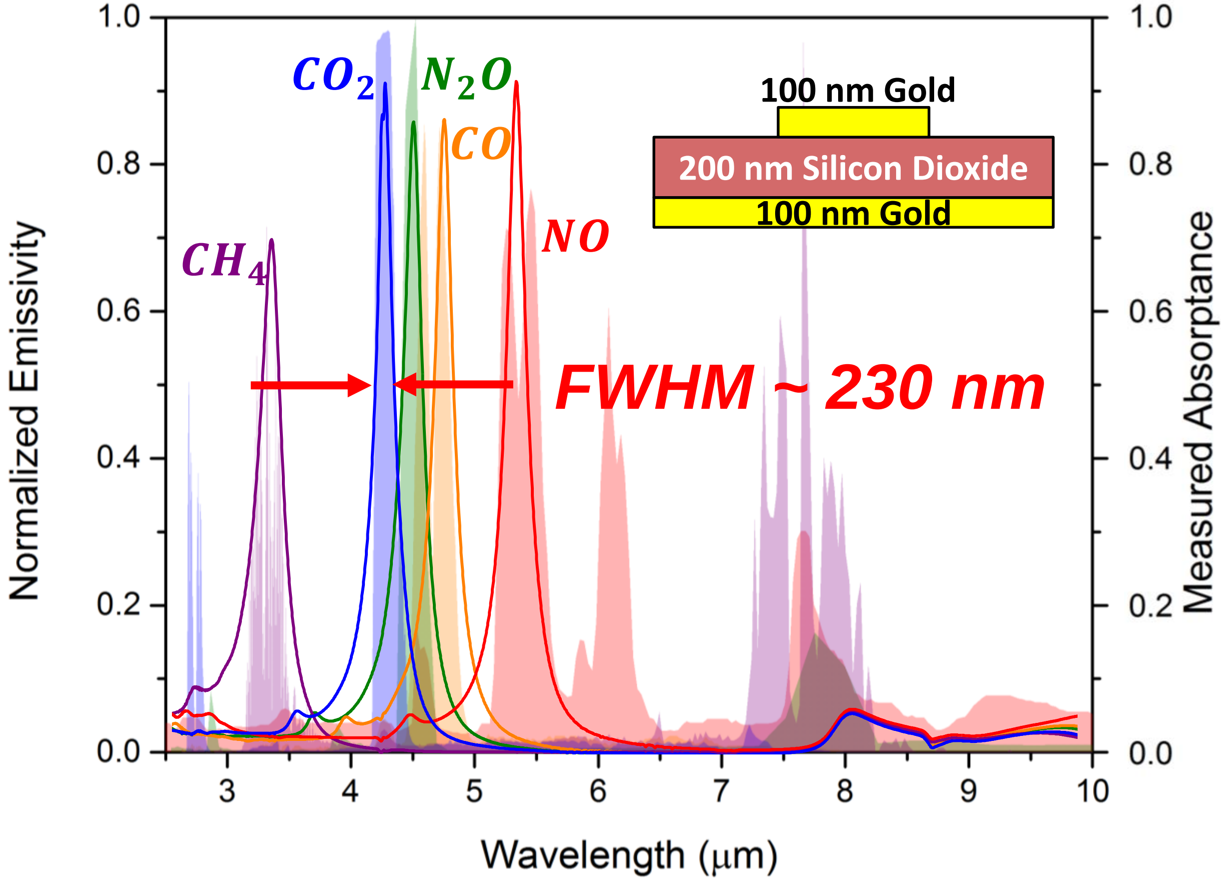
$\Delta f_{noise} \approx 3.7$ ppb/Hz$^{1/2}$

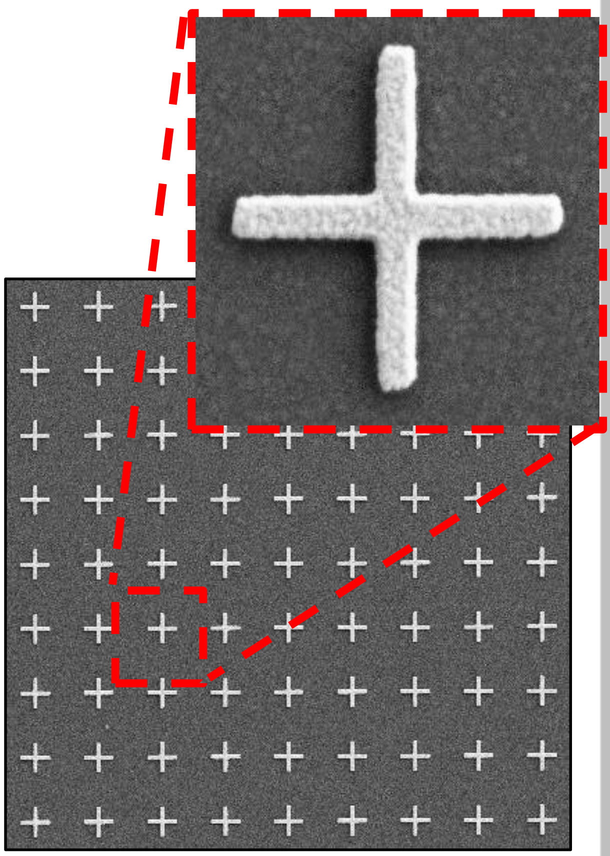
$NEP \approx 633$ pW/Hz$^{1/2}$ (at 4.7 μm)

Z. Qian, S. Kang, V. Rajaram and M. Rinaldi; Proceeding of the IEEE Sensors 2016 Conference (Sensors 2016), pp. 1-3, doi: 10.1109/ICSENS.2016.7808614

Spectral Selectivity for Trace-Gas Emission

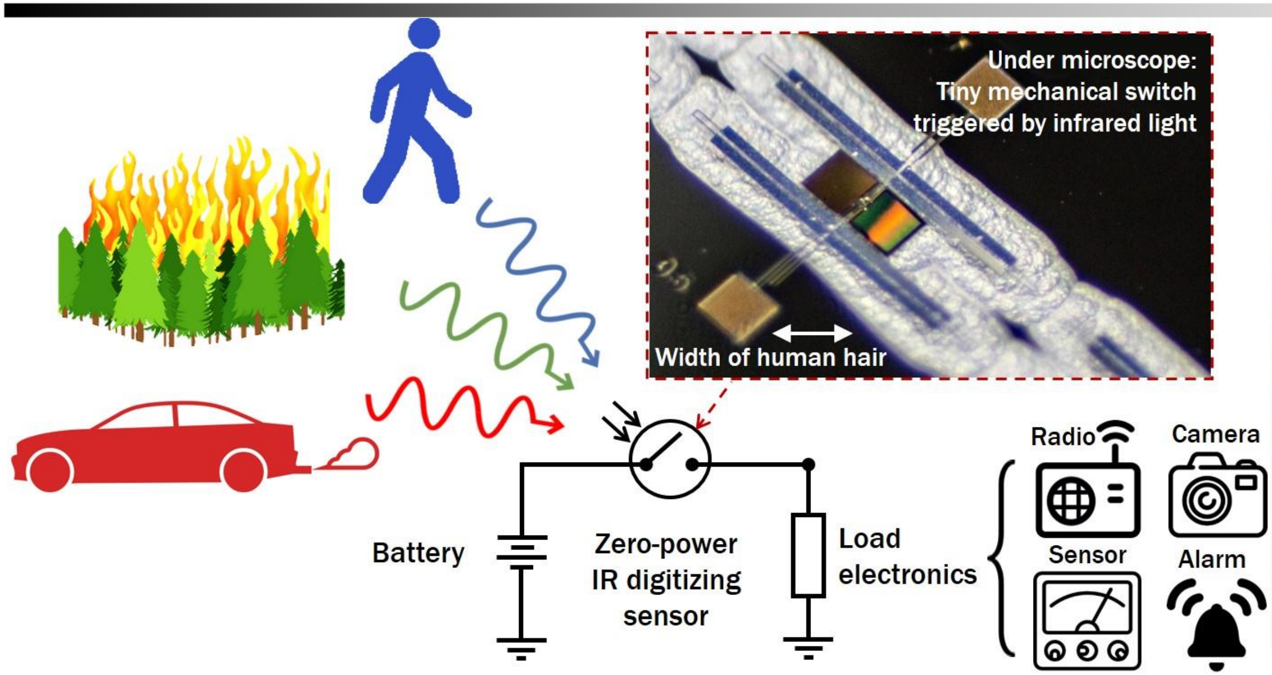
- Absorbers tuned to match 5 major trace-gas emission
- FWHM < 5% allows a superior selectivity for closely-located IR signatures
- Peak wavelength tuned only via lithography



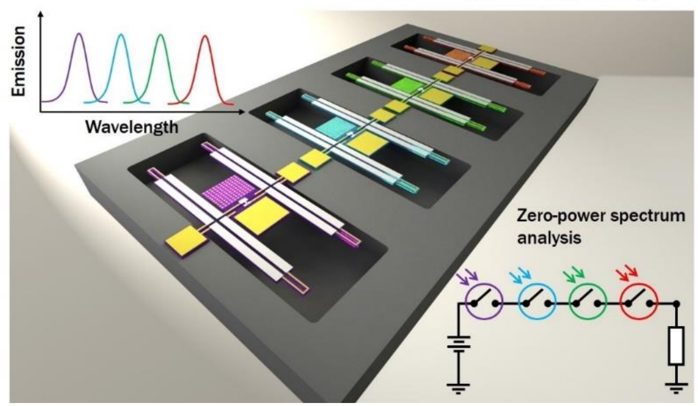


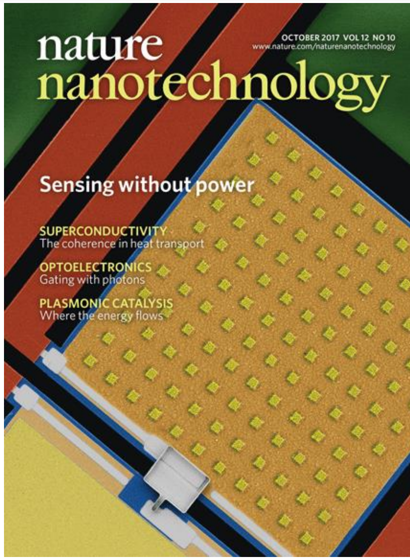
S. Kang, Z. Qian, V. Rajaram, A. Alu' and M. Rinaldi, Proceedings of the 19th International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers 2017), pp. 886-889. doi: 10.1109/TRANSDUCERS.2017.7994191.

Zero-Power Infrared Digitizing Sensors



- A **passive microsystem** that combines **sensing**, **signal processing** and **comparator** functionalities.
- The sensor produces **a digitized output bit** in the presence of the unique **IR spectral signatures**.





*Z. Qian, S. Kang, V. Rajaram, C. Cassella, N. McGruer and M. Rinaldi, "**Zero Power Infrared Digitizers Based on Plasmonically-enhanced Micromechanical Photoswitches**", Nature Nanotechnology, 12, 969-973, doi:10.1038/nnano.2017.147*

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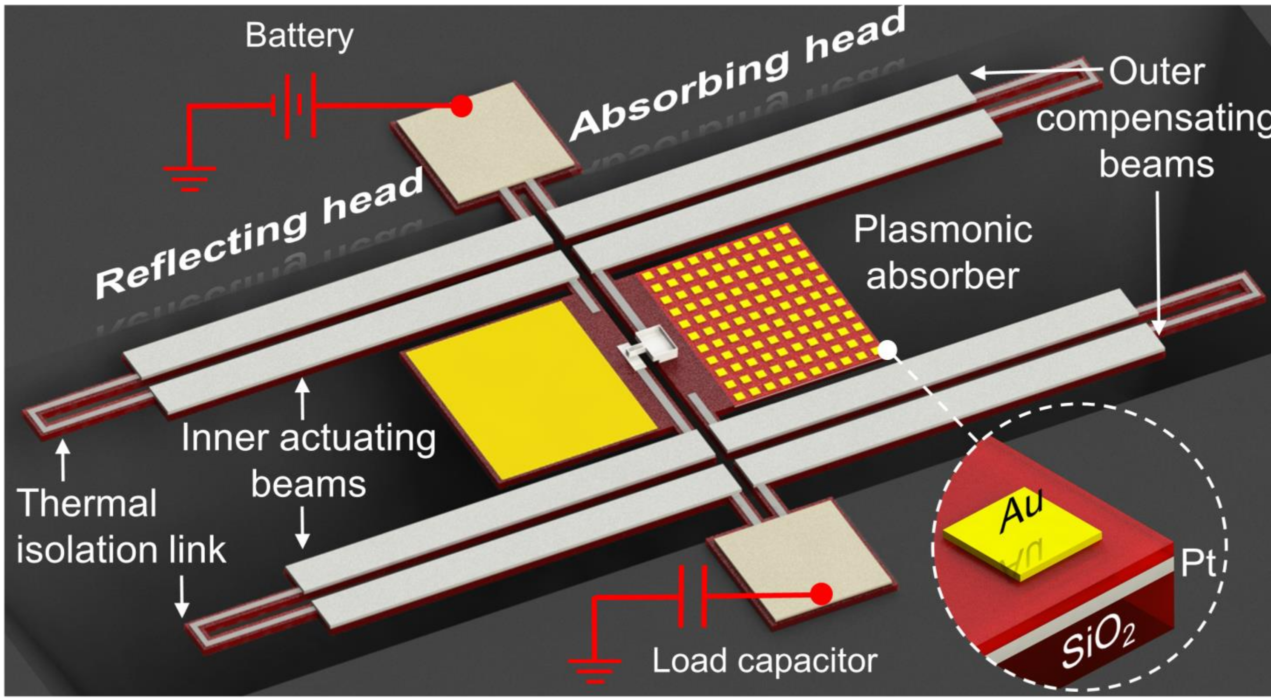
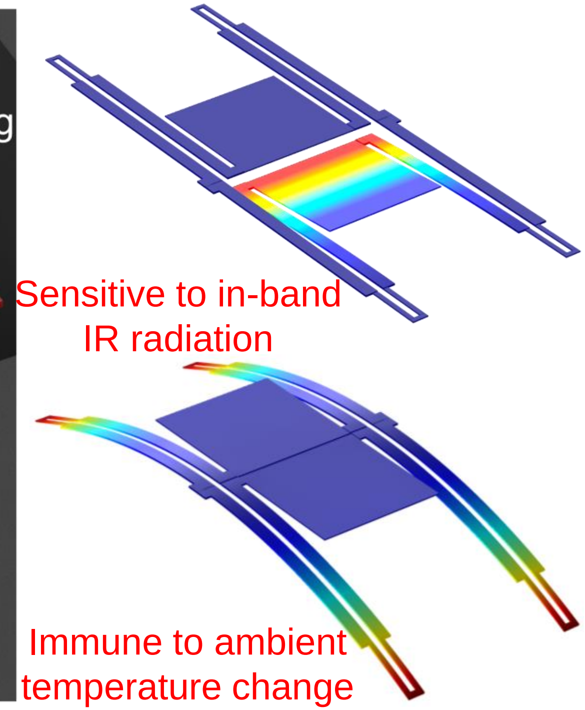
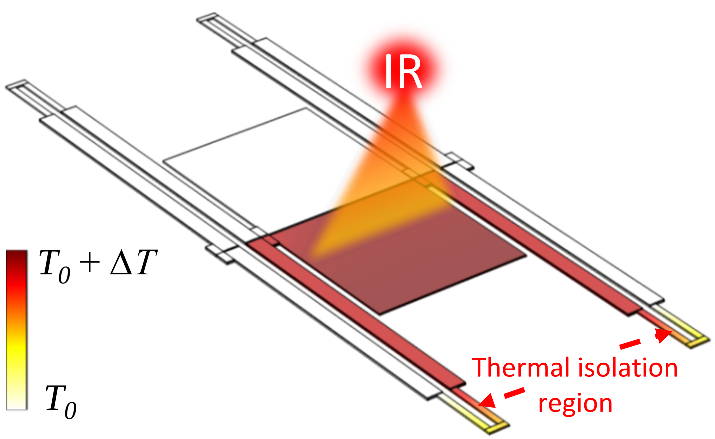
Plasmonically-enhanced Micromechanical Photoswitch (PMP)





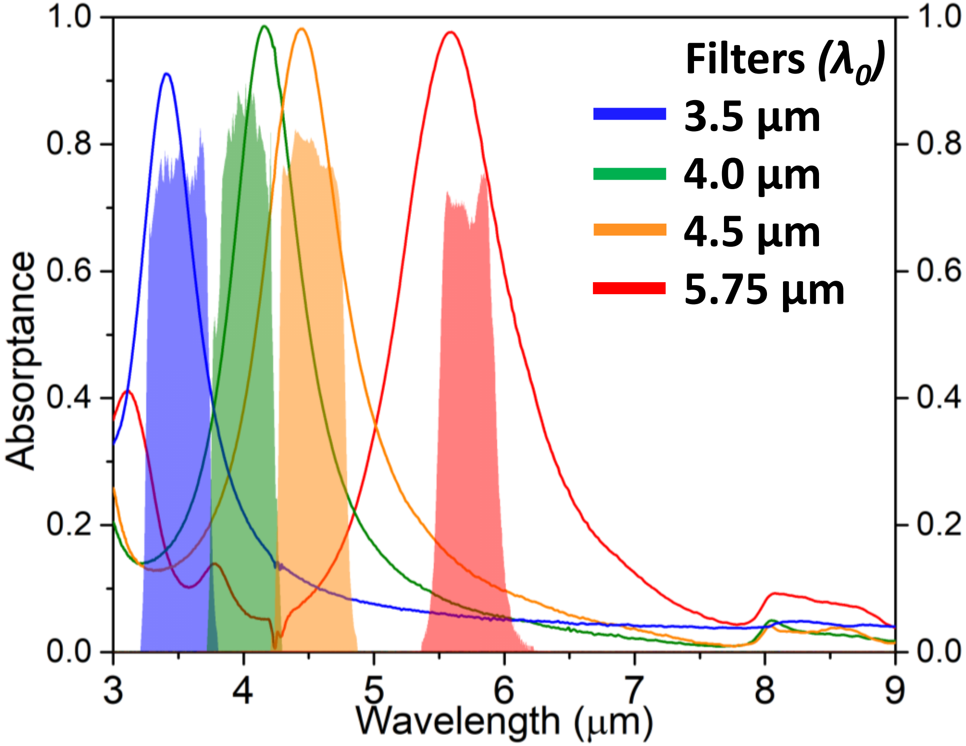


- Micromechanical switch selectively triggered by IR radiation at a specific spectral wavelength through a **plasmonically-enhanced thermomechanical coupling**
- **Immune to ambient temperature changes and residual stress**

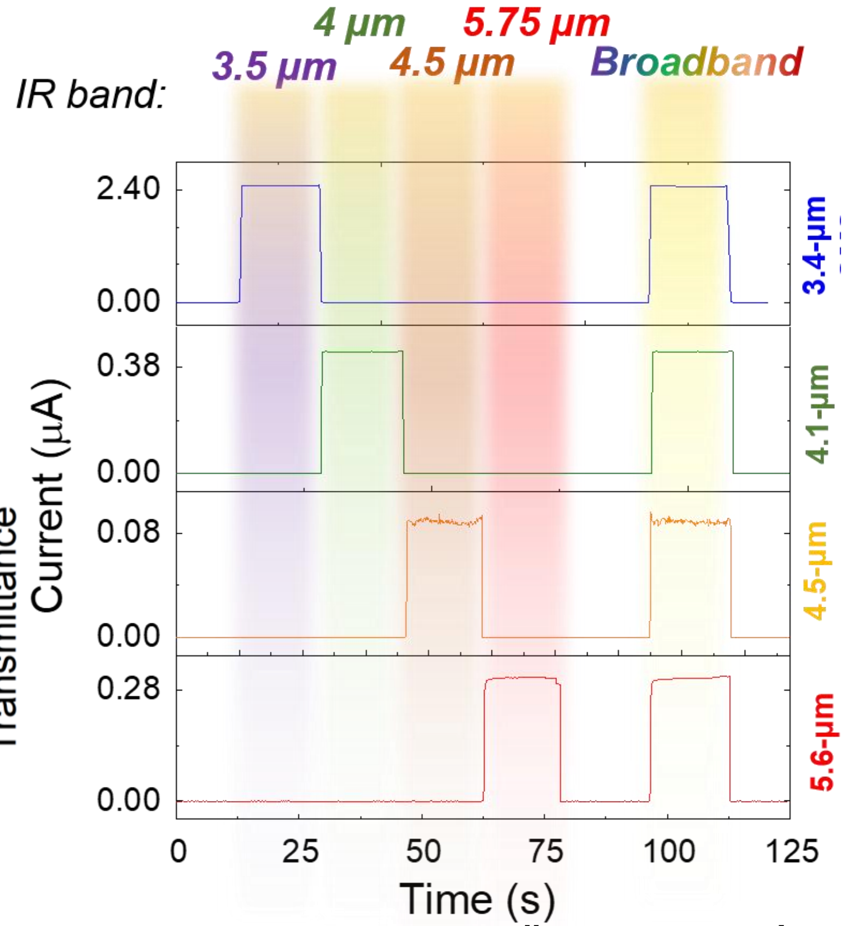
*Z. Qian, S. Kang, V. Rajaram, C. Cassella, N. McGruer and M. Rinaldi, "**Zero Power Infrared Digitizers Based on Plasmonically-enhanced Micromechanical Photoswitches**", Nature Nanotechnology, 12, 969-973, doi:10.1038/nnano.2017.147*

Spectral Selectivity

Device	Infrared Spectral State				
	3.5µm Band	4.0µm Band	4.5µm Band	5.75µm Band	Broad-band
3.4µm PMP	1	0	0	0	1
4.1µm PMP	0	1	0	0	1
4.5µm PMP	0	0	1	0	1
5.6µm PMP	0	0	0	1	1



- PMPs turn **ON** only at **the specific IR band radiation** with absorbed power **> 500 nW**, and remain OFF otherwise.



V. Rajaram, Z. Qian, S. Kang, C. Cassella, N. McGruer and M. Rinaldi, Proceedings of the 19th International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers 2017), pp. 846-849. doi: 10.1109/TRANSDUCERS.2017.7994181

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Collaborators:

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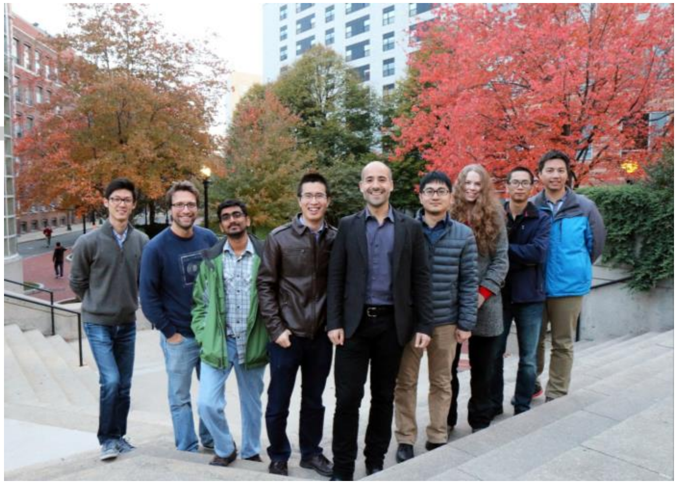
- Prof. Andrea Alu'



Young Faculty Award
N66001-12-1-4221
DARPA RF-FPGA Program
N66001-14-1-4011
DARPA NZero Program
HR0011-15-2-0048
HR0011-15-C-0138
DARPA SPAR Program
HR0011-17-2-0002

CAREER Award
ECCS-1350114
NeTS Small
CNS-1618731
MRI

W.M. Keck Foundation

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