HIGH PERFORMANCE INFRARED/TERAHETZ DETECTORS BASED ON PIEZOELECTRIC NANO PLATE RESONATORS

Northeastern Sensors & Nano Systems Laboratory
www.northeastern.edu/nemslab

PI: Matteo Rinaldi

Northeastern University, Boston, Massachusetts, USA

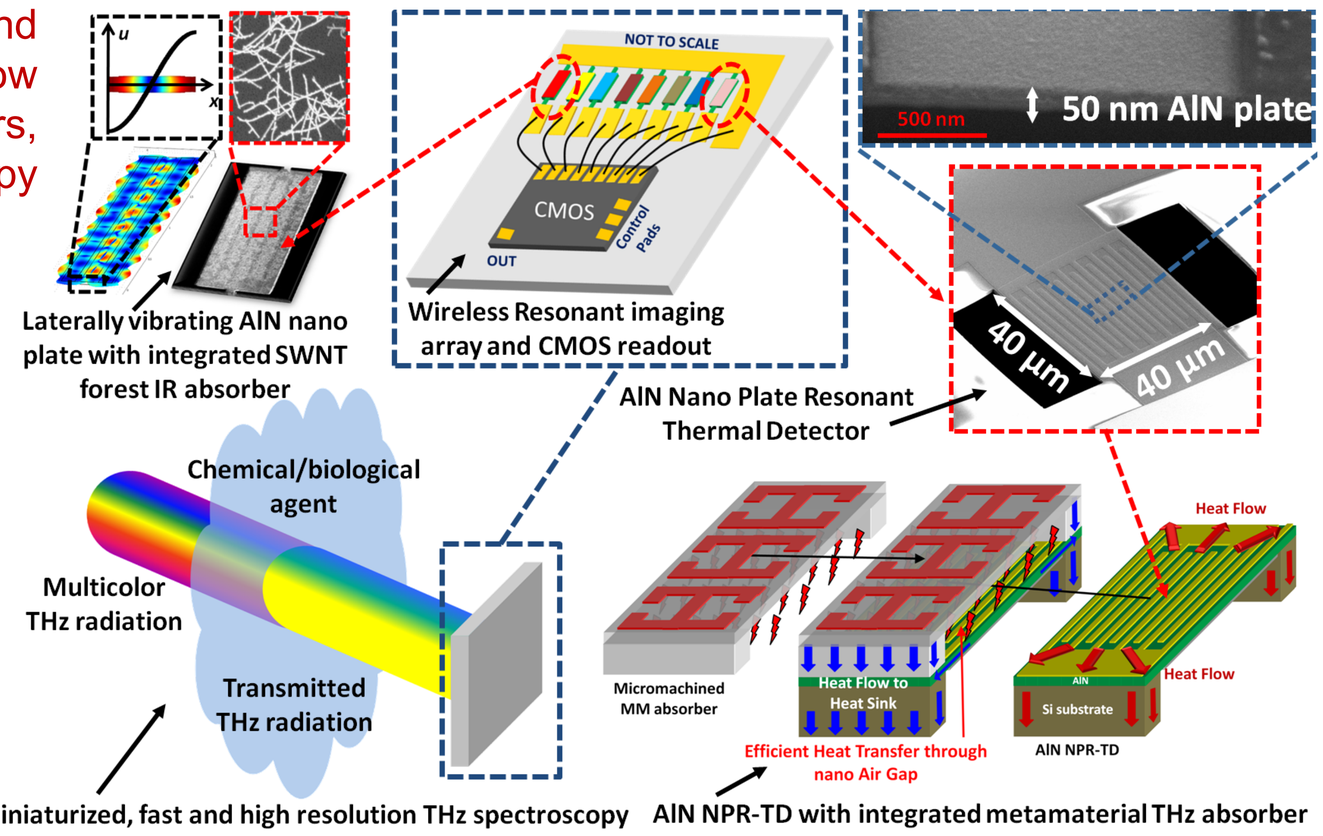
Northeastern

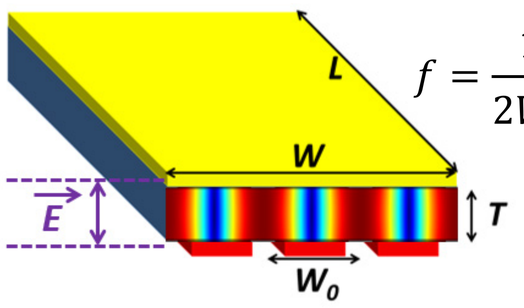
Overview and Motivations

Our research focuses on the design, fabrication and characterization of high performance, miniaturized and low power uncooled MEMS/NEMS resonant infrared detectors, which can potentially revolutionize the field of IR spectroscopy and multi-spectral imaging systems.

The unique thermal detection capabilities of AlN nano-plate resonators make it excellent candidate for high performance infrared detectors:

Thermal Detector Metrics	Enabling features	Performance
Sensitivity	High TCF and excellent thermal isolation from a heat sink ⇒ very low thermal conductance	10s ppm/nW
Time Constant	Extremely low-mass device ⇒ very low heat capacity	µs - ms
Noise Performance	Demonstrated very low Phase Noise performance	$\Delta f_{noise} \approx$ ppb



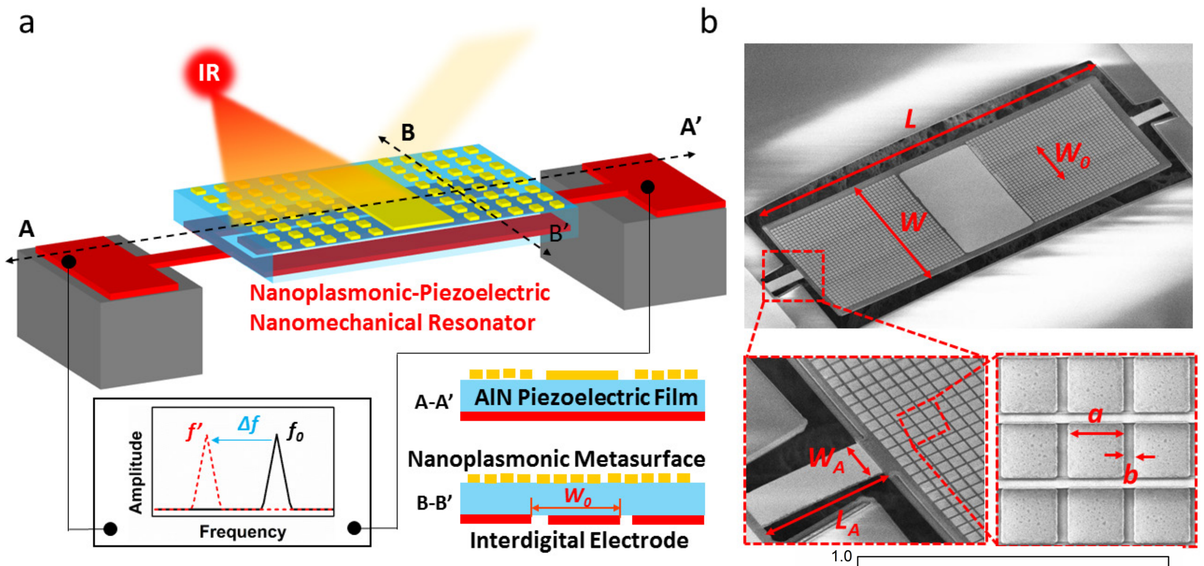


$$f = \frac{1}{2W_0}\sqrt{\frac{E_{eq}}{\rho_{eq}}}$$

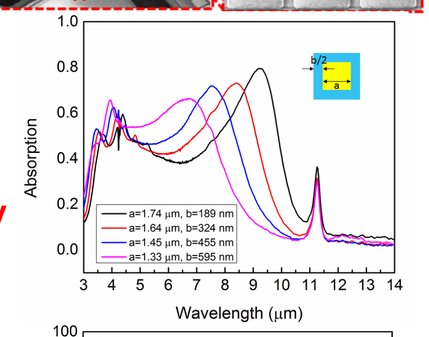
- Spectrally selective IR detection
- NEP ~ pW/Hz$^{1/2}$
- NETD ~ mK
- Thermal time constant < 1ms
- Low power CMOS readout

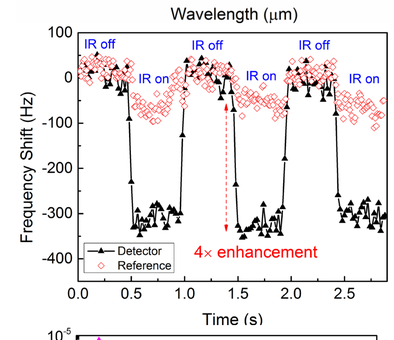
Ideal candidate for the implementation of high resolution, ultra-fast, miniaturized and low power infrared/THz spectroscopy systems for standoff detection and identification of trace chemical residues

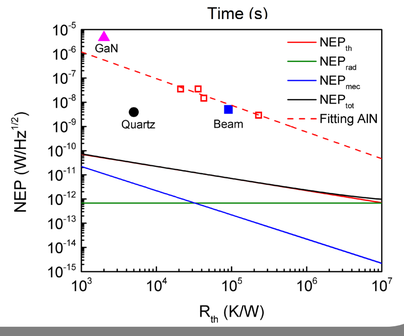
Spectrally selective IR/THz detectors



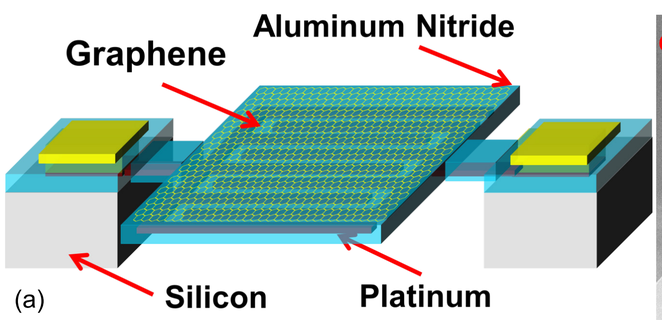
- Ultra-thin (600 nm thick) nanoplasmonic piezoelectric metamaterial to form the resonant body of the NEMS structure
- High IR absorption of 80% at lithographically defined wavelength in the LWIR range
- High figure of merit AlN piezoelectric metamaterial nano-plate resonator: *FOM = $k_t^2 \cdot Q$ > 10*
- High sensitivity (AlN nano-plate resonant technology): extracted responsivity of *500 Hz/ µW*
- Fast device response (overall reduced device volume): measured thermal time constant of *440 µs*
- Ultra-high resolution (low noise performance): Noise Equivalent Power (*NEP*) of *~2.9 nW/Hz$^{1/2}$*

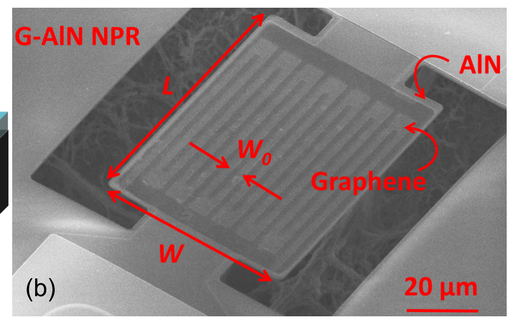




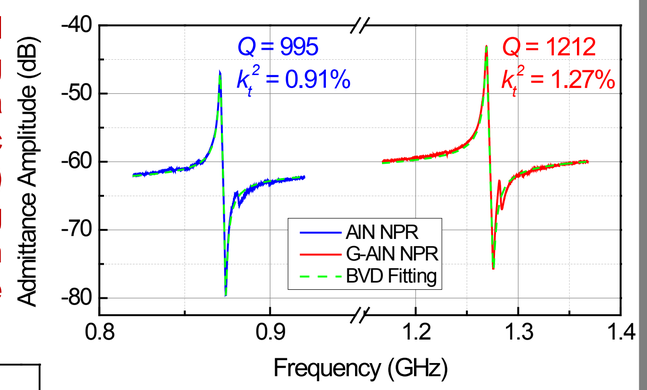


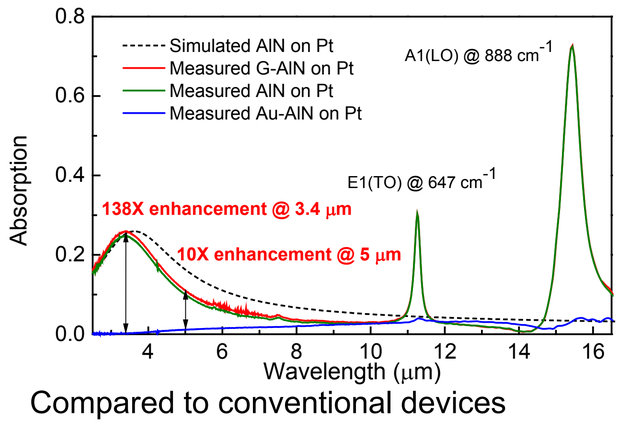
2D material-coupled NEMS IR detectors

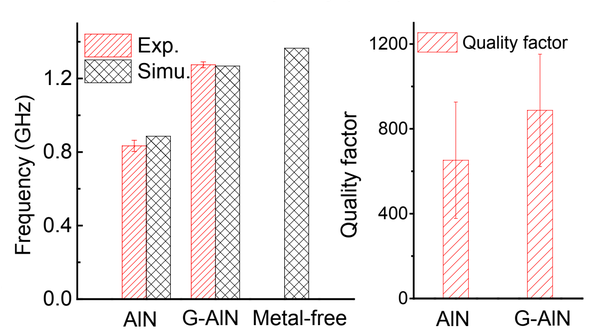




For the first time, a virtually massless and high electrical conductivity graphene layer, floating at the van der Waals separation of a few angstroms from a piezoelectric nano-plate (zero interfacial strain) was employed as top floating electrode to confine the excitation field across the thickness of the piezoelectric layer.







Compared to conventional devices employing 100nm Au electrodes, graphene devices achieved:

- Improved electromechanical performance: 2X improved *f·Q*
- Enhanced IR detection capabilities: Theoretically, 138X improved IR absorptance @ 3.4µm Experimentally, 12X improved IR responsivity @ 5µm