

Adaptive Focal Plane Array - A Compact Spectral Imaging Sensor

William Gunning

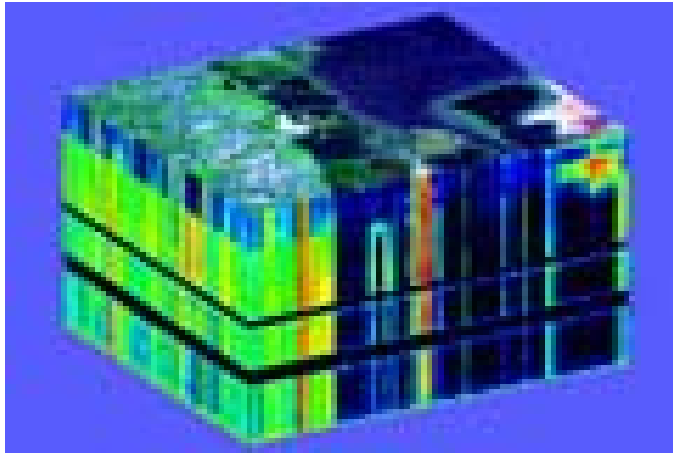
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Motivation for LWIR / MWIR Adaptive FPA



- Conventional hyperspectral imaging systems
 - Large and Heavy
 - Generate large volumes of data
 - Typically scanning systems
- Conventional multispectral imaging systems
 - Fixed detection wavelengths limit capability

AFPA Objective: Develop a compact spectral imaging sensor to enable enhanced target detection / ID in a device that can be deployed on SWAP-constrained platforms and provide real time information

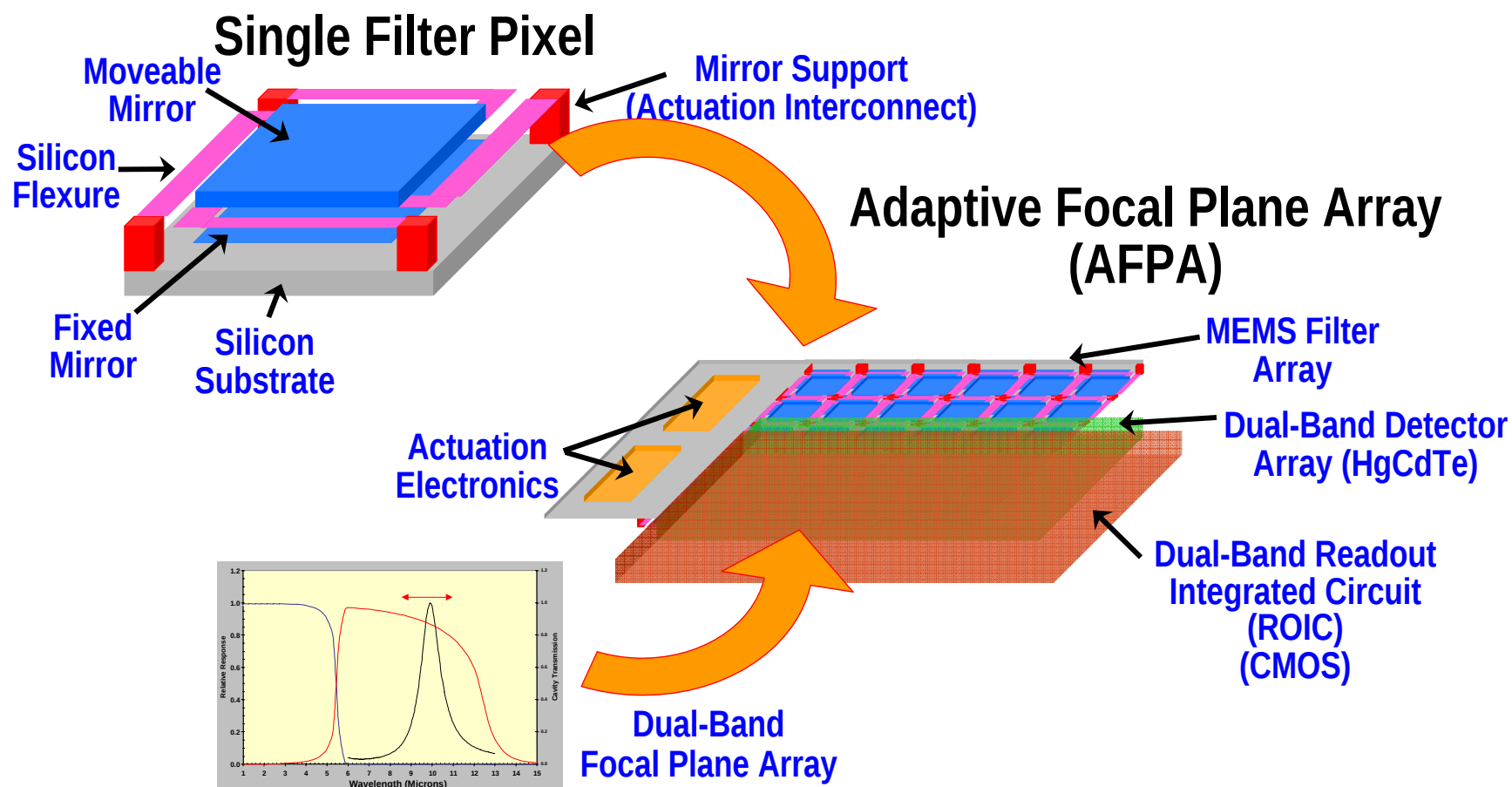
- Wavelength tuned LWIR (8 – 11 μm / $\Delta\lambda$ FWHM ~ 100 nm)
- Simultaneous pixel-registered broadband MWIR (3 – 5 μm)
- Spatially resolved, intelligent spectral analysis

AFPA Parameter Objectives

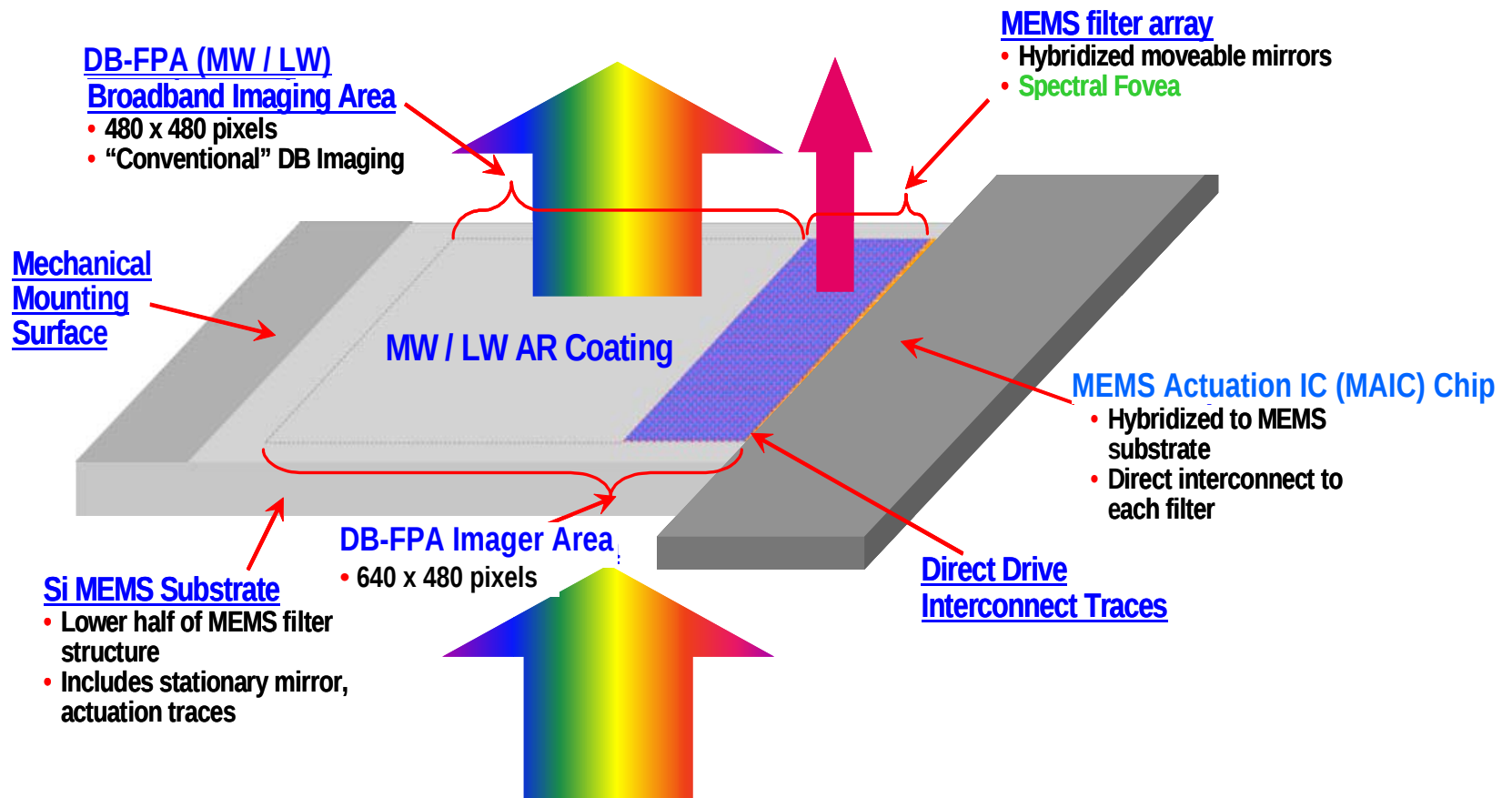


- MEMS tunable filter array integrated with a dual-band focal plane array
- Parameters:
 - Tuning range (individual filters or checkerboard): $8.0\ \mu\text{m} \Rightarrow 11.0\ \mu\text{m}$
 - Filter bandwidth (FWHM): $100\ \text{nm} \pm 20\ \text{nm} @ 10.0\ \mu\text{m}$
 - MWIR detection band: $\sim 3.5 - 5\ \mu\text{m}$ (nominal)
 - Filter dimension: $\sim 400\ \mu\text{m}$ center-to-center spacing
 - Filter optical fill factor: $\geq 50\%$
 - FPA/ROIC: $640 \times 480\ 20\ \mu\text{m}$ DB-FPA
 - Filter format: Spectral fovea (nominally 8×24 filters)
 - Operating temperature: $\sim 80\text{K}$
 - Filter tuning speed: $\sim 1\ \text{msec}$

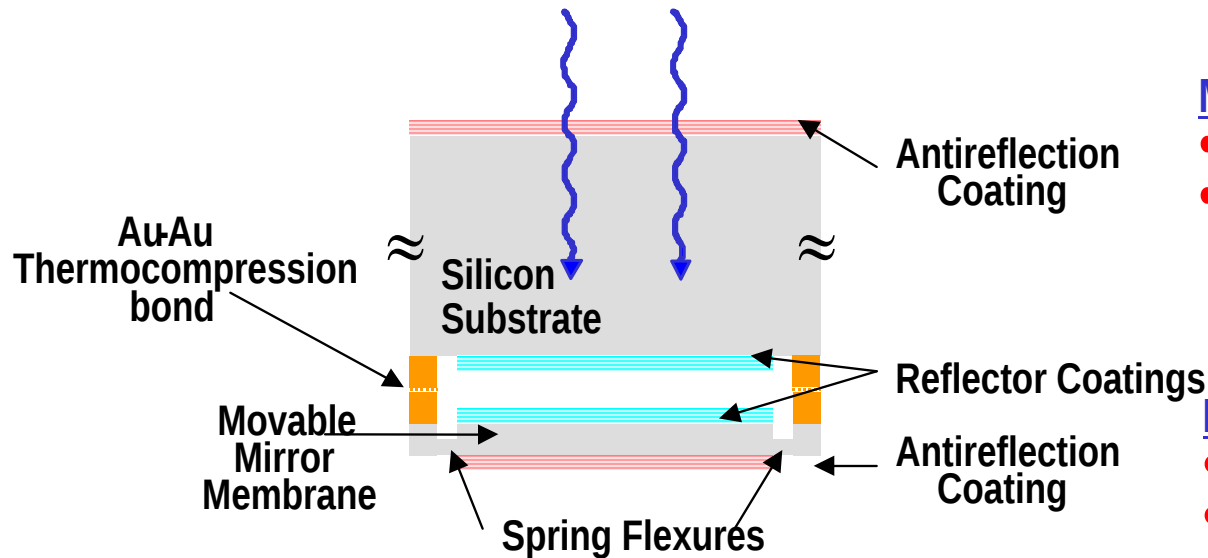
TS&I MEMS Filter / AFPA Architecture (Notional)



AFPA Phase II MEMS Tunable Filter Array



MEMS Fabry-Perot Filter Design



MEMS structure

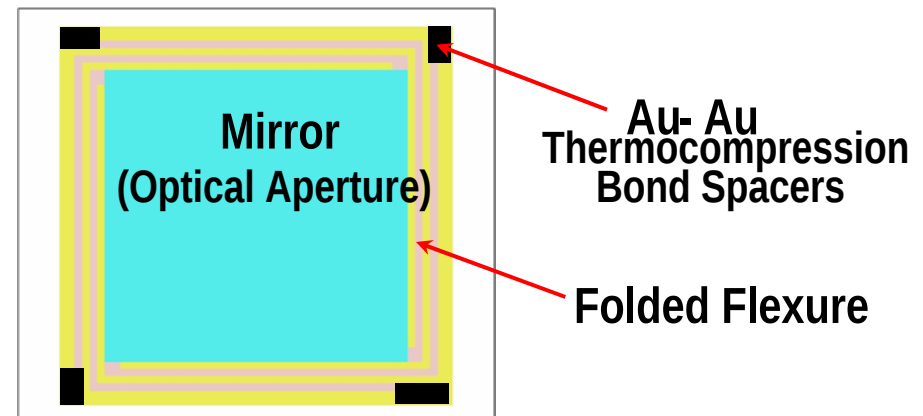
- Bulk micromachining
- Hybrid assembly using Au-Au thermocompression bond

Filter characteristics

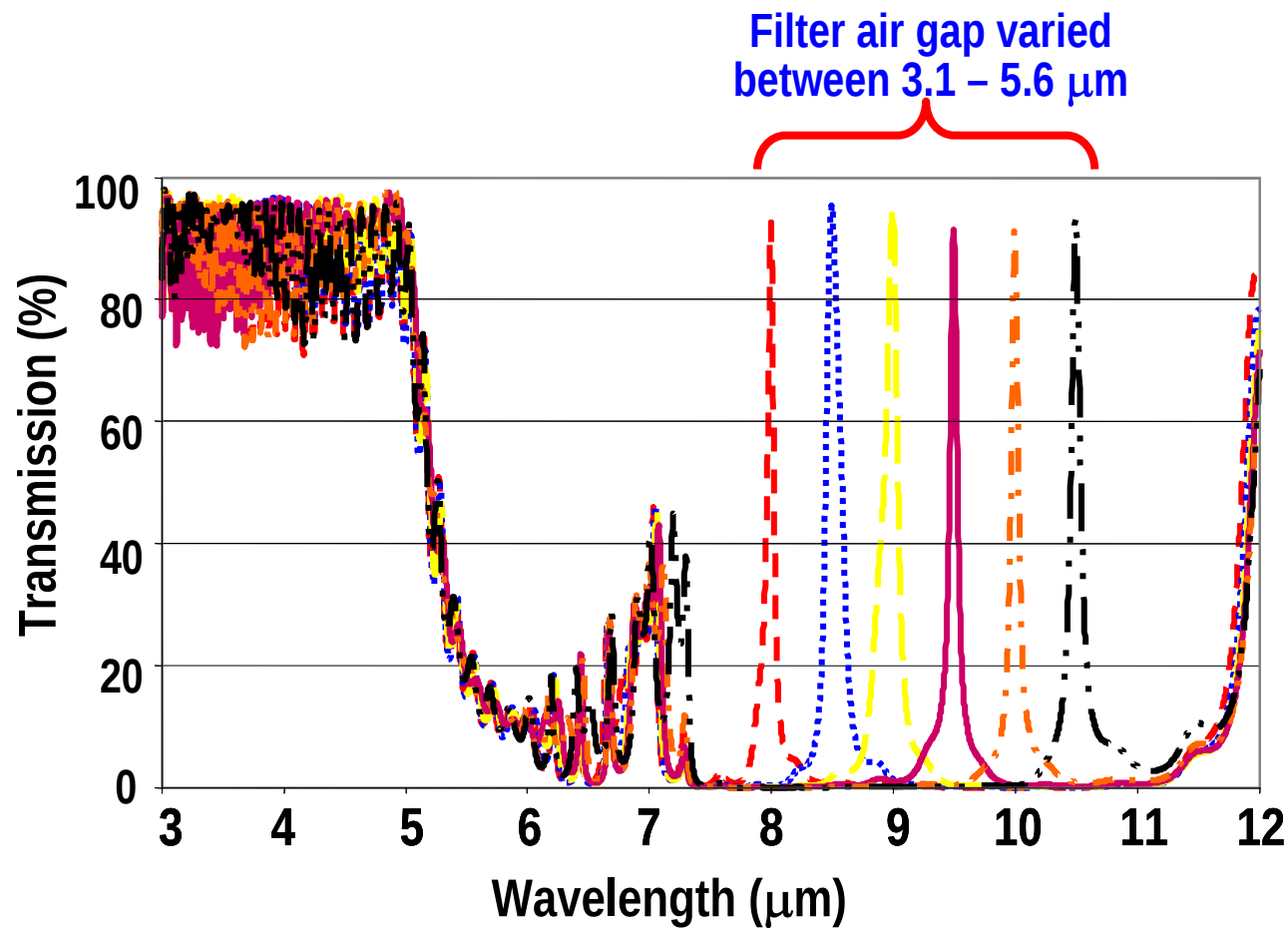
- Fabry-Perot filter design
- Tuning band determined by reflection band of dielectric mirrors

Filter Actuation

- Filter actuated by applying potential between moveable mirror and substrate mirror
- Displacement driven by electrostatic attraction
- Restoring force provided by Si flexure springs
- Prototype devices - direct drive



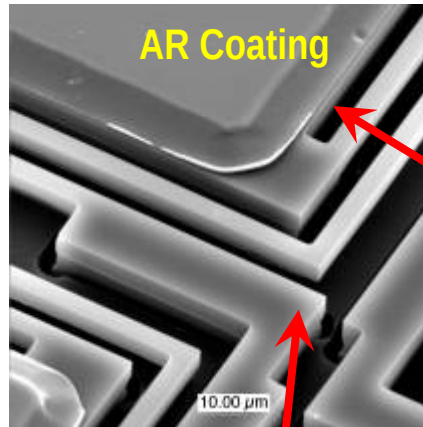
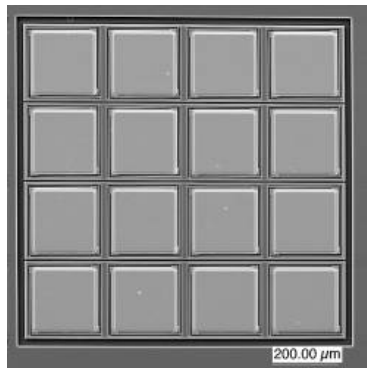
Modeled MWIR / LWIR Spectral Performance (Transmission Averaged over F/6.5 Incident cone)



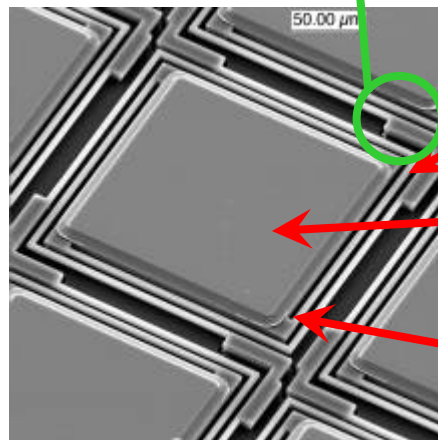
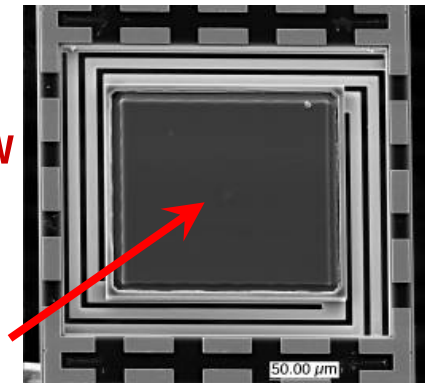
MEMS Filter SEM Images



Top View

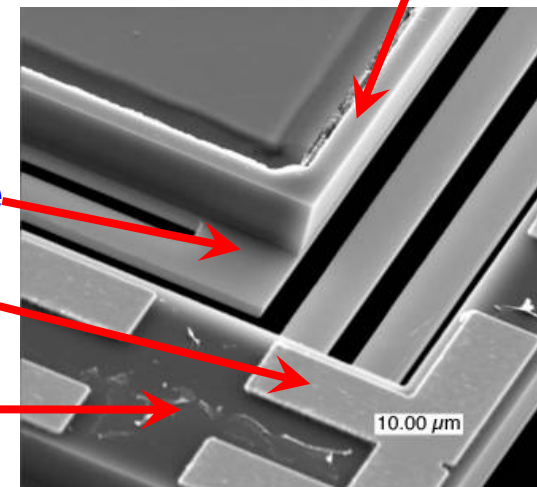


Bottom View



Thinned Flexure

Au Bonding Pads
Mechanical Support

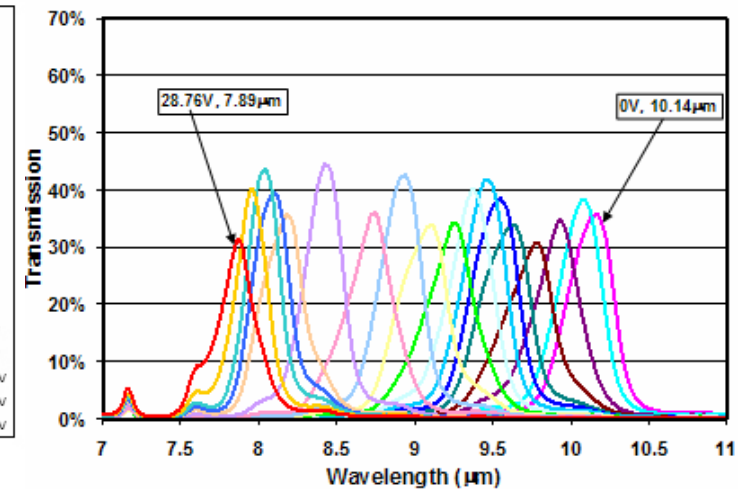
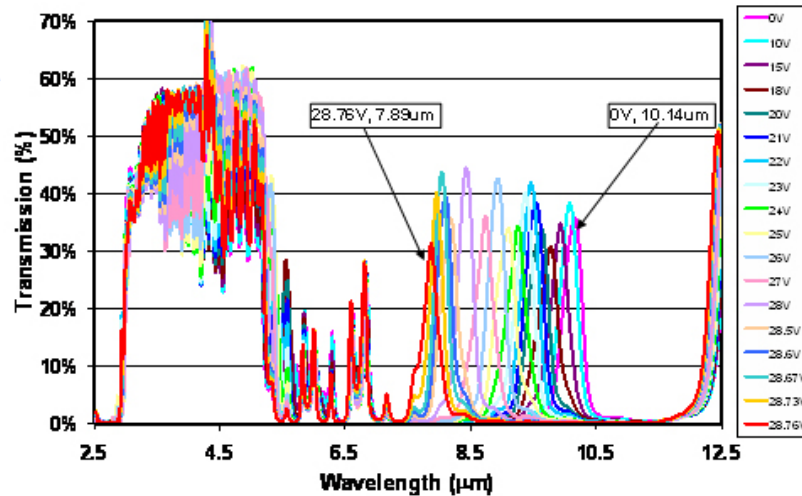


MEMS Tunable Filter

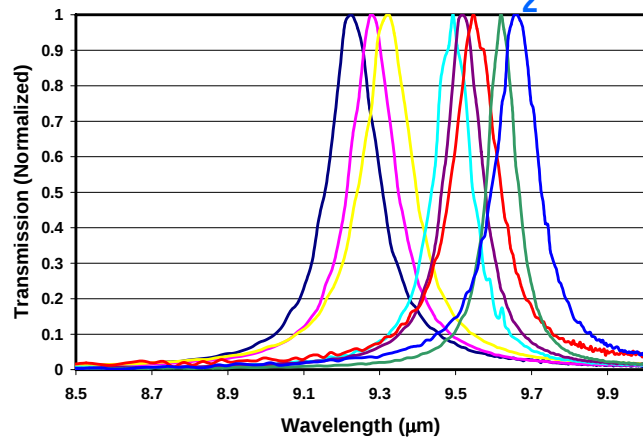
Measured Optical Performance



IR Microscope Transmission

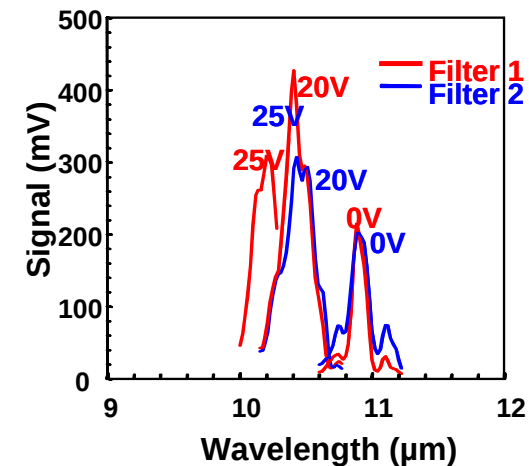


Scanned Filter Transmission of Tunable CO₂ laser



CO ₂ Laser Wavelength (μm)	Filter Bandwidth (nm FWHM)
9.23	144
9.28	138
9.32	145
9.49	108
9.52	112
9.55	145
9.62	90
9.66	129

LWIR Detector Spectral Response with Tunable MEMS Filter

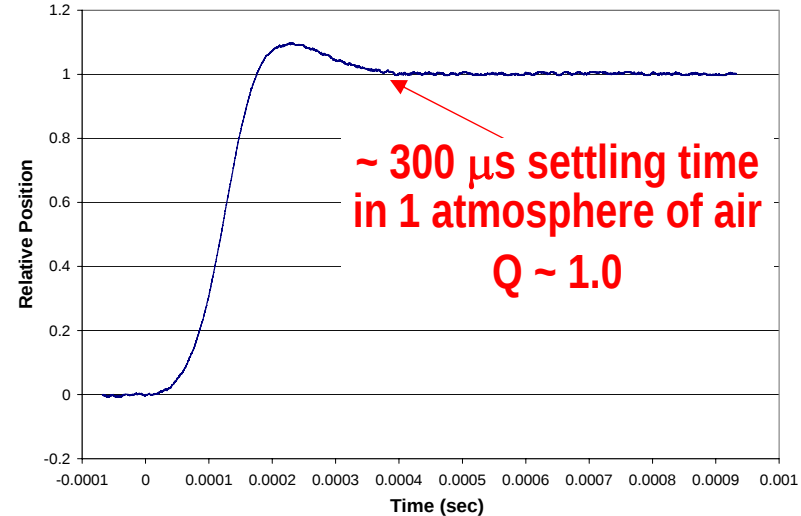
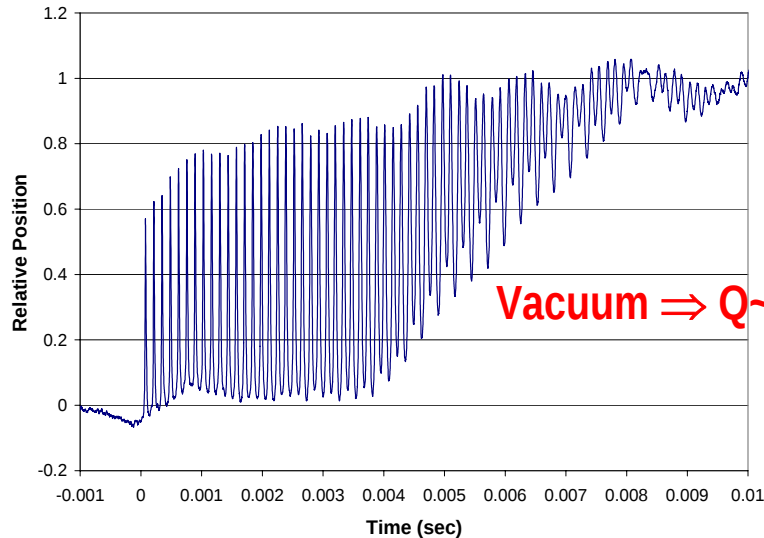


Tunable MEMS Filter Mechanical Response



- Low energy dissipation in Si MEMS structure leads to mechanical “ringing” under vacuum operation
 - 300 μ s in air, but may be >10’s (or even 1000’s) msec in vacuum
- Exploit gas damping for increased response speed
 - Requires sealed, backfilled package
 - Neon gas provides necessary viscosity for 77K operation

MEMS Filter Response to Voltage Actuation Step

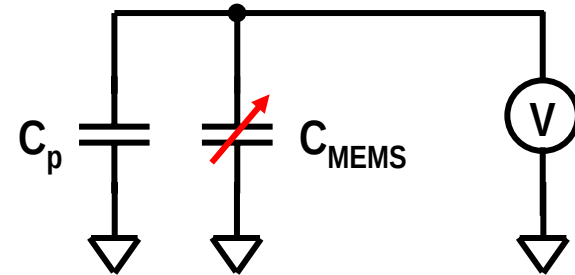
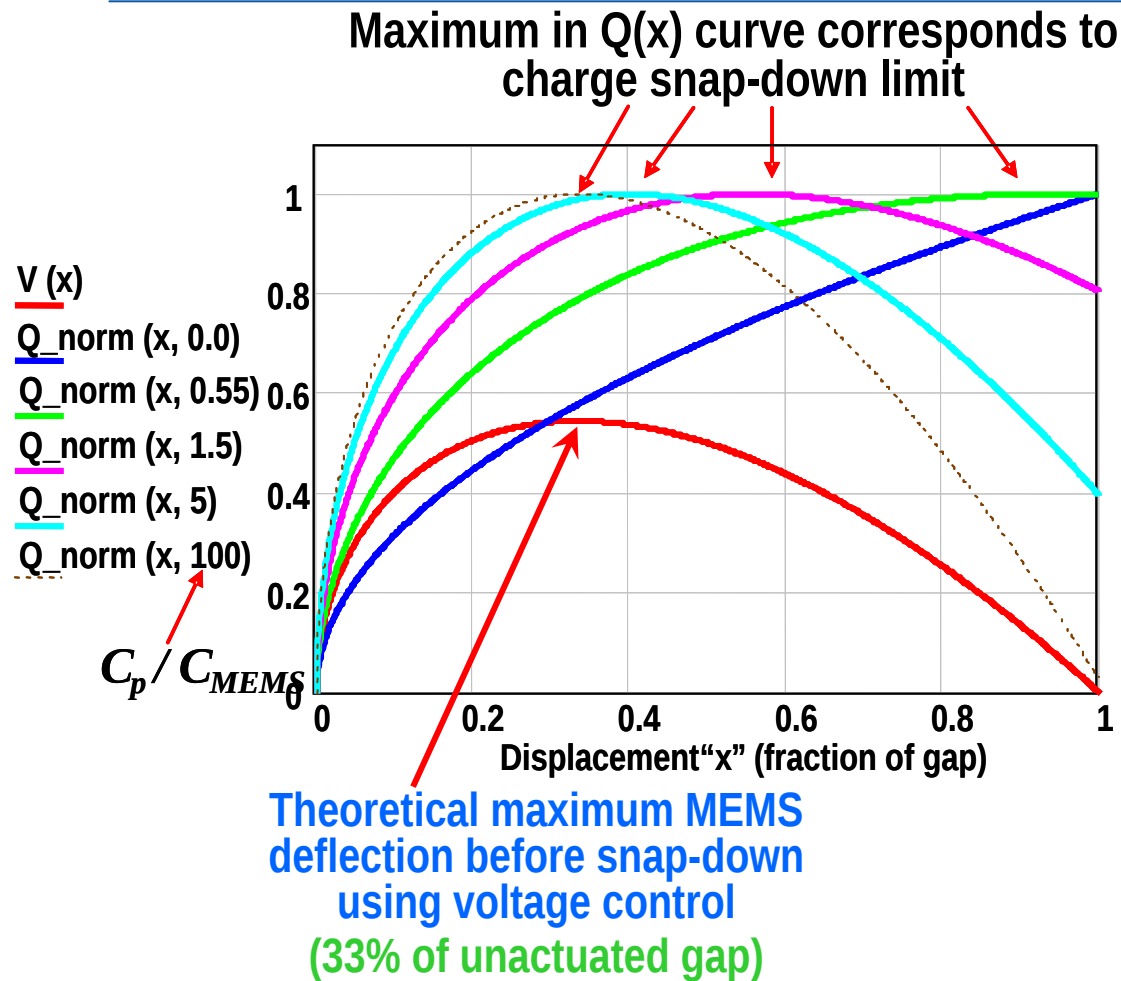


AFPA Phase II Imaging Device Objectives



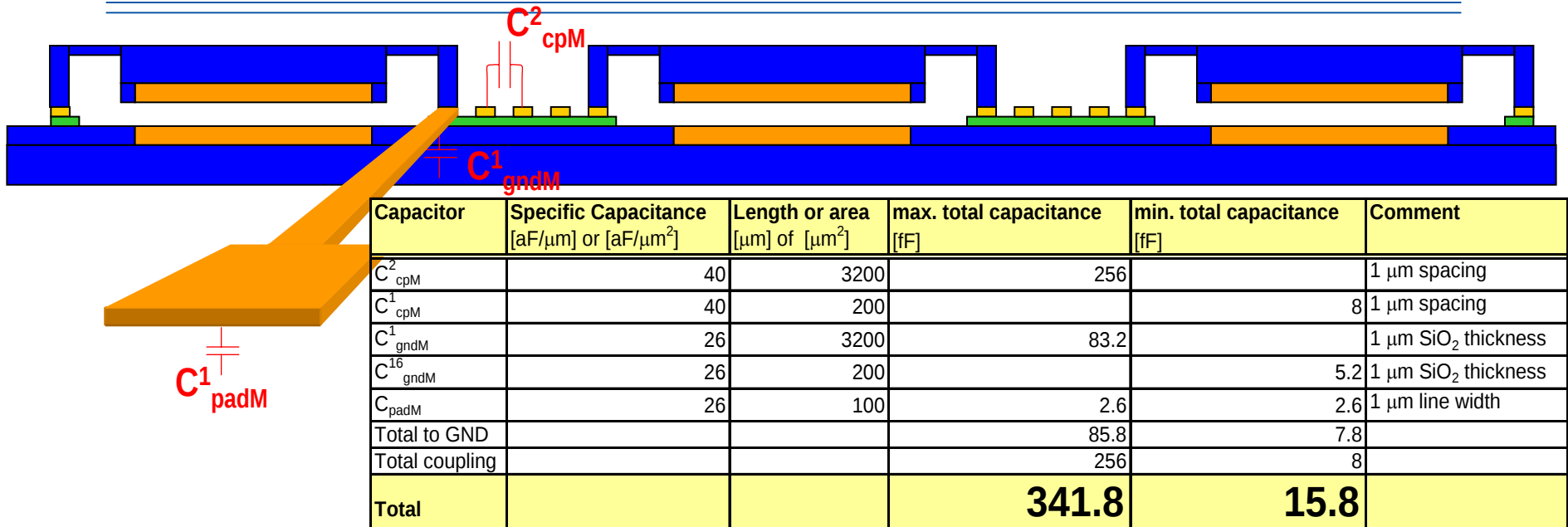
- **Demonstrate full capability MEMS filter array**
 - Individual, independent filter tunability
 - Extended tuning range: 8.0 – 11.0 μm
 - Narrower bandwidth: 100 nm $\pm$ 20 nm @ 10.0 μm
 - Design and implement CMOS MEMS Actuation IC (MAIC) for full array actuation
- **Demonstrate prototype AFPA sensor**
 - Imaging structure with tunable MEMS array coupled with dual-band FPA
 - Demonstrate spectral tunability in an imaging array
 - Spectral Fovea configuration
- **Technical challenges**
 - Overcome tuning limit imposed by MEMS snap-down phenomenon
 - Optimized optical filter design
 - Implement negative capacitance MEMS actuation to overcome parasitic
 - Provide viscous MEMS damping
 - Heterogeneous technology integration in an integrated optimal subsystem
 - Tunable MEMS filter array coupled to DB-FPA in a compact, gas-filled, optical, cryo-enclosure

MEMS Actuation and Snap-down



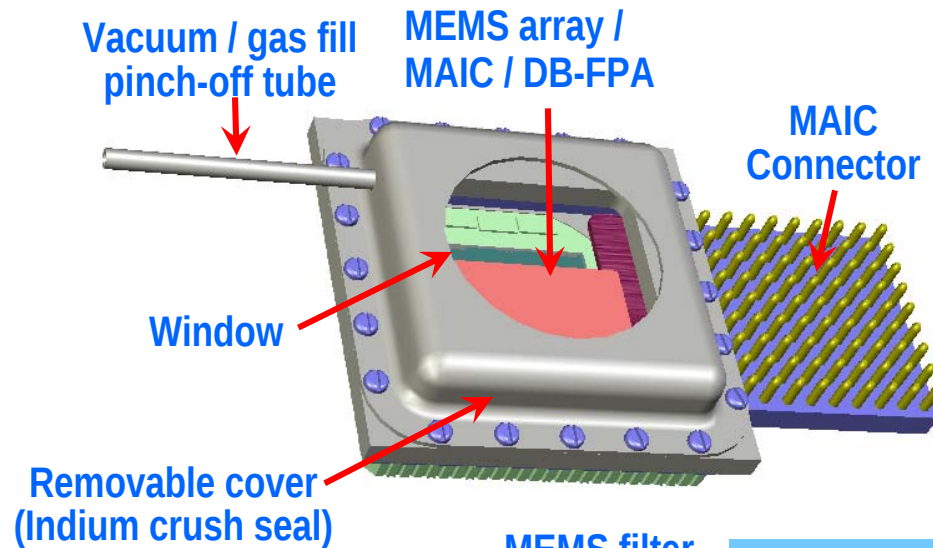
- Charge control enables tuning beyond snap-down
- Limited by parasitic capacitance between driver and MEMS device
- Negative capacitance circuit can overcome C_p
- Requires low MEMS Q to prevent oscillation past stable point
- Optimize optical coatings to maximize tuning slope / minimize demands on $-C_p$ tuning

Primary Sources of Parasitic Capacitance



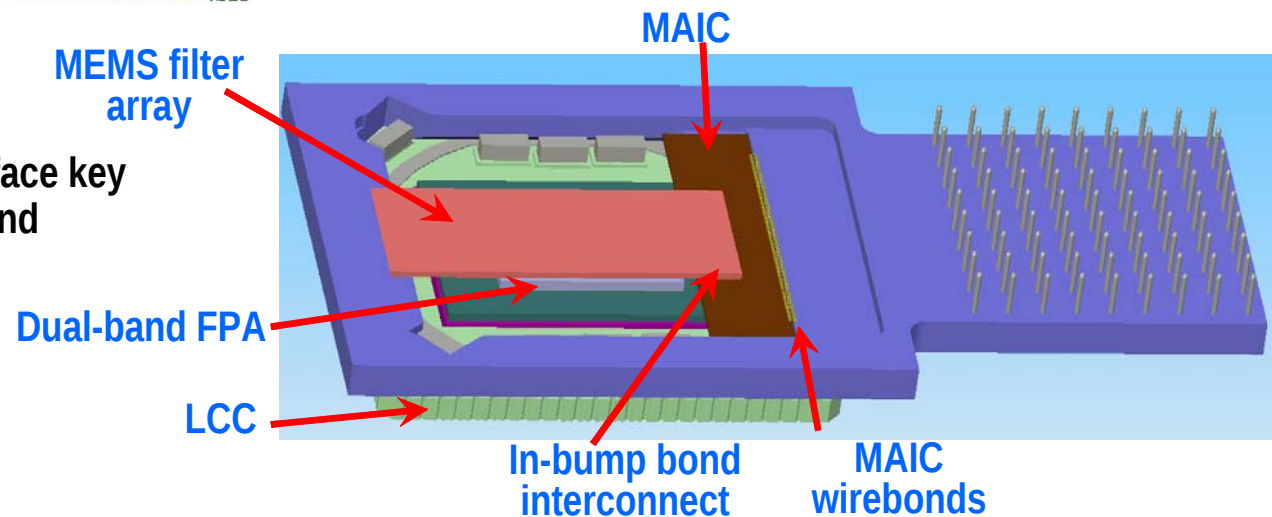
- Parasitic Capacitance dominated by coupling capacitance
 - Values depend position inside filter array
 - Largest parasitic cap determines tuning range for entire array
- MAIC will add similar capacitance
- Negative capacitance actuation circuit under development to overcome C_p limited snap-down

Integrated AFPA Assembly (Conceptual)



- Gas filled enclosure enables viscous gas damping of MEMS filters
- Resealable cover enables reuse and testing of MEMS filter array component

- MAIC / MEMS array interface key to achieving tuning beyond snap-down



Planned AFPA Prototype Demonstration



Lab bench level testing planned using prototype AFPA sensor

- **Demonstration of LWIR spectral response tunability**
 - Independent filter actuation
- **Demonstration of spectral analysis capability**
 - Synthetic input spectra (filtered illumination)
 - Target materials of military interest
- **Demonstration of spectral imaging of scene (lab)**
- **Demonstration of simultaneous LWIR tuning / broadband MWIR imaging**
- **Future development of field-testable camera with integrated optimal spectral interrogation and analysis algorithms**

Summary



- **Phase I - LWIR tunable MEMS filter capability demonstrated**
 - Tuning range 8.0 – 10.0 μm
 - Filter bandwidth 90 – 150 nm
 - Tuning speed ~ 1 msec
 - Simultaneous broadband MWIR transmission
 - Filters as small as 280 x 280 μm
- **Phase II - Integrated dual-band AFPA sensor configuration established**
 - Spectral fovea configuration
 - Wide tuning range (8.0 – 11.0 μm) achievable using novel actuation and optimized optical design
 - Independent filter tunability
 - Sensor package combining MEMS array, CMOS MAIC, Dual-band FPA with mechanical MEMS damping
 - Optical configuration requires minimal optical imaging sensor modifications



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