Mind the Gap/UVSTIG
AAS Winter 2024 Splinter Session
January 9, 2024

Detectors for UV/Visible Spectroscopy

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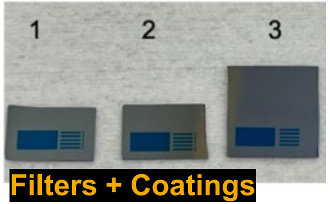
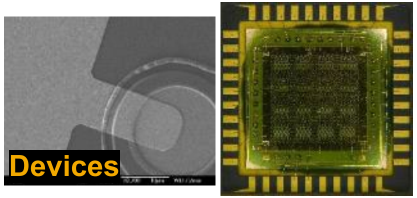
Jet Propulsion Laboratory
California Institute of Technology

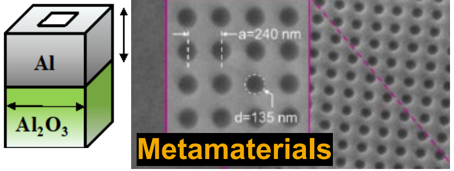
Ultraviolet Technologies, Instrumentation, and Missions

TRL 1-3

Research & Technology Development;
Process Development

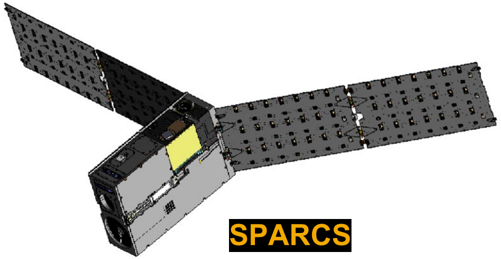






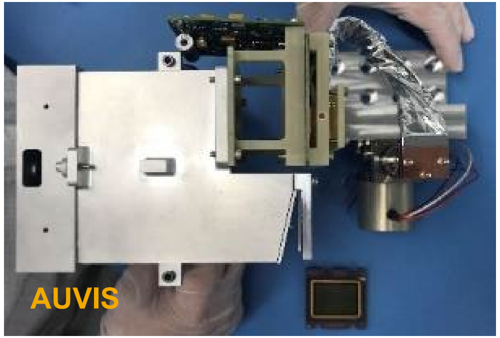
TRL 7-9

CubeSat Missions
SmallSat Mission



TRL 4-6

Instrumentation
Suborbital Missions
Commercial Collaborations



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Future

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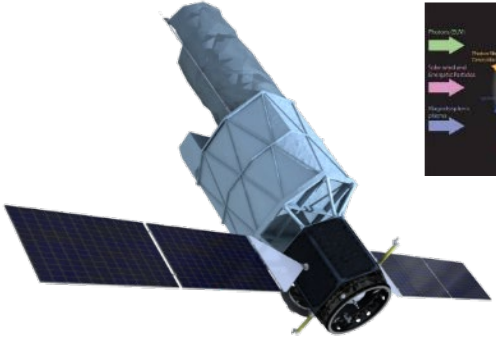
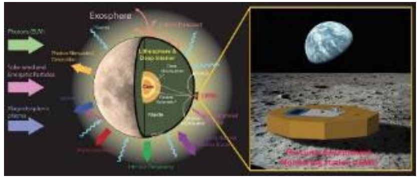
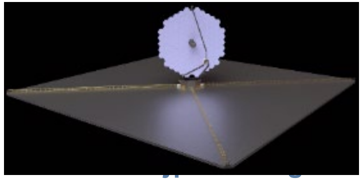
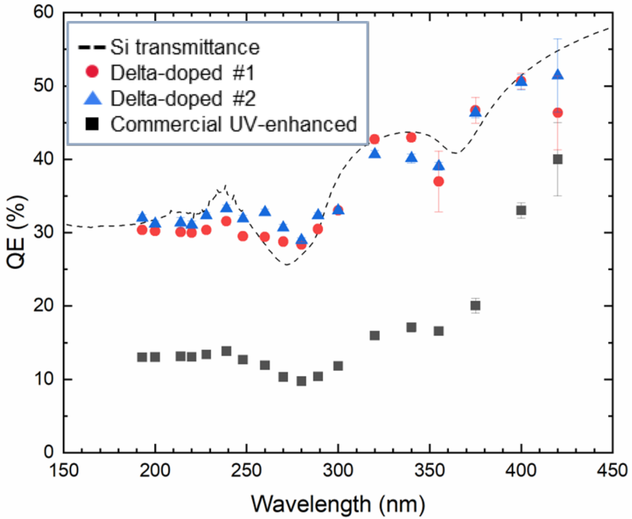
Next Generation Flagship Missions



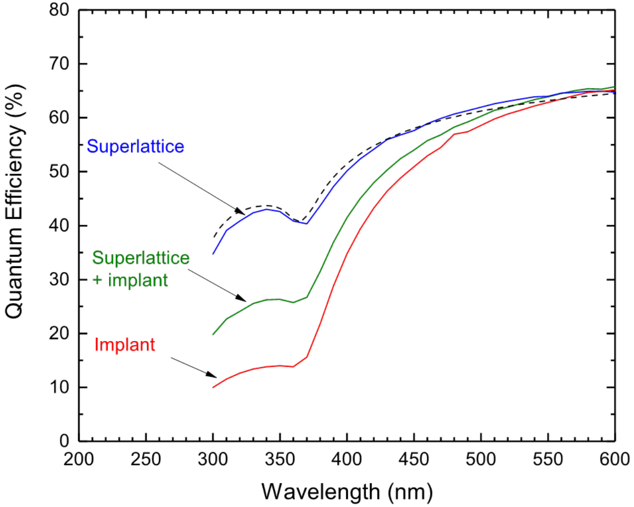




Delta-doped Silicon UV/Visible Detectors at JPL

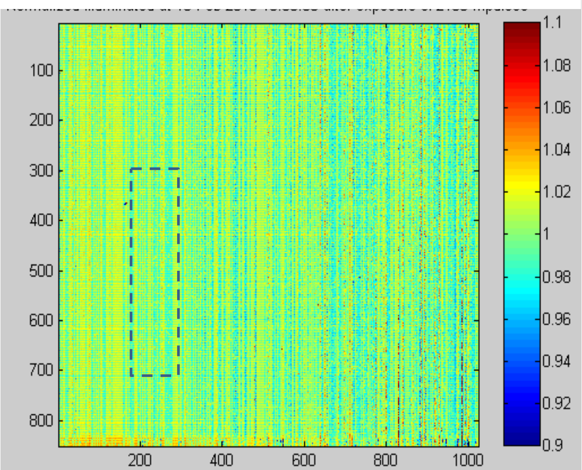


JPL's delta-doped Si detectors exhibit near 100% internal QE for reflection-limited response



Passivation by delta doping mitigates losses related to surface/interface defects and avoids the creation of bulk defects associated with the commonly used ion-implantation process

Normalized spatial response following 2.1 billion saturating laser pulses at 193nm



In lifetime tests, delta-doped detectors exhibited response stability against surface damage caused by high-energy radiation

Hoenk et al., *Proc. SPIE*. **9154** (2014)
Hoenk et al., *Proc SPIE* **12191** (2022)
Looker et al., *Nuclear Inst. and Methods A* **916** (2019) 148

Atomic Layer Deposition for UV Antireflection Coatings

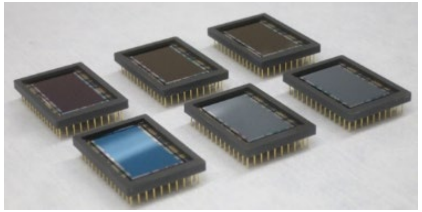
Detector response is tailored/optimized for specific applications with AR coatings

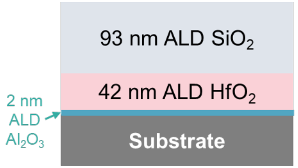
Our group was among the first to utilize ALD for UV/optical film preparation recognizing distinct advantages:

- Nanometer-scale control of film thickness
- Films are conformal and uniform
- Interfaces are sharp/well-defined

Delta-doped detectors with simple, single layer AR coatings achieve >50% QE throughout the UV range

Band width limited by the AR coating material and the highly variable optical properties of Si in the UV



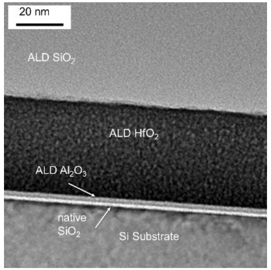


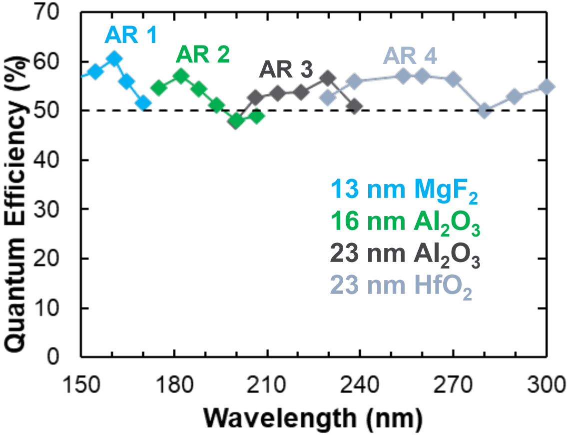
93 nm ALD SiO_2

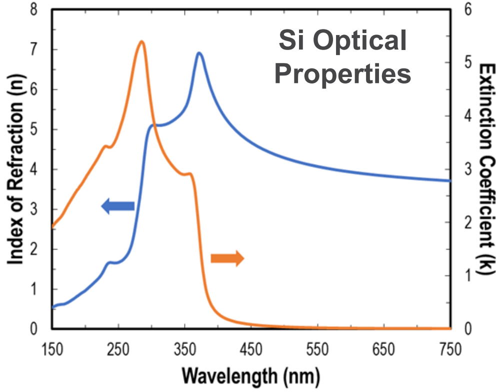
42 nm ALD HfO_2

2 nm ALD Al_2O_3

Substrate



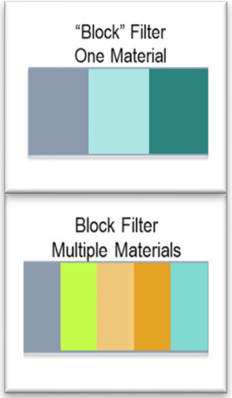


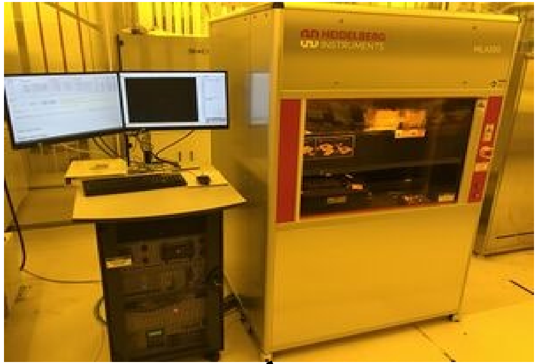


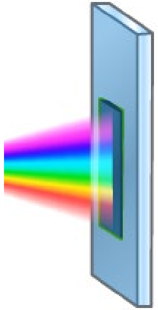
Nikzad et al., *Applied Optics*, **51**, (2012) 365
Jewell et al., *Proc SPIE* **8820** (2013) 88200Z

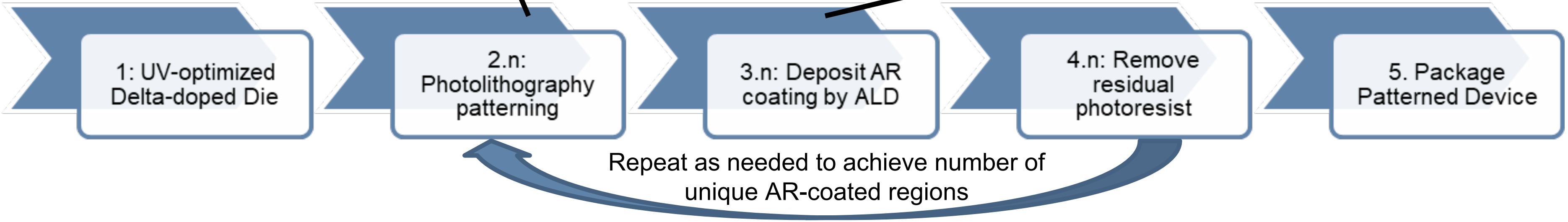
Patterned Coatings for Spectroscopy Applications

We have developed new coatings methods for preparing silicon detectors with patterned AR coatings for a spatially varying response spanning the ultraviolet (UV) and visible wavelength ranges.









1: UV-optimized Delta-doped Die

2.n: Photolithography patterning

3.n: Deposit AR coating by ALD

4.n: Remove residual photoresist

5. Package Patterned Device

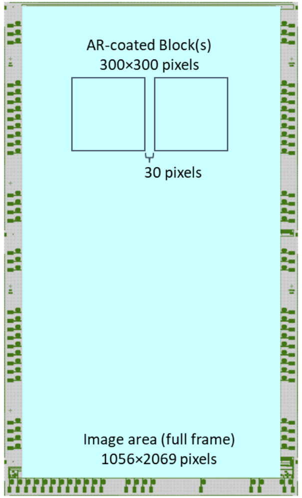
Repeat as needed to achieve number of unique AR-coated regions

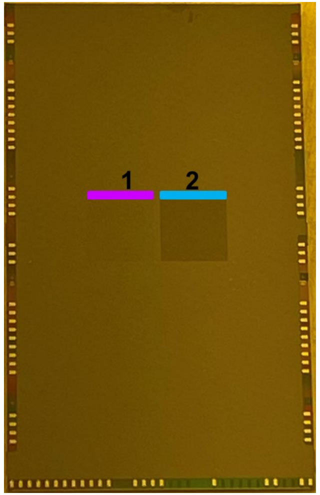
New Technology Report Number 52422; July 20, 2022

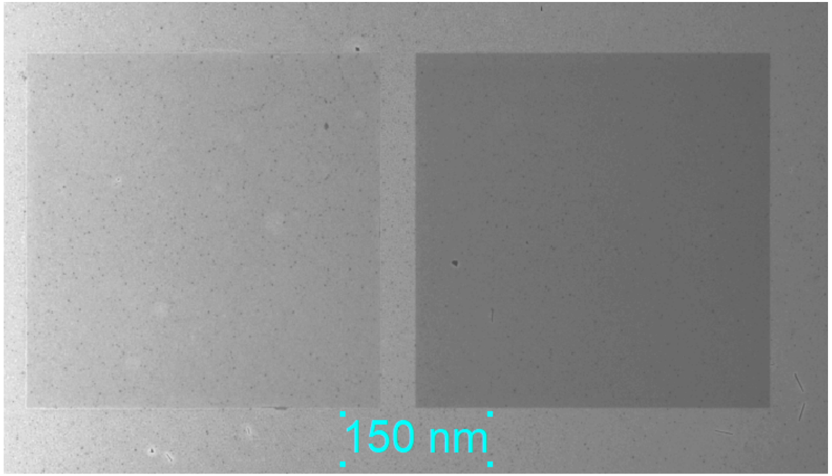
Successful Prototypes!

First Prototype

- Two regions each with a unique AR coating (two different thicknesses of Al_2O_3)
- The contrast/sensitivity of the individual AR coated regions varies as a function of wavelength
- The edges of the patterned regions look sharp/well-defined







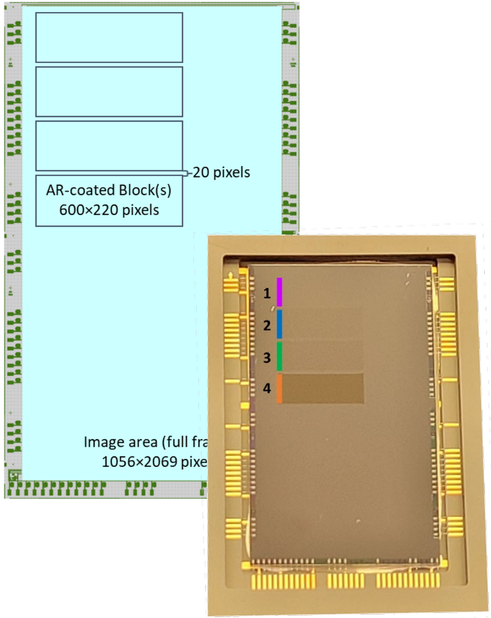
Images acquired at three illumination wavelengths spanning 150 nm to 200 nm

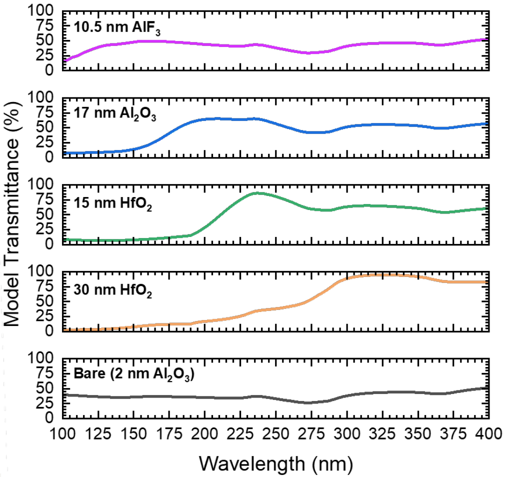
Jewell et al., *SPIE ATI* **12181**, Montreal, Quebec, Canada, July 2022

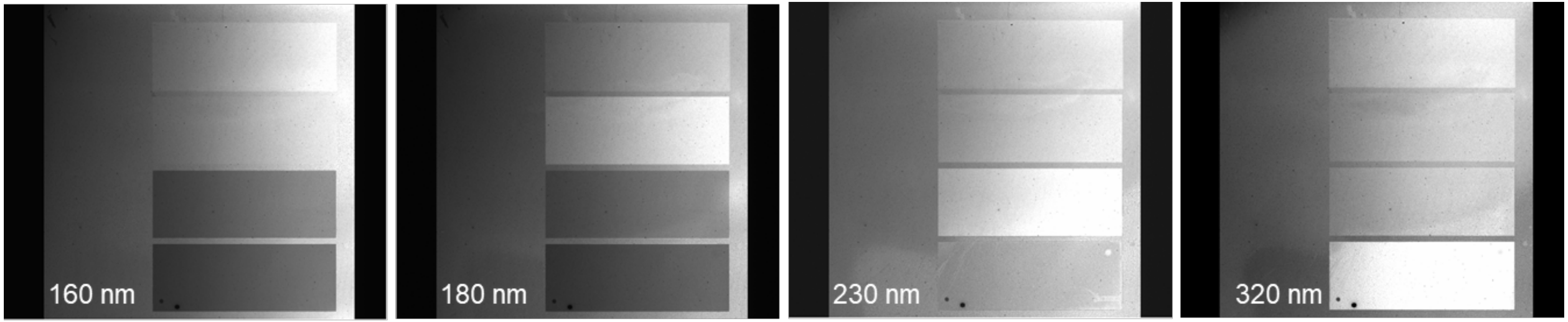
Successful Prototypes!

Second Prototype

- Four regions each with a unique AR coating
- The contrast/sensitivity of the individual AR coated regions varies as a function of wavelength
- The edges of the patterned regions look sharp/well-defined

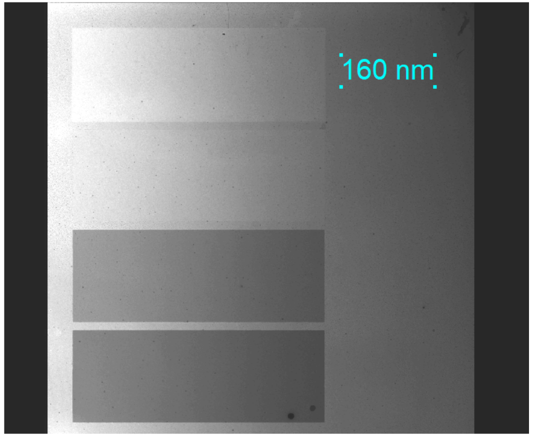






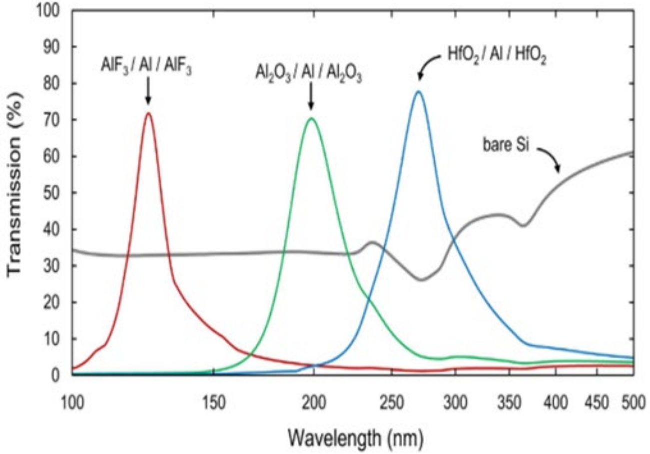
Jewell et al., *SPIE Optics + Photonics* **12678**, San Diego, CA, August 2023

Summary and Next Steps



- Successfully demonstrated butcher block style AR coatings on two prototype detectors.
- Response behavior would be ideal for spectroscopy applications where each region of the detector would be optimized to match the spectral dispersion

- Explore region separation/overlap limits and “gap penalty”
- Improve deposition methods to eliminate cosmetic defects
- Environmental/stability studies
- Implementation with UV bandpass filters (ref. John Hennessy’s presentation)



Hennessy et al., *Proc. SPIE* **10639** (2018) 106391P
Jewell et al., *SPIE Optics + Photonics* **12678**, San Diego, CA, August 2023

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Patterning

Photolithography

Advantages

- Compatible with silicon device manufacturing
- Existing tools and processes in place within the MDL facility
- Ability to control patterning at the pixel scale (5-15 μm)
- Compatible with die level and/or wafer scale processing

Lithography bay in MDL

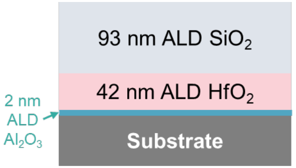
Atomic Layer Deposition for UV Coatings and Filters

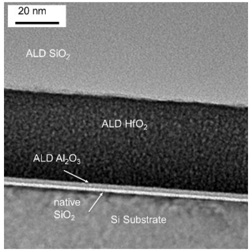
Our group was among the first to utilize ALD for UV/optical film preparation recognizing distinct advantages:

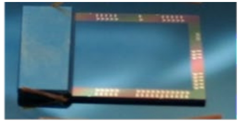
- Nanometer-scale control; ALD growth rate is measured in Å/cycle
- Films are conformal and uniform
- Interfaces are sharp/well-defined

Implementation of a patterned coating on Si presented some challenges:

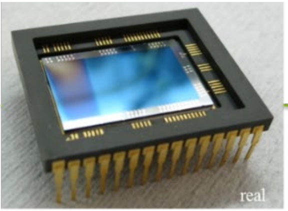
- ALD is not a line-of-site deposition technique, shadow masking not effective
- Published ALD patterning processes assumed substrate was varying, but in this case the substrate is always silicon



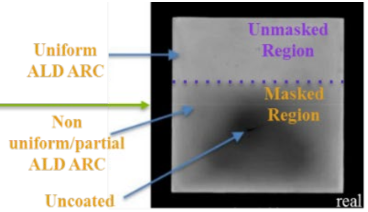




ALD growth can infiltrate even the smallest gap to coat substrates with high aspect ratio structures. Traditional physical shadow masks (shown) are not appropriate ALD blockers.



Uneven film growth occurred under the physical shadow mask. The ARC in the unmasked region is highly uniform.



The resulting UV flat field image (different device) is non uniform.

Jewell et al., *Proc SPIE* **8820** (2013) 88200Z

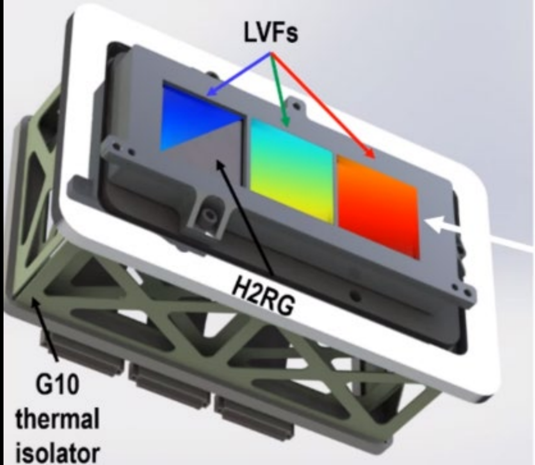
Linear Variable Filters (LVF)

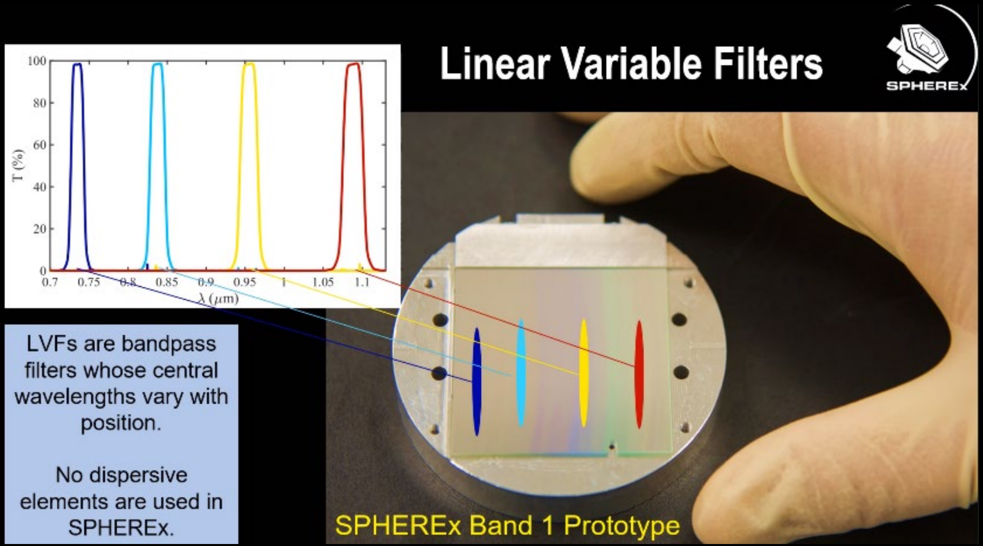
Example from the Infrared Community

SPHEREx: An All-Sky Spectral Survey

The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer Mission

- Four focal planes each with an LVF mounted directly over the detectors (100 μm separation)
- Slew telescope in dispersion direction to build spectra
- Optical and near-infrared wavelengths: bandpass filters with ~100% T





LVFs are bandpass filters whose central wavelengths vary with position.

No dispersive elements are used in SPHEREx.

Crill et al., *Proc. SPIE* **11443** (2020) 114430I