PRIMA The PRobe far-Infrared Mission for Astrophysics

Kilopixel Silicon Microlens Arrays for PRIMA Detector Arrays

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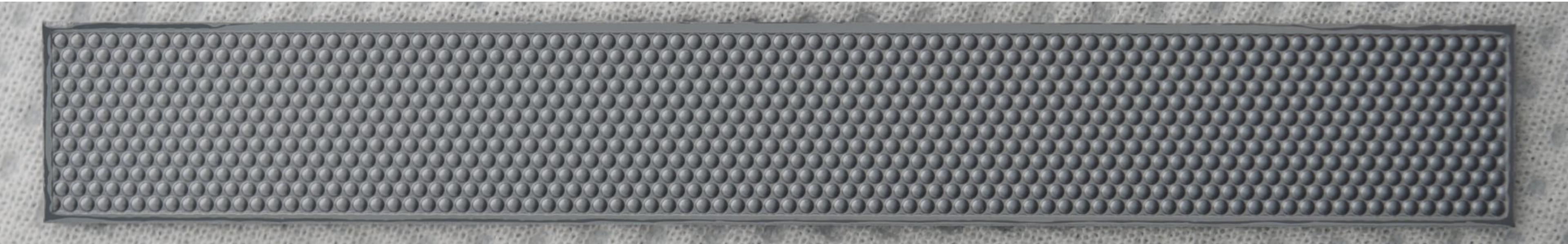
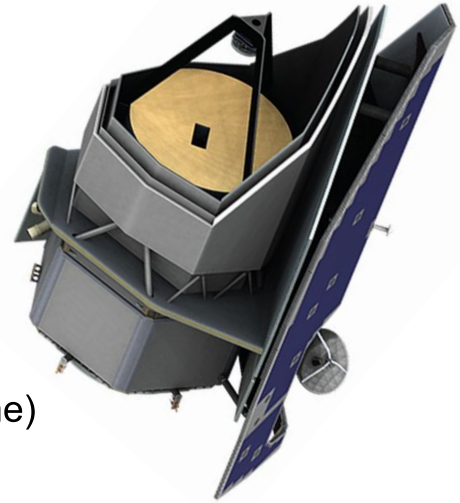


The Probe far-Infrared Mission for Astrophysics

- PRIMA Science
  - AGN Feedback, interstellar medium physics in galaxies
  - Evolution of stars, black holes, heavy elements, dust

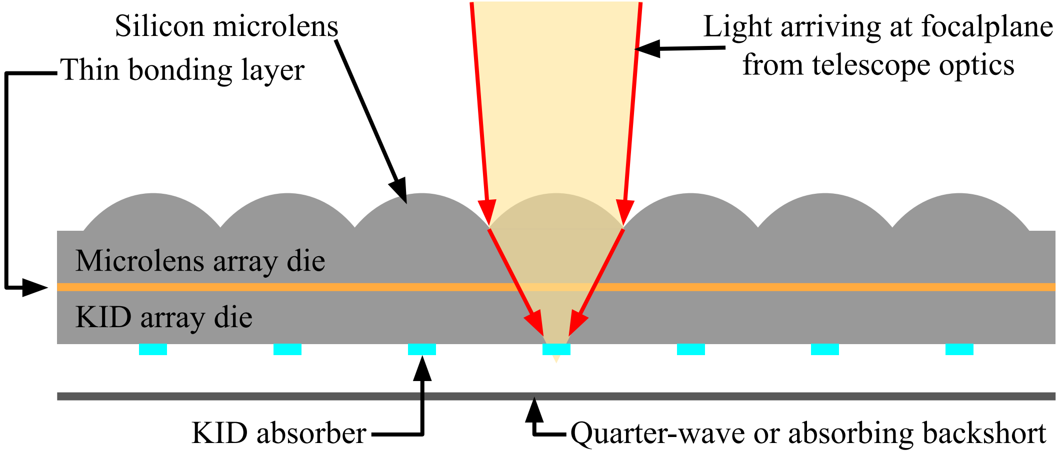
- PRIMA Observatory
  - 1.8-meter 4.5-Kelvin telescope, λ ~ 24 – 261 μm
  - Imager and spectrometer modules
    - PRIMAger and FIRESS
  - Many kilopixel arrays of kinetic inductance detectors
    - (See presentations by Logan Foote, Chris Albert, Elijah Kane)
  - RFSOC Readout
    - (See presentation by Sumit Dahal / Tom Essinger-Hileman)
  - Silicon microlens arrays
    - This talk

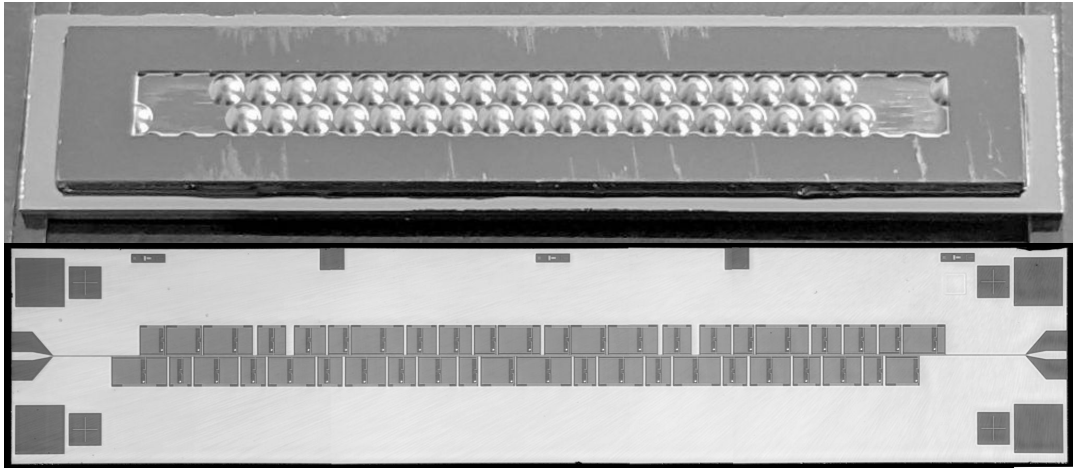


Microlens coupled Kinetic Inductance Detectors

- Detector-telescope optical coupling
  - Detector absorbers smaller than pixels
  - 900 µm pitch hexagonally packed pixels
  - 105 µm diameter light-absorbing area
  - Must concentrate light onto absorbers

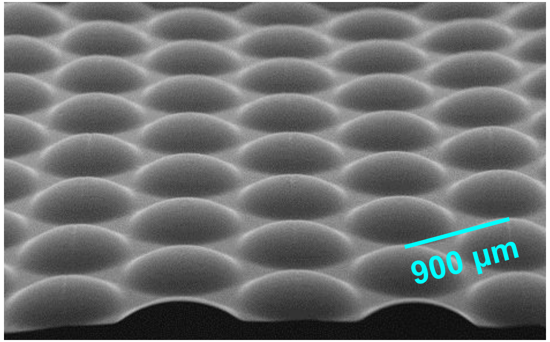
- Monolithic silicon microlens arrays
  - One microlens for each pixel
  - Fabricated separately from detectors
  - Dies aligned and epoxy bonded

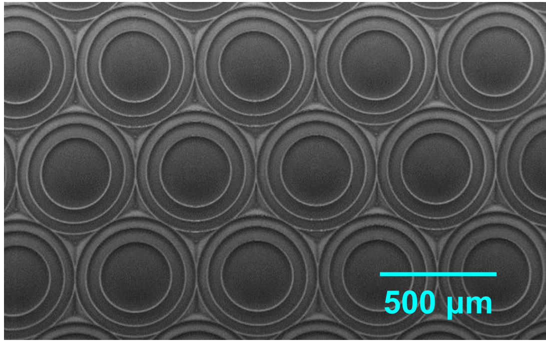


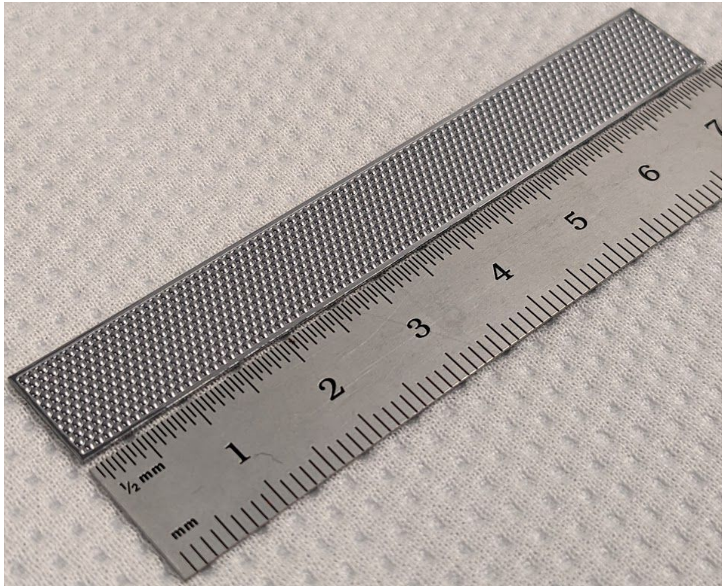


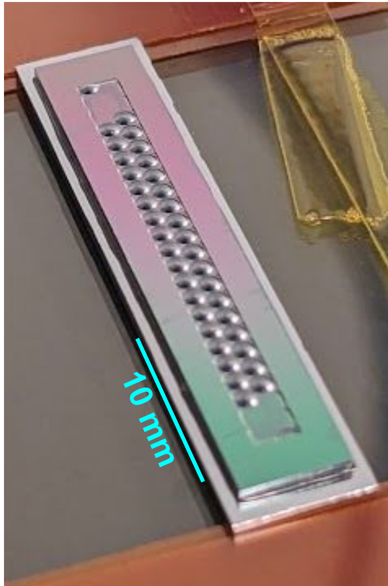
Microlens Fabrication

- Grayscale Lithography
  - Direct-write laser exposure
  - Discretized laser intensity
  - Develop into 3D resist profiles
- Deep reactive ion etching
  - Transfer resist profile into silicon
  - Tune etch selectivity to control depth
- Antireflection coatings
  - Quarter wavelength Parylene-C
  - Cryogenically robust
- Product arrays
  - Kilopixel and small-format
  - Full-sag and Fresnel design





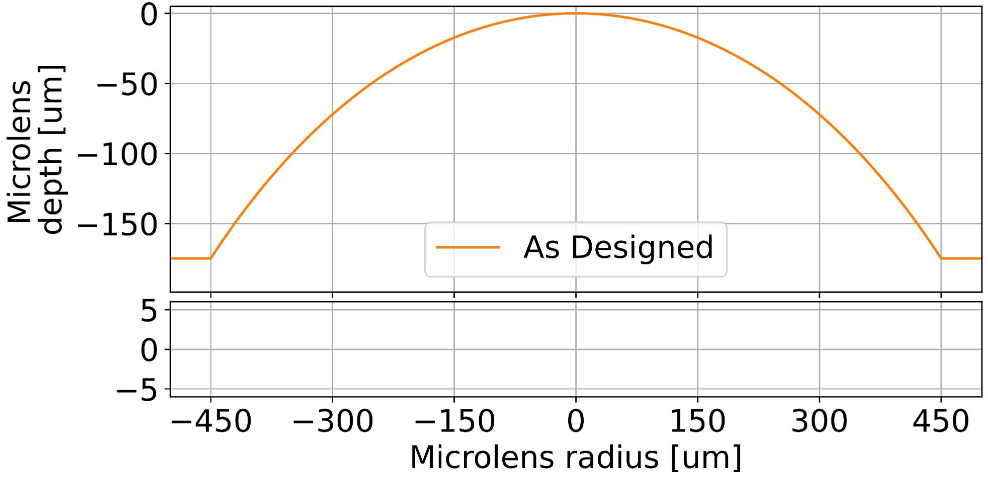


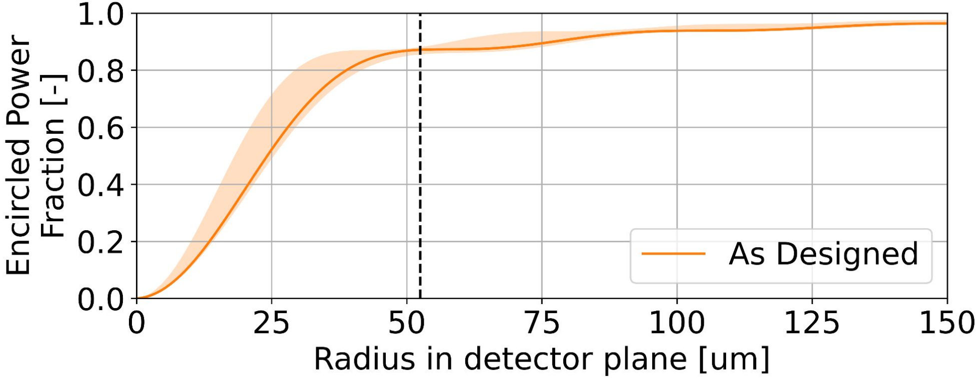


Designed lens profile

- Elliptical lens design
  - Intentionally defocus to uniformly illuminate absorber

- PRIMA FIRESS 135 – 210 μm band
  - Target total sag ~ 175 μm
  - Target f-number ~ 4.5
  - 900 μm lens diameter
  - 105 μm absorber diameter
  - Expected encircled power fraction 87%

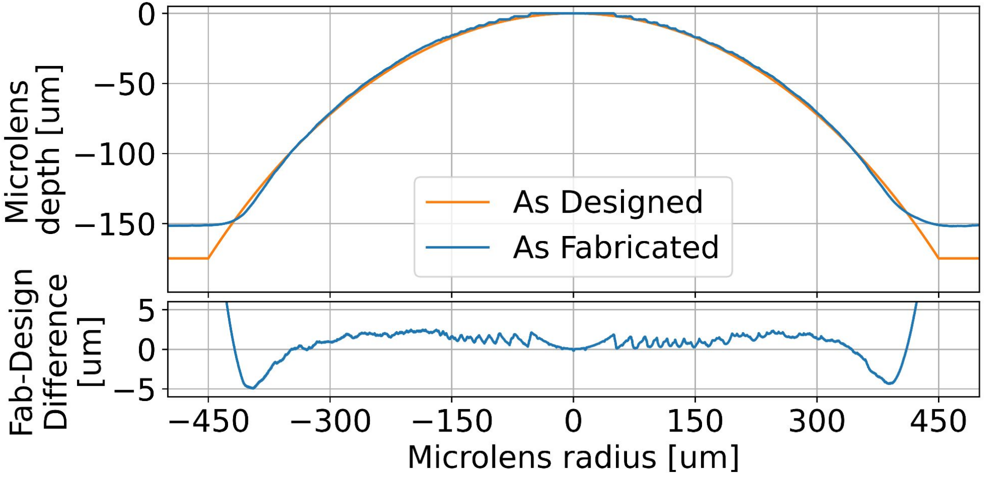


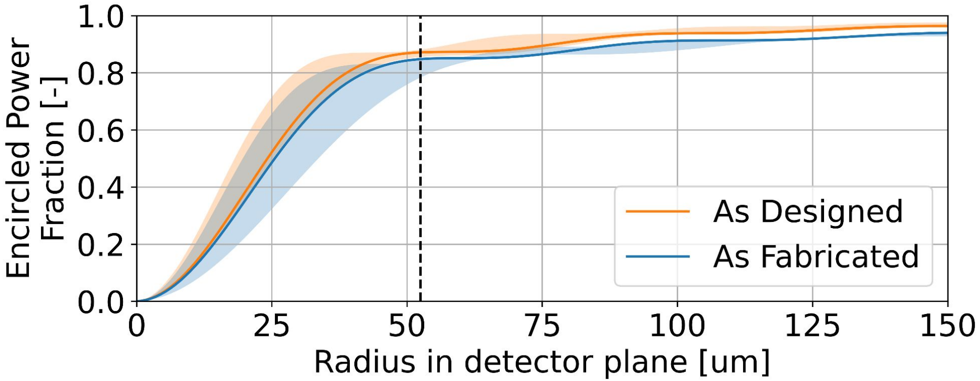


Fabricated lens profile

- Fabricated profile
  - Closely matches design
  - Micron-level deviation from design out to ~350 μm radius
  - Surface roughness dominated by grayscale lithography steps
  - Achieved sag ~150 μm

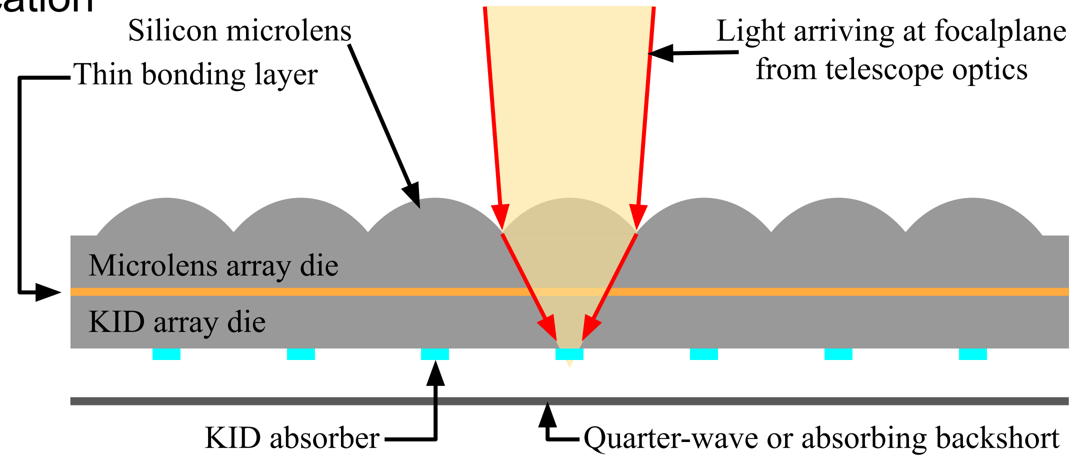
- Calculated encircled power fraction
  - Design: 87%
  - Fabricated: 85%

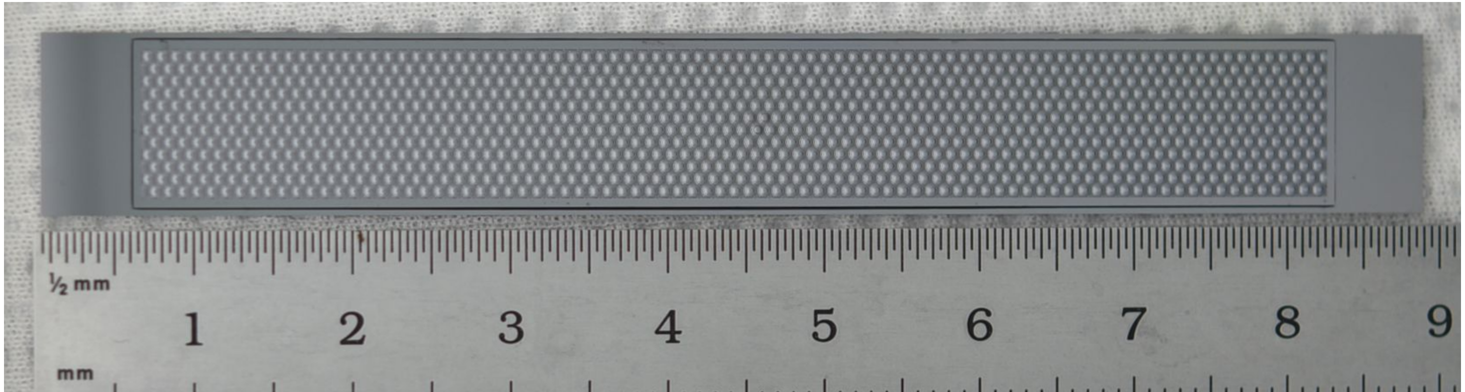




Microlens-Detector Hybridization

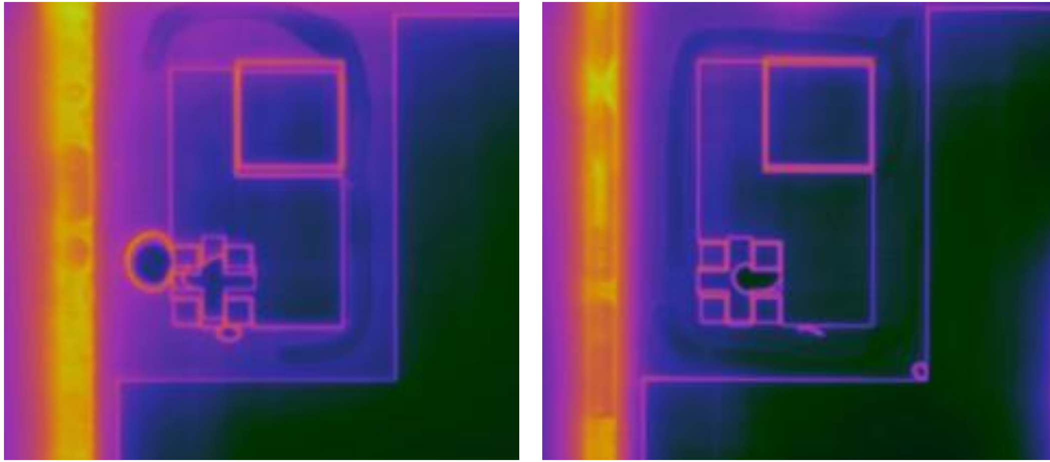
- Separate microlens and detector fabrication
  - Alignment marks on both bond surfaces
- Dies must be aligned and bonded
  - Lateral lens-detector alignment ≤ 3 μm
  - Bond layer thickness ~ 0.5 μm
- Flip-chip bonder
  - Bidirectional microscope used to align
  - Overnight Epo-Tek 301 cure at 65 C



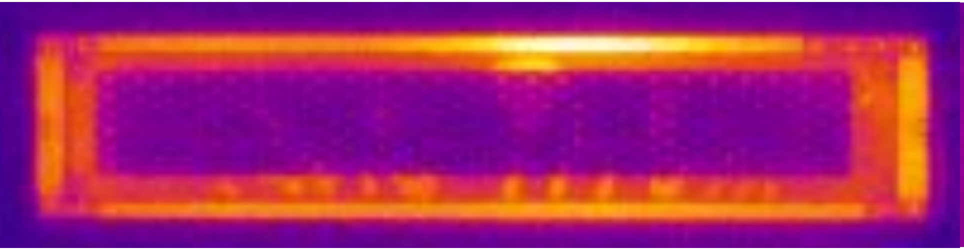


Infrared imaging for voids and checking alignment

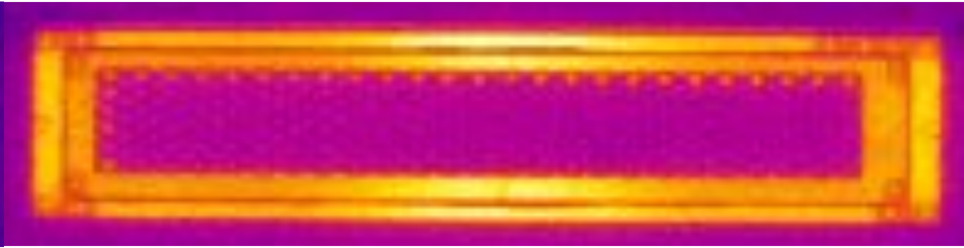
- Teledyne FLIR cameras
  - Look through silicon
  - Post-bond quality checks
  - Confirm alignment accuracy
  - Check for bubbles in bond layer



Microscope FLIR image of misaligned (left) and aligned (right) alignment marks



Early hybridization prototype with voids in epoxy layer

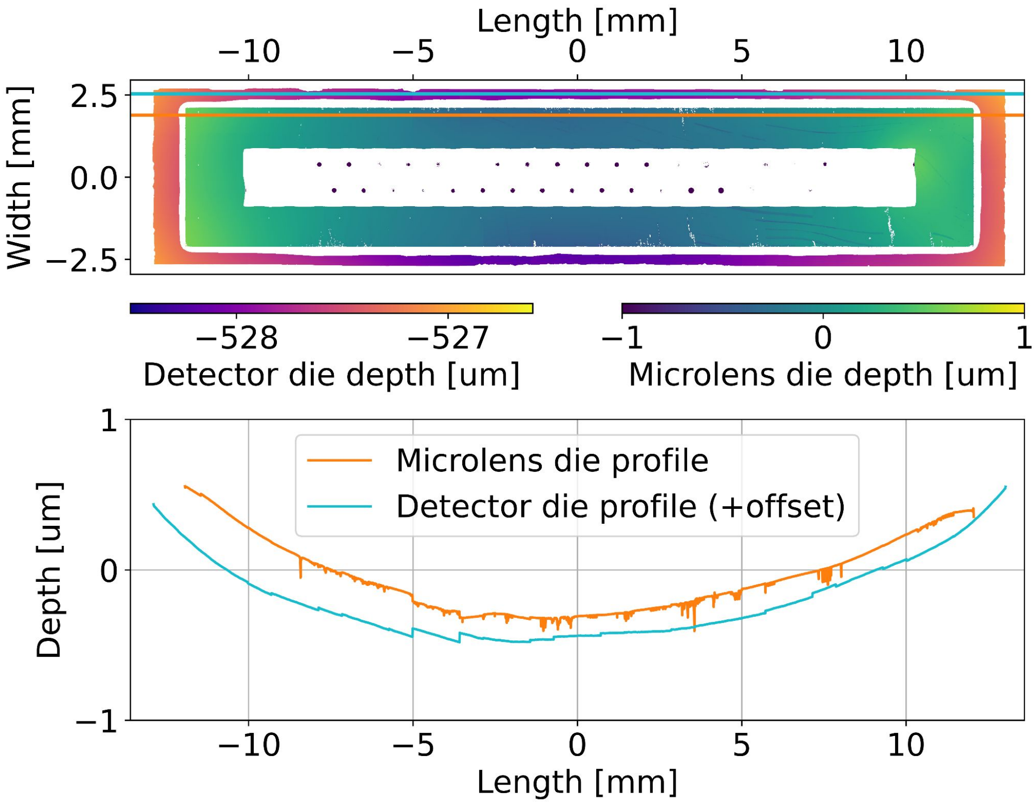


Improved hybridization prototype without voids in epoxy layer

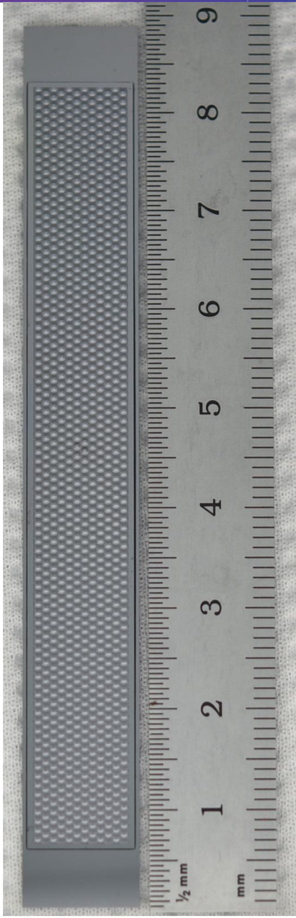
Optical profilometry for bond layer uniformity

- Zygo optical profilometer
  - Measure surface height of microlens and detector die frames

- Check for bond layer uniformity
  - Conforming profiles indicate uniformity
  - Can detect wedges due to dust or asymmetric load during epoxy cure



Conclusions and Next Steps



- Monolithic kilopixel silicon microlens arrays
  - Demonstrated fabrication and hybridization
  - Successful THz/far-IR optical coupling method
- Next steps
  - Hybridize microlens-detector arrays for detector development
  - Fabricate flight-like microlens arrays in all four FIRESS bands
  - Refine grayscale to compensate for lateral DRIE etch
  - Optimize Ti mesh at bond-layer to block stray light

Upcoming PRIMA Presentations at SPIE:

Chris Albert (Caltech)	PRIMA LED mapping	Wed 17:30-19:00	G5, North -- 1F
Shahab Dabironezare (SRON)	PRIMAger absorber coupled KIDs	Thu 15:50-16:10	G318/319, North -3F
Sumit Dahal (GSFC)	PRIMA RFSOC readout development	Fri 11:20-11:40	G318/319, North -1F
Willem Jellema (SRON)	PRIMAger linear variable bandpass filters	Fri 15:50-16:10	G318/319, North -3F

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