Monolithic Kilopixel Silicon Microlens Arrays for Future Far-Infrared Observatories

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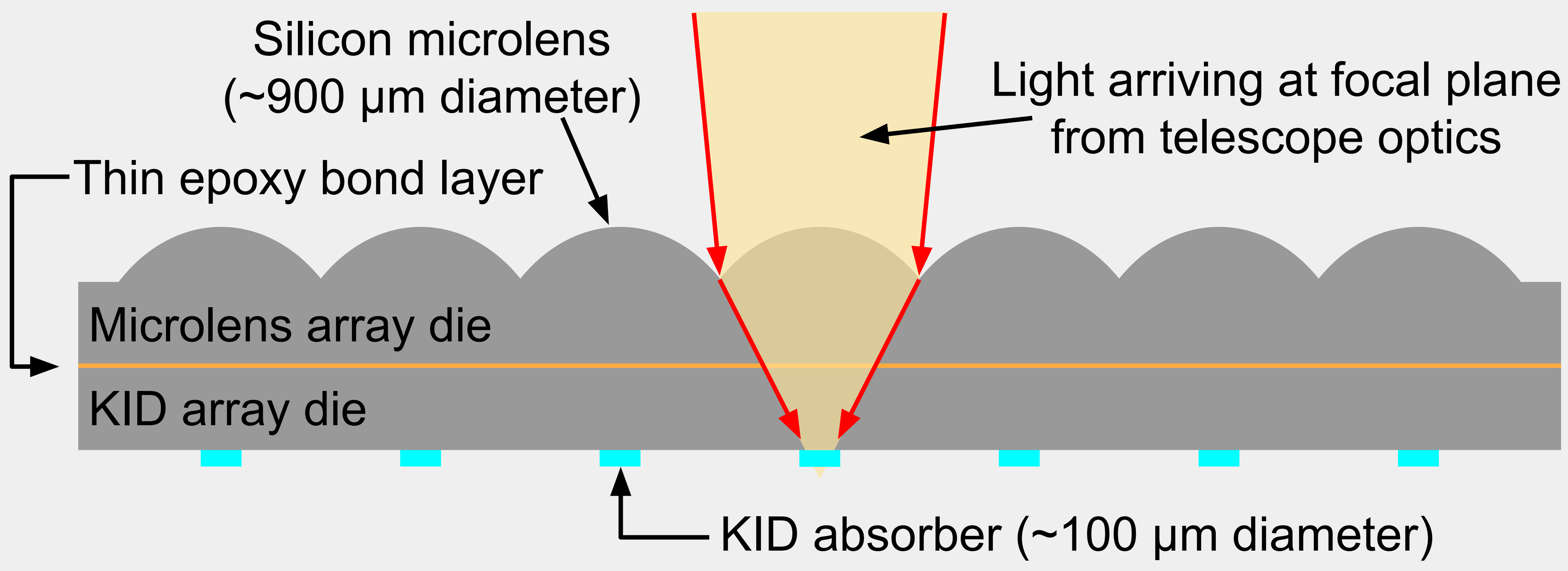
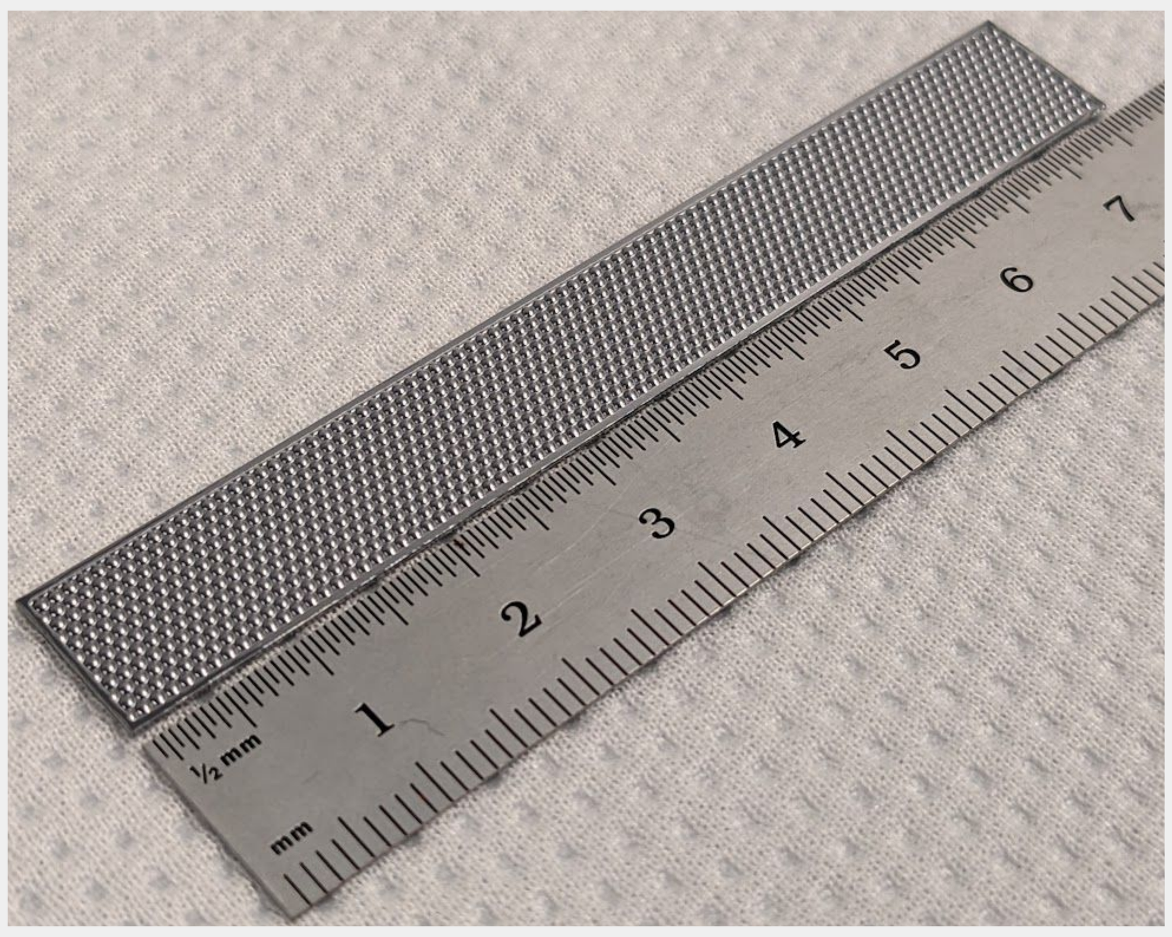
Far-IR Monolithic Silicon Microlens Arrays

- The PRobe far-Infrared Mission for Astrophysics (PRIMA)
  - Observations of AGN feedback, interstellar medium physics in galaxies
  - Growth over cosmic time of stars, black holes, heavy elements, dust
  - Far-IR Kinetic Inductance Detector (KID) arrays [1,2,3]
  - Many arrays, each with thousands of detectors, λ ~ 24 – 240 μm
- Silicon monolithic microlens arrays for KID arrays
  - One microlens for each pixel
  - Concentrate optical power on to detector
- Fabrication methods developed:
  - Lithography-based microfabrication
  - Detector-microlens array hybridization

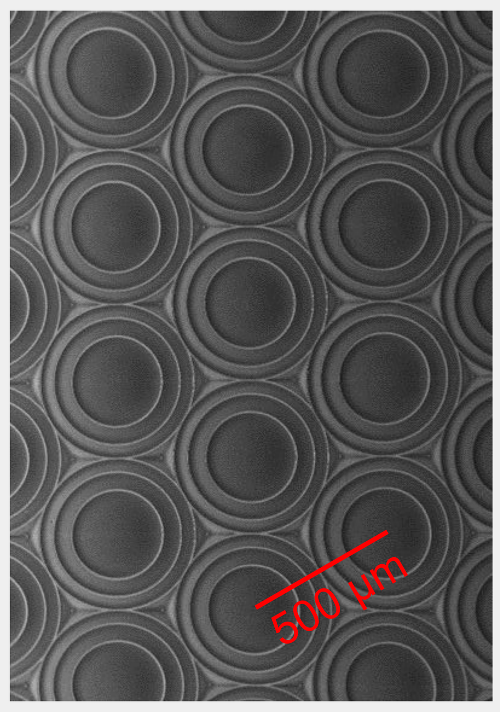


Fabrication of Microlens Arrays

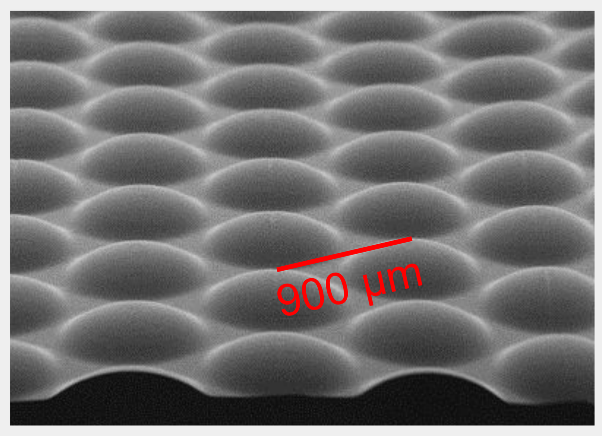
- Microlens array patterned with grayscale lithography
  - Calibrate dosage via exposure-contrast curve
- Plasma etching to transfer lens profile into silicon
  - Control etch selectivity to achieve desired profile
- Successful demonstration of lens depths of ~ 150 μm
  - Microlens pitches in the range 500 – 900 μm
  - Fresnel-style and full-sag lenses



Left: Kilo-pixel full-sag microlens array for λ ~200 μm.



SEM image of λ ~ 25 μm Fresnel microlens array.

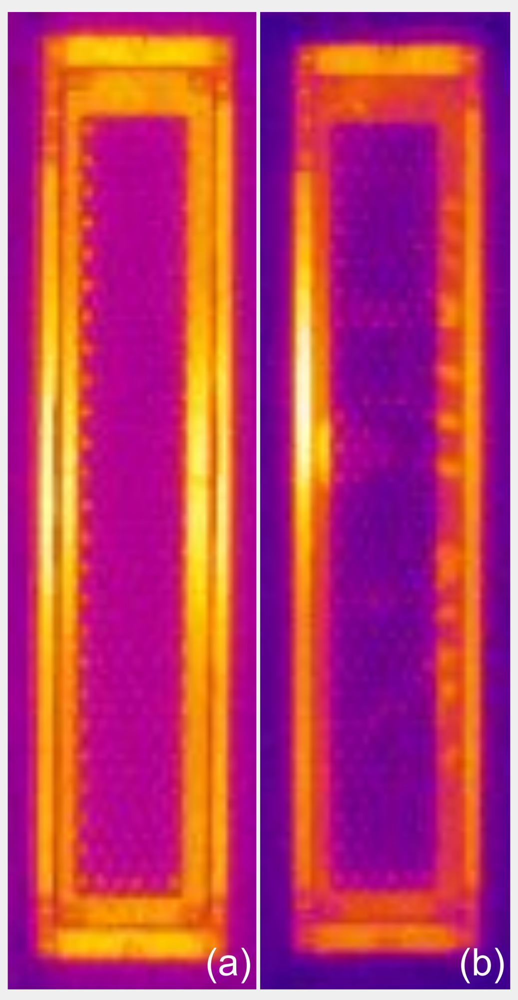


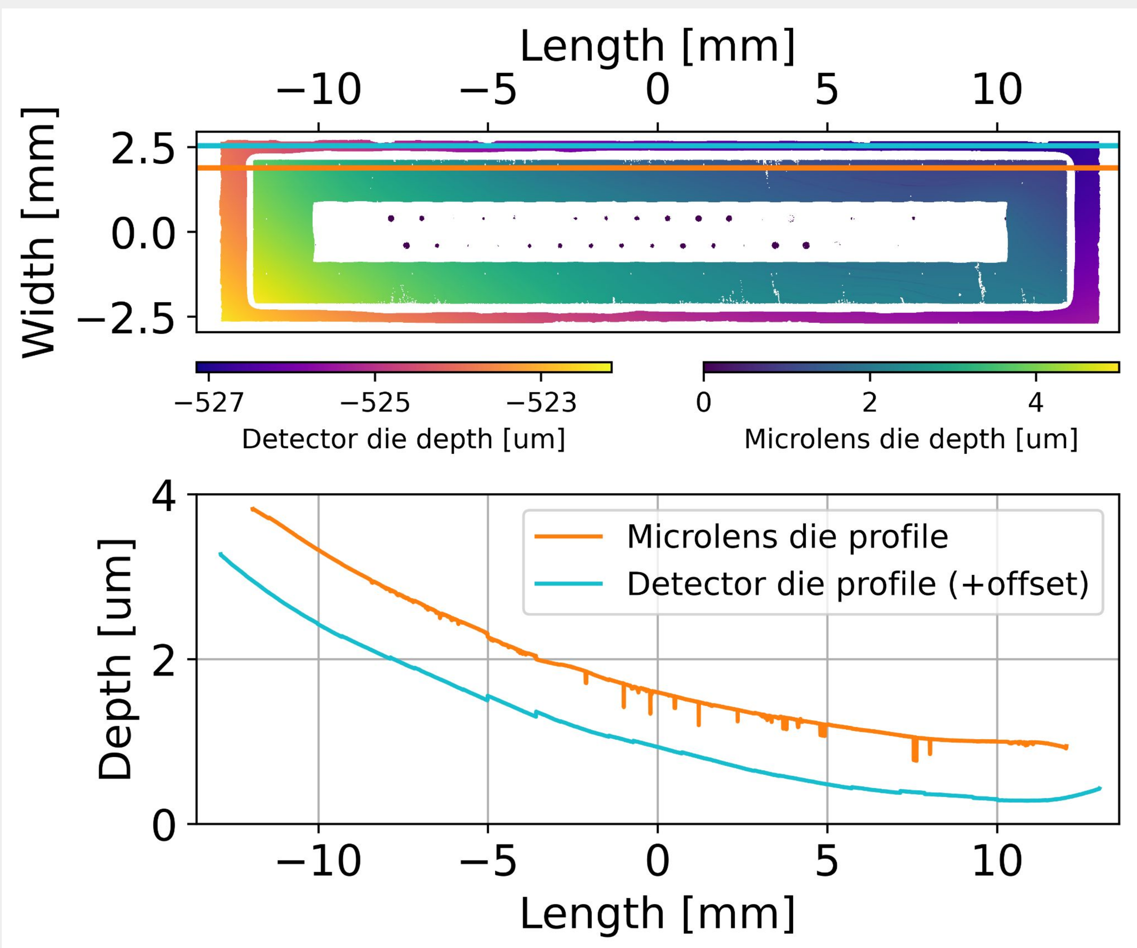
SEM image of λ ~ 200 μm full-sag microlens array.

Hybridization of Microlens Arrays with Detector Arrays

- Successful demonstration of hybridization
  - Microlens-detector array bonding
  - Precision alignment better than 10 μm
  - Low-loss sub-micron thick epoxy layer
  - No voids or dust between dies
  - Quarter-wavelength Parylene-C AR coating
- FLIR (λ ~ 10 μm) and Zygo imaging used to verify:
  - Absence of inclusions between dies
  - Bond layer thickness uniformity
- Successful repeated cryogenic cycling tests
  - Robust bond and no ARC delamination

Above: Photograph of λ ~ 25 μm hybridized microlens array.
Below: FLIR photographs showing prototype hybridized arrays with (right) and without (left) inclusions.

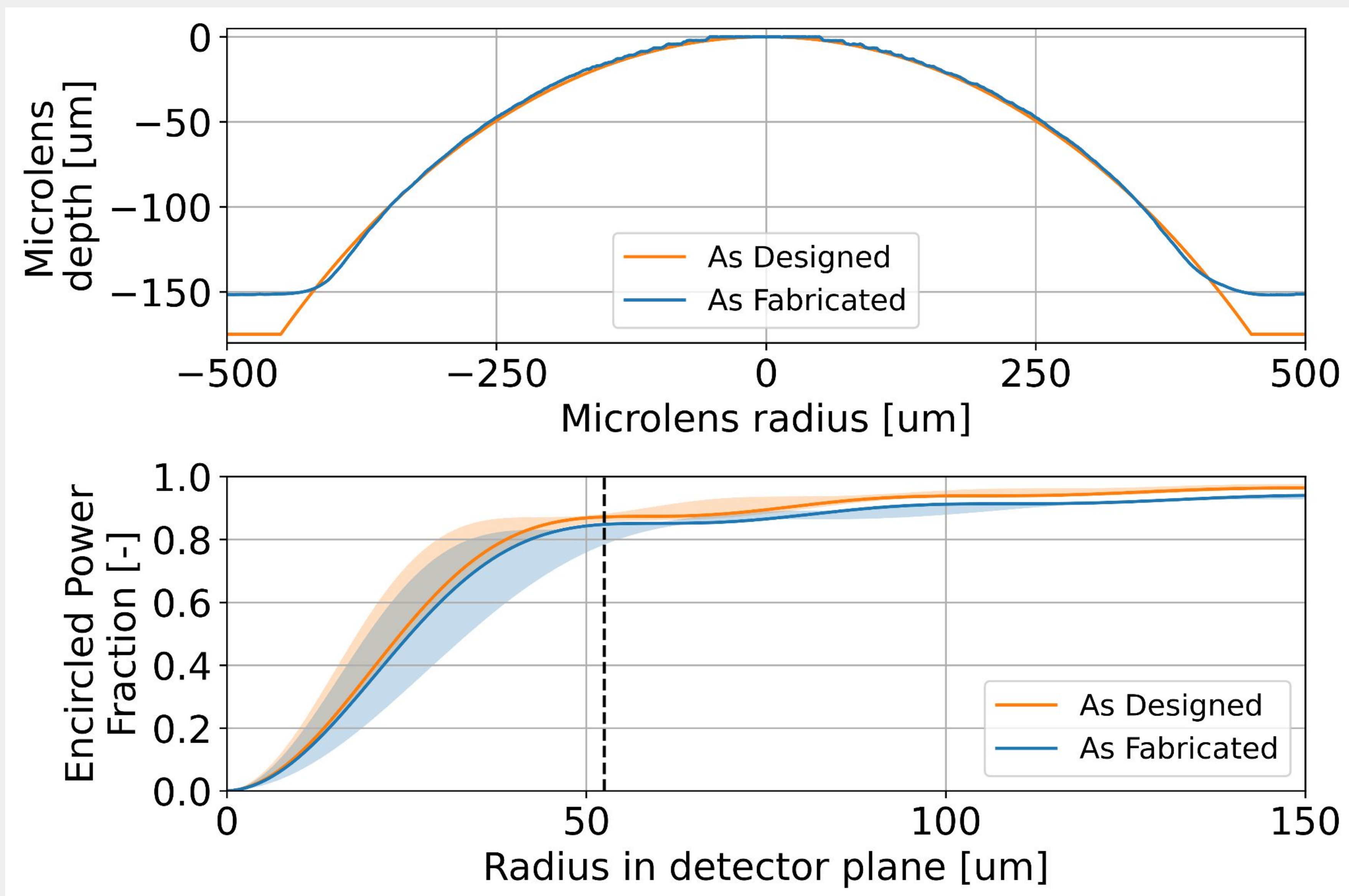




Above: Zygo optical profilometer measurement of hybridized array showing that the microlens die and detector die conform with a uniform bond thickness.

Surface Accuracy and Estimated Efficiency of Fabricated Arrays

- Successful demonstration of lens figure and surface roughness
  - Microlens surface figure deviations ≲ ±3%
  - Sub-micron surface roughness across lens
- Diffractive calculation to estimate expected encircled power
  - 85% efficiency for 105 μm absorber diameter
- Microlens arrays currently in use for PRIMA detector development [1]



Upper plot: Designed versus fabricated profile of a prototype microlens designed for λ ~ 200 μm with a pitch of 900 μm.
Lower plot: Calculated encircled power fraction for designed and fabricated microlens profiles. Solid lines indicate center wavelength (180 μm). Shaded regions indicate performance spanning this PIRMA band (135 – 240 μm).

Conclusions and Next Steps

- Successful demonstration of monolithic microlens arrays
  - Fabricated prototypes exceed required performance
  - Hybridization method proven and robust
- Hybridized microlens arrays in use for PRIMA detector development [1,2,3]
  - λ ~ 30 μm hybrids used for sensitivity measurements
- Next steps:
  - Fabricate and hybridize PRIMA brassboard demonstration arrays
  - Extend to use for other projects (BEGINS [4])

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