Microconcentrators for improving and augmenting focal planes

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Chris Mann, Nanohmics, Inc.

cmann@nanohmics.com

Overview

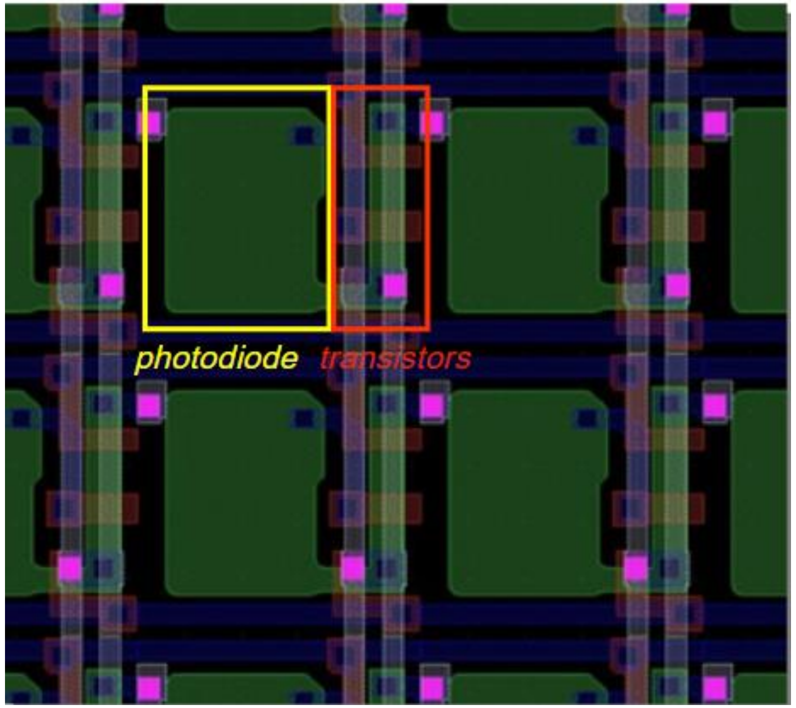
We are fabricating microconcentrators to augment focal planes in order to improve detector fill factor and enable new imaging modes for compact telescopes, emphasizing CubeSats

Nanohmics Background

- Based in Austin, TX
- Founded 2002
- Staff of ~35
    - Primarily scientists, engineers, and technicians
- 13,500 sq. ft. of industrial R&D flex space
- Member of the NNCI at University of Texas at Austin
- Core capabilities:
    - Microfabrication
    - Novel materials
    - Electro-optics
    - Instrumentation engineering
    - Sensors & diagnostics

State of the art

- Specialty focal planes often have extra electronics on each pixel, increases device complexity
  - Amplifiers, electronic bandpass filters, shutter control, etc.
- Actual “pixel” is not always square, and is often a small fraction of total area
  - Alternatively, vertical integration by bonding wafers with interconnects increases complexity & cost
  - For low-cost scientific CubeSats, often not an option
- Commonly, a microlens array is added to improve light collection
  - Can have chromatic effects
  - Often unsuitable in IR
  - Incomplete fill factor
  - High aspect ratio is tough
  - Often asymmetric angular acceptance
  - Some solutions can increase pixel-pixel crosstalk



M. Loose, A. Hoffman, V. Suntharalingam, CMOS Detector Technology, Scientific Detector Workshop, Sicily 2005

Motivation

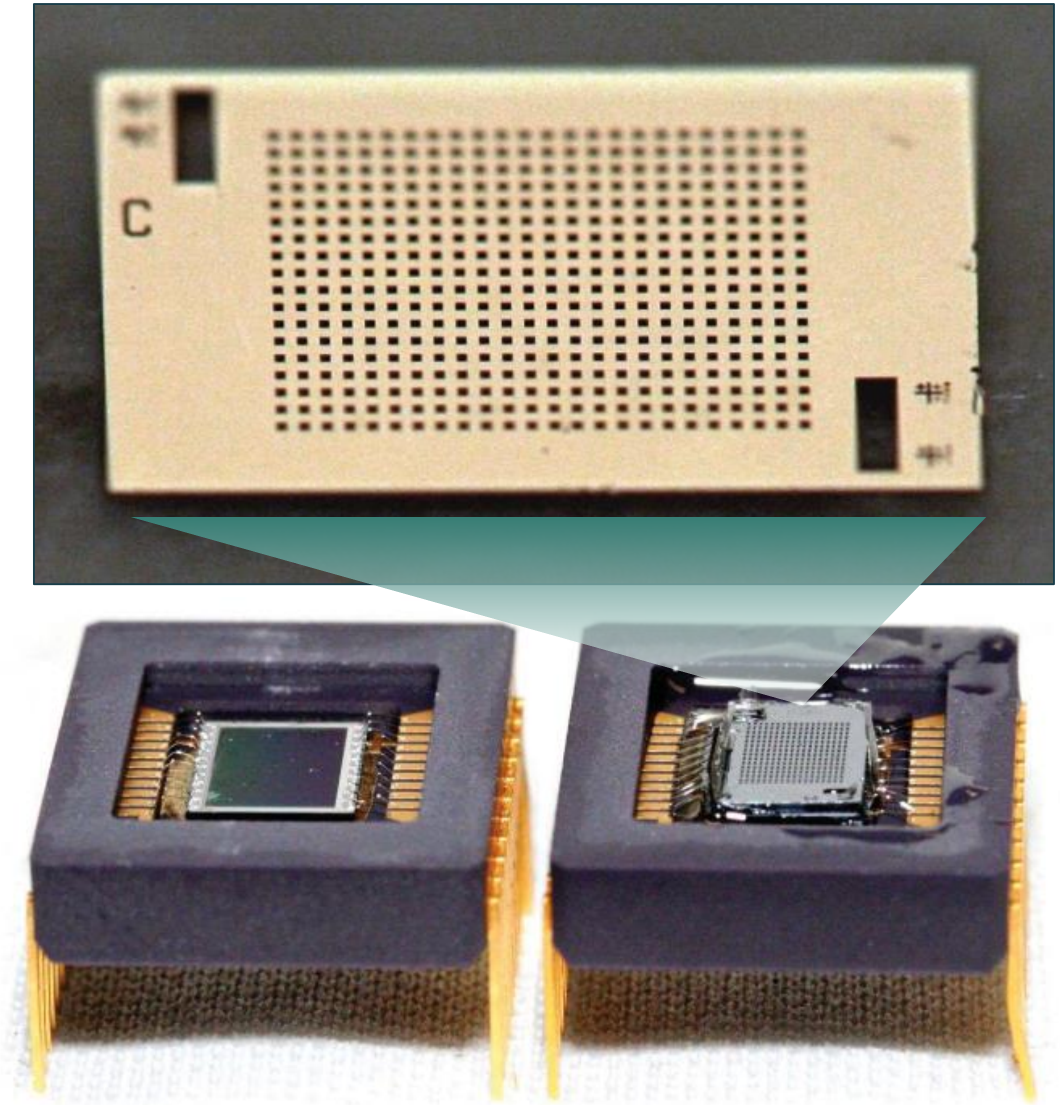
- CubeSats have stringent limitations on size, mass, and cost
  - Need to miniaturize instruments with minimal compromise
- Nanohmics is developing novel chip-scale imaging technologies to improve and enhance COTS focal planes
- Our active CubeSat hyperspectral imaging NASA STTR program has a major fill factor challenge:
  - Need to bring ~75µm x 75µm superpixels down to ~ 10 x 10 µm area with minimal loss or chromatic bias
  - Without mitigating, getting ~1-2% total incident light into our microspectrometers

Solution:

- Fabricate microconcentrator arrays
- Microconcentrators are broadband micro-optical elements for maximizing detector fill factor
  - This can enable commercial detectors to operate closer to scientific-grade performance, or improve custom FPAs
  - Rely on reflection, not transmission; can be tailored for EUV-THz
- In most cases, expect to be able to find a configuration for ≥90% collection, depending on IFOV
- We are interested in applying this to other sensors

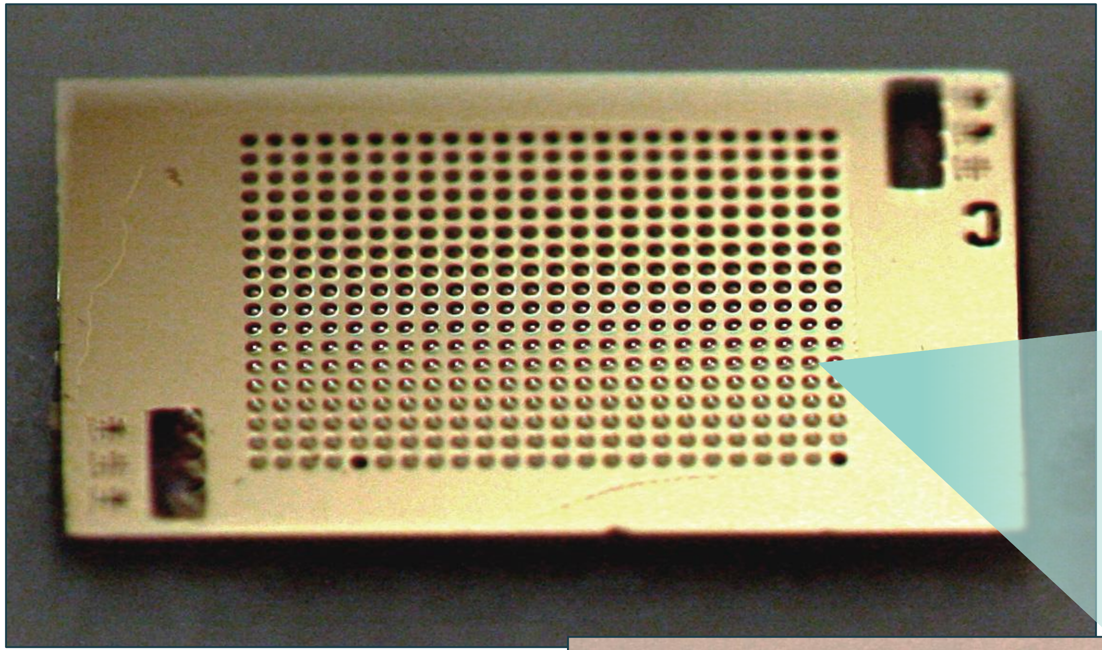
Hyperspectral chip

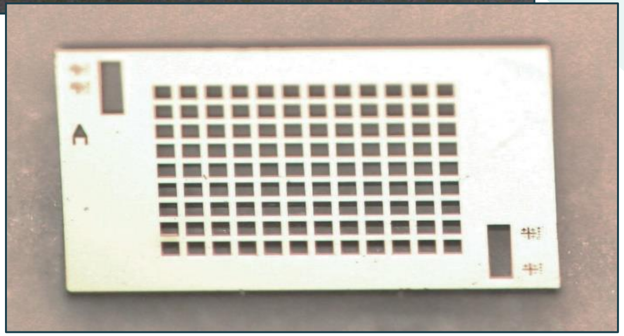
- Focal plane augmentation, add ~1 gram of mass by adding a chip onto, or very nearly on, an FPA
  - Shifts focal plane by ≤1 mm
- Our prototype hyperspectral chip is shown on right
  - Uses microconcentrator array

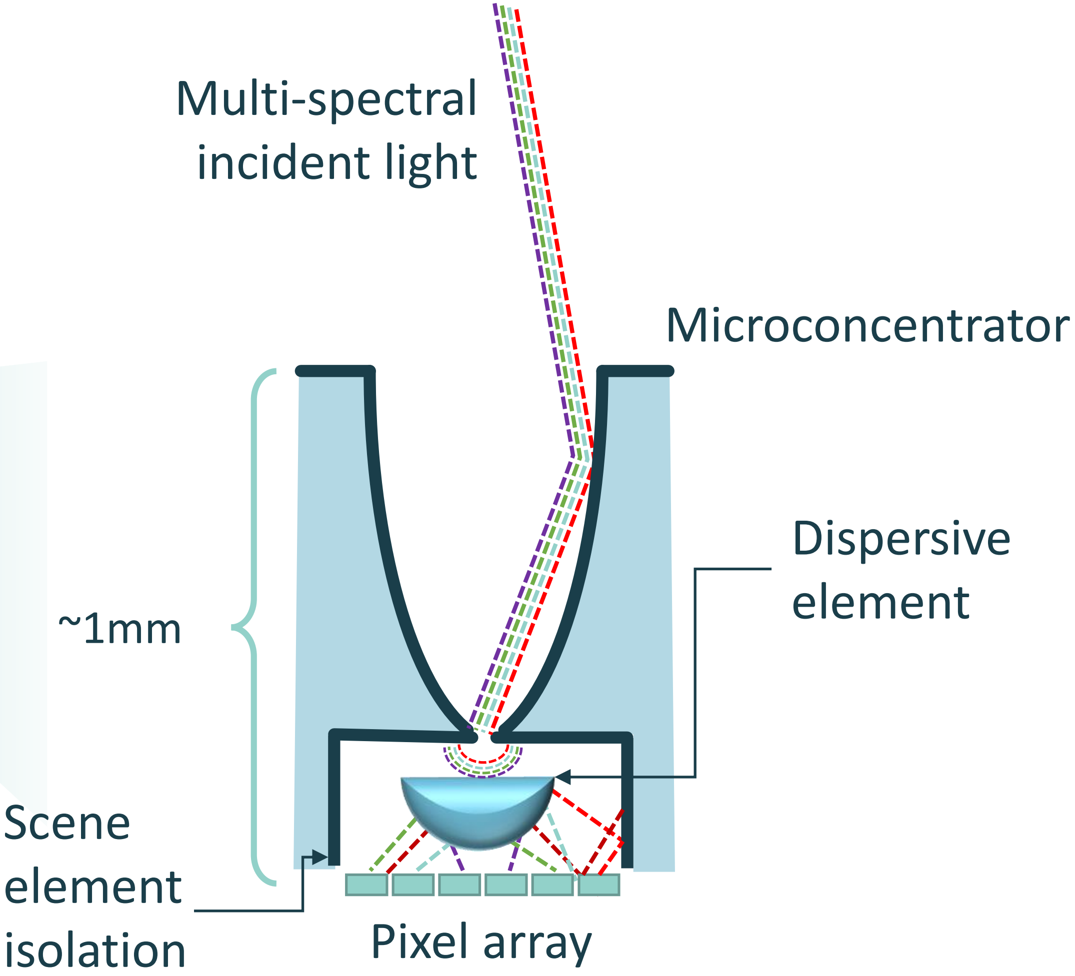


COTS FPA   Augmented FPA

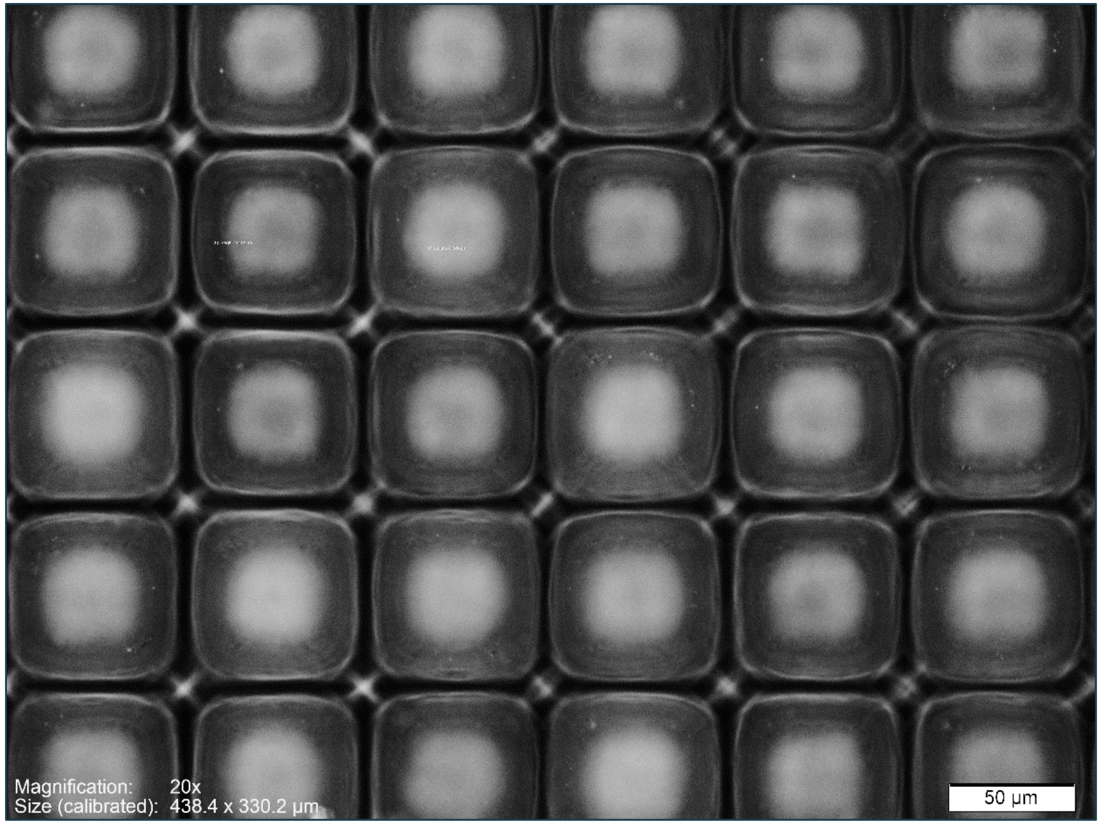
Hyperspectral chip technology



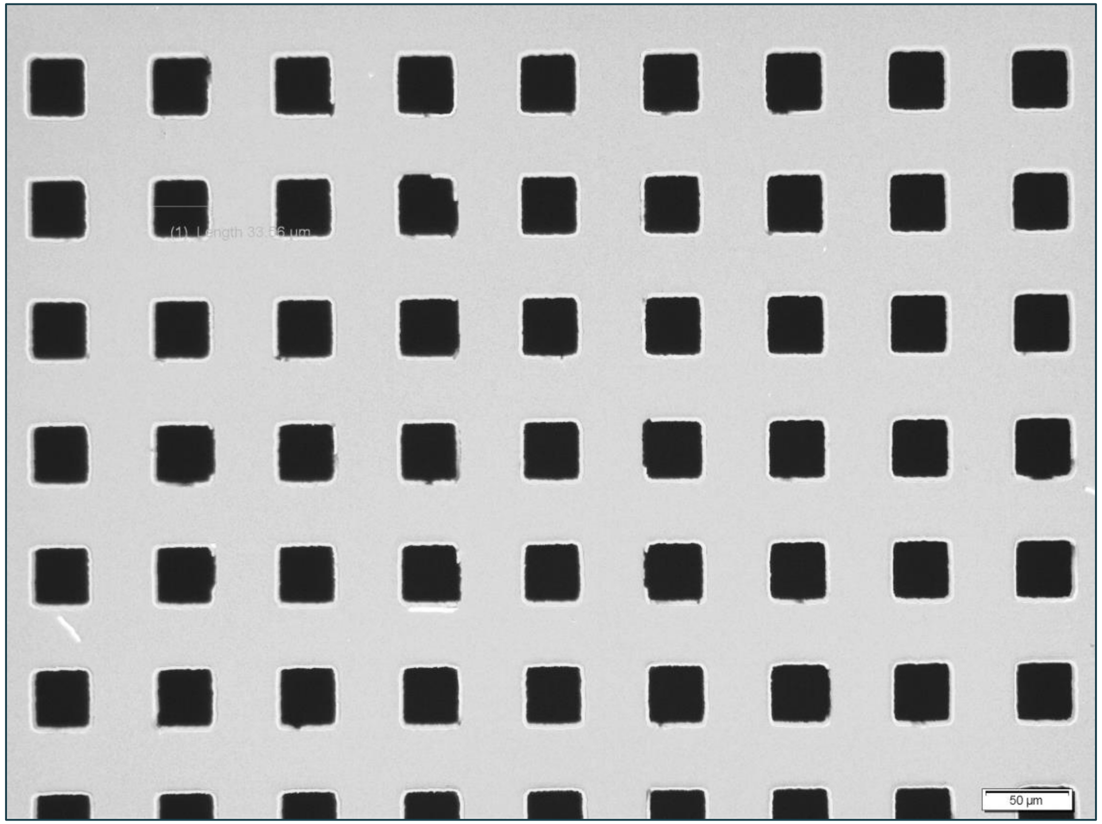




Optical concentration



Optical micrograph – view from top



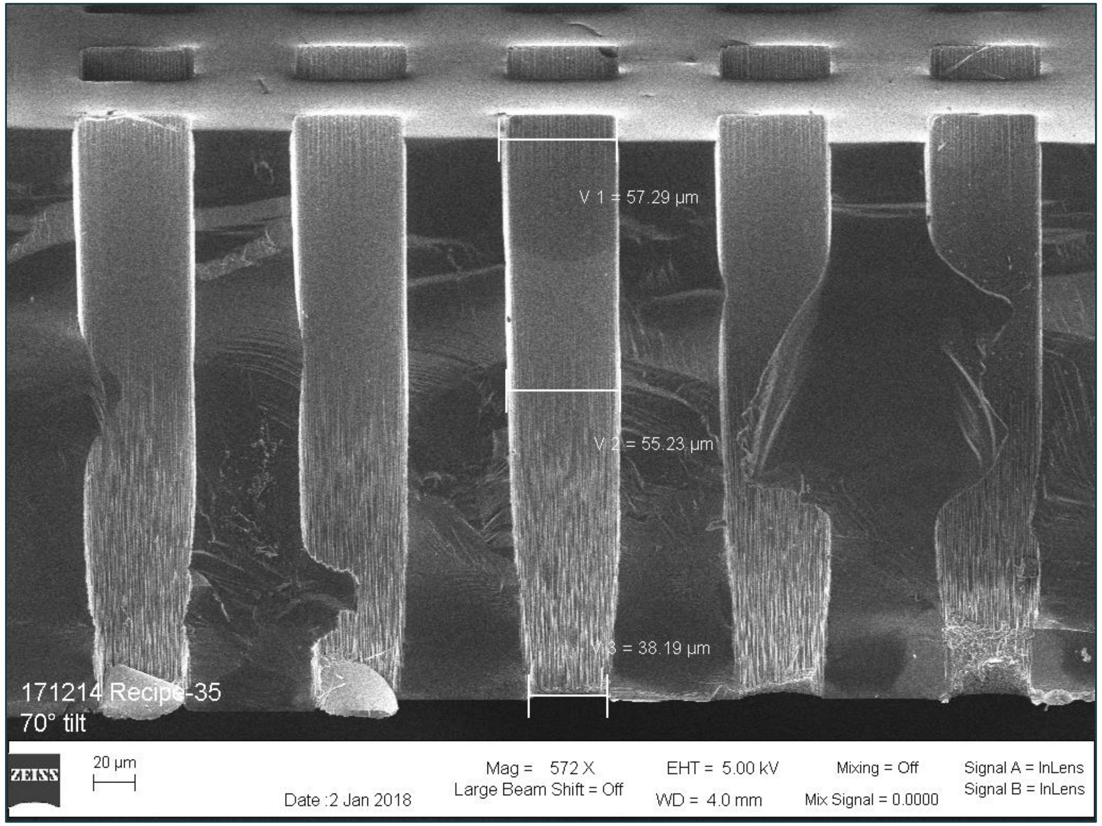
Optical micrograph – view from bottom
(note, different sample)

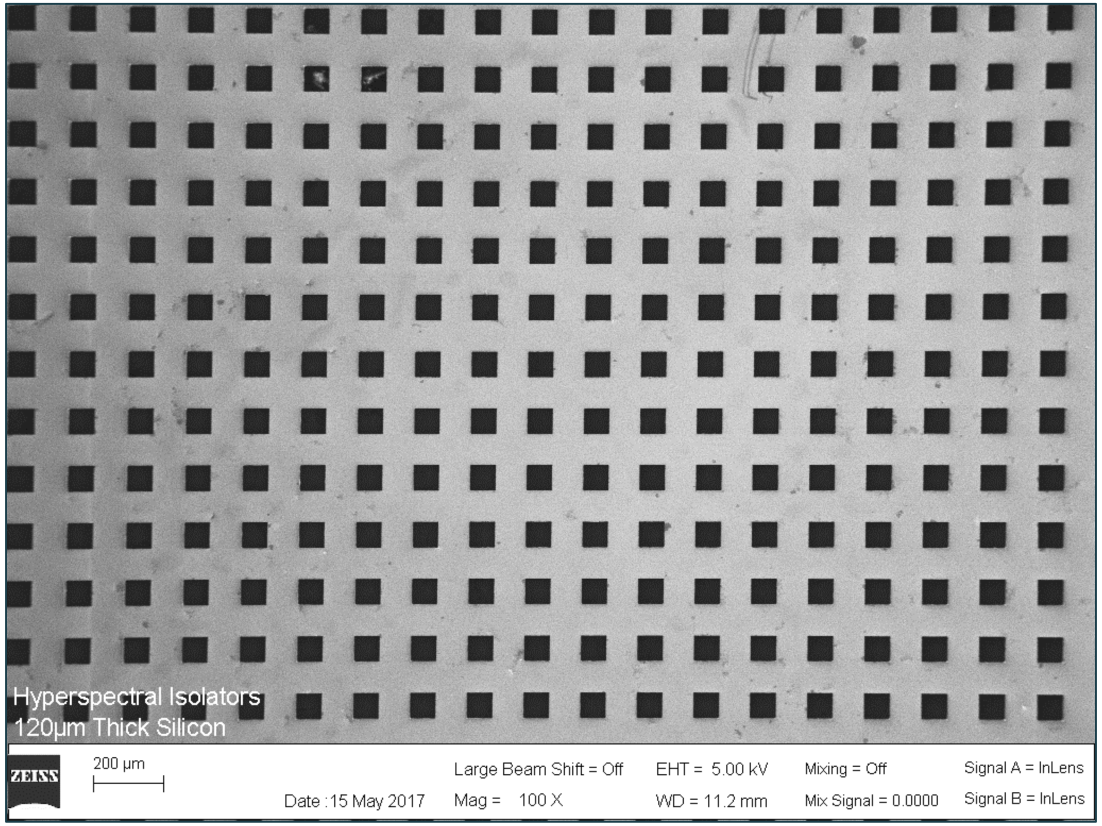
Sketch of process flow

1. Photolithography of desired pattern
2. Transfer pattern into a hard mask, such as Al_2O_3
3. Deep reactive ion etching, custom process
4. Post-etch smoothing (custom wet & plasma process)
5. Add reflective sidewall coating

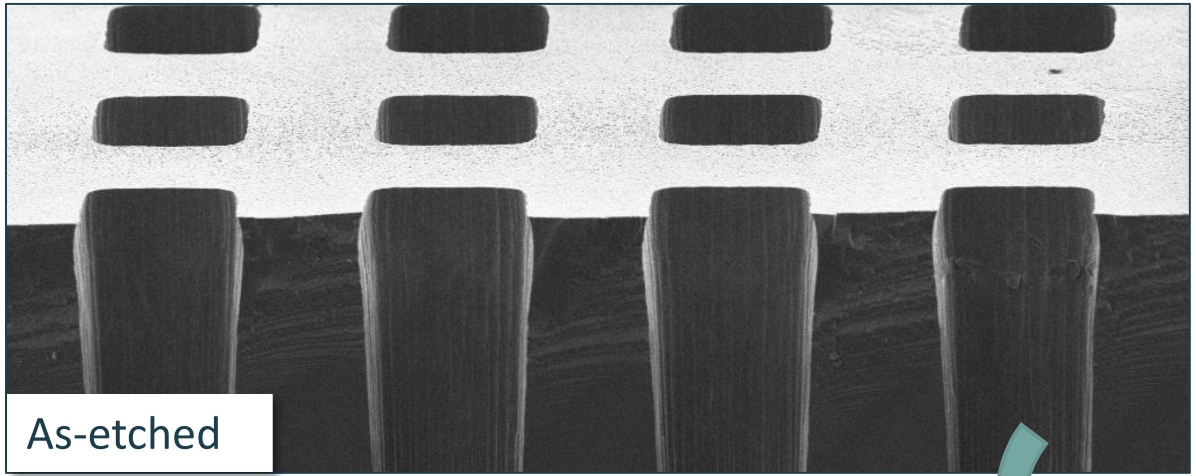
Microconcentrator SEMs

As etched, prior to smoothing

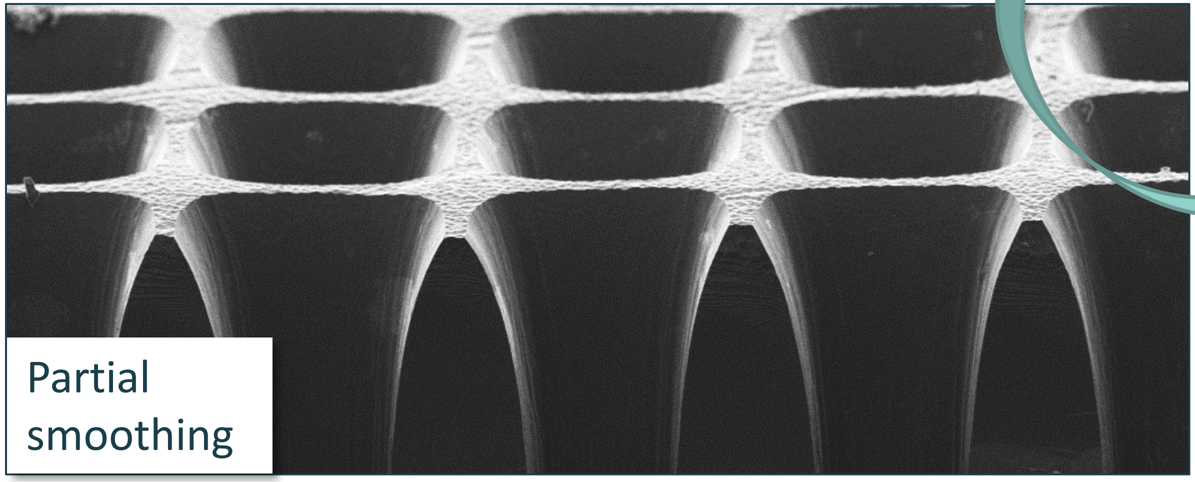


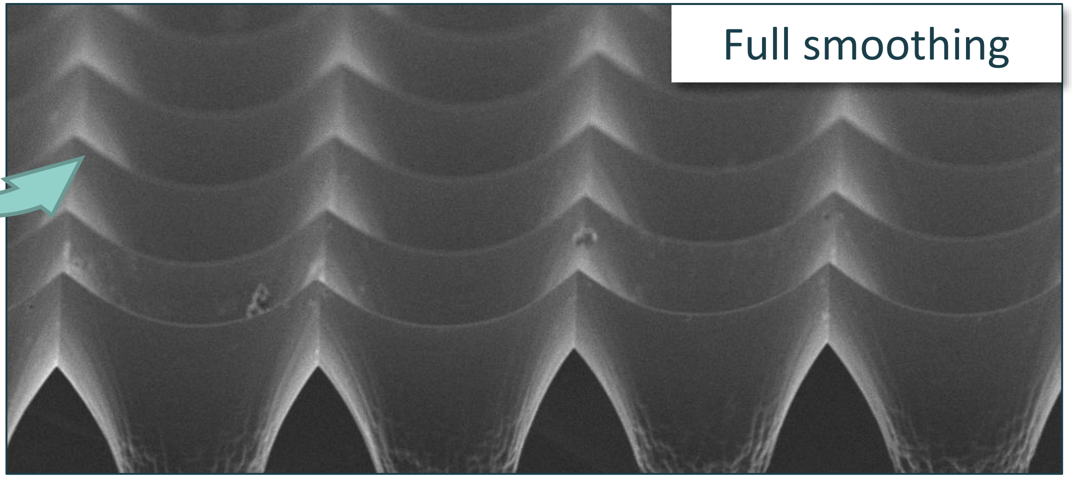


Tailoring concentrator entrance



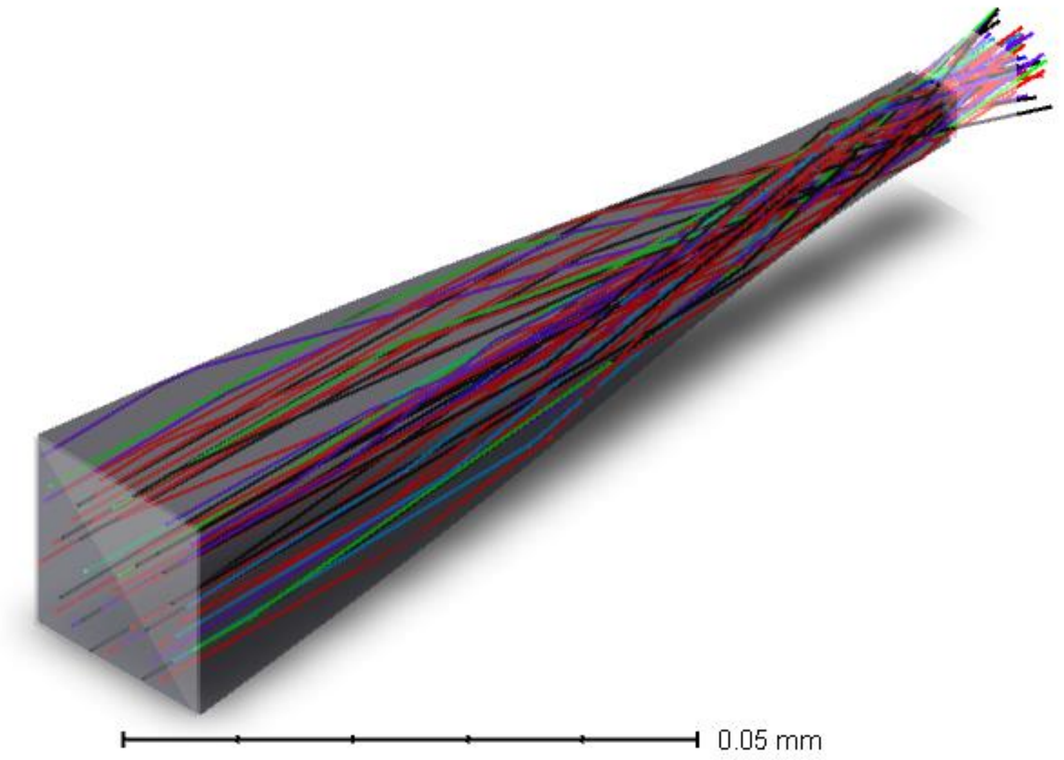
- Perform a post-etch sidewall cleanup to maximize fill factor, reduce roughness
- Tunable chemical & plasma etch processes





Models and simulations

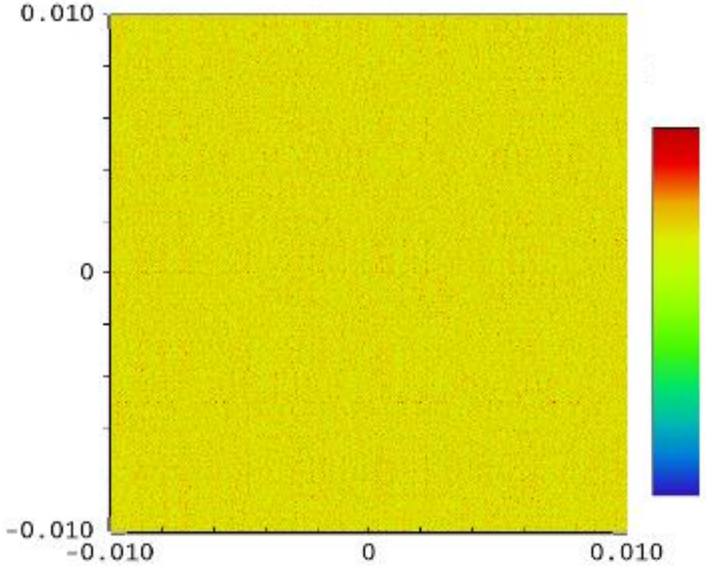
- Zemax simulations of representative concentrator profiles
- Can include parameters like sidewall coating/roughness
- On right:
  - 20 µm pitch, 5 µm x 5 µm pixel
  - 100 µm long
  - No concentrator, 6.25% fill factor



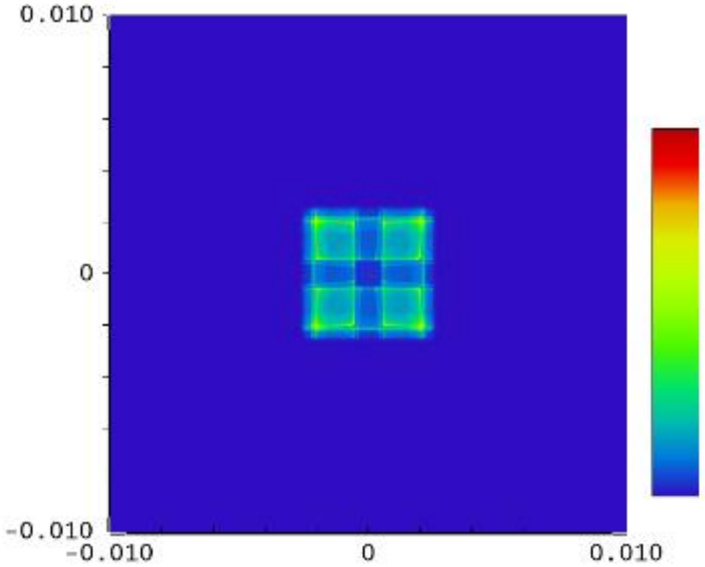
Normal incidence, 400-1000nm band

Incident rays

Spatial distribution at bottom of concentrator



20µm x 20µm collection area

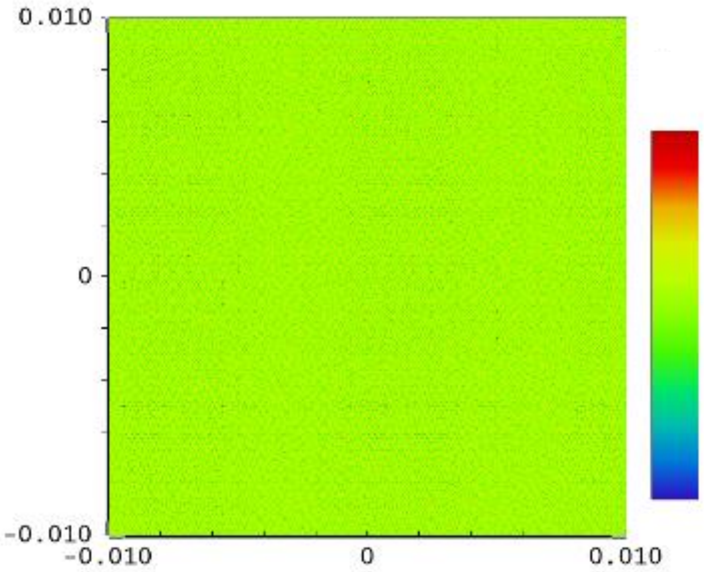


5µm x 5µm output

97.4% throughput with Ag sidewall coating

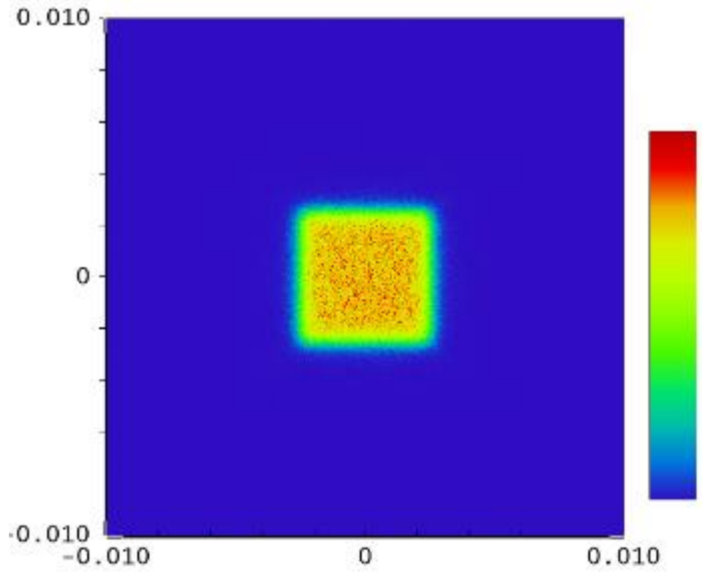
[+10°, -10°] incidence, 400-1000nm band

Incident rays



20µm x 20µm collection area

Spatial distribution at bottom of concentrator

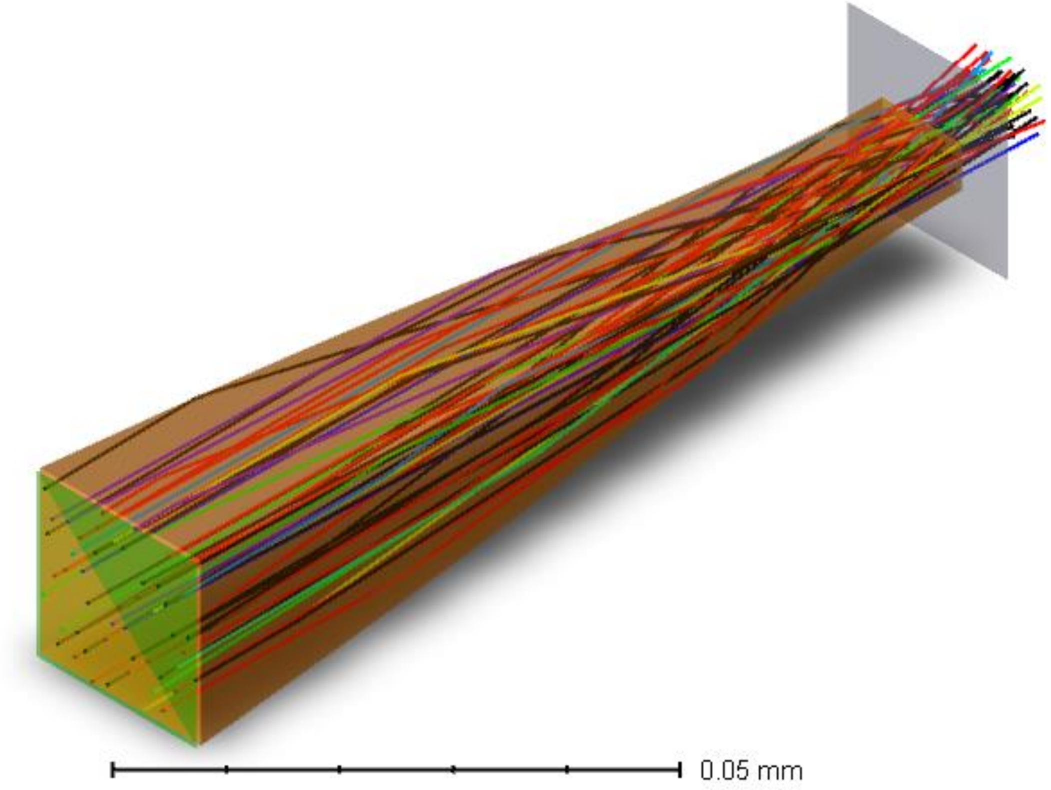


5µm x 5µm output

91.1% efficient with Ag sidewall coating

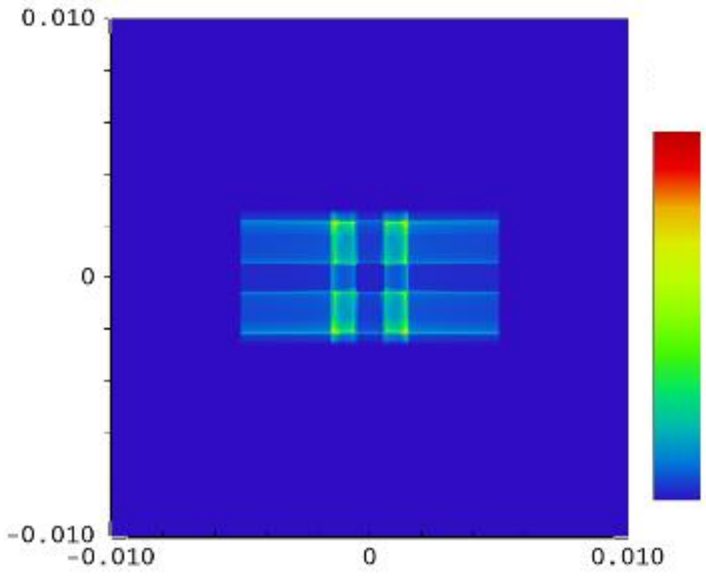
Models and simulations

- Double-side process enables different input and output geometries
- On right: square to rectangle
  - 20 µm pitch, 10 µm x 5 µm pixel
  - 100 µm long
  - No concentrator, 12.5% fill factor



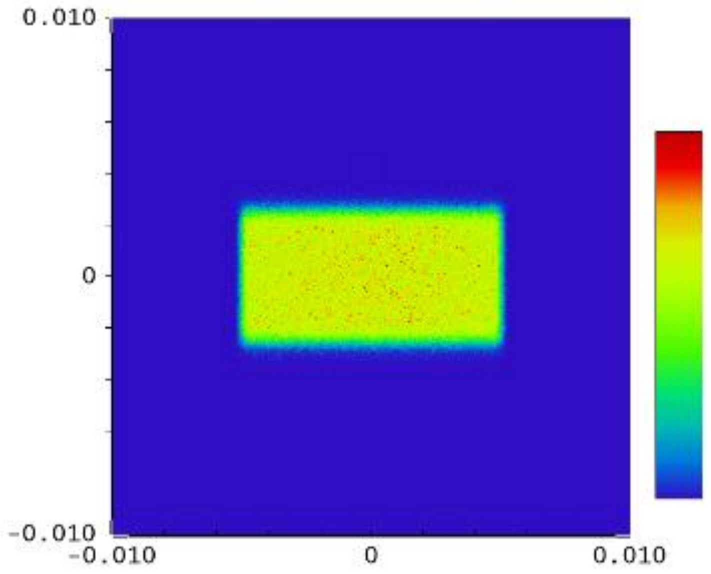
100 µm long, 20 µm pitch, 5 µm x 10 µm pixel

Normal incidence



98.4% efficient with Ag sidewall coating

[10°, -10°] uniformly distributed



95.0% efficient with Ag sidewall coating

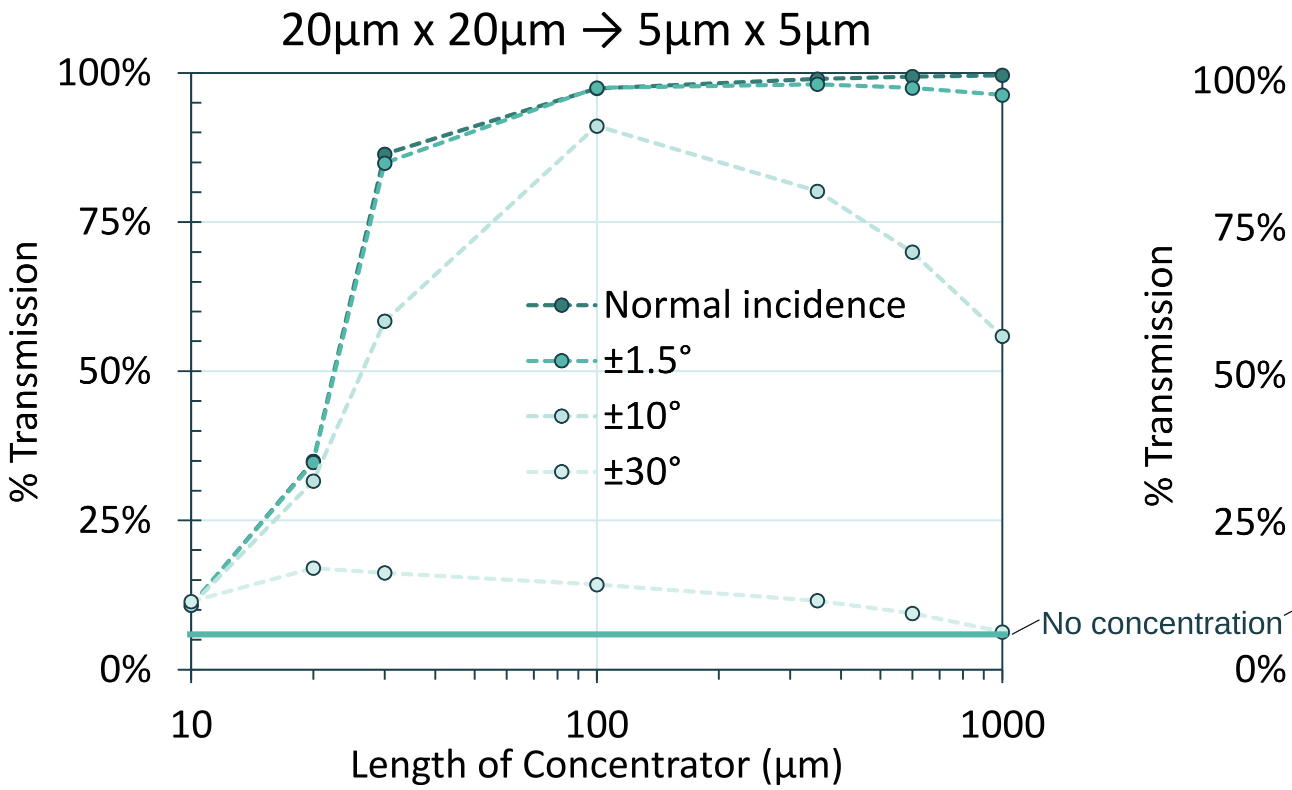
Conclusions

- Microconcentrators can improve detector fill factor for EUV to THz
- Custom, lithographically defined input and output ports can be tailored to nearly any detector (COTS or custom)
- We are developing custom sidewall coatings for each wavelength band, currently focusing on VIS/NIR
- Wide acceptance angles are possible, good for low-*f*-number optics (like telescopes on CubeSats)
- Niche value-add component, can improve hardware after it's already designed
- We are interested in teaming on projects, let us know your application!
  - cmann@nanohmics.com

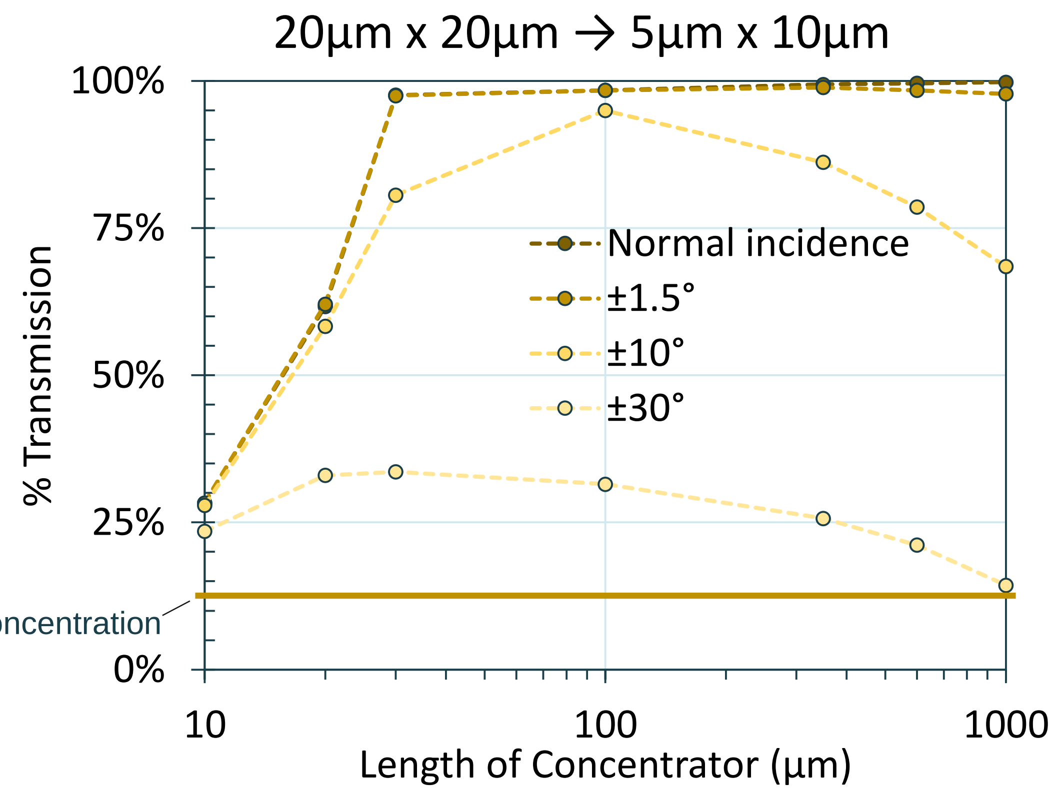
Questions?

400-1000nm band simulation results

Square

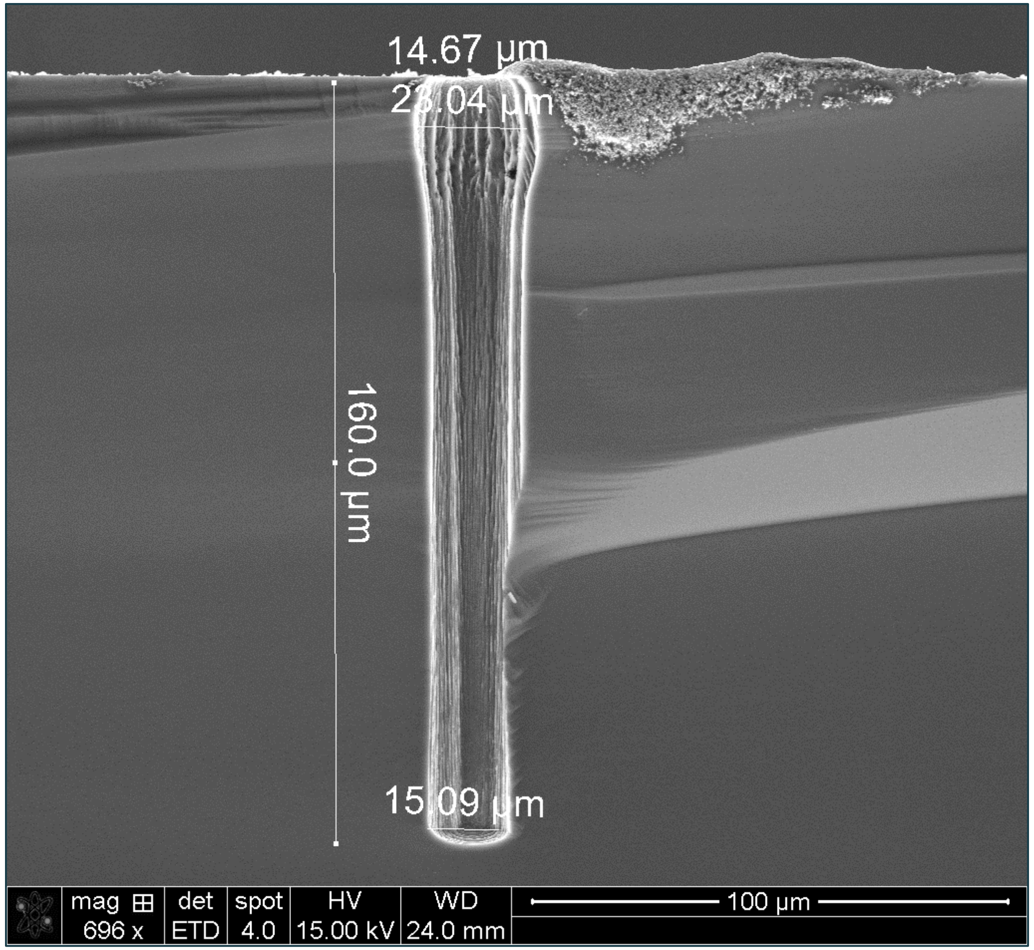


Rectangle



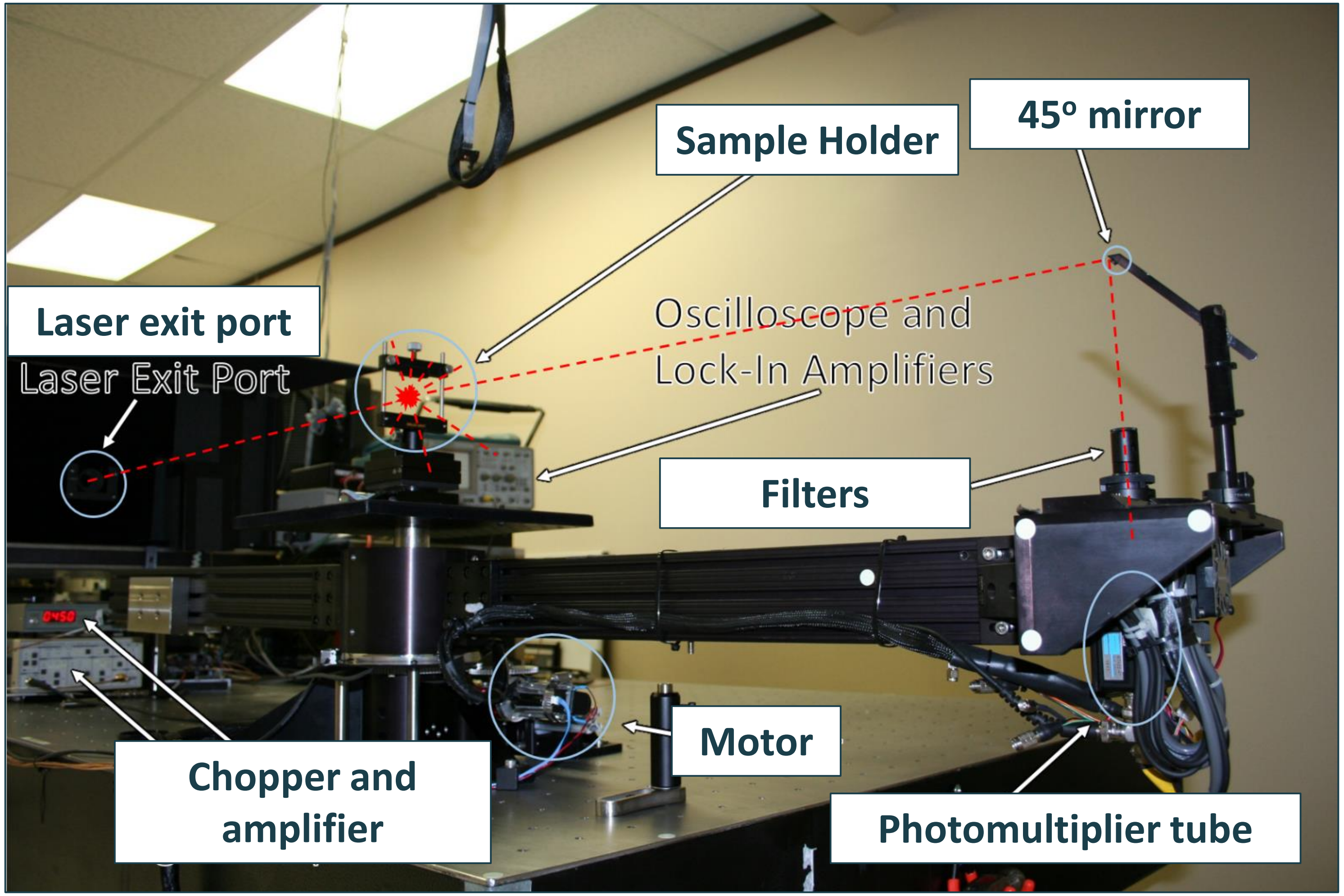
Accessible dimensions

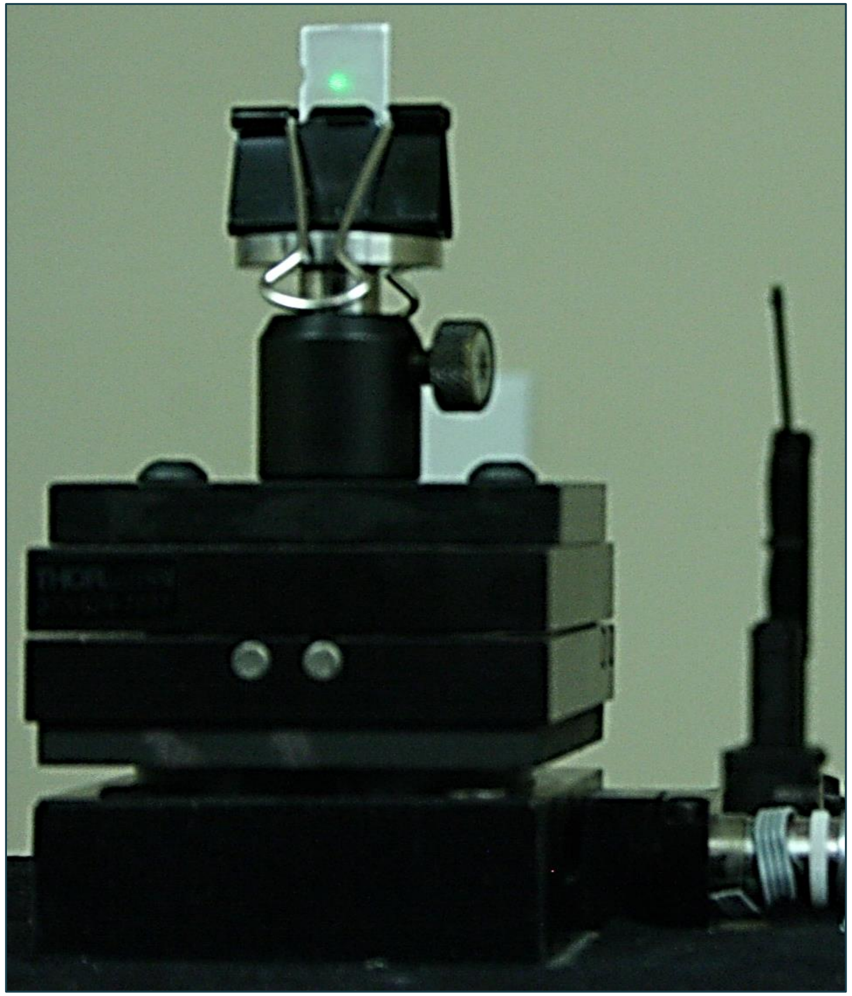
- Original work was for ‘superpixels,’ typically 75-500µm wide
- New work is exploring 5-50µm regime (Right)
  - Viable for individual pixel optical concentration



Scatterometer

We offer full polarization-sensitive BRDF testing as a commercial service





Microconcentrator testing

- First light measurements shown on right
  - Uncoated Si concentrator array
- Broadband LED source
  - Lock-in signal
- Measure the relative intensity of light scattered into each angle as a function of input angle
  - Determine acceptance angle and sidewall reflection losses