

# Integrated Photonic Spectrometer for Hyperspectral Sensing

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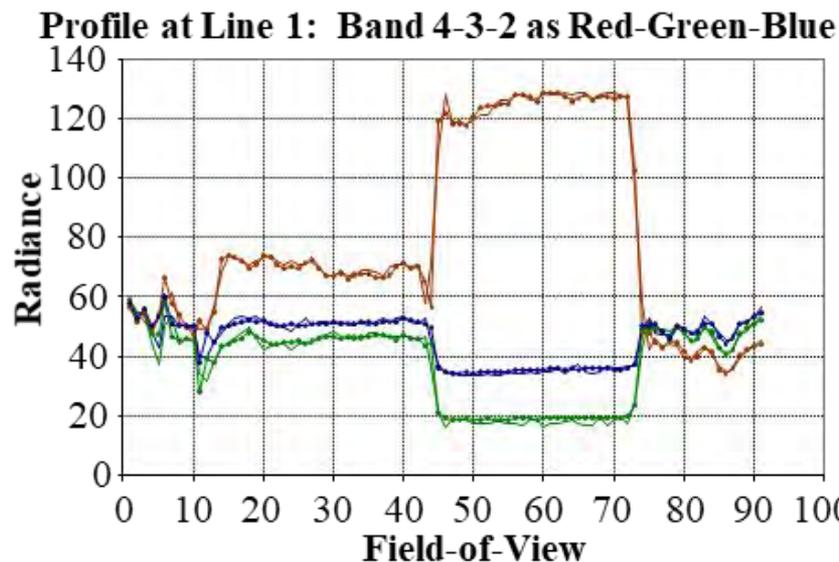
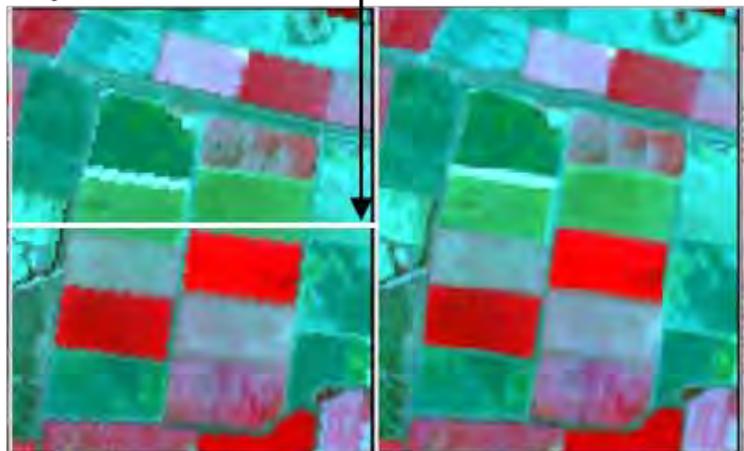
Earth Science Technology Forum 2020

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# Hyperspectral Synthesis of Multispectral Bands

Hyperion Aggregated to Synthesis Landsat 7

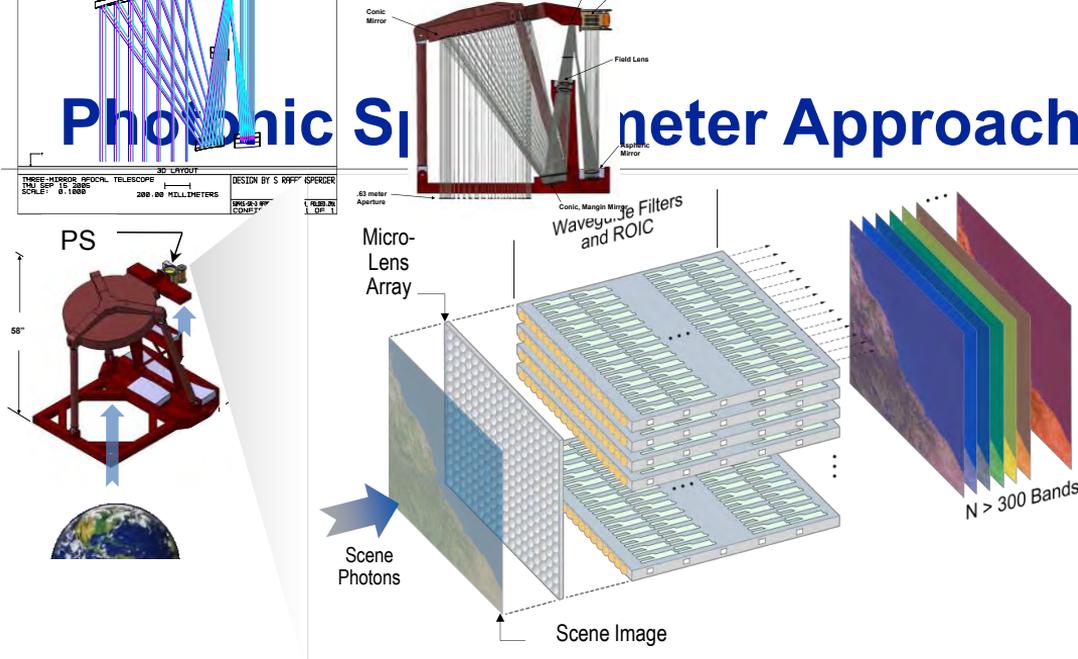


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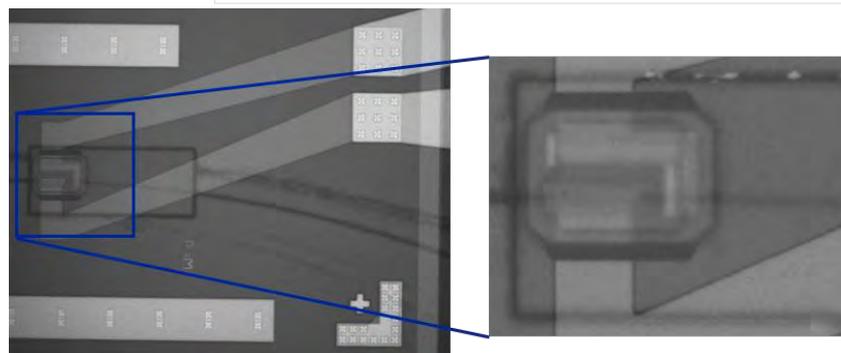
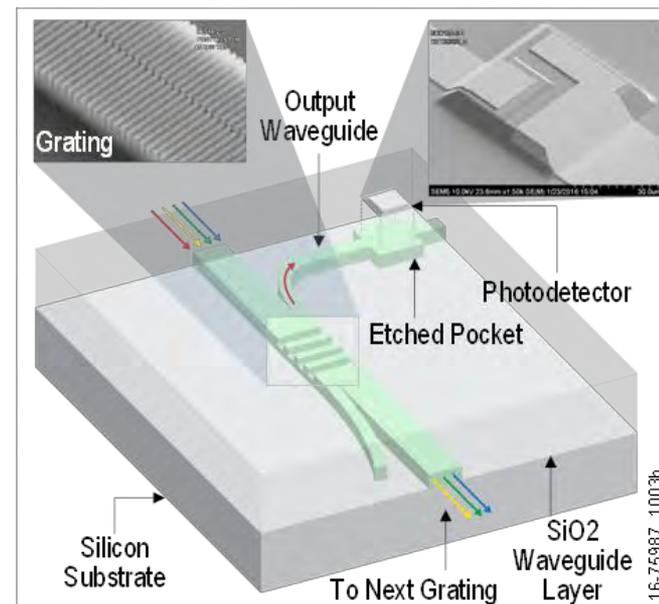
Comparison of cross section through Landsat 7 multispectral data and aggregated Hyperion hyperspectral data for the same scene. Hyperion and Landsat 7 are in the same orbit with Hyperion < 1 minute behind Landsat 7

- Legend:**
- Landsat Red
  - Hyperion Synthesis of Landsat Red
  - Hyperion Synthesis of Landsat Green
  - Hyperion Synthesis of Landsat Blue
  - Landsat Green
  - Landsat Blue

# Photonic Spectrometer Approach



- Micro-fabricated photonic filters and DAHI integrated photodetectors replace free-space optics
- Enables new image acquisition modes (staring, TDI)



## DAHI Integration

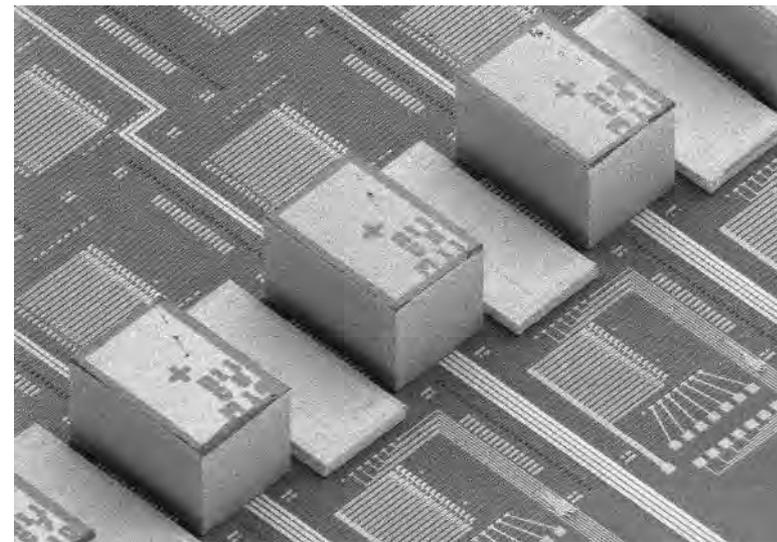
## Sustainable Land Imaging –Technology Program

NG is currently executing a 5-year development program funded by the NASA Earth Science Technology Office to build and test a heterogeneously integrated photonic instrument

- Covers two SLI bands: Band 9 (1.36 – 1.39 $\mu$ m at 3nm resolution) and Band 6 (1.56 – 1.66 $\mu$ m at 6nm resolution).

Demonstrating:

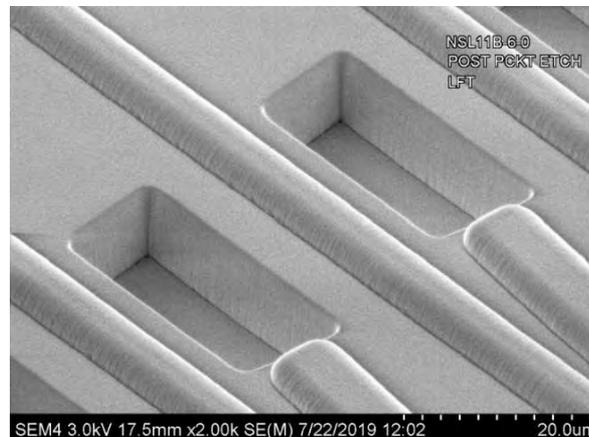
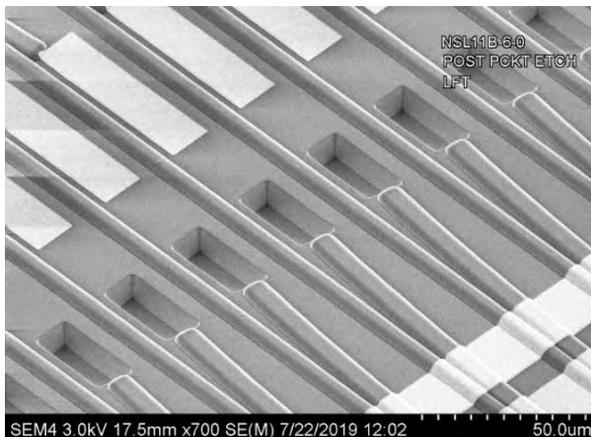
- Scalability to SLI VNIR and SWIR bands
- Integration of novel NG ROIC
- Radiometric performance estimates and testing



SWIR Integrated Photonic Spectrometer developed for NASA SLI-T (detail showing detectors and mechanical ROICs)

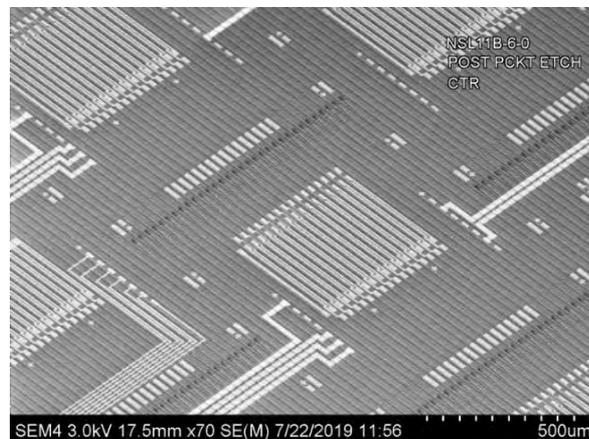
Planned exit TRL = 6 in September 2021

# Waveguide Layer Fabrication



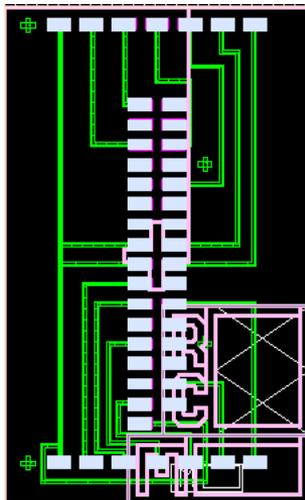
Excellent waveguide definition  
and metal step coverage

Approach produces extremely  
smooth etched surfaces with no  
fabrication artifacts

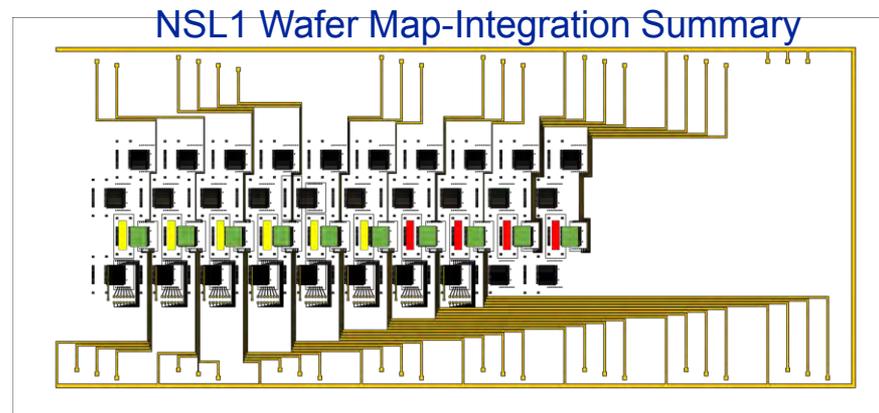
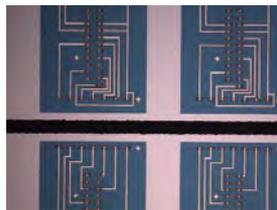


# Detector – ROIC Integration

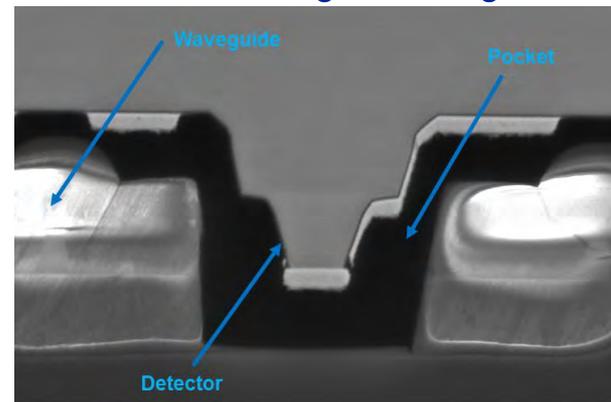
Our integration processes have resulted in consistently high accuracy detector placement (within 0.2  $\mu\text{m}$ ) in the photonic integrated circuit



Mechanical ROIC  
Layout and Fab

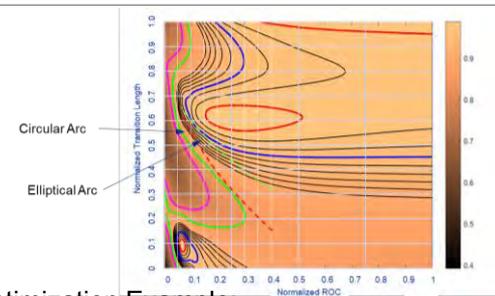


Detector to Waveguide Integration



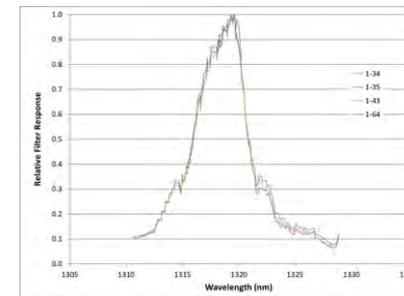
# Integrated Spectrometer Testing

- Demonstrated an initial spectrometer prototype
  - 1.39  $\mu\text{m}$  wavelength range, 10 spectral channels, 3nm resolution
- Optical testing has been carried out on devices with optimized waveguide designs
  - Devices had been integrated with four detector chiplets and four mechanical ROICs
  - Testing addressed 3 spatial pixels (waveguides) and 4 spectral filters per pixel for a total of 12 detector outputs.
- Filter responses were compared across all waveguides and filters under test
  - Excellent consistency in filter lineshape from pixel to pixel and very good agreement between measured and designed filter center wavelength.
- Optical test results represent the first time the photonic spectrometer has been functionally demonstrated as a fully integrated device.



### Design Optimization Example:

Results of 3D modeling showing filter throughput efficiency versus transition section length and merge section radius of curvature. Total filter length treated as fixed constraint under which an elliptical waveguide shape offers higher throughput than a circular waveguide shape



### Optical Test Example:

Filter #1 ( $\lambda_0 = 1319.8 \text{ nm}$ ) normalized response across 4 pixels showing consistent lineshape from pixel to pixel

# Summary

Completed the first-ever demonstration of a functional photonic spectrometer operating as a fully integrated device with excellent agreement in data measured across pixels

Developed and optimized multiple design and fabrications processes

- Validated 2-D and 3-D photonic integrated circuit models
- Demonstrated numerous successful integrations
- Optimized waveguide and detector fabrication

Completed ROIC design

- Unit cells fabricated and tested
- Final design has been fabricated

Currently designing and fabricating

- Waveguide geometries optimized for high throughput
- Integrated spectrometer fully metallized for connection with functional ROICs

*We would like to thank NASA ESTO for their continued support through SLI-T grant  
80NSSC18K0107*

**NORTHROP**  
**GRUMMAN**

The logo symbol consists of a thick horizontal line on the top left, a thick vertical line on the right, and a thick horizontal line on the bottom right, forming an open square shape.