Photonic Integrated Circuits
NASA Goddard Space Flight Center

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AGENDA

- NASA Application Areas for Integrated Photonics
- Laser Communication Relay Demonstration (LCRD) modem
- Photonic Integrated Circuit (PIC) – Examples
- **Direct-Write** Waveguides, Machining, Patterning, Bonding...
- Our Early Stage Innovators
- Acknowledgements
NASA Applications:

➢ Sensors – Spectrometers - Chemical/biological sensors:
  ◦ Lab-on-a-chip systems for landers
  ◦ Astronaut health monitoring
  ◦ Front-end and back-end for remote sensing instruments including trace gas lidars
  ◦ Large telescope spectrometers for exoplanets.

➢ Microwave, Sub-millimeter and Long-Wave Infra-Red photonics:
  ◦ Opens new methods due to Size, Weight and Power (SWAP) improvements, radio astronomy and THz spectroscopy

➢ Telecom: inter and intra satellite communications.
  ◦ Can obtain large leverage from industrial efforts.
LCRD
Laser Communications Relay Demonstration

Bridging the Gap to the Next Era of Space Communications
1.25 Gbps Downlink From ISS
50 Mbps Uplink To ISS
1.25 Gbps Downlink From ISS
A Vector For Directional Networking

NASA – Space Flight 2019:
- NASA-GSFC: Laser Communication Relay Demo
- Raw rate: 2.5 Gbps Differential Phase Shift Keying
- Developed in-house process for packaging fiber optic system for LCRD
- Laser transmitter/receiver for space payload & ground terminal
- Space terminal began fabrication in mid-2015
- Launch Readiness Date (LRD): 2019.

Space Modem
(26”L x 6.3”H x 15.5”W)

Terrestrial commercial – Infinera (2014)
Deployed in South Africa

5 x 114Gb/s Transmitter
442 Elements: AWG mux, lasers, modulators, detectors, VOAs, control elements

5 x 114Gb/s Receiver
171 Elements: AWG demux, local laser oscillator, 90deg Hybrid, Balanced detectors, control elements
NASA Space Communication and Navigation (SCaN)
Integrated LCRD LEO-User Modem and Amplifier (ILLUMA)

Provides pathway to near-Earth low-cost lasercom terminals

- Reduce Size, Weight, and Power (SWAP) plus Cost of spaceflight modems. Use integrated electronics/photonics where cost effective.
- Establish US industrial LEO space-flight modem suppliers compatible with LCRD
- Use vendor up-screened COTS parts where possible.
Transmitter front-end PIC DFB with Integrated MZ modulator
(need high extinction ratio ~20 dB)
Comparison of integrated InP to LiNbO3

Fig. 2. (a) A cross-view of a SI buried ridge. (b) Transmitter chip mounted on HF submount. Photographies of integrated (c) BPSK & 2ASK-2PSK transmitter, (d) QPSK transmitter and (e) packaged QPSK transmitter.

Monolithic Integrated InP Transmitters Using Switching of Prefixed Optical Phases
Guilhem de Valicourt, Haik Mardoyan, M. A. Mestre, P. Jennevé, J. C. Antona, S. Bigo, O. Bertran-Pardo, Christophe Kazmierski, J. Decobert, N. Chimot, and F. Blache
Monolithic Silicon Photonic Integrated Circuits for Compact 100+ Gb/s Coherent Optical Receivers and Transmitters

Po Dong, Member, IEEE, Xiang Liu, Senior Member, IEEE, S. Chandrasekhar, Fellow, IEEE, Lawrence L. Buhl, Ricardo Aroca, and Young-Kai Chen, Fellow, IEEE

(Invited Paper)

Fig. 3. Polarization-diversity coherent receiver using Si PIC. (a) Photonic circuit diagram. PBS: polarization beam splitter; PR: polarization rotator; TIA: transimpedance amplifier. (b) Photograph of the receiver PIC. PD: photo detector; IT: inverse taper; MMI: multimode interference coupler. (c) Photograph of the packaged coherent receiver. PCB: printed circuit board.
Erbium-doped spiral amplifiers with 20 dB of net gain on silicon

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• Internal net gain = 20 dB
• Noise figure of 3.75 dB small-signal-gain regime.

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Femtosecond Direct-Write laser

Dielectric Breakdown of Air at Laser Focus

Fused Silica Witness Sample Etched by Femtosecond Laser
Direct-write laser system is multi-use

- Optical waveguides
- Precision Machining
- Patterning graphene
- Milling/Bonding/welding glass
- Glass/copper weld
- Additive manufacturing with laser sintering (3D printer principle)
Figure 1. Ultrafast laser inscription setup: A femtosecond laser is tightly focused into the bulk of the sample, nonlinear breakdown occurs, which causes a localized material modification. By translating the sample with respect to the focal spot, arbitrary 3 dimensional structures can be inscribed.
Fig. 1. (a) Schematic of fs-laser inscription process in Yb:YAG ceramics for the double cladding waveguides, and their cross sectional microscope images, which consist of tubular central structures with 30 µm diameter, and concentric larger size tubular claddings with diameters of (b) 200, (c) 150 and (d) 100 µm, respectively.
NASA Space Technology Mission Directorate (STMD)
Early Stage Innovation (ESI)
Integrated Photonics for Space Communication

* Karen Bergman, Columbia University
  Ultra-Low Power CMOS-Compatible Integrated-Photonic Platform for Terabit-Scale Communications

* Seng-Tiong Ho, Northwestern University
  Compact Robust Integrated PPM Laser Transceiver Chip Set with High Sensitivity, Efficiency, and Reconfigurability

* Jonathan Klamkin, University of California-Santa Barbara,
  PICULS: Photonic Integrated Circuits for Ultra-Low size, Weight, and Power

* Paul Leisher, Rose-Hulman Institute of Technology
  Integrated Tapered Active Modulators for High-Efficiency Gbps PPM Laser Transmitter PICs

* Shayan Mookherjea, University of California-San Diego
  Integrated Photonics for Adaptive Discrete Multi-Carrier Space-Based Optical Communication and Ranging
Acknowledgments

NASA STMD
NASA SCaN
DoD IP-IMI
AETD colloquium

Thank you!

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