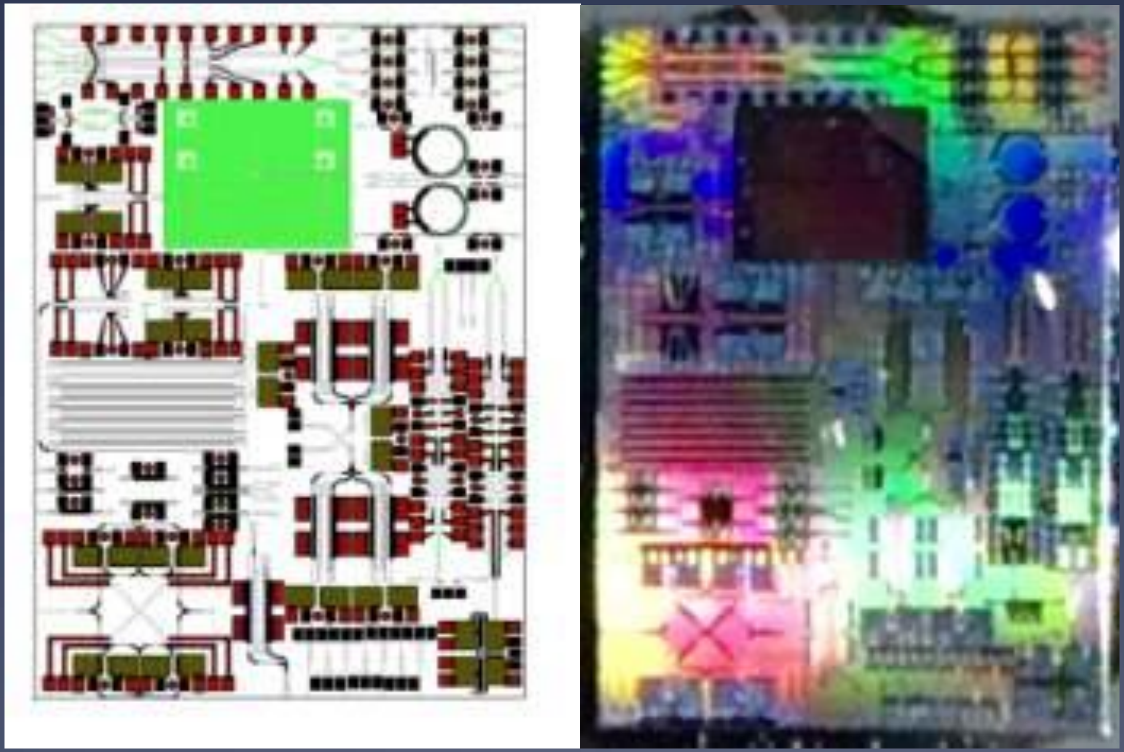
Photonic Integrated Circuits

NASA Goddard Space Flight Center

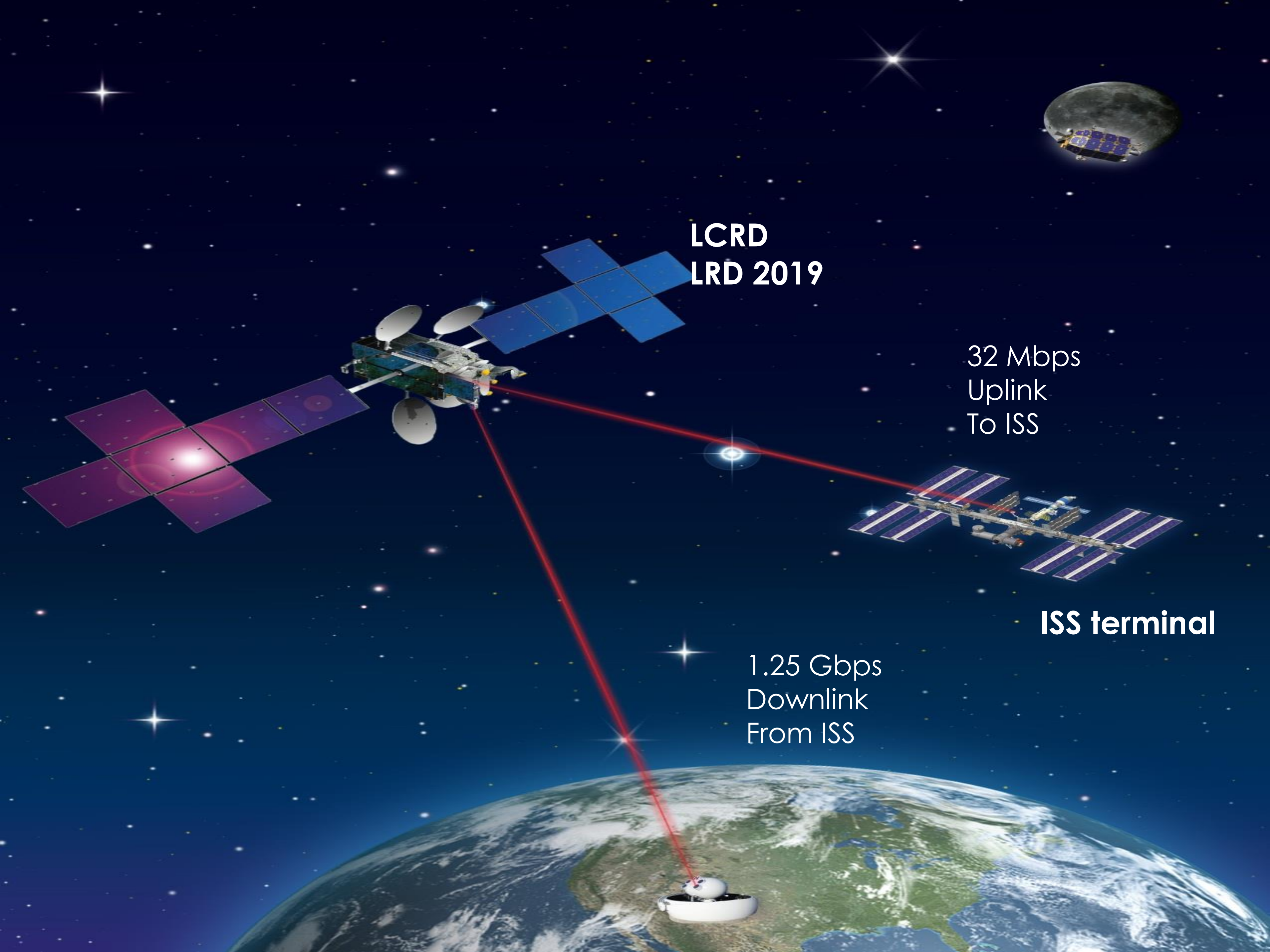
Dr. Scott Merritt
Dr. Michael Krainak



AGENDA

- LCRD modem
- Integrated photonics – examples
- Direct-Write ideas
- NASA EXAMPLES
- SUMMARY


LCRD
Laser Communications Relay Demonstration
Bridging the Gap to the Next
Era of Space Communications
Ground Station
California
LCRD Mission
Operations Center
White Sands
Ground Station
Hawaii


LCRD
LRD 2019
32 Mbps
Uplink
To ISS
ISS terminal
1.25 Gbps
Downlink
From ISS

NASA – Example 5 -Telecom

Free Space Laser Communication

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 to begin fabrication in mid-2015
- Launch: 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

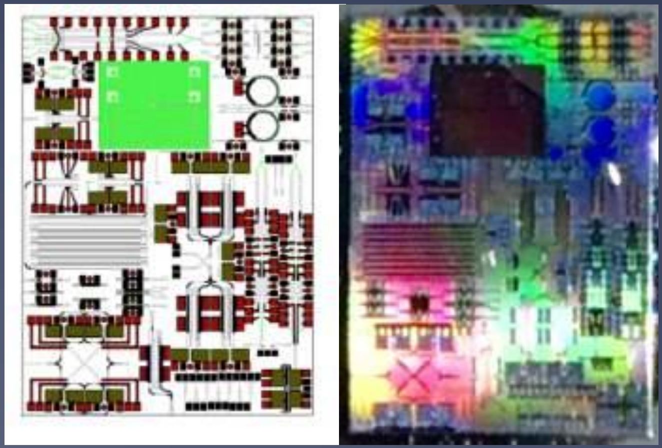
5 x 114Gb/s Receiver
171 Elements: AWG demux, local laser oscillator, 90deg Hybrid, Balanced detectors, control elements

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, Power and Cost of spaceflight modem. Use integrated electronics/photonics where cost effective.
- Establish US industry LEO space-flight modem supplier that is compatible with LCRD
- Use vendor up-screened COTS part where possible.



Transmitter front-end
DFB with Integrated MZ modulator
(need high exttinction ratio ~20 dB)
Comparison of integrated InP to LiNbO3

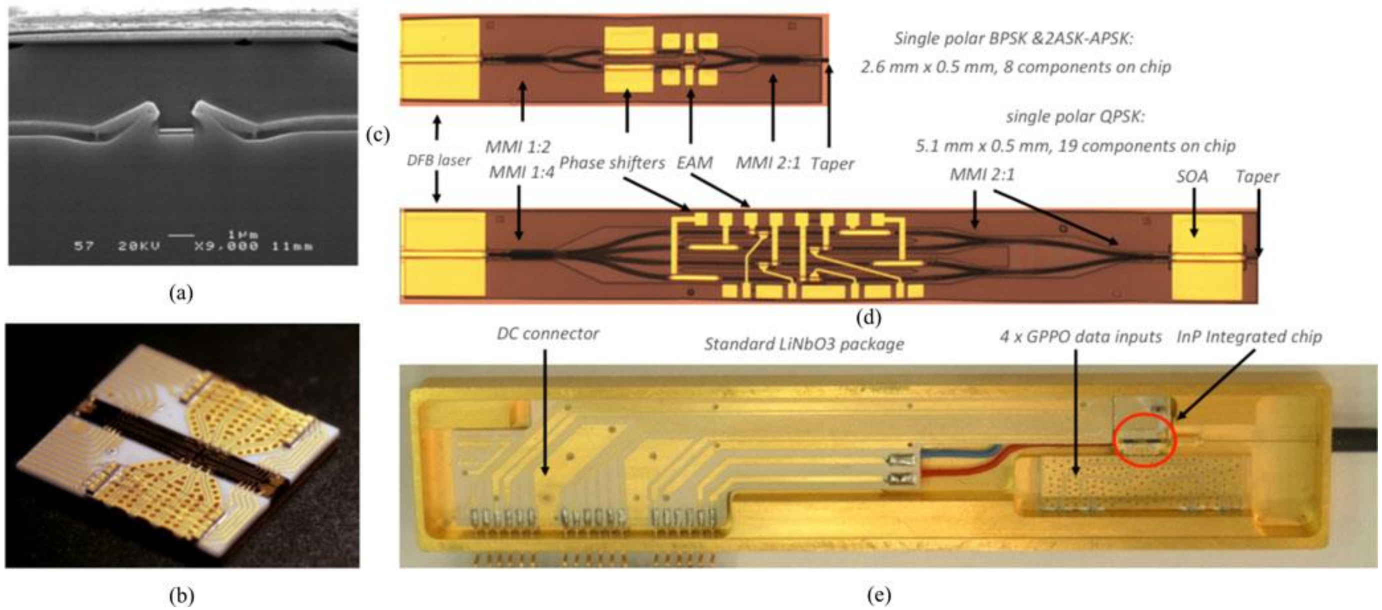


Fig. 2. (a) A cross-view of a SI buried ridge. (b) Transmitter chip mounted on HF submount. Photographies of integrated (c) BPSK & 2ASK-2PSK transmitter,

JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 33, NO. 3, FEBRUARY 1, 2015 663

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

Coherent receiver

6100108 IEEE JOURNAL OF SELECTED TOPICS IN QUANTUM ELECTRONICS, VOL. 20, NO. 4, JULY/AUGUST 2014

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)

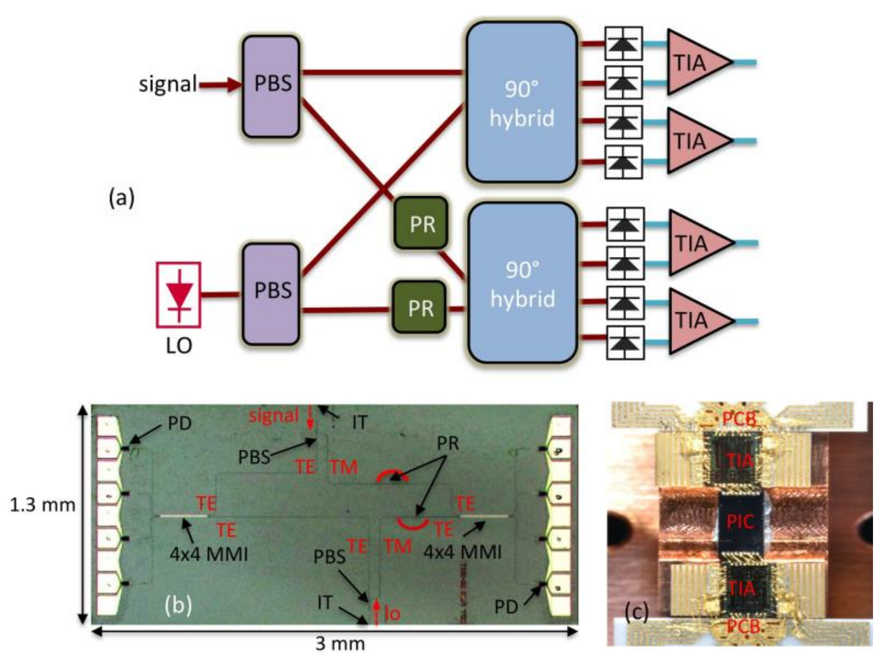


Fig. 3. Polarization-diversity coherent receiver using Si PIC. (a) Photonic circuit diagram. PBS: polarization beam splitter; PR: polarization rotator; TIA: transimpedance amplifier. (b) Photograph of the receiver PIC. PD: photo detector; IT: inverse taper; MMI: multimode interference coupler. (c) Photograph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

Receiver preamplifier PIC

Erbium-doped spiral amplifiers with 20 dB of net gain on silicon

Sergio A. Vázquez-Córdova,[1,2,*] Meindert Dijkstra,[1,2] Edward H. Bernhardi,[1] Feridun Ay,[1,3] Kerstin Wörhoff,[1] Jennifer L. Herek,[2] Sonia M. García-Blanco,[1,2] and Markus Pollnau[1,4]

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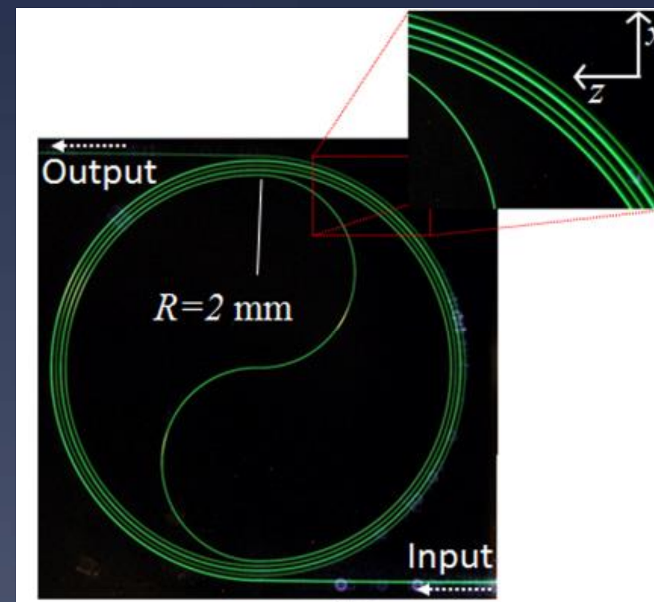
[*]*s.a.vazquezcordova-1@utwente.nl*



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

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High sensitivity pre-amplified coherent receiver

Demonstration of Record Sensitivities in Optically Preamplified Receivers by Combining PDM-QPSK and *M*-Ary Pulse-Position Modulation

Xiang Liu, *Senior Member, IEEE, Fellow, OSA*, Thomas H. Wood, *Fellow, IEEE, Fellow, OSA*, Robert W. Tkach, *Fellow, IEEE, Fellow, OSA*, and S. Chandrasekhar, *Fellow, IEEE, Fellow, OSA*

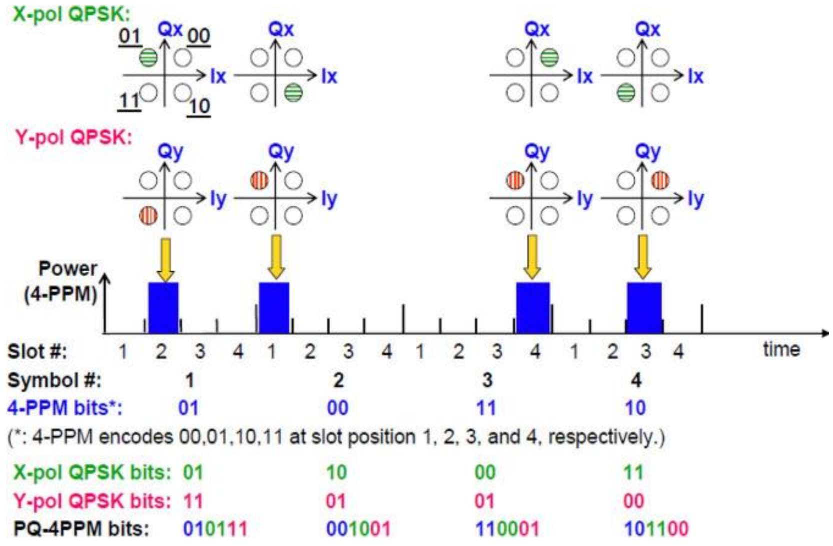


Fig. 1. Encoding of a PQ-4PPM signal.

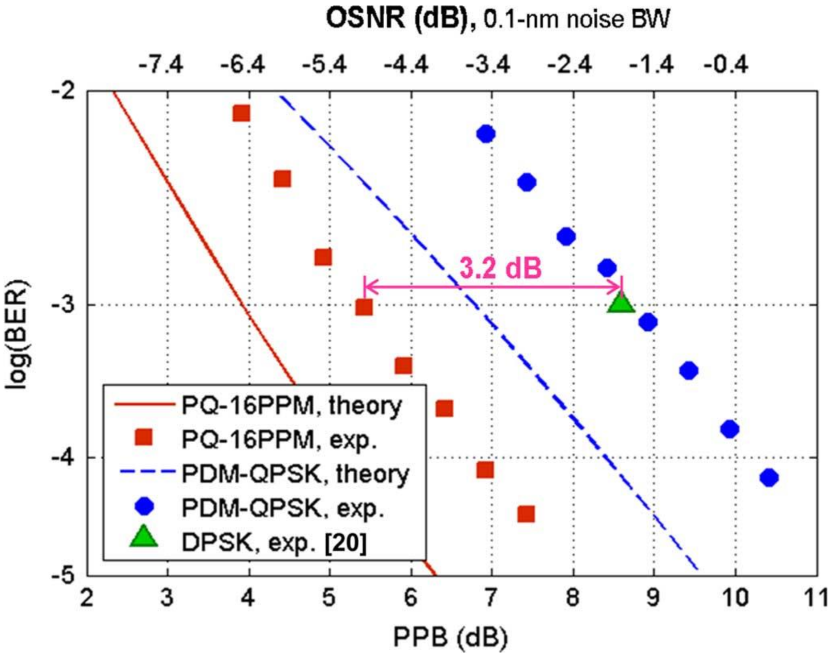


Fig. 11. Experimental BER performance of the 2.5 Gb/s PQ-16PPM signal as compared to PDM-QPSK.

Direct write waveguide fabrication

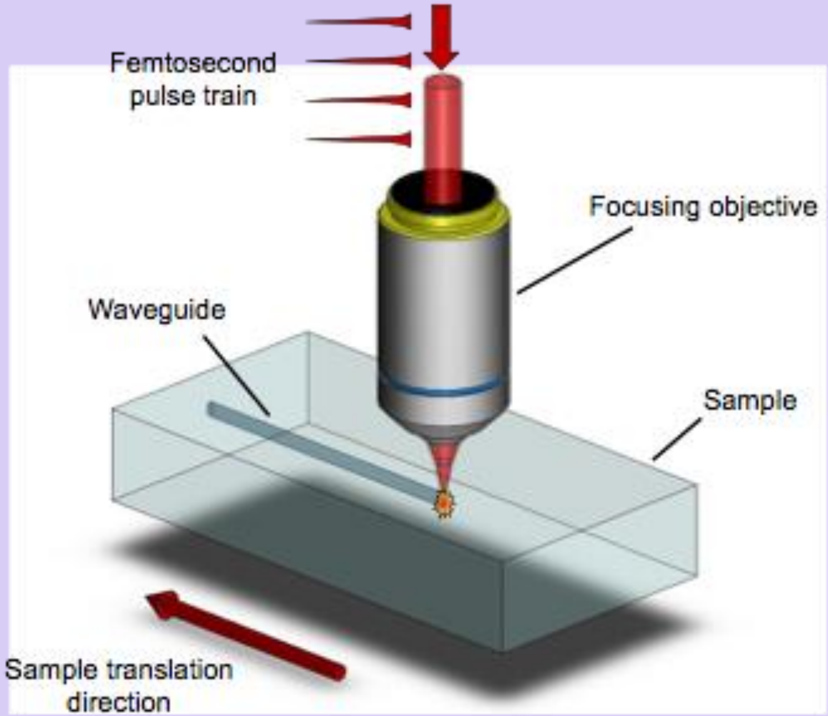
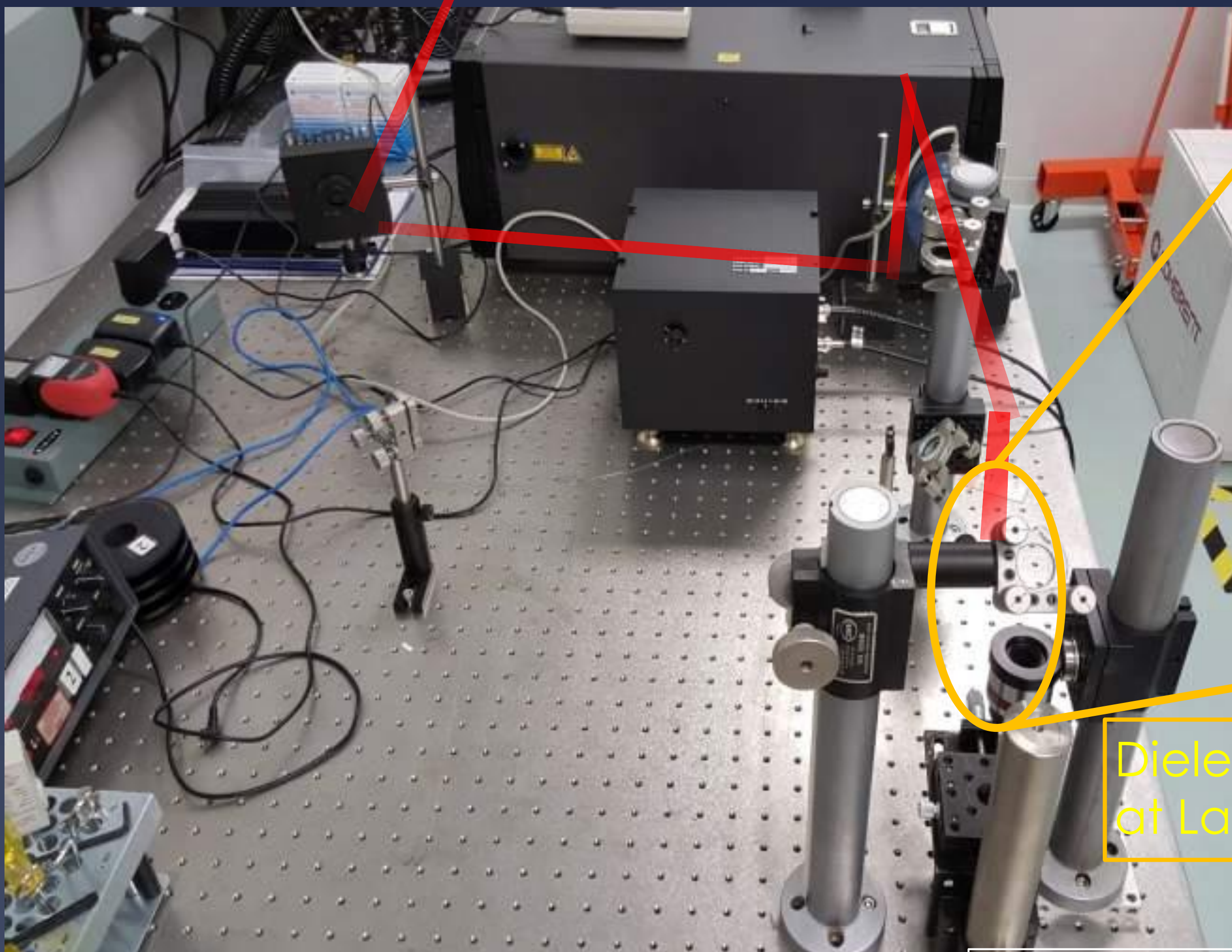


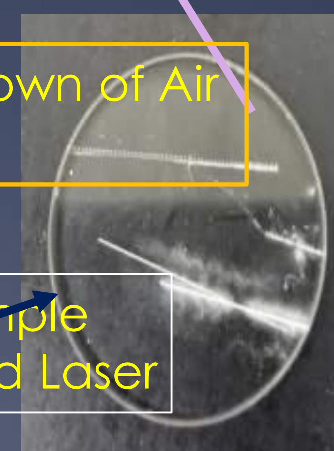
Figure 1. Ultrafast laser inscription setup: A femtosecond laser is tightly focused into the bulk of the sample, nonlinear breakdown occurs, which causes a localized material modification. By translating the sample with respect to the focal spot, arbitrary 3 dimensional structures can be inscribed.

Goddard Code 554

Femtosecond Direct-Write laser

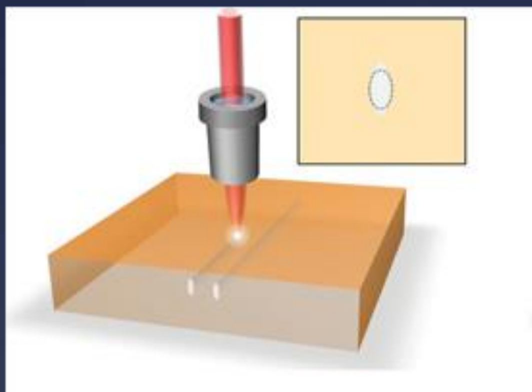


Dielectric Breakdown of Air at Laser Focus

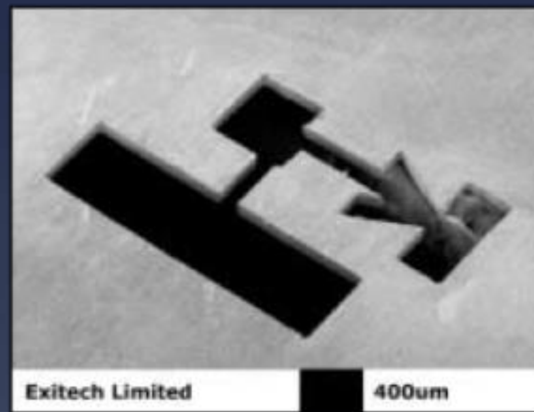


Fused Silica Witness Sample Etched by Femtosecond Laser

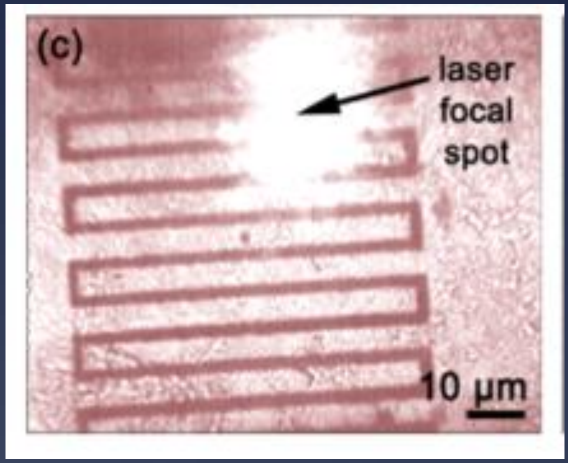
Direct-write laser system is multi-use



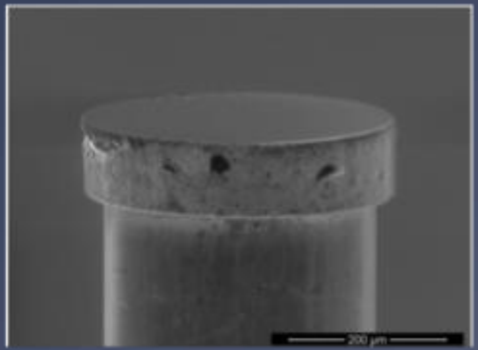
Optical waveguides



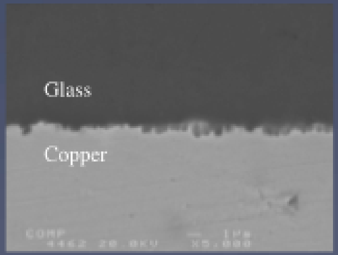
Precision Machining



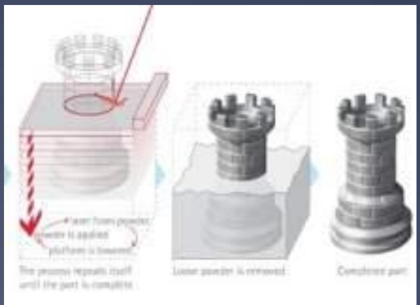
Patterning graphene



Milling/Bonding/welding glass



Glass/copper weld



Additive manufacturing with laser sintering (3D printer principle)

NASA Example 7 –
Making lasers with a laser

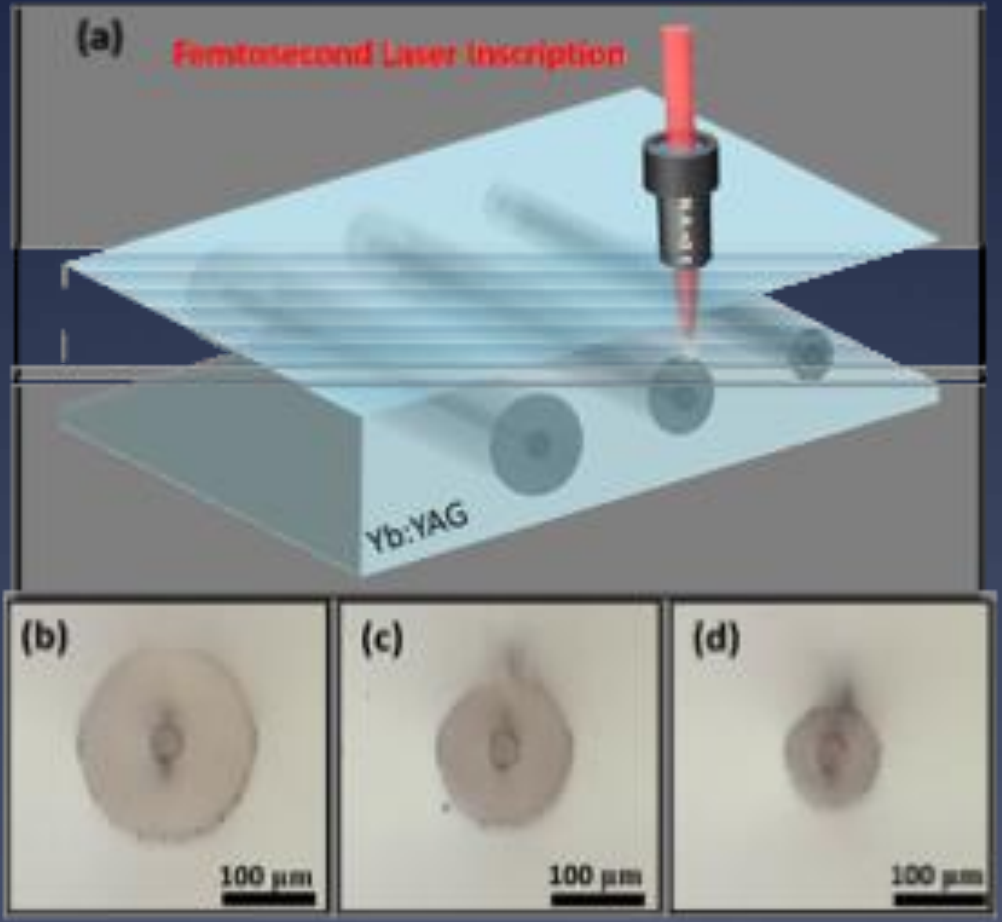


Fig. 1. (a) Schematic of fs-laser inscription process in Yb:YAG ceramics for the double cladding waveguides, and their cross sectional microscope images, which consist of tubular central structures with 30 μm diameter, and concentric larger size tubular claddings with diameters of (b) 200, (c) 150 and (d) 100 μm, respectively.

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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

NASA Integrated Photonics

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 improvements, radio astronomy and THz spectroscopy
- Telecom: inter and intra satellite communications.
  - Can obtain large leverage from industrial efforts.

Acknowledgments

NASA STMD

NASA SCaN

DoD IP-IMI

AETD colloquium

Thank you!