NASA Integrated Photonics

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***Abstract*— Photonic integrated circuits permit size, weight, power and cost reductions. This is particularly critical for spacecraft platforms. We review recent progress on integrated photonic circuits for NASA that industry and academia are developing for: (1) Sensors (2) Analog RF applications (3) Computing and free space communications.**

Keywords—photonic integrated circuits, lasers, detectors, waveguides

I. Introduction

The development of photonic integrated circuits permits size, weight, power and cost reductions for spacecraft microprocessors, communication buses, processor buses, advanced data processing, free space communications and integrated optic science instrument optical systems, subsystems and components. This is particularly critical for small spacecraft platforms.

II. Integrated Photonics for Space Communication

NASA is developing integrated photonics for space communication. There are several programs underway including: (1) "Ultra-Low Power CMOS-Compatible Integrated-Photonic Platform for Terabit-Scale Communications". In this project we exploit recent breakthrough 3D monolithic integration of photonic structures, particularly high-speed graphene-silicon devices on CMOS electronics to create CMOS-compatible high-bandwidth transceivers for ultra-low power Terabit-scale optical communications.

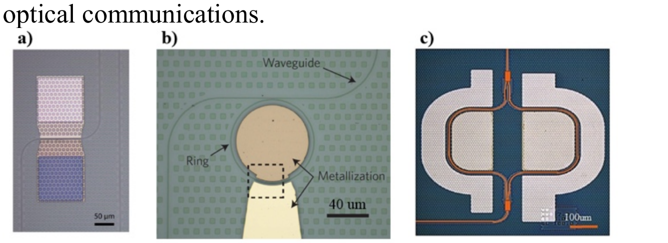

Fig. 1. a) Linear graphene absorption modulator b) Integrated graphene microring modulator c) Graphene phase modulator with minimal absorption variation

An integrated graphene electro-optic modulator has been demonstrated with a bandwidth of 30 GHz [1]. Integrated graphene modulators were also fabricated to operate in a phase modulation regime with minimal effects on the absorption, demonstrating the potential for graphene modulators to be employed for both amplitude and phase modulation.

Graphene microring modulators are especially attractive for dense wavelength division multiplexed (DWDM) systems. Experimental analysis of the intermodulation crosstalk for the graphene microring modulators show that 25 GHz channel spacings are supported, compared to 100 GHz channel spacings for a more traditional silicon photonic microring modulator [2].

(2) "PICULS: Photonic Integrated Circuits for Ultra-Low size, Weight, and Power."

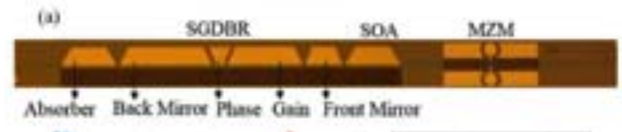

Fig. 2. (a) Schematic of SGDBR laser-modulator transmitter. SGDBR laser

This work [3] has been focused on high-performance indium phosphide (InP) PICs and hybrid integration of InP lasers/PICs with silicon photonics. The PIC demonstrates error-free (BER < 1e-9) for up to approximately 20 dB of free space attenuation, which corresponds to a link distance of 120 m.

(3) "Integrated Photonics for Adaptive Discrete Multi-Carrier Space-Based Optical Communication and Ranging".

This project (Fig. 3) has demonstrated generating a variable number of channels from a single laser using breadboard components, using a single-sideband carrier-suppressed (SSBCS) modulator driven by an externally-supplied RF tone (arbitrary RF frequency), a tunable optical bandpass filter, and an optical amplifier which are placed in a loop [4]. A microchip version which uses silicon photonics technology for all the components (except the optical amplifier) has been fabricated using a silicon foundry process (Sandia National Labs, Albuquerque, NM) and is currently being tested at UC San Diego.

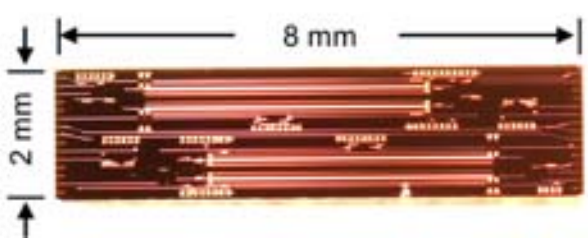

Fig. 3. (Photograph of silicon photonic microchip, which integrates the single-sideband suppressed carrier modulator, tunable optical bandpass filters, couplers, polarization filters, monitoring and stabilization points, and other required components except the amplifier and the seed laser.

(4) "Integrated Optical Transmitter for Space Based Applications." The Freedom Photonics PIC is based on an InP technology platform and includes a tunable laser, a Semiconductor Optical Amplifier (SOA), high-speed Mach-

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Zehnder Modulator (MZM), and an electroabsorption (EAM) modulator. Fig. 4 shows a photograph of the PIC on a carrier. See Reference [5] for modulation experiment results.

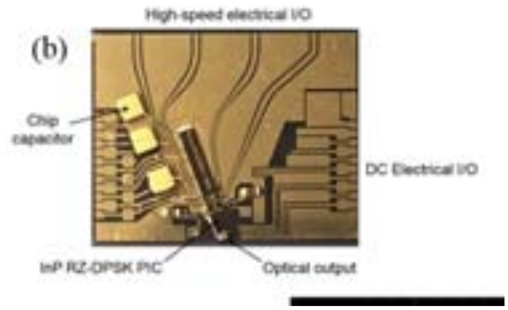

Fig. 4. RZ-DPSK transmitter PIC.

III. Integrated Photonics for Space Sensors

NASA is developing integrated photonics for space sensors. There are several programs underway including:

(1) "Multifunctional Integrated Photonic Lab-on-a-Chip for Astronaut Health Monitoring" In this Small Business technology Transfer (STTR) program, an innovative miniaturized *lab-on-a-chip* device is being developed to directly monitor astronaut health during missions using ~3 drops of body fluid sample like blood, urine [1], and potentially other body fluids like saliva, sweat or tears. The first-generation system comprises a miniaturized biosensor based on PICs (including Vertical Cavity Surface Emitting Laser – VCSEL, photodetector and optical filters and biochemical assay that generates a fluorescent optical signal change in response to the target analyte [6].

(2) "Integrated Circuit (PIC) Photonic Spectrometer-on-a-Chip".

Fig. 5. SEM images showing key components of a MWIR PIC spectrometer fabricated in silicon include a combiner and an array of rib waveguides.

Nanohmics, Inc., in collaboration with researchers at the Catholic University of America (CUA), have begun the development of a low-cost, real-time spectrometer that demonstrates photonic IC spectroscopic capabilities in the MWIR spectral band, with no moving parts and extremely small size, weight, and power requirements (SWaP). [7]. Fig. 5 shows initial PIC waveguide components already fabricated as part of NASA STTR program in 2017.

IV. Integrated Photonic Circuits for Analog RF Applications

A SiN-platform integrated photonic circuit suitable for a spectrally pure chip-scale tunable opto-electronic RF oscillator (OEO) that can operate as a flywheel in high precision optical clock modules, as well as radio astronomy, spectroscopy, and local oscillator in radar and communications systems is needed.

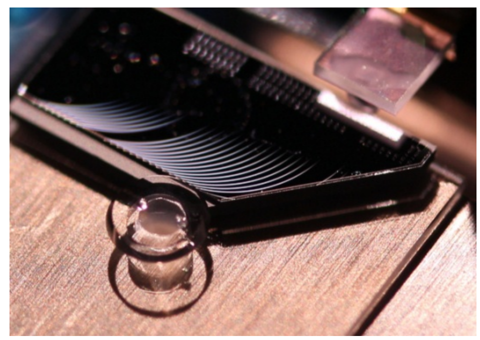

Figure 6: A high-Q MgF2 WGM resonator coupled with a low loss SiN waveguide.

In this NASA STTR program, OEwaves Inc., along with a UC Davis team, will demonstrate an integrated tunable Ka-band oscillator based on hyper-parametric optical oscillations in crystalline whispering gallery mode (WGM) resonators [8]. We have demonstrated [9] a low noise optical frequency combs generation from a small OEO prototypes containing very low loss (~1 dB) waveguide couplers of various shapes and sizes integrated with an ultrahigh-Q MgF2 resonators. The experiment is illustrated by Figure 6.

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