National Aeronautics and Space Administration

Integrated Photonics Fourier Transform Infrared spectrometer on chip

Principal Investigator: A. Soibel, 389G

Program: R&TD Innovative Spontaneous Concept Proposal

Project Objective:

Integrated photonics offer a new paradigm for manipulation of light using optical circuits and integration of photonic and electronic components on the same chip. The integrated photonics has potential to enable a new generation of low Size, Weight and Power (SWaP) infrared instruments for Earth and planetary applications. Novel infrared sensors, hyperspectral imagers and spectrometers utilizing integrated photonics will be simpler, smaller, lighter, and less expensive to produce than the current instruments. Moreover, integrated photonics will be not only applicable to the instrument, but to the whole spacecraft as well by providing new ways to communicate, monitor and control.

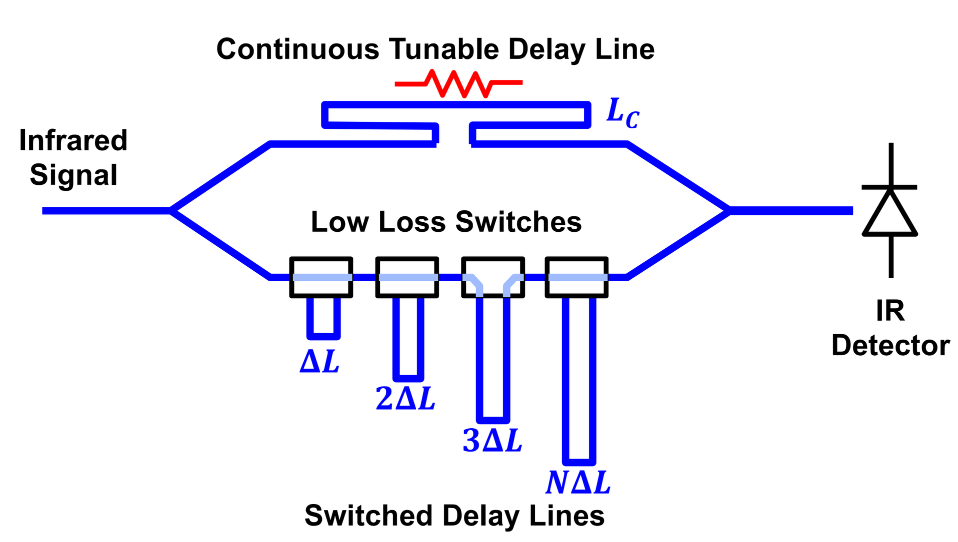

Figure 1. Schematic of the proposed of monolithic FTIR

We explored a revolutionary concept in monolithic Fourier Transform Infrared (FTIR) (Fig. 1) that is fully integrated with silicon photonic waveguides. The proposed FTIR consists of a Mach-Zehnder interferometer (MZI). A series of switched delay lines is inserted in one of the interferometric arms. The low-loss silicon photonic switches with MEMS-actuated vertical adiabatic coupler waveguides (Fig. 2) has been recently developed by Prof. M. Wu at UC Berkley. We already established a close collaboration with Prof. M. Wu who expressed interest to work with JPL on demonstration of this FTIR.

To bridge the gap between the discrete delay lines (and improve spectral resolution), a small section of continuously tunable delay line will be used. This delay line only needs to tune over the length of the shortest discrete delay, which is much shorter than the overall delay. It can be realized using either thermo-optic or electro-optic tuning. An equivalent moving mirror is realized by turning on the switched delay lines sequentially and sweeping the continuous delay line at each bias point. This FTIR can be monolithically integrated on silicon photonics platform, without macro moving parts.

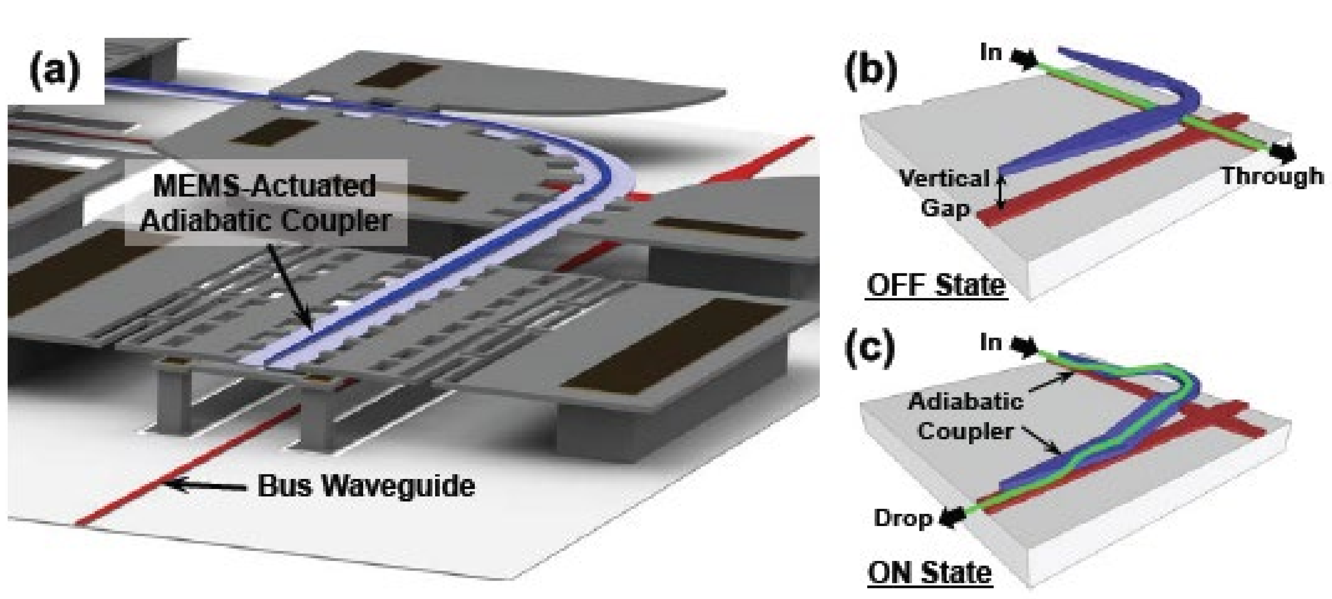

Figure 2.(a) Schematic of low-loss silicon photonic switch with MEMS-actuated vertical adiabatic coupler waveguides. The optical paths for the OFF and ON states are shown in (b) and (c), respectively

FY18/19 Results:

In this work we designed and analyzed key components of integrated Fourier Transform Infrared (FTIR) spectrometer such as waveguides, constant and tunable delay lines. We based design of the photonic circuit on the design of “Bus Waveguide” (Fig. 2) developed by our collaborators in UC Berkley for realization of silicon photonic switch with MEMS-actuated vertical adiabatic coupler waveguides These switches are used to route light into constant delay lines as shown in figure 1. Using the same “Bus waveguide” (Fig 3) allows us to use the developed switches without any modification of the design or fsbrication process.

We used commercially available Limerical photonics simulation software to create models of integrated photonics components. Lumerical MODE and FTDT packages were employed to design, model and optimize passive components such as waveguide, waveguide bends, splitters and couplers. Active component, such as continuous tunable delay line, based on pn depletion base shifter were simulated with DEVICE and MODE packages. The output of these simulations provides a complex scattering matrix, or S-matrix, that describes the relationship between its bidirectional ports as well as the relationship .between the modes supported. These component were imported into Lumerical INTERCONNECT package in which the S-parameter simulator calculates the overall frequency domain response of the circuit from the S-matrices of the individual elements. This allows to analyze performance of complex photonics circuits, such an integrated FTIR. . .
Below are results of the simulations:

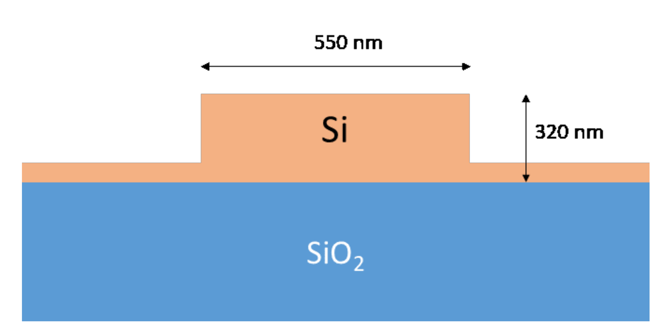

Figure 3. Cross section of “Bus waveguide”

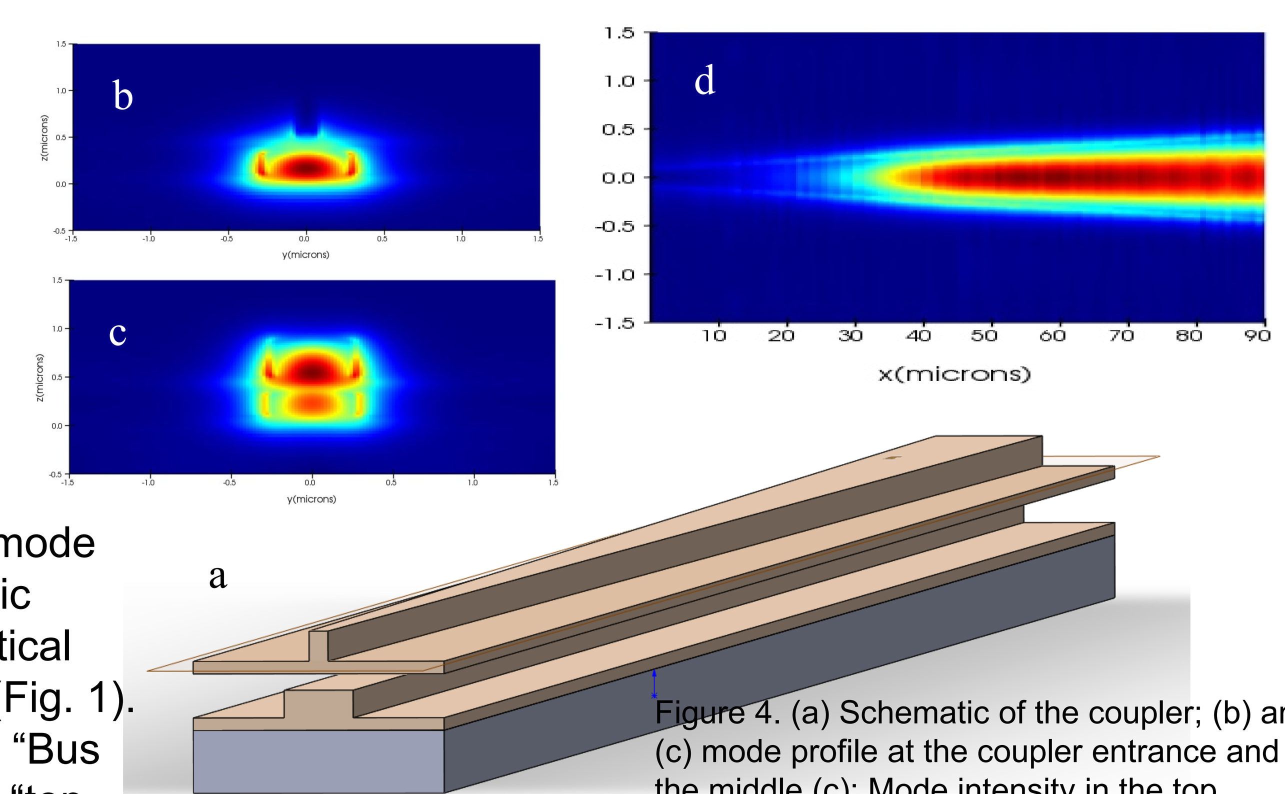

Figure 4 shows detailed geometry and mode analysis of the MEMS-Actuated adiabatic coupler (Fig. 2) designed for guiding optical mode in and out of switched delay line (Fig. 1). Optical mode propagating in the bottom “Bus waveguide” (Fig. 4b) is coupled into the “top waveguide” as shown in Fig. 4c and 4d.

Figure 4. (a) Schematic of the coupler; (b) and (c) mode profile at the coupler entrance and in the middle (c); Mode intensity in the top waveguide vs distance along the coupler showing mode transition from bottom into the top waveguide.

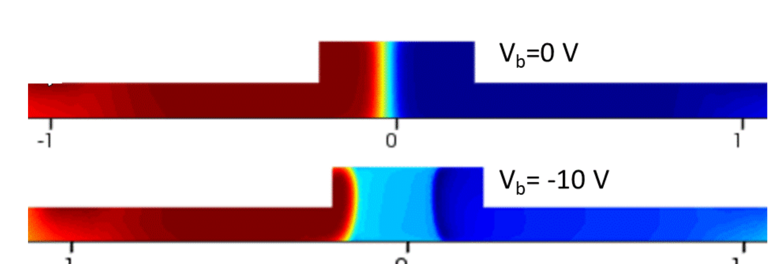

Figure 5. Charge distribution across pn shifter at various applied biases as indicated

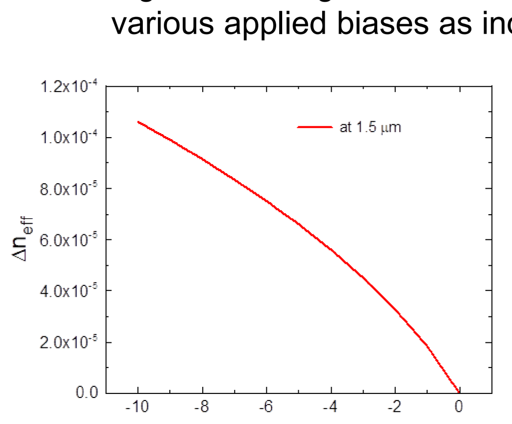

Figure 6. Change of the refractive index of the shifter vs applied bias

We designed and modeled continuous tunable delay line that is based on the Bus waveguide with a core into which p – and n-dopant are implanted to create pn junction. As shown in figure 5, application of electrical bias changes the carrier distribution across the junctions and modifies the refractive index (Fig. 6). We performed initial analysis of the refractive index and optical loss change with doping and applied bias. The resulting S-matrix was then imported into INTERCONNECT.

Figure 7 shows INTERCONNECT layout of photonic circuit of integrated FTIR, which consists of Y-splitters, direct and bend waveguides and tunable delay line in one of the arms. We performed initial analysis of the FTIR performance as presented in figure 8 that shows transmission through the FTIR at zero applied bias on the delay line.

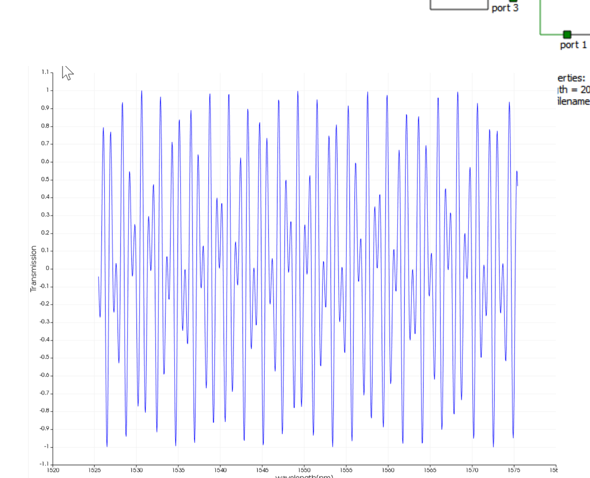

Figure 8. Modeled transmission through FTIR

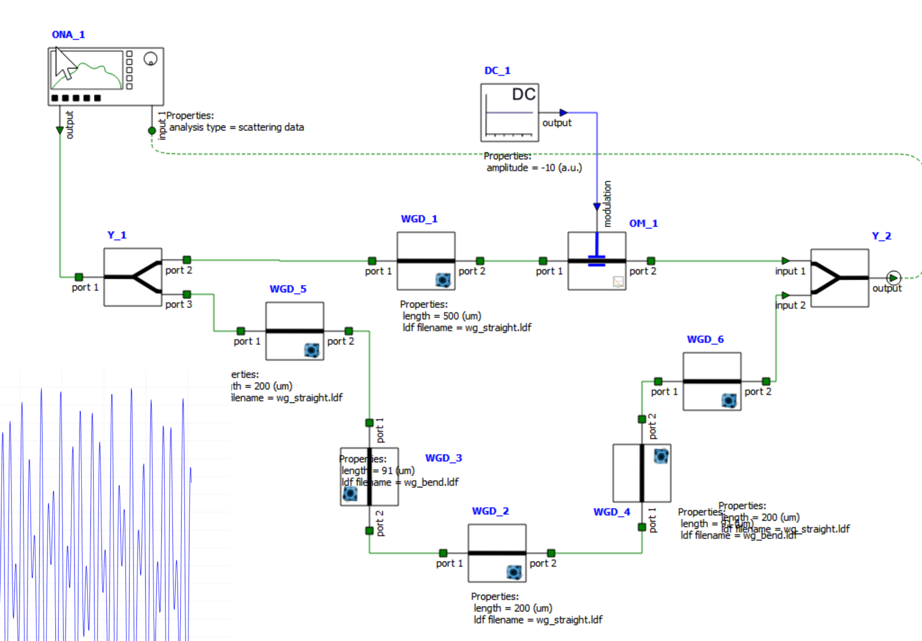

Figure 7. INTERCONNECT layout of photonic circuit of integrated FTIR.

Benefits to NASA and JPL:

This development has potential to enable new generation of compact spectrometer for detection of H_2O, CO_2 and various hydroxide containing compounds (e. g. Fe-hydroxide) on Moon, Mars, asteroids and icy bodies with hydrothermal activity that can be deployed on next generation of mobile platforms such as surface probes, PUFFER, small helicopter, etc.

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Poster No. 40