National Aeronautics and Space Administration

Development of Lithium-Niobate-on-Insulator Waveguides for Nonlinear Integrated Photonics

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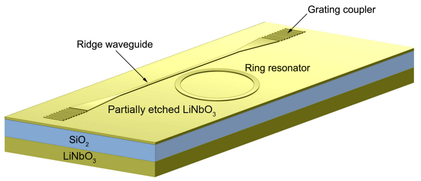
Program: R&TD Innovative Spontaneous Concepts

Project Objective:

The objective of this work was to develop a process to fabricate photonic waveguides in lithium-niobate-on-insulator (LNOI) with low propagation loss and high optical confinement as a compact platform for a broad range of photonic devices of interest to JPL. For Lithium niobate ($LiNbO_3$) is a key material in the photonics industry due to its wide spectral transparency, low intrinsic loss, and large second-order nonlinearity. However, traditional attempts to produce integrated waveguides in bulk LiNbO3 have suffered from low optical confinement, leading to relatively large components.



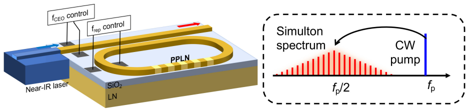
We have demonstrated micron-scale waveguides in thin-film LNOI with 1.5 dB/cm propagation loss, which are an essential building block for miniaturized high-speed modulators, photonic phased arrays, optical frequency combs, and parametric oscillators.

Benefits to NASA and JPL:

Leveraging this new technology at JPL, we are building stable on-chip frequency combs as a robust, miniaturized alternative to full-rack frequency standards for Very Long Baseline Interferometry.

The Atacama Large Millimeter Array used for long-baseline heterodyne imaging of celestial objects.

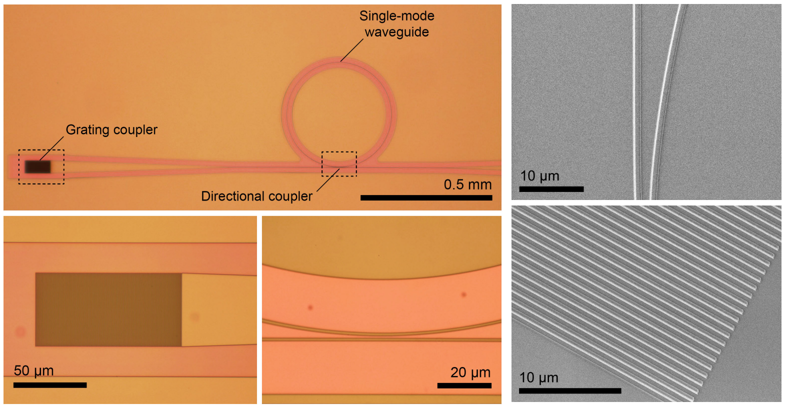
Simulton-based combs have been shown in table-top systems to enable octave-spanning spectral coverage with phase locking to a relatively broad pump. With the on-chip LNOI platform, we are designing compact, integrated simulton combs capable of operating with semiconductor pump lasers (currently funded under the PDRDF program). This platform also enables other systems needed for space exploration, including visible/near-infrared astrocombs for spectrometer calibration, tunable spectroscopy sources, dynamic beam forming optics, and optical communications transceivers.



Concept for on-chip simulton frequency comb generation.

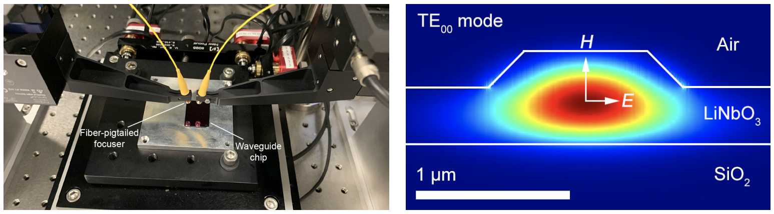
FY19 Results:

We developed a LNOI waveguide fabrication process using electron-beam lithography and high-bias plasma etching. We used LNOI wafers with a 700-nm-thick *x*-cut $LiNbO_3$ film on a 2-μm-thick SiO_2 isolation layer and a 500-μm-thick matched $LiNbO_3$ substrate. To validate the fabrication process, we patterned grating-coupled single-mode bus waveguides evanescently coupled to waveguide ring resonators designed for operation near 1.5 μm wavelength. The gratings enable coupling of light with free-space optics, which allows for rapid testing of many devices without packaging. By measuring the frequency response of the ring resonators, the waveguide propagation loss can be measured independent of free-space-to-chip coupling efficiency.



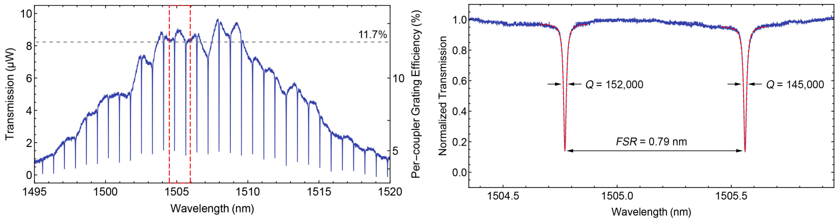
Optical and electron microscope images showing a JPL-fabricated LNOI waveguide device with gratings for free-space coupling and a ring resonator for characterizing waveguide loss.

Fabricated LNOI waveguide devices were characterized using a JPL custom-built waveguide testing setup. Light from a broadly tunable external-cavity diode laser was sent through a polarization controller and then focused into the input grating coupler of the device under testing using a fiber-pigtailed aspheric lens pair. The bus waveguide transmission was then collected from the output grating and sent to a near-infrared optical power meter. By sweeping the laser emission wavelength, we measured the frequency response of the bus waveguide and the evanescently coupled ring resonator.



The testing setup used to characterize waveguide devices near 1.5 μm wavelength (left), and the calculated field profile for the transverse-electric (TE) mode supported by the fabricated waveguide geometry (right).

The characterization of the fabricated LNOI waveguide revealed a maximum per-grating coupling efficiency of nearly 12% and typical loaded resonator quality factors (*Q*) of 150,000. Accounting for loss due to coupling to the bus waveguide, this corresponds to an intrinsic Q factor of 270,000 and propagation loss of 1.5 dB/cm.



Measured transmission spectrum of a fabricated LNOI waveguide device with a 200-μm-radius ring resonator.

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Poster No. RPC-184