Compact, Low Power, Visible Band Frequency Combs for Extreme Precision Radial Velocity Measurements

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Objectives

Our goal is to create a low-power, visible-band (400-800 nm), high repetition rate (~10-20 GHz) frequency comb for precision radial velocity (PRV) spectrograph calibration. We are achieving this through sum frequency generation and nonlinear spectral broadening of frequency combs generated in the near-infrared (NIR) by integrating them with high second- and third-order nonlinear coefficient ($\chi^{(2)}$ and $\chi^{(3)}$) waveguides. We are targeting waveguide materials, including thin-film lithium niobate-on-insulator (LNOI) and aluminum nitride (AlN), that will enable a dramatic reduction in pulse power over that needed in state-of-the art NIR comb broadening technology based on silicon nitride, silicon oxide, and other materials that lack second-order nonlinearity. We are also developing fiber-coupled waveguide packaging and compact NIR pump combs to enable a field demonstration of a visible-band comb at the conclusion of this strategic effort.

Background

The NASA/NSF Extreme Precision Radial Velocity (EPRV) working group identified the development of robust, long-lived visible band spectrograph calibration sources as a critical technology in the search for habitable worlds. This Strategic R&TD effort combines expertise in the area of high-precision and high-accuracy frequency standards at JPL and among collaborators at NIST/CU Boulder, Caltech, and NRL to create a visible-band laser frequency comb for PRV spectrograph calibration starting in the NIR and progressing into visible wavelengths where most spectral content for solar-type stars is concentrated.

Significance/Benefits to JPL and NASA

- Detecting the 9 cm/s signature of an Earth-like planet orbiting a solar-analog requires precision and stability of ~1 cm/s over years
- Current solutions, particularly at visible wavelengths, are problematic in terms of output power, reliability, and resolution
- Ground-based observations may not achieve the necessary performance due to atmospheric noise; therefore, a space-based solution such as the EarthFinder mission may be needed
- This current effort will extend frequency comb capability in the NIR to visible wavelengths, and our integrated photonics approach is well-suited for space-based platforms

Approach and Results

This year, we focused on three main tasks to achieve visible-band, high repetition rate combs:

- Chirped upconversion using sum frequency generation in bulk lithium niobate waveguides with chirped poling (Fig. 1)
- Design, fabrication, and implementation of thin-film LNOI waveguides with periodic poling to achieve efficient simultaneous harmonic and supercontinuum generation (Fig. 2)
- Advancement of NIR combs as pump sources for waveguides generating visible combs, including the demonstration of a pulse rate multiplication device and fiber-pigtailed waveguides for NIR pre-broadening (Fig. 3)

Acknowledgments

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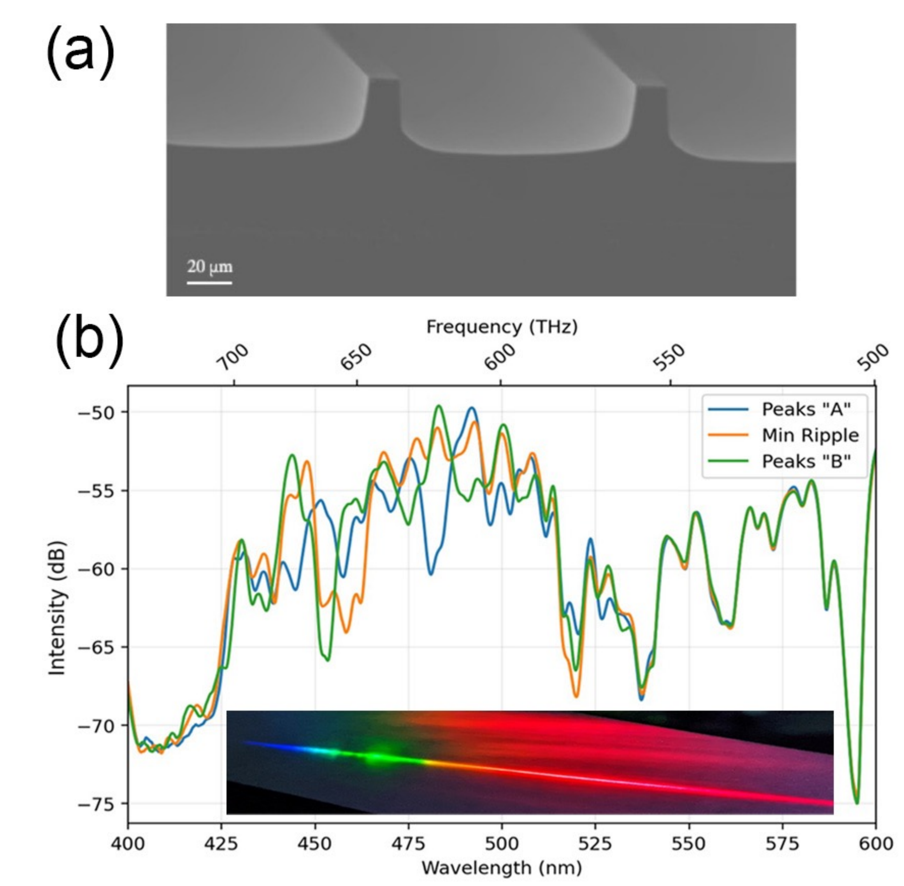

Figure 1. (a) Scanning electron micrograph of diffused bulk periodically poled lithium niobate (PPLN) waveguides used to demonstrate chirped sum frequency generation. (b) Measured visible spectra from PPLN waveguides.

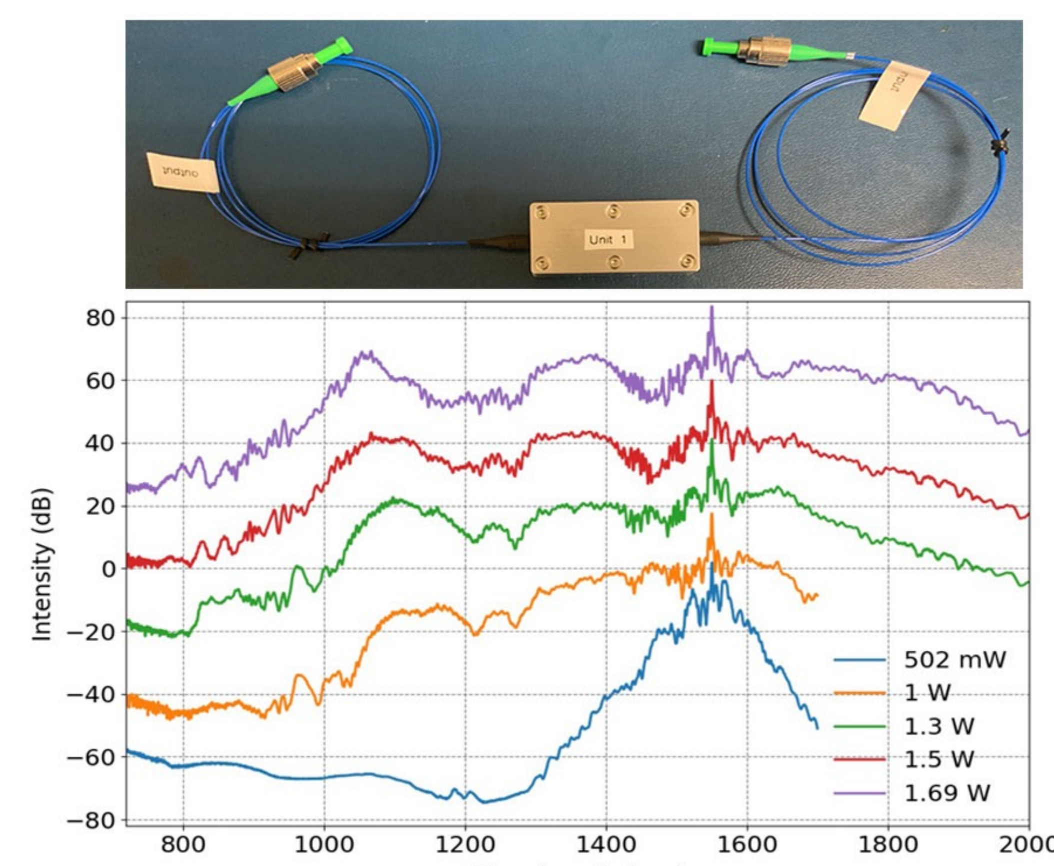

Figure 3. Fiber-pigtailed tantalum oxide waveguide packaged by Octave Photonics, and output spectra measured as a function of pump power with a 10 GHz input frequency comb centered at 1550 nm.

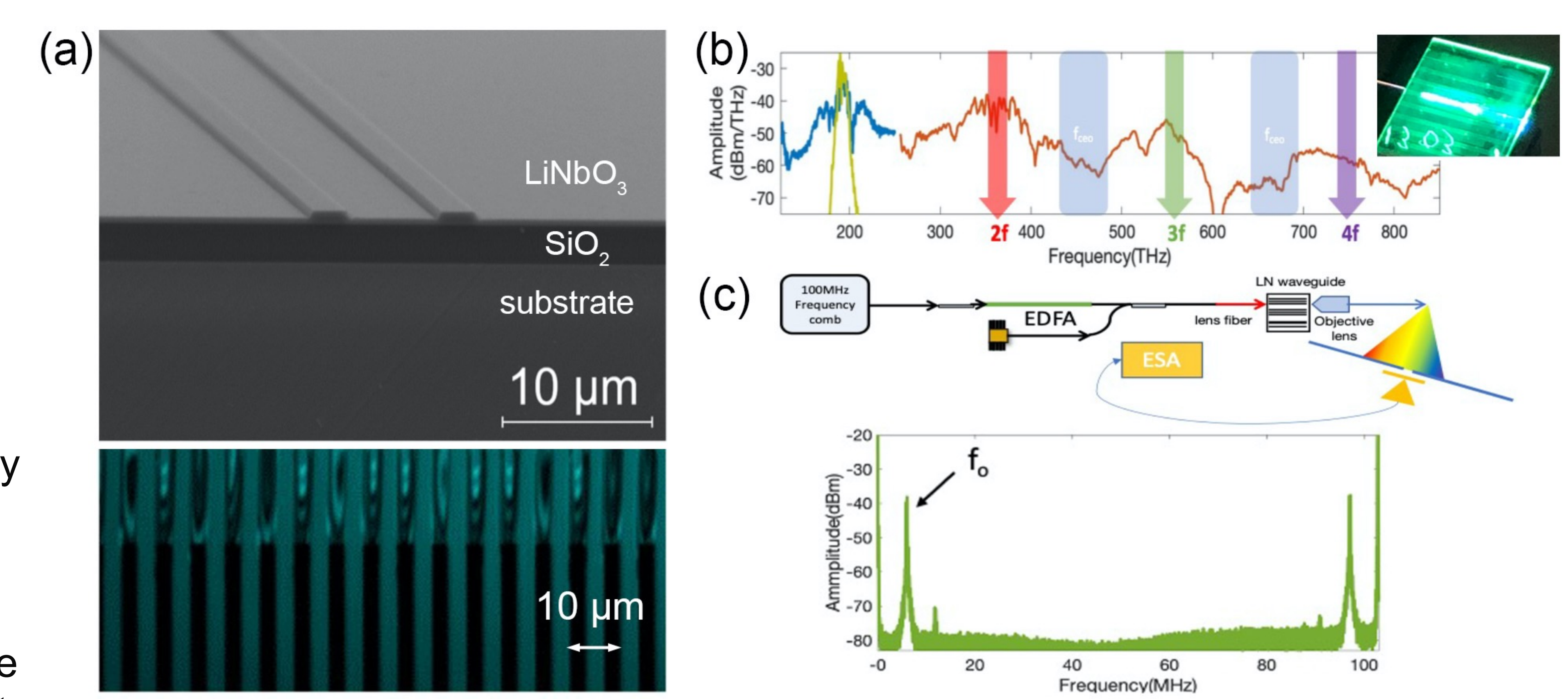

Figure 2. (a) Scanning electron micrograph of etched thin-film PPLN waveguides fabricated at Caltech, and a second-harmonic microscopy image showing periodic poling. (b) Emission spectra from a thin-film PPLN waveguide, measured at NIST/CU Boulder, showing supercontinuum generation from the NIR to ultraviolet wavelengths. (c) The measured beat note between components of the supercontinuum spectrum show the visible comb is coherent.

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