National Aeronautics and Space Administration

Thin-film lithium niobate integrated continuous-wave optical parametric amplifier for ultra-high-speed space-space/space-ground optical communications.

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Objectives:

To evaluate the feasibility of producing a novel on-chip optical parametric amplifier that can operate in the CW regime and can be designed for custom wavelength ranges.

Background:

Photonic integrated circuits promise a reduction in size, weight, and power consumption of optical modems used in crosslink communication between small spacecraft. This requires the integration of lasers, amplifiers, and modulators. The thin- film lithium niobate platform is a leading candidate for this integration since it supports fast electro-optic modulators and heterogeneous integration of diode lasers. However, high-power optical amplifiers remain to be demonstrated. The native gain mechanism in lithium niobate is parametric amplification in which energy from a pump laser can be transferred to a longer- wavelength signal under the correct phase-matching conditions. We have recently demonstrated optical parametric amplifiers in this platform, achieving record bandwidth and gain levels, but only using ultrafast pump pulses (<100 fs) which are not suitable for most applications that use arbitrary modulated waveforms. Translating these results to the continuous-wave (CW) regime poses a combination of challenges including low gain per unit length, phase matching bandwidth over long waveguides, and potential back-conversion from the signal wave towards the pump wave. Here, we propose a novel way to tackle these issues and produce on-chip amplification of modulated signals, including phase and amplitude modulation, like those used in coherent communication systems

Approach and Results:

- The key insight is that by attenuating the idler wave in an optical parametric oscillator, monotonic growth of the signal wave is possible (Figure 1).
- Attenuation is obtained by absorption in the silica buried oxide layer located just below the thin-film lithium niobate layer (Figure 2).
- Parametric amplifiers can be designed to operate in hard to reach wavelengths and over large bandwidth by engineering the waveguide dispersion (Figure 3).
- Using an incoherent pump generally results in signal fluctuations, but this topic requires further research (Figure 4).

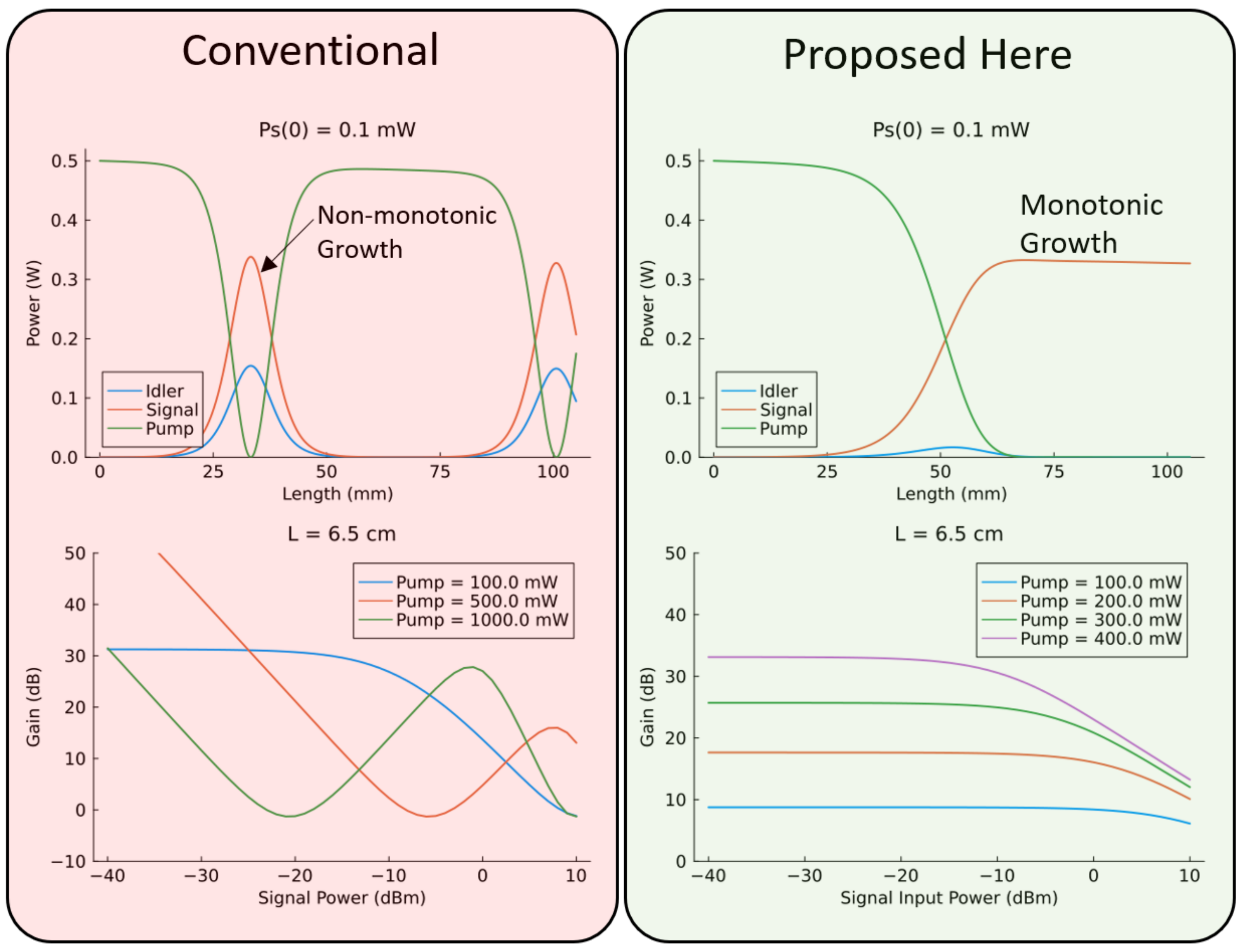

Figure 1. Conventional OPA compared to the implementation proposed here. In a conventional implementation, the flow of energy from the pump towards the signal is non-monotonic and the gain is a strong function of amplifier length, signal input level, and pump level. In our design, the growth of the signal is monotonic and the gain is a predictable function of the pump level.

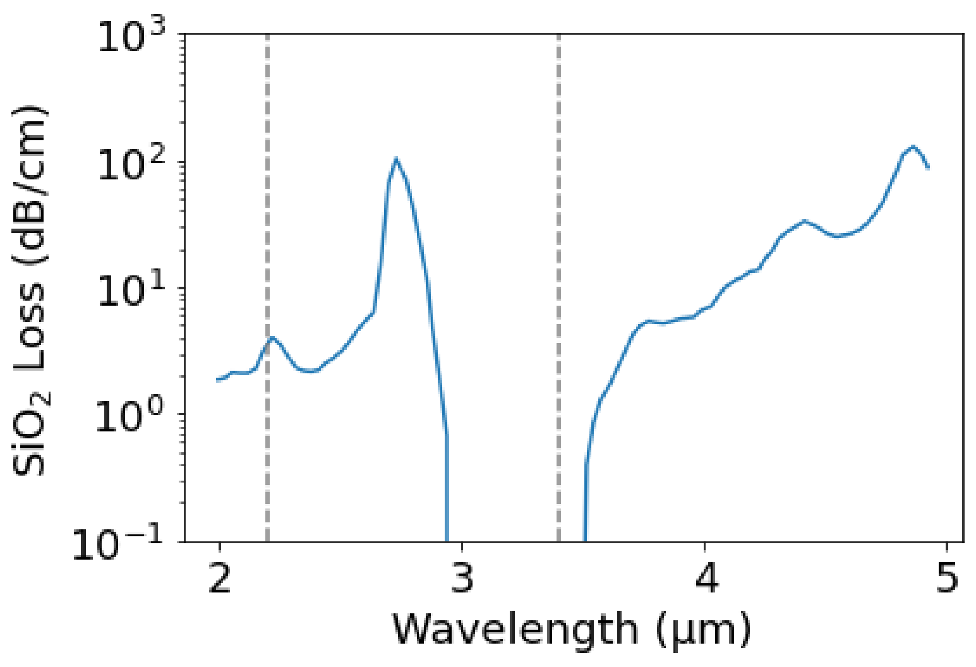

Figure 2. Loss of silica buried oxide layer, showing am absorption peak around 2.8 µm, and a wideband absorption window after 3.5 µm.

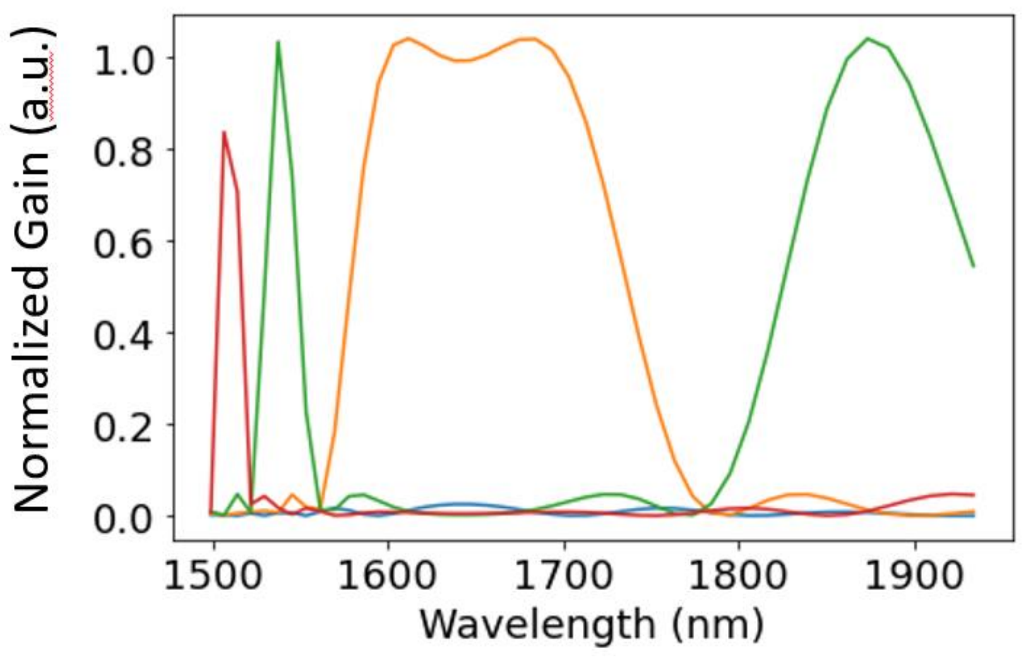

Figure 3. Normalized gain of several devices. Dispersion engineering allows large gain-bandwidths hard to obtain with other gain mechanisms. This example shows gain over the 1600 nm band, which lies outside the reach of gain based on Er-ion doping.

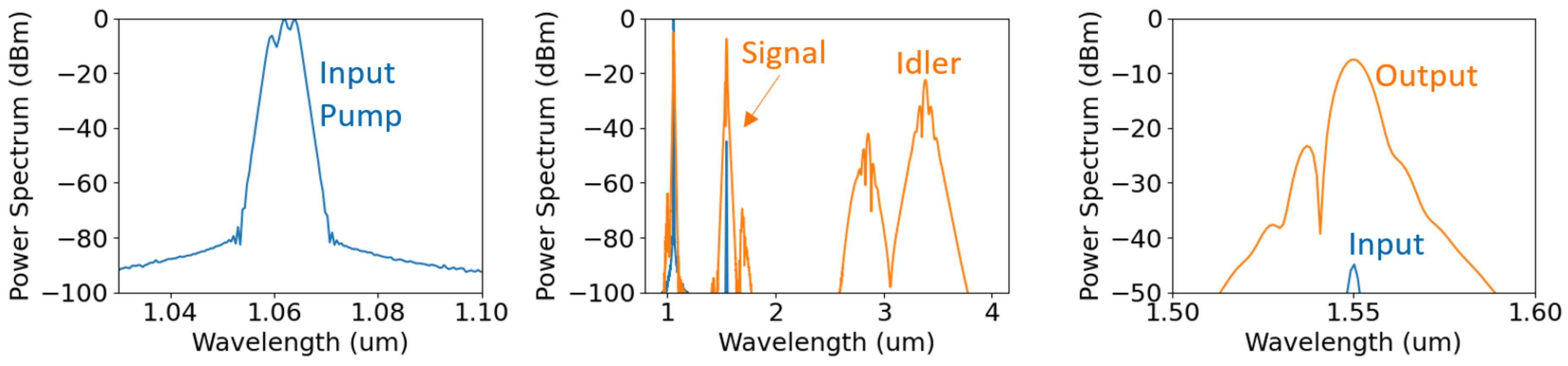

Figure 4. Nonlinear simulation using an incoherent pump. The idler initially inherits all the incoherence from the pump and then it is coupled to the signal.

Significance/Benefits to JPL and NASA:

The ability to produce integrated optical parametric amplifiers providing optical gain at unconventional wavelengths can enable a number of NASA applications, from communications over novel optical bands, to amplification of light for remote and in-situ sensing. While tabletop optical parametric amplifiers have already been considered for NASA applications, on-chip solutions promise lower size, weight and power requirements compatible with fly project requirements. We have shown that by removing the unwanted idler wave produced by parametric amplification, a monotonic amplification of the signal wave is obtained. Furthermore, this process also works when using incoherent pump sources, as the multimode behavior of the pump is transferred to the unwanted idler wave.

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