High-power 2-µm frequency combs for rapid greenhouse gas sensing

20th Anniversary Challenge OPTICA — Category: Environment

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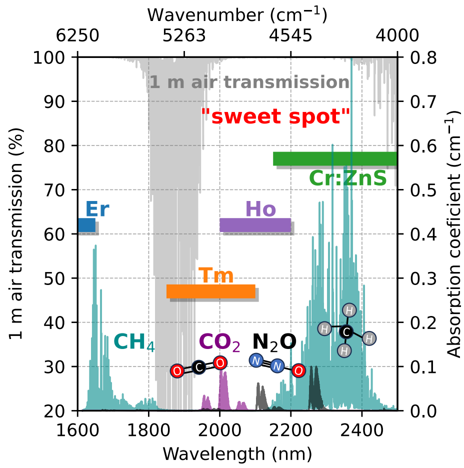
Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) compose 98% of global greenhouse gas emissions, and significantly contribute to global warming. Despite their importance, effectively understanding and monitoring regional emissions through sensitive remote detection of these gases remains challenging today. Dual-frequency-comb based remote sensing has emerged as a unique tool for this purpose in the 'eye-safe' wavelength range of 1.6 µm. Despite the remarkable progress in Er-fiber-based laser systems at this wavelength for this application, the 1.9-2.4 µm wavelength region offers potential advantages due to stronger absorption lines of the greenhouse gas, making it attractive for sensitive tracking of small concentration variations. I propose here employing a **high-power Ho-laser based frequency-comb system (HoLa-Comb) for rapid greenhouse gas detection**.



Laser emission range (1.6-2.5 µm) illustrated. Ho-laser operates at the 'sweet spot' for max. air transmission, covering both greenhouse gas lines.

The success of 2-µm rapid remote sensing relies on lasers meeting specific requirements: firstly, the air transmission at 2 µm is low due to water vapor in the atmosphere, necessitating **high average power** levels for long-distance remote sensing. Moreover, to cover the absorption band of the greenhouse gas (about 450 cm^{-1} from 2000-2200 nm), a sufficiently **broadband source** is needed. Additionally, **high repetition rate** is beneficial for measurement speed and detection sensitivity in dual-comb spectroscopy.

In this regard, Tm-, Ho-, and Cr-lasers emitting direct broadband pulses at 2-µm are desirable due to compactness, simplicity, and stability without nonlinear conversion stages or amplifiers. However, their average power is typically below Watt-scale, limiting long-distance remote detection. Ho-laser is operating at the "sweet spot" in this wavelength region, where air transmission is maximum, and the emission is possible to cover both gas absorption lines. Recently, we achieved significant milestones with Ho-laser, including a record-high average power mode-locked laser using all commercially available parts, as well as long-term stability and low-noise. Motivated by its outstanding performance and potential applications, I plan to develop a compact high-power single cavity dual-comb based on Ho-laser and polarization-multiplexing, named **HoLa-Comb**, and demonstrate the proof of concept for rapid greenhouse gas sensing.

The project's impact extends beyond greenhouse gas sensing, benefiting various fields such as next-gen MIR-spectroscopy for environmental monitoring and medical diagnostics, exploring the 2-µm waveband for communications, and enhancing GHz-burst fs-laser ablation at 2-µm, advancing precise material processing on silicon and transparent materials. We are currently exploring the option of creating a spin-off with our Ho-laser, and funding from this proposal is crucial to fully explore its commercial potential, establish a strong foundation for market entry, and drive innovative solutions that benefit society.