Tunable all-fiber laser for remote sensing of methane near 3.4 µm

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1. Introduction

As global warming causes permafrost to melt, it sometimes leaves behind thermokarst lakes rich in methane (CH_4), a climatically-active gas. To study the methane emissions from these lakes, climate scientists require a tool capable of measuring a wide range of gas concentrations over a large area with great precision and reliability. In this regard, mid-infrared all-fiber lasers, with their exceptional beam quality, power and portability, as well as their ability to target methane absorption lines up to 100 times stronger than in the near-infrared wavelength range, are prime candidates. However, while some previous experiments have targeted methane bands under 3.3 µm in wavelength, little work has been done to push fiber laser detection tools past 3.4 µm, where methane absorption lines are mostly decoupled from the absorption spectra of water vapour, readily found above lakes. Hence, we present a tunable all-fiber laser emitting near 3.43 µm and capable of remotely sensing methane with minimal detection tools.

2. Experimental setup

2.1 Tunable laser system

- Dual-pumped laser design[1] (1976 nm pump in the fiber core and 976 nm pump in the cladding) employing a singlemode erbium-doped ZBLAN fiber
- Laser cavity formed by a narrowband, highly reflective input fiber Bragg grating (HR-FBG) which dictates laser wavelength and a broadband, low reflectivity output coupler (LR-FBG) to accommodate wavelength tunability
- Tunability is achieved by mechanically stretching the HR-FBG by bending its affixed groove with a piezoelectric actuator (PA)

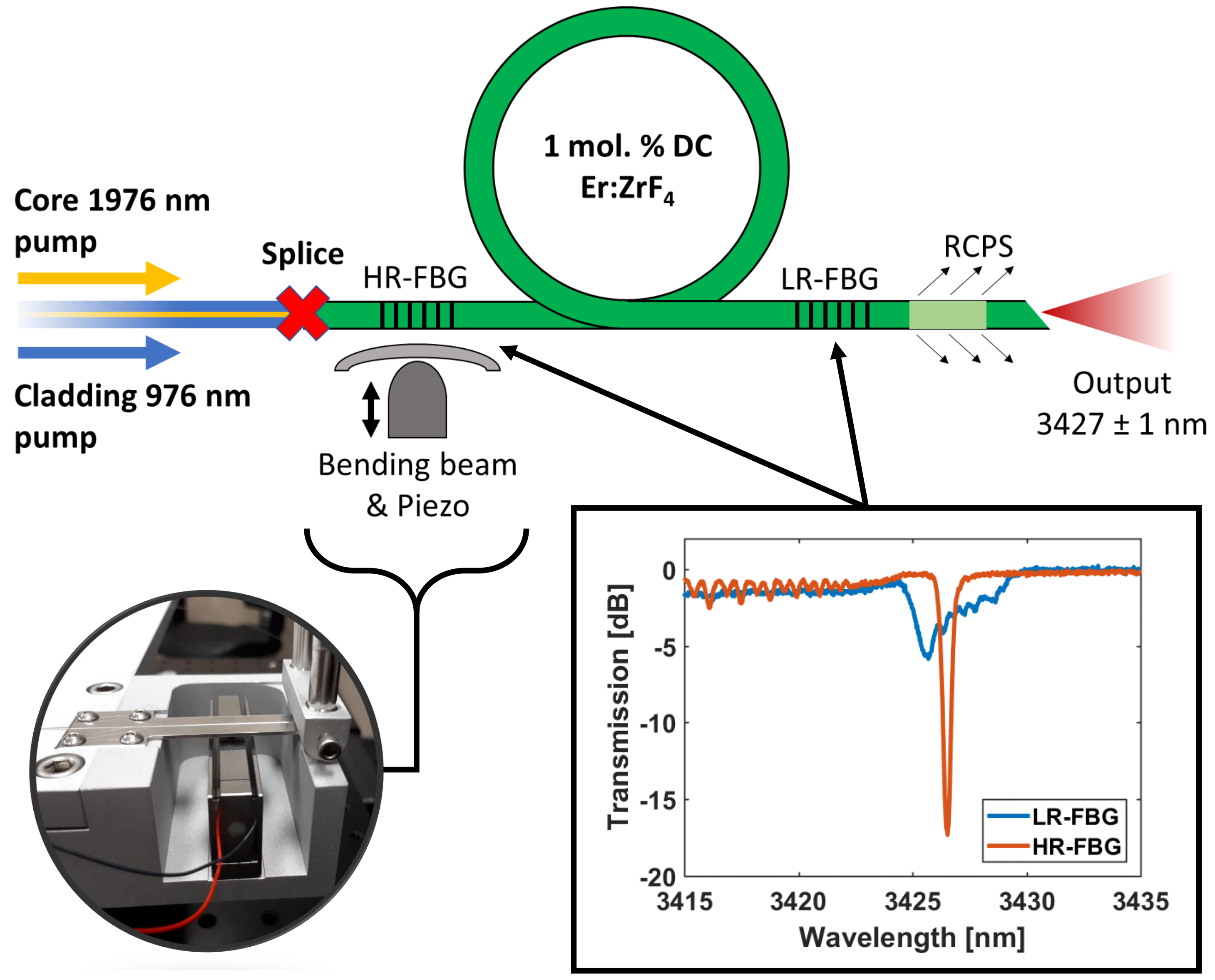

Figure 1. Experimental setup of the tunable laser. A close-up of the tuning system is shown on the bottom left, while FBG spectra are shown on the bottom right. RCPS= Recoated Cladding Pump Stripper.

2.2 Gas sensing benchmarking

- A gas cell is filled with various quantities of methane and argon (noble gas) to simulate different gas concentrations at atmospheric pressure
- Two power detectors are used: one to measure laser power after the gas cell ("external" detector) and one to account for any variation in initial laser power ("internal" detector)

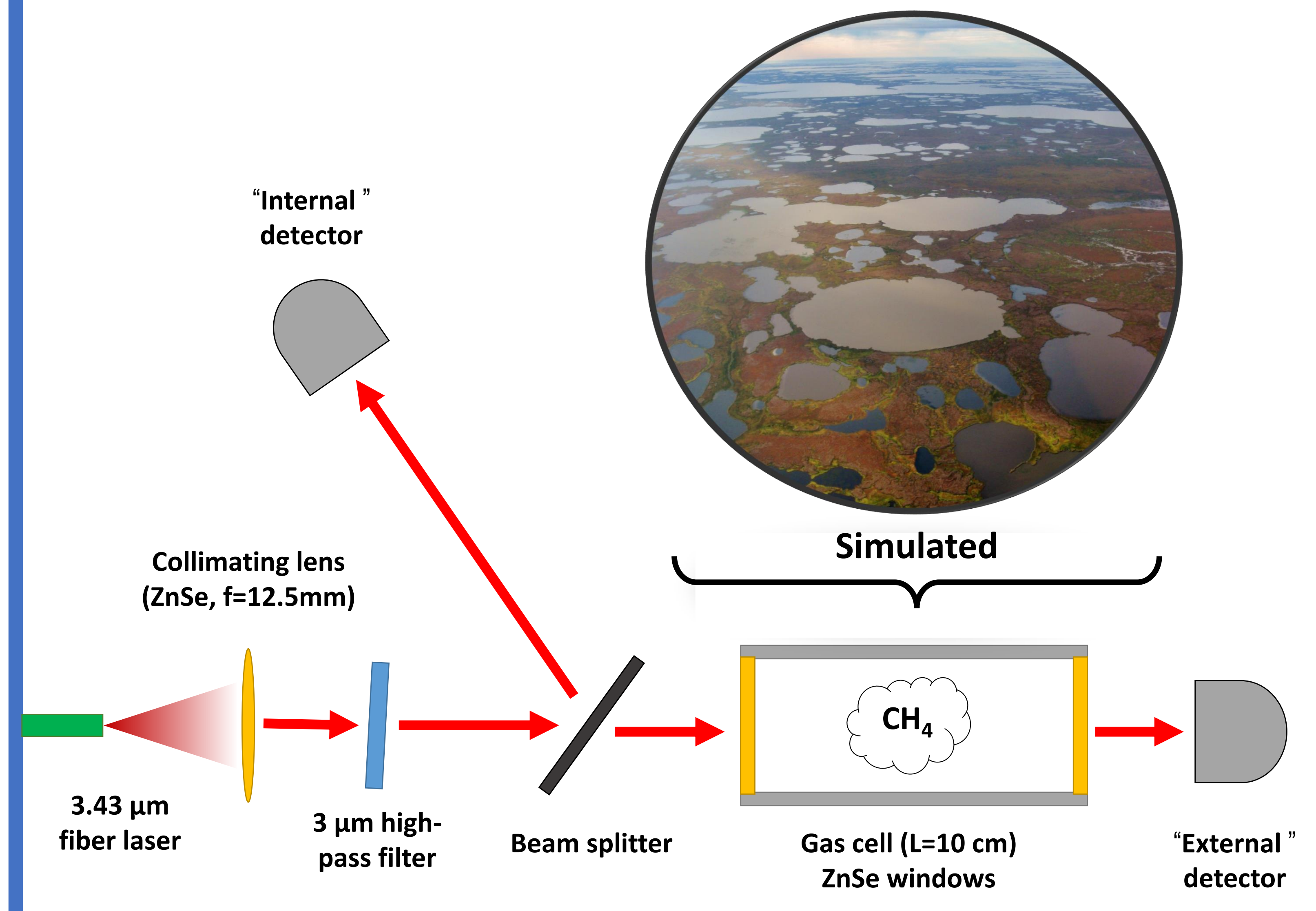

Figure 2. In-lab setup for experiments with a simulated environment in a gas cell.

3. Results

3.1 Tunable laser performance

- Enough power (3 W) to enable long-distance sensing or diffused lighting over a large field of view for selective camera-based detection
- Laser linewidth (<0.3 nm) comparable with methane absorption linewidth
- Electronically-controlled tuning in a 2 nm range
- Tuning reaches extrema (min-max) of the methane spectrum, which allows self-referencing during each tuning cycle

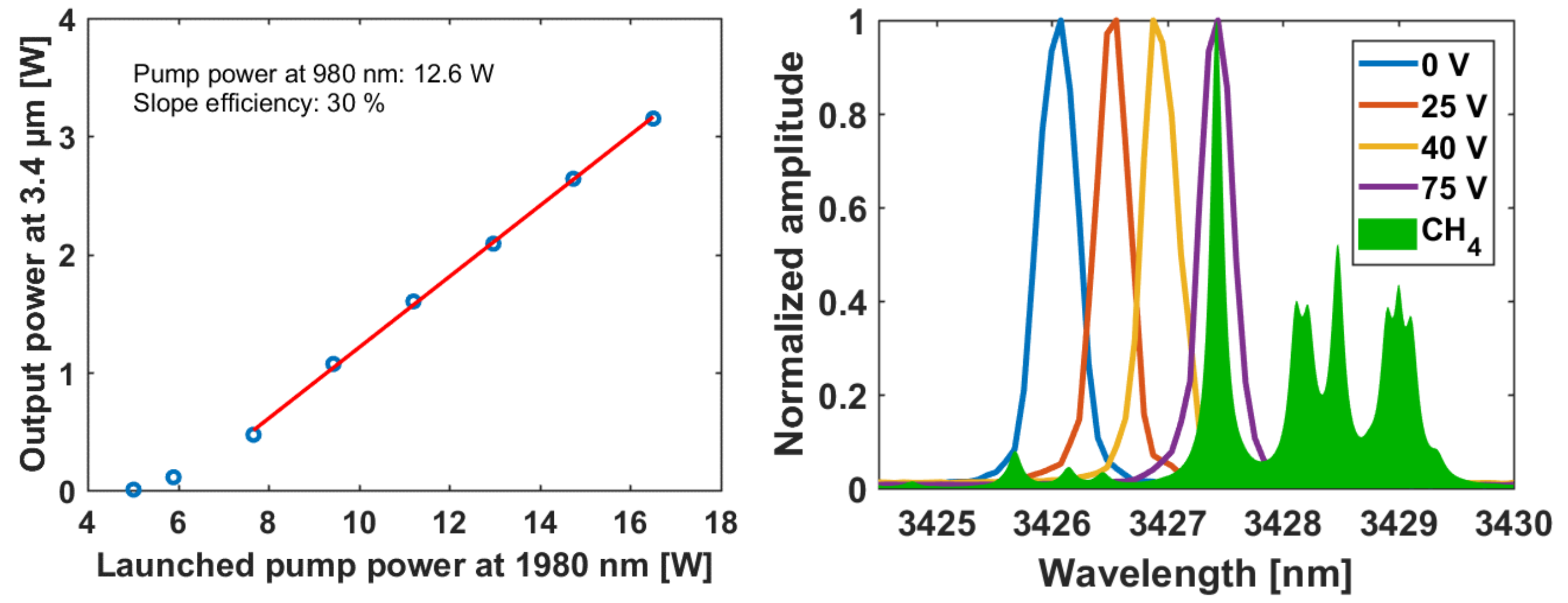

Figure 3. (Left) Power curve of the laser for a given pump power at 980 nm. (Right) Tunable spectrum of the laser compared with the absorption spectrum of methane[2]. Actual laser linewidth is smaller than shown (<0.3 nm), the graph being limited by spectral measurement resolution.

3.2 Early gas sensing results and outlook

- Good theoretical agreement and reliable gas detection down to about 1000 ppm · m.
- Despite saturation at 13% CH_4, the system is sensible enough to gather data points along the profile of the absorption line.

As the lowest methane concentration expected in the field is the normal atmospheric concentration of ~1.7 ppm, the current system would thus require at least 600 meters of total laser path length for compliant operation. While this may be manageable in the field, a tenfold improvement is still desired to encompass various lake sizes and topologies. Such an improvement should be attained in the coming months by using a higher performance detector, controlling the laser polarization, improving FBG spectrum, and all-together improving the stability of the laser.

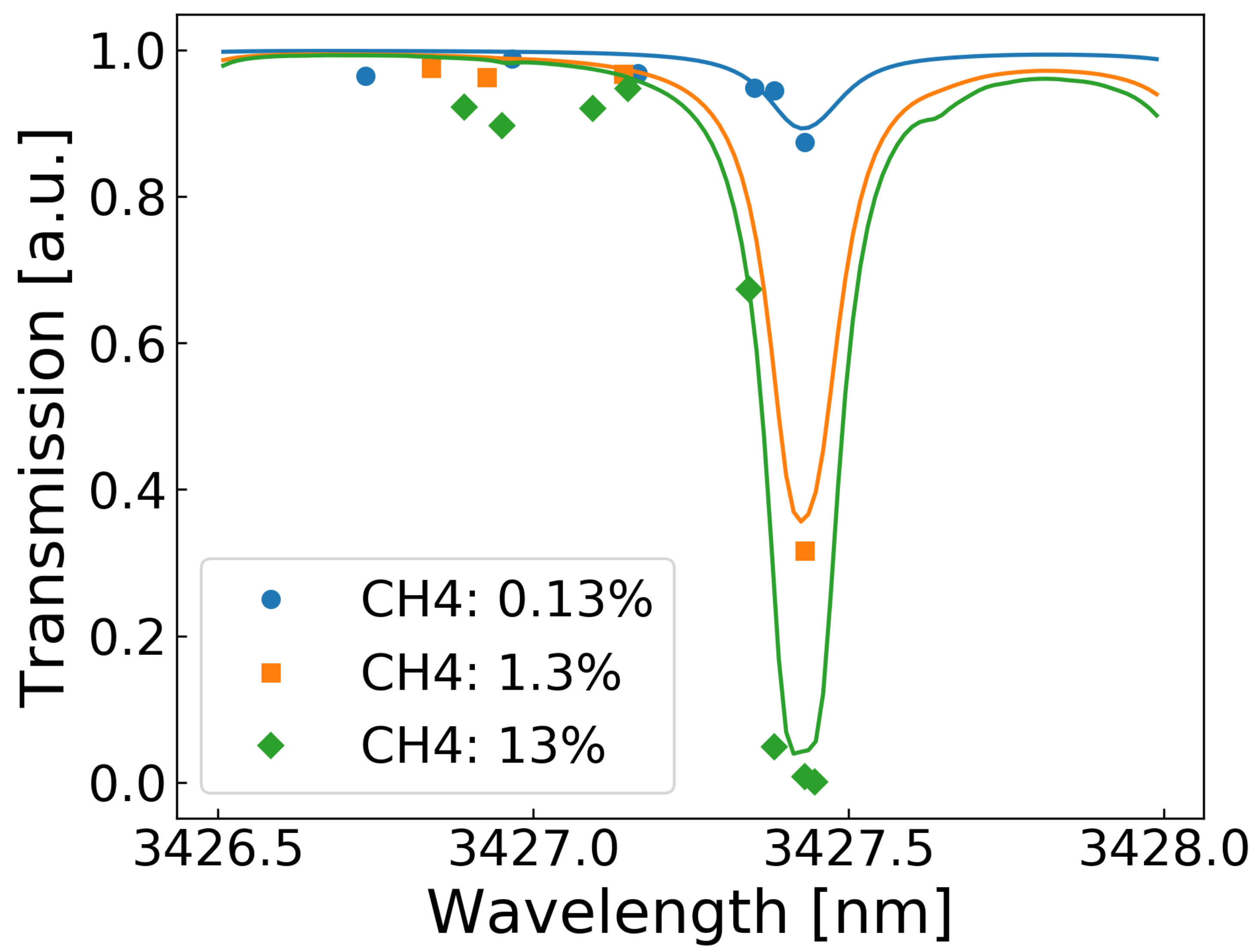

Figure 4. Wavelength-dependent laser transmission through the gas cell at various methane concentrations and atmospheric pressure. Continuous lines are theoretical fits based on HITRAN simulations.

4. Conclusion

We have demonstrated 1000 ppm·m methane sensing from a singlemode tunable all-fiber laser emitting near 3.43 µm in the mid-infrared. We expect near-future work to improve these detection capabilities several times, while the high power (3 W) of the laser will enable selective lighting for further camera-based experiments.

References

[1] F. Maes et al., Opt. Lett. 42, 2054 (2017).
[2] I.E. Gordon et al., J. Quant. Spectrosc. Radiat. Transfer. 203, 3-69 (2017).

Acknowledgements

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