LED-based Sensing of Hydrogen and Hydrocarbon Blends in Pipelines

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Introduction

- There is a **critical technology gap for H_2 metering** in a decarbonized natural gas network.
- Current H_2 sensing technologies **lack the necessary speed, accuracy (<1%), selectivity, and cost-effectiveness**, particularly for high-concentration applications.
- Our proposed approach introduces a new solution based on collision-induced infrared absorption that will lead to **the first low-cost optical sensors for direct measurement of H_2 in fuel blends**

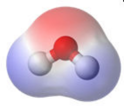
	Proposed Method	Gas Chromatography	Electrochemical	Raman Spectroscopy
Range	Moderate/Wide (40-100%) (potential to extend lower)	Wide (ppm to high percentage)	Moderate (ppm to low percentage)	Wide (ppm to high percentage)
Accuracy	High (≤1% absolute error)	High (<1% absolute error)	Moderate/High (≤5-10% relative error)	High (<1% absolute error)
Response	Fast (>1Hz up to kHz)	Slow (minutes to hours)	Moderate (seconds to minutes)	Fast (one to low seconds)
Affordability	Low Cost (<$1,000)	High Cost (>$10,000)	Low Cost (<$1,000)	High Cost (>$10,000)

Methodology

- **Infrared molecular absorption spectroscopy** is a well-established gas sensing technique that utilizes the resonant interaction between light and gas molecules with intrinsic electric dipole moment

$$\alpha(\nu) = -\ln\left(\frac{I}{I_0}\right) = \sigma(\nu)nL$$

*Molecular absorption scales **linearly** with density*



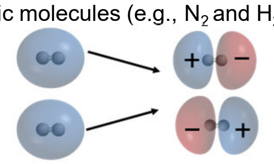
Electric dipole in H_2O due to asymmetry

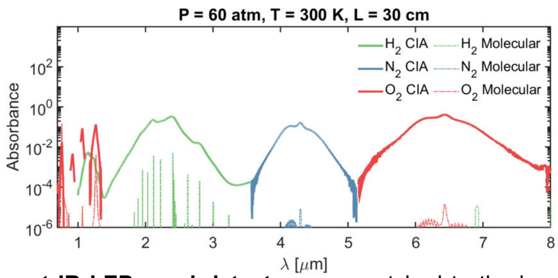
No dipole in Homonuclear diatoms (like N_2, O_2, and H_2)

- **Collision-induced absorption** (CIA) arises from transient electric dipole moments through collisions in dense gases and allows for direct sensing of homonuclear diatomic molecules (e.g., N_2 and H_2)

$$\alpha_{CIA}(\nu) = \sigma^{(2)}(\nu) \cdot n^2 \cdot L$$

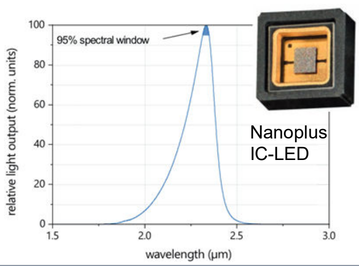
*CIA scales **quadratically** with density*





- **Low-cost IR LEDs and detectors** are matched to the broadband needs of the absorption band

Double heterostructure and Interband cascade LEDs

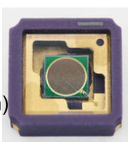


Nanoplus IC-LED

PbS detector (1-3 μm)

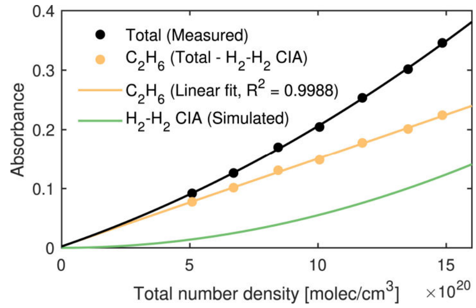
Agiltron

InGaAs detector (1-2.6 μm)



Results/Progress

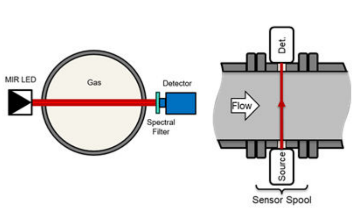
- **A multi-pressure sensing strategy** was developed to separate H_2 CIA from molecular interferences (scales linearly with pressure/density) in practical environments



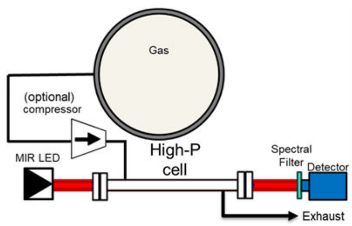
- Successful laboratory demonstration of hydrogen sensing in hydrogen/fuel blends[1]
- H2 measurement uncertainties <2% in multi-component fuel mixtures
- Preliminary tests and uncertainty analysis show promising results with potential applications in hydrogen technologies

Application	Pressure (Bar)	Temperature (°C)	H_2 concentration
National Grid	1.5-20	Ambient	0-6%
Gas Turbine	20-40	50-90	0-50%
Turquoise H_2 Production	1-30	250-400	50-100%
H_2 Membranes	40-60	150-300	80-100%

In-line Sensor Configuration



Sampling Sensor Configuration



Conclusion

A low-cost, real-time sensor for metering H_2-rich fuels is needed to overcome a critical technology gap impeding decarbonization of the natural gas network.

LED-based H_2-CIA sensors offer an elegant, low-cost solution that could be the core element of a distributed sensor network across the entire H_2 and natural gas grid.

Empower the safe & profitable use of decarbonized natural gas through intelligent sensing

1. **C. Wei***, A. Klingberg, C. L. Strand, & R. K. Hanson, *Measurement of hydrogen and nitrogen via collision-induced infrared absorption*, International Journal of Hydrogen Energy, 2024, doi.org/10.1016/j.ijhydene.2024.10.318.