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NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Distributed Fiber Optic Chemical Sensing for marine CO_2 Detection and Removal applications

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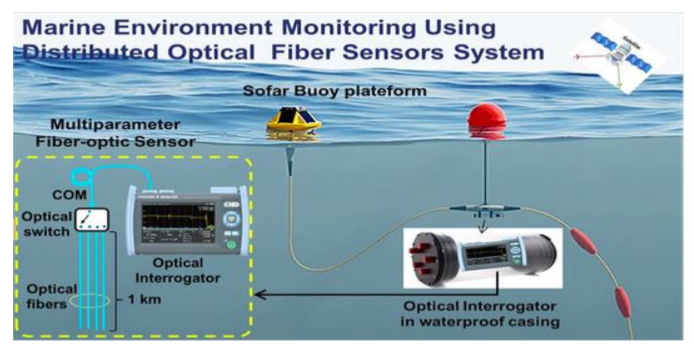
Introduction

Accurate, low-concentration CO_2 detection is crucial for environmental monitoring, particularly in oceanographic studies. Exceptional absorption of anthropogenic-derived CO_2 emissions has decreased the pH of the surface oceans, known as ocean acidification (OA) which will significantly impact the marine environment.

Fiber optic sensors which are immune to EM interference offer more stable distributed chemical sensing with high sensitivity, resolution as well as fast responses in extreme harsh conditions.



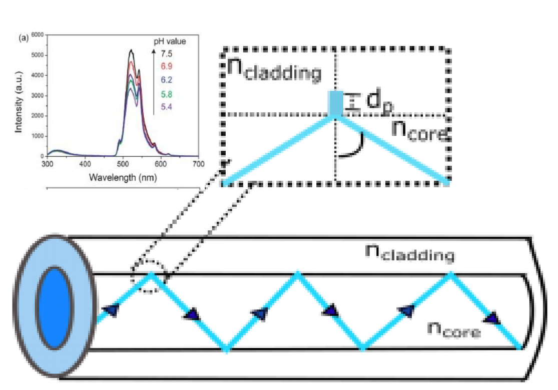
Research Objectives

- **Hybrid Distributed fiber optic pH and CO_2 Sensing for Monitoring and Verification of Marine Carbon Dioxide Removal Applications**
  - ➢ Quantitative characterization of carbon-related oceanographic properties
  - ➢ Distributed Chemical (pH and CO_2) Sensing (DCS) using sensing layer integrated fibers
  - ➢ Selection and synthesis of polymer-based sensing layers and additives for pH and CO_2 sensing
  - ➢ Demonstration of distributed pH and CO_2 sensing in seawater application

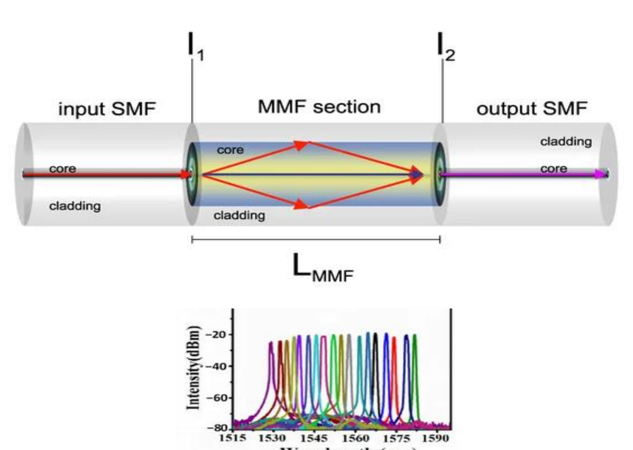
Initial specifications for evanescent-wave-based distributed sensing

	Distributed pH sensing	Distributed CO_2 sensing
Range	pH 5.00 - pH 9.00 (point)	200 – 1500 ppm (point)
Resolution	0.01 pH (point)	+/- 5 ppm (point)
Spatial range	≥ 1Km	≥ 1Km
Spatial resolution	≤ 5m	≤ 5m

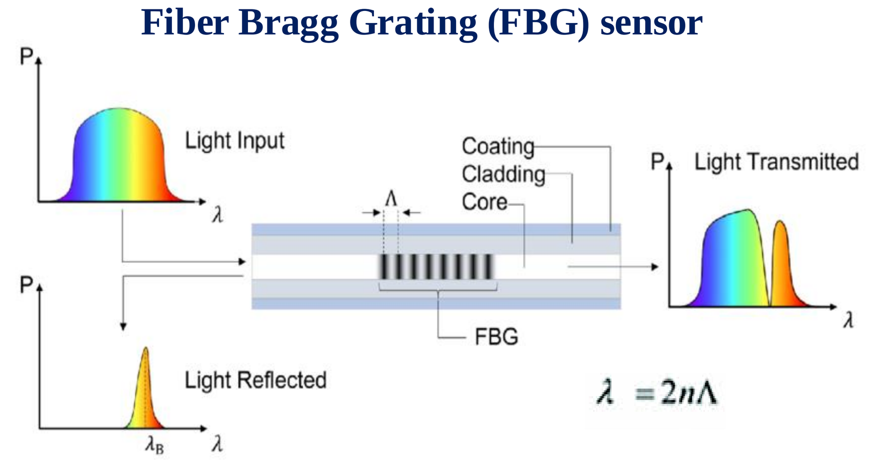
Evanescent wave absorption/ intensity based optic fiber sensor



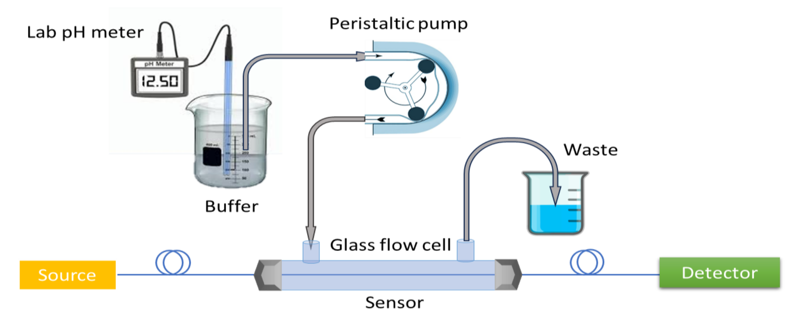
Interferometric/ wavelength based optic fiber sensor

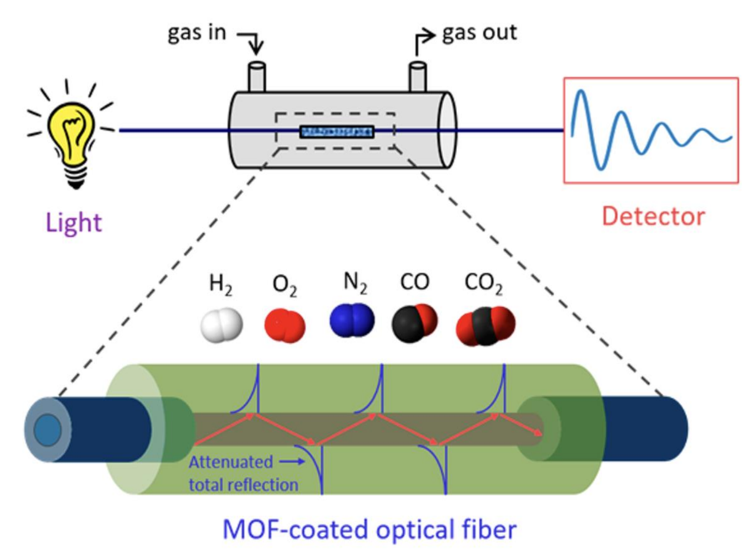


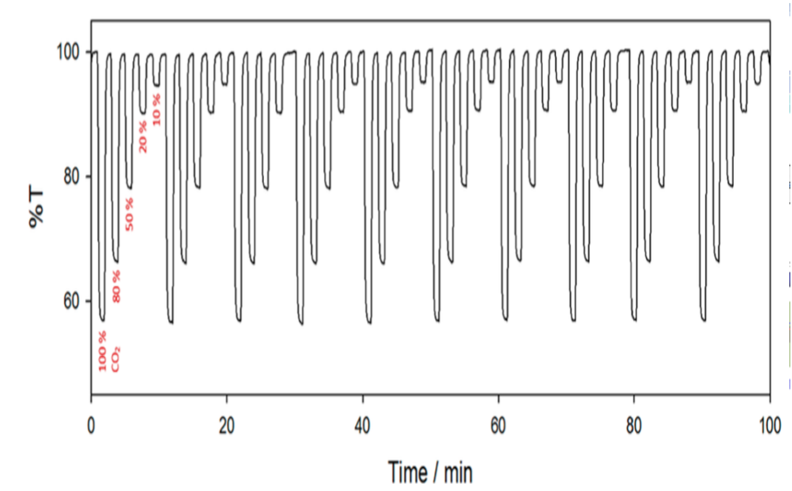
Fiber Bragg Grating (FBG) sensor



Sensing test setups



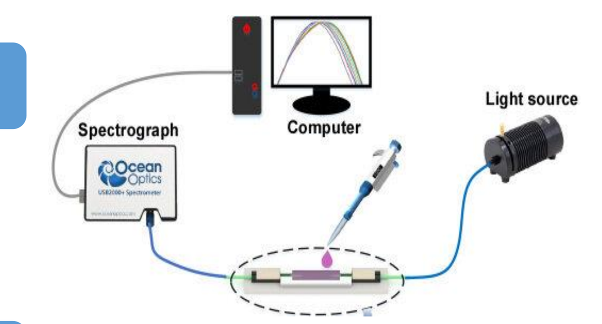




Primary pH sensing mechanisms

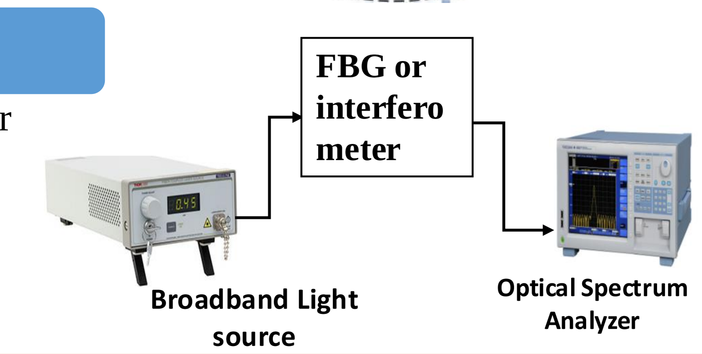
Absorbance-based pH sensing

- Principle: Change in absorption or fluorescence properties of a pH sensitive indicator results in a change in the intensity of the light transmitted through the fiber
- Sensing element: pH sensitive indicator
- Measured parameter: Intensity of transmitted light



Strain-based pH sensing

- Principle: Swelling or shrinking of pH sensitive material induces strain on the fiber causing change in refractive index and hence light propagation through the fiber
- Sensing element: pH sensitive hydrogel or polymer
- Measured parameter: Wavelength shift or intensity



Sensing materials for pH sensing

Sensing mechanism	pH sensing layer	Synthesis method	Compatibility with reel-to-reel coating	Advantages
Absorption-based	Base sensing layer matrix + indicator dye	Entrapment of indicator dye in sol gel matrix	Could be (Dip coating)	Promote hydrophobicity, reduce dye leaching, reduce film cracking, fast response
Strain-based	Swelling polymers	Oxidative polymerization	May not be (In situ polymerization)	Excellent environmental stability, resistance to solvent, Absorption coefficient in visible and NIR region
		Photopolymerization	Yes (Dip coating)	Excellent linearity over pH 5 – 9, stability, repeatability and fast response

Sensing materials for CO_2 sensing

Material	Refractive Index	Hydrophobicity	CO2 Detection Limit	Notable Properties
Polymer	~1.41	High	To Be Determined	Biocompatible, flexible
MOF (Metal-Organic Framework)	~1.4	Moderate	TBD	High surface area, tunable porosity

Synthesis of CO_2 sensing layer and coating

1. **Polymer Preparation**: Mix with curing agents at a certain weight ratio.
2. **Incorporation of Fillers**: Add **ten wt%** of MOFs; ensure thorough mixing.
3. **Coating**: Coat optical fiber with the mixed matrix material.
4. **Curing**: Cure the coated fiber in a controlled environment.

Future Work

- ➢ Conduct long-term testing to evaluate sensor stability in varying environmental conditions.
- ➢ Explore additional sensing materials compatible with reel-to-reel coating and demonstration of distributed sensing

References

1. https://pubs.acs.org/doi/abs/10.1021/acssensors.7b00808?ref=vi_sensors-and-industry
2. https://pubs.acs.org/doi/10.1021/acs.est.2c02723?ref=pdf

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