Real Time Carbon Dioxide (CO_2) Monitor in Rebreathers of Navy Divers

Polestar Technologies Inc.
220 Reservoir Street
Needham Heights , MA 02494

Principal Investigator:
Dr. R. Shashidhar, Senior VP, Polestar Technologies Inc.
Phone: 703-615-1023, Email: rshashidhar@polestartech.com

Sponsor: NAVSEA
Ongoing Program: Phase II

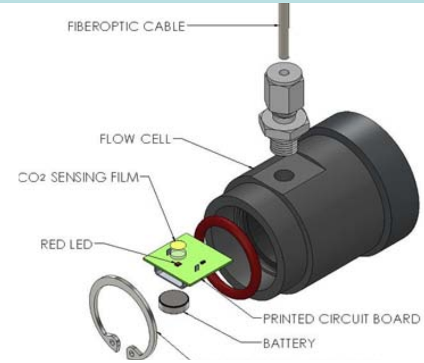
Real Time CO_2 Monitor for Navy Diver

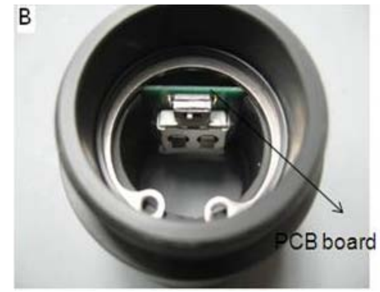
Background: It is of vital importance to monitor the CO_2 level in the inspiration side of the rebreather used by a Navy Diver such that the scrubber can be replaced before the CO_2 level gets dangerously high, thereby giving the diver time to replace the scrubber and/or undergo decompression. Currently, no CO_2 sensor exists for Navy deep sea divers.

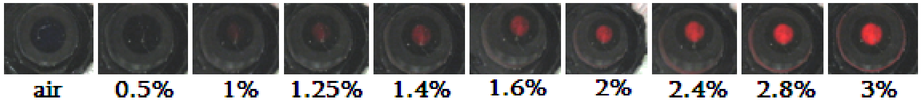
Work Effort Benefits: The current work effort will provide deep sea Navy Diver a CO_2 monitor that can be directly interfaced with the MK-16 or MK -25 rebreathers. It will serve to mitigate the dangers of the diver being exposed to increased CO_2 levels during the dive conditions.

Status: ONGOING, Phase II started on March 24, 2010

Sensor integrated to MK-25 Rebreather







Objectives: The overall objective of the program is to develop a simple and fully autonomous sensor that gives the diver a visual indication when the CO_2 level approaches 1.5%.

Key attributes required (specified by NEDU):

1) *Operation at high humidity,*
2) *T range 15-40ºC, working at 300 FSW.*

Deliverables:

☑ **Flow cell with integrated sensor**
☑ **Procedure for integration with MK-25 rebreather**
☑ **DVD on flow cell integration procedure for Diver use**
☑ **Biannual reports**

Goals/Milestones

FY11 Goals:

☑ **Design, fabrication & assembly of the sensor system**
☑ **Integration of sensor with electronics into MK-25 rebreather**
☑ **Preliminary tests, Characterization of system electronics,**
☑ **On-board temperature compensation**

FY12 Goals –

- Pressure compensation
- Sensor integration with MK-16 rebreather

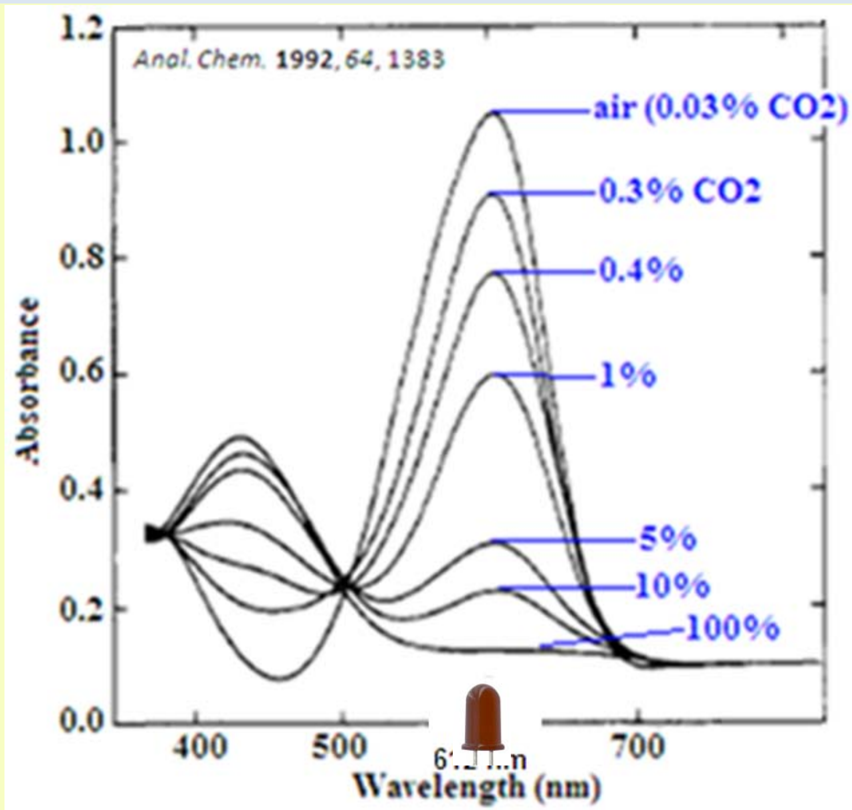
Principal Investigator: Dr. R. Shashidhar, Polestar Technologies Inc,, 703-615-1023; *rshashidhar@polestartech.com*

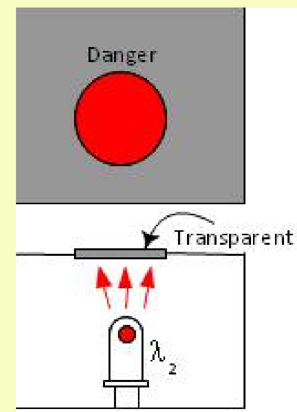
Sensor Principle

Absorbance vs. CO_2 concentration, m-Cresol Purple ion pair

$\{Q^+D^- \cdot xH_2O\} + CO_2(g)$ • • $^+HCO_3^- \cdot (x-1)H_2O \cdot HD$

Color A (blue, opaque) Color B (yellow, transparent)





The sensor film transmits red light at high CO_2 levels

Flow cell (with sensor) Integration to MK-25 Rebreather

Flow cell grafting between the tube and the rubber bag

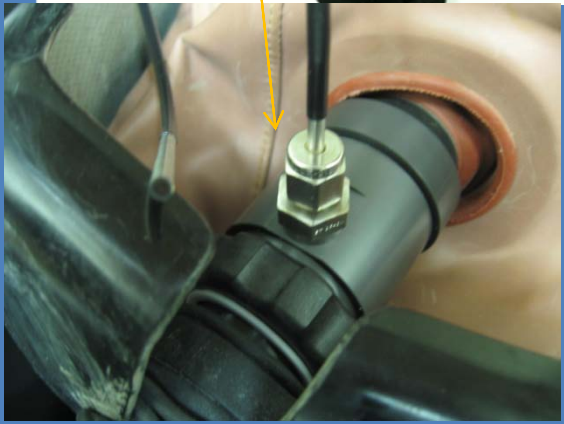
CO_2 canister

O_2 tank

Inhalation Gas outlet

Exhalation Gas inlet

Figure 1-1. MK 25 Mod 2 UBA in Donned Position (Front View).

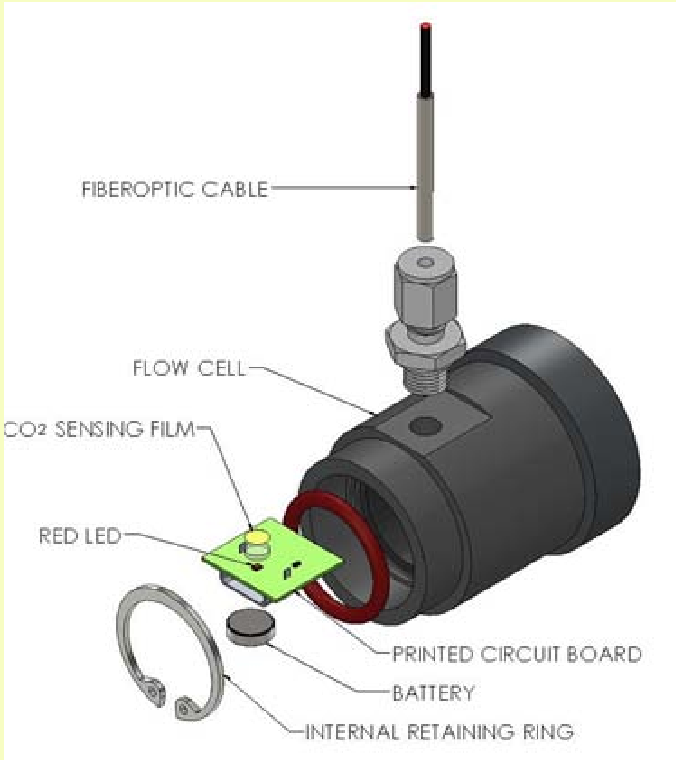


Flow cell integrated to the inspiration side of rebreather

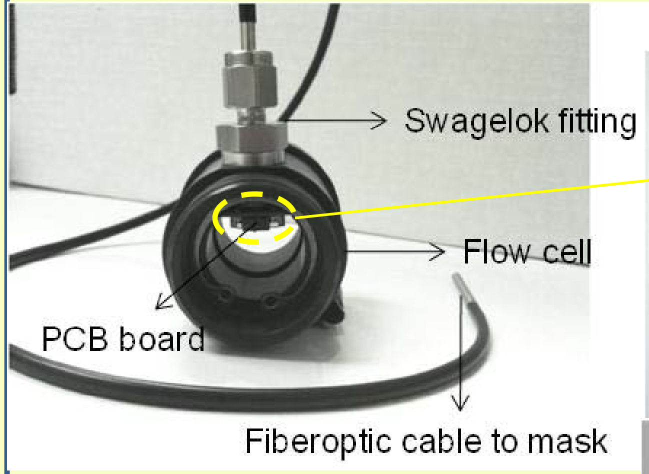
Acknowledgments: Master Diver James Costin & Mr. James Fenner (NAVSEA) Mr. Kevin Lang (ISEA USMC, NSWC)

Sensor Integration to Flow Cell

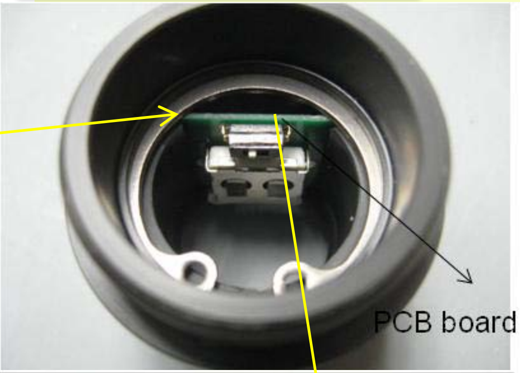
Schematic of flow cell with sensor & electronics

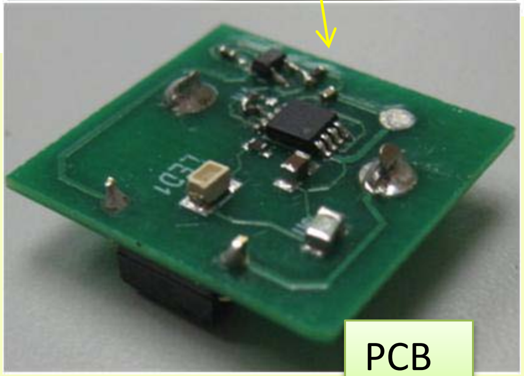


Assembled sensor with electronic board



PCB inside flow cell





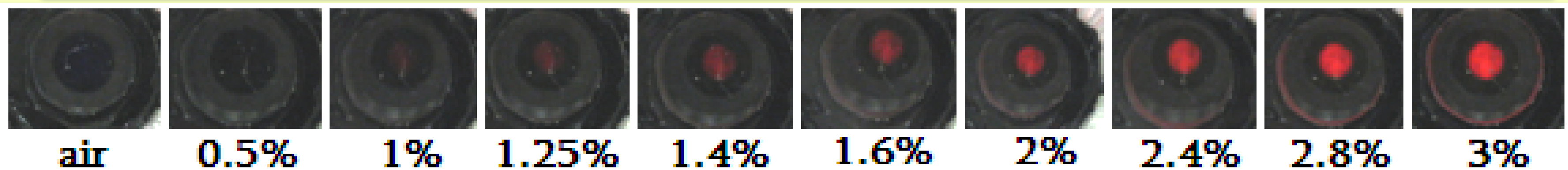
PCB

Features:

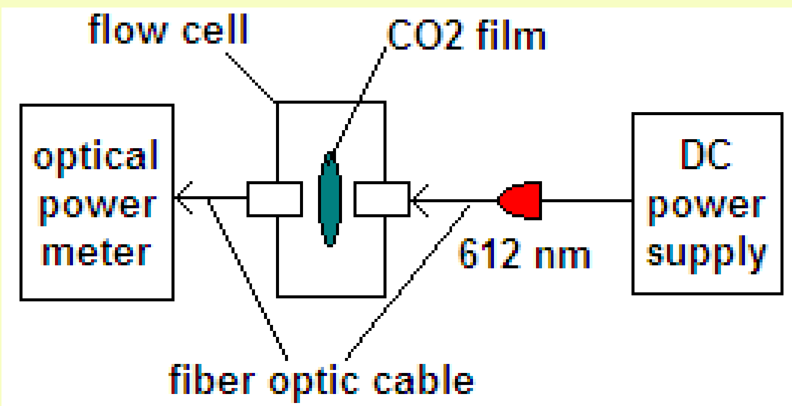
- **Sensor and all electronics (including temperature compensation) miniaturized to fit into the flow cell**
- **Sensor film on top of flashing RED LED, (pulse frequency 1Hz)**
- **Single coin cell battery, lasts 75 hours of diving**

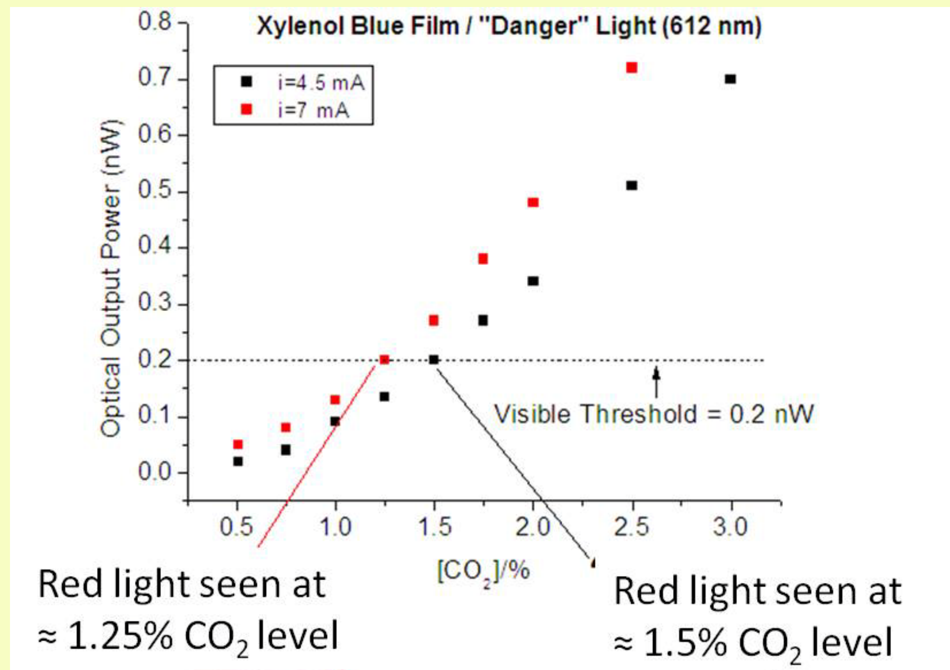
Visual indication at different CO_2 levels

Pictures of end of fiber optic cable carrying light transmitted through the sensor optic cable



Digitized optical power vs. CO_2 level

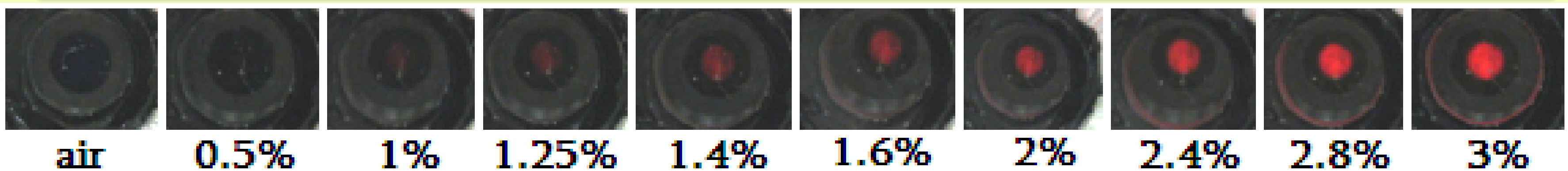




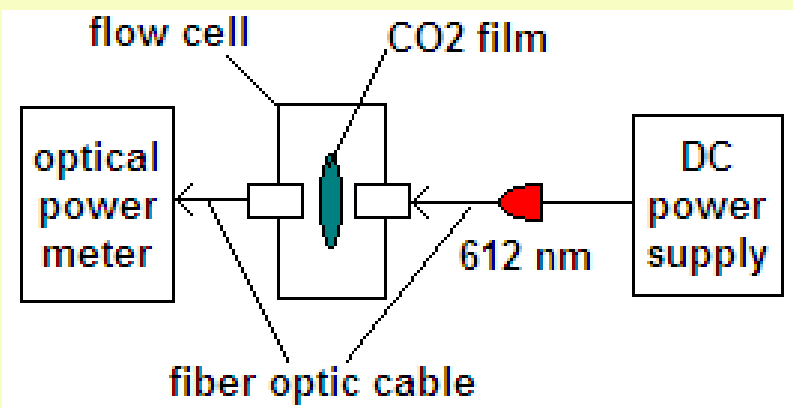
The red light seen faintly for CO_2 levels > 1% , becomes very pronounced at 1.4%

Visual indication at different CO_2 levels

Pictures of end of fiber optic cable carrying light transmitted through the sensor optic cable



Digitized optical power vs. CO_2 level

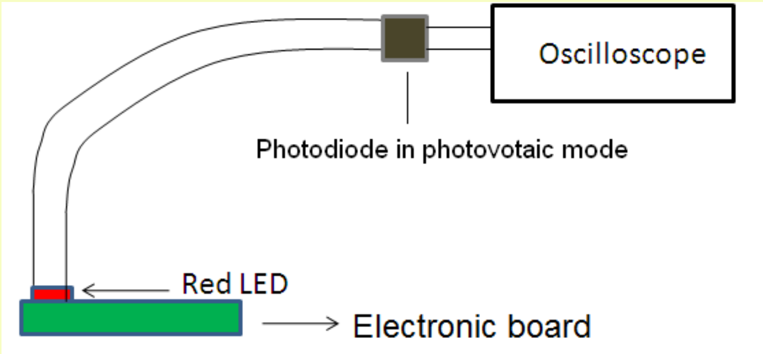


The red light seen faintly for CO_2 levels > 1% , becomes very pronounced at 1.4%

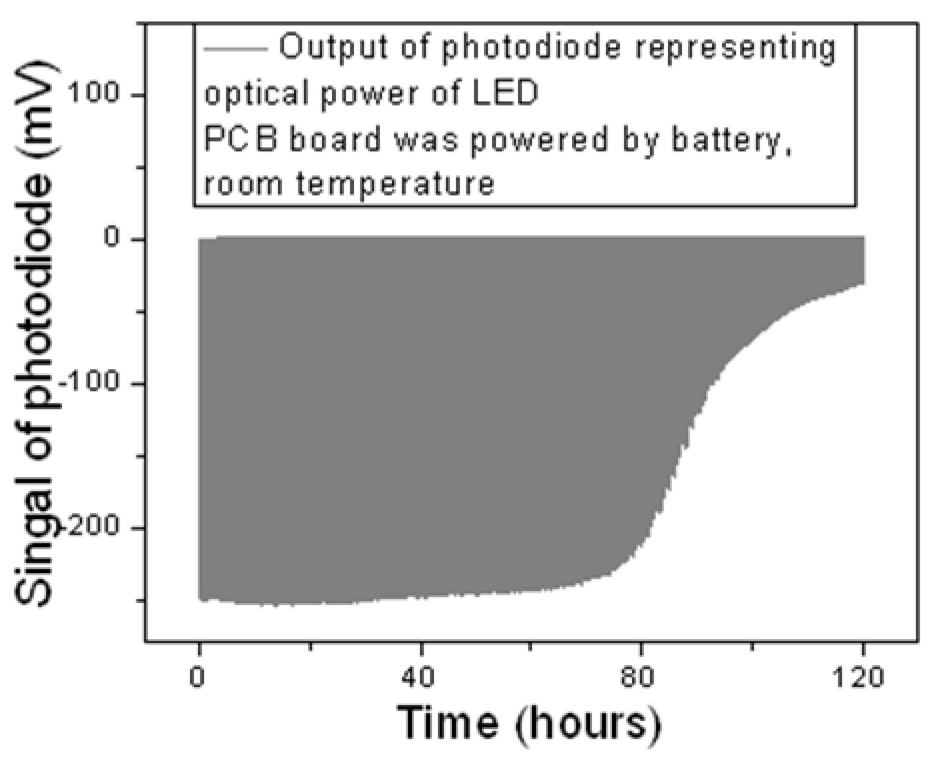
Battery Life Time

Experimental setup

- Coin cell battery
  (rated capacity of 48 mAh)
- Loading current for system



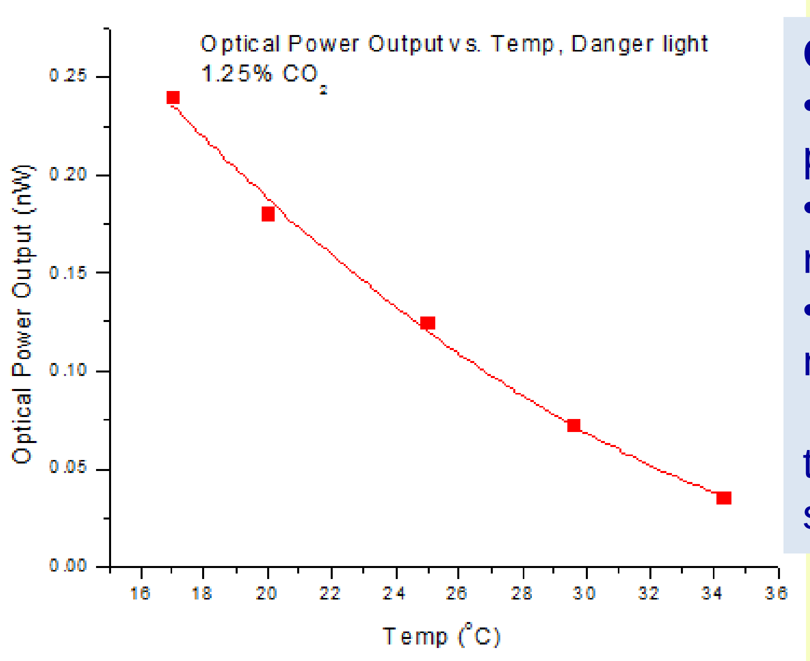
Experimental result



The served battery life time at room temperature is 75 hours

On-board Temperature Compensation

Optical power vs. temperature



Temperature compensation by on-board thermistor

Concept:

- Temperature compensation by varying the output power of the LED as a function of temperature
- T- dependent change in total loading resistance results in a change in driving current for the LED
- Sensor film is more sensitive at low temperature, a negative temperature coefficient

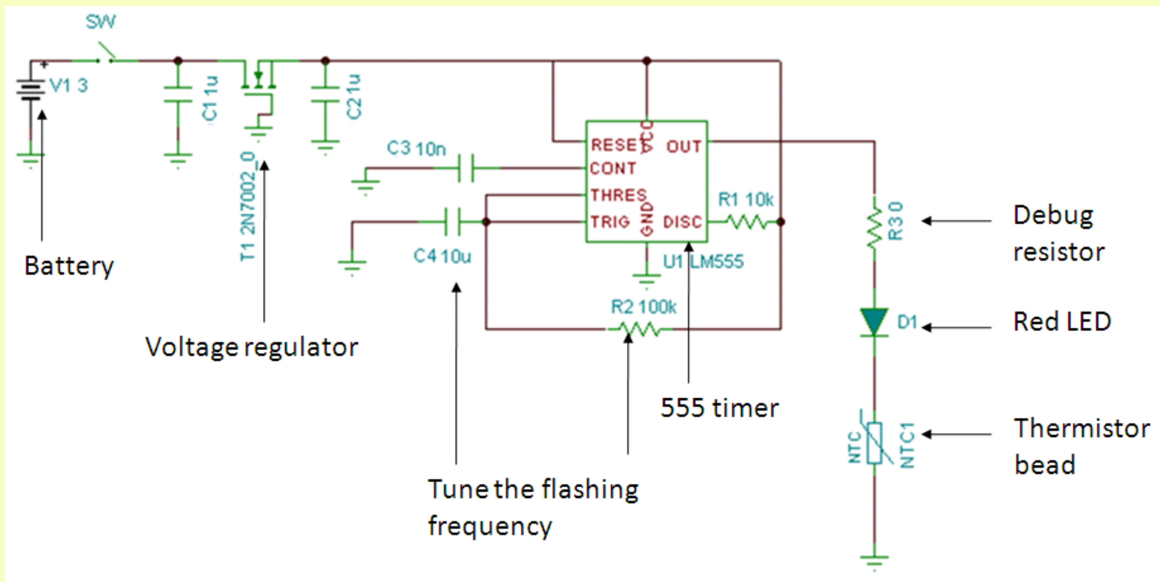
Light intensity of LED increases with increasing temperature to match the change the sensing film sensitivity

June 16, 2011

The on-board thermistor bead provides the temperature compensation.

On-board Temperature Compensation

Temperature compensation by on-board thermistor

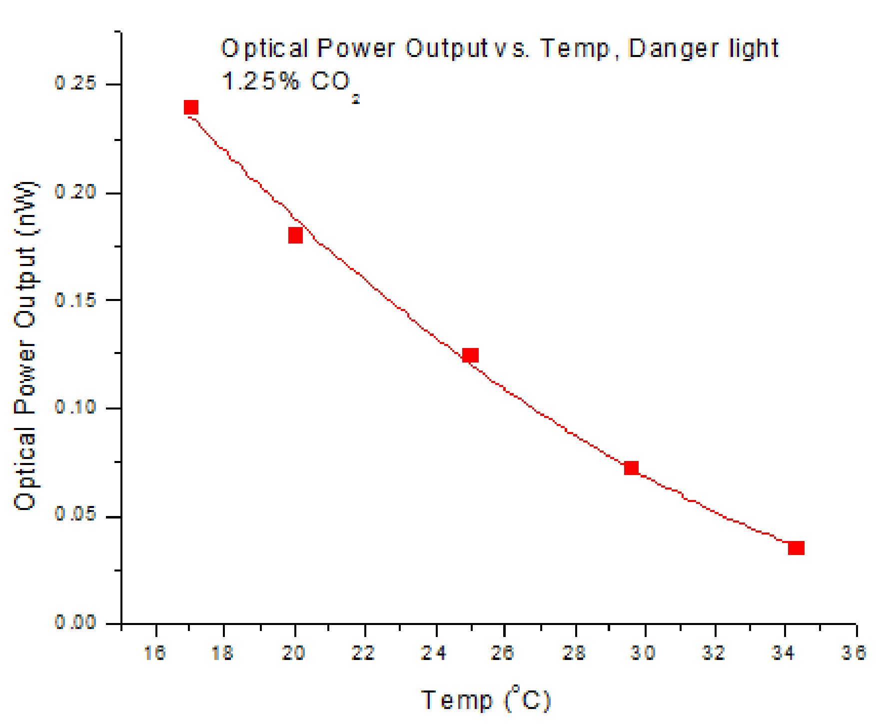


Concept: Temperature compensation achieved by varying the output power of the LED as a function of temperature using a temperature sensitive resistor (thermistor) in the LED drive circuit.

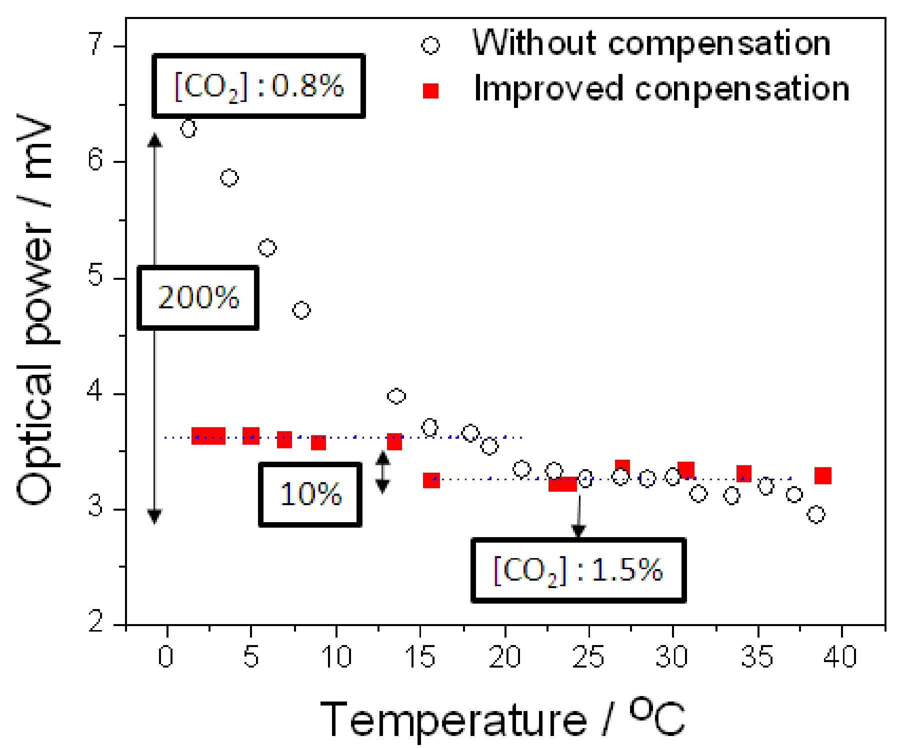
The on-board thermistor bead provides the temperature compensation.

On-board Temperature Compensation

Optical power vs. temperature



Temperature compensation by on-board thermistor



The on-board thermistor bead provides the temperature compensation.

Caustic Cocktail Problem

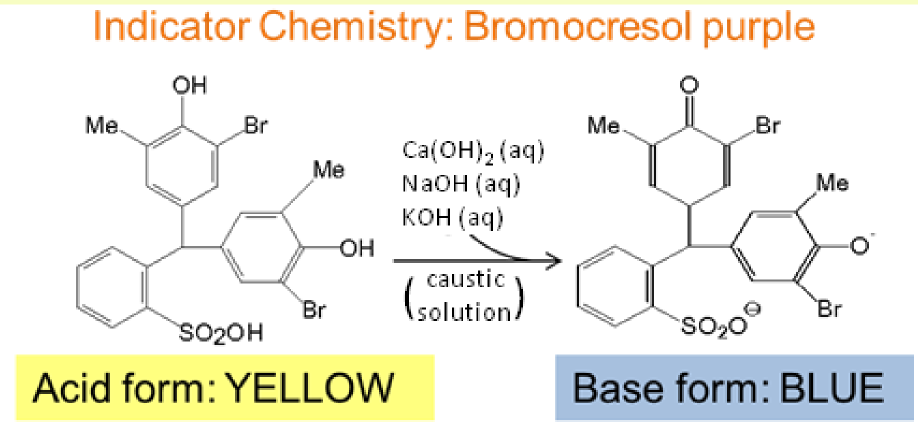
- **Scrubber for CO2 contains soda lime**
- **When the scrubber floods, a "Caustic Cocktail" (mixture of soda lime and water) is formed**
- **It gives rise to a chalky taste**
- **Forces the diver to switch to an alternative source of breathing gas and rinse his or her mouth out with water**

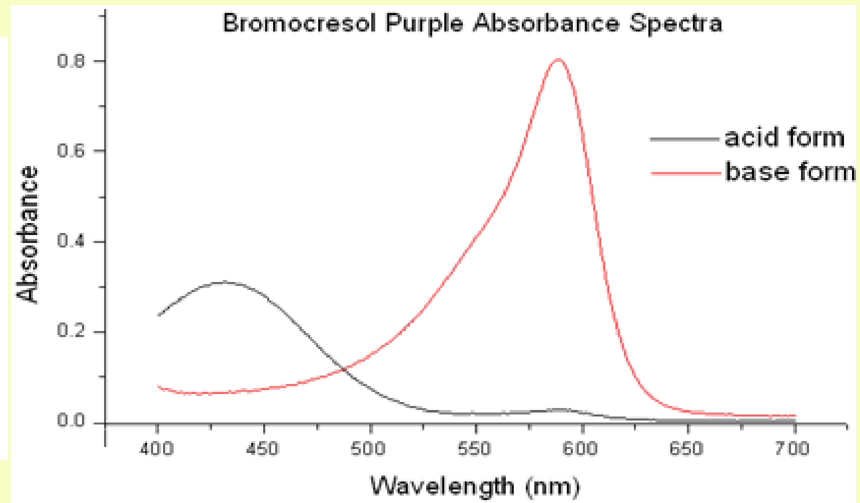
Need for a sensor that can detect the caustic cocktail at low concentrations, well before the diver can taste it

Sensor for Caustic Cocktail

Acid and basic forms

Spectra of two forms

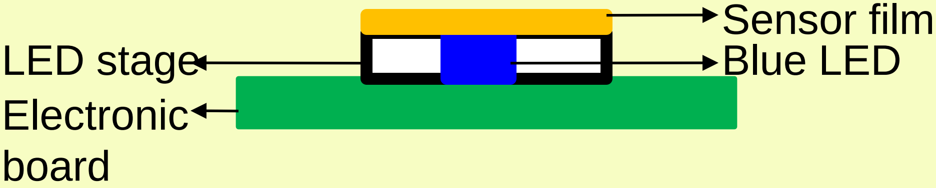


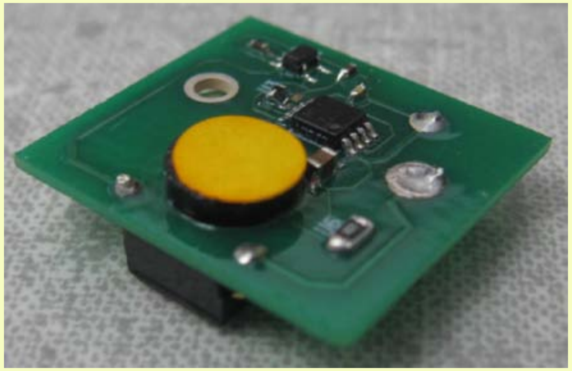


The acid form of the sensor film blocks blue light, basic form transmits blue light.

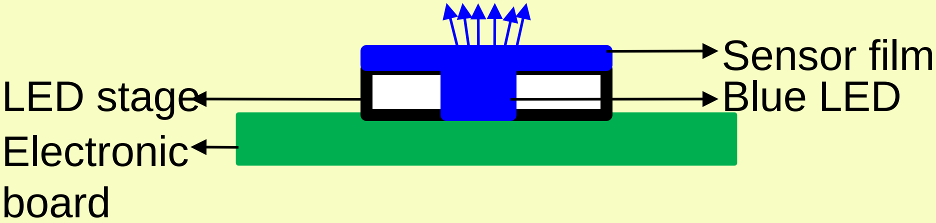
Caustic Cocktail Detection

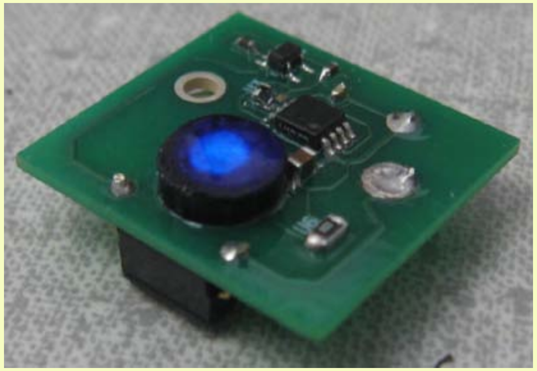
Blue LED (465nm) is always on. Acid form of the sensor film (yellow) blocks the blue light





Blue LED (465nm) is always on. Basic form of the sensor film (blue) transmits the blue light

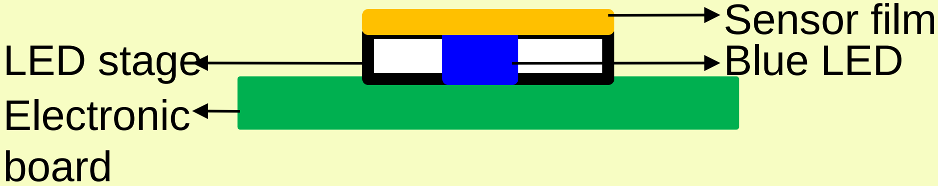


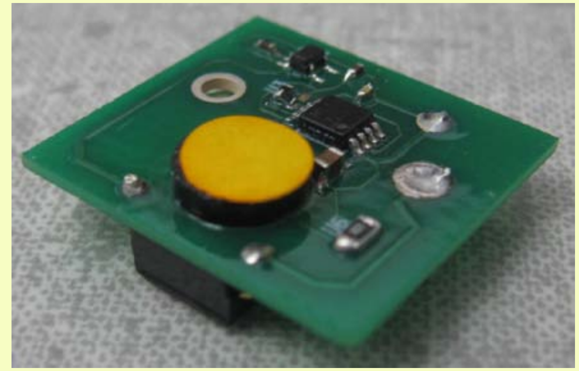


Flashing blue light is seen when the sensor film turns to blue in presence of caustic cocktail solution

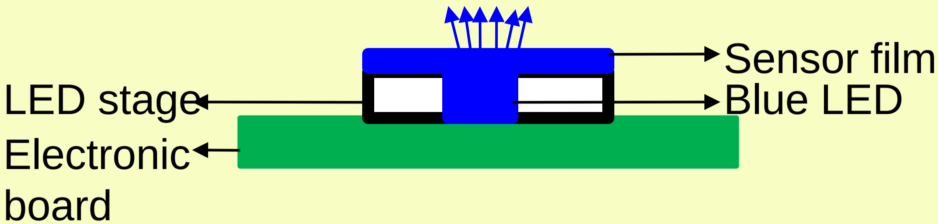
Caustic Cocktail Detection

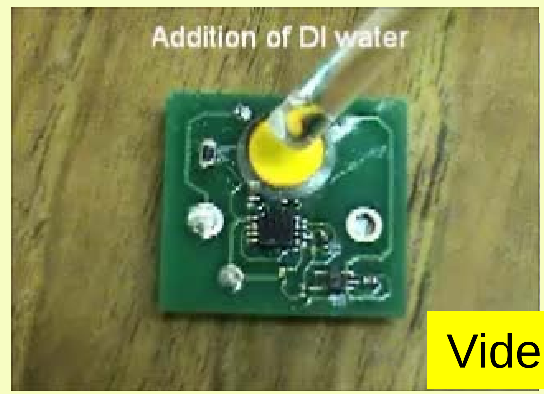
Blue LED (465nm) is always on. Acid form of the sensor film (yellow) blocks the blue light





Blue LED (465nm) is always on. Basic form of the sensor film (blue) transmits the blue light





Video

Flashing blue light is seen when the sensor film turns to blue in presence of caustic cocktail solution

Future Plans

- Pressure compensation and feasibility to 300 FSW operation
- Integration to MK-16 rebreather
- Water proofing of electronics and battery compartments
- Combining CO_2 and caustic cocktail sensors on the same electronic board
- Transition Planning for tests in NEDU test bed

Key Participants & Acknowledgements

Key Participants:

- Dr. James Kane
- Dr. Xiulan Li
- Ms Melissa Ricci

Acknowledgements:

- Mr. James Fenner (NAVSEA)
- MDV James Costin (NAVSEA)
- Mr. Kevin Lang (ISEA USMC, NSWC)
- Dr. John Clarke (NEDU)