Investigation of Fiber Optics Sensors in Detection of Chemical Contaminants

Sridhar Shastry, Abdi Abdeq, A. G. Agwu Nnanna and Nabil Ibrahim
Purdue Calumet Water Institue
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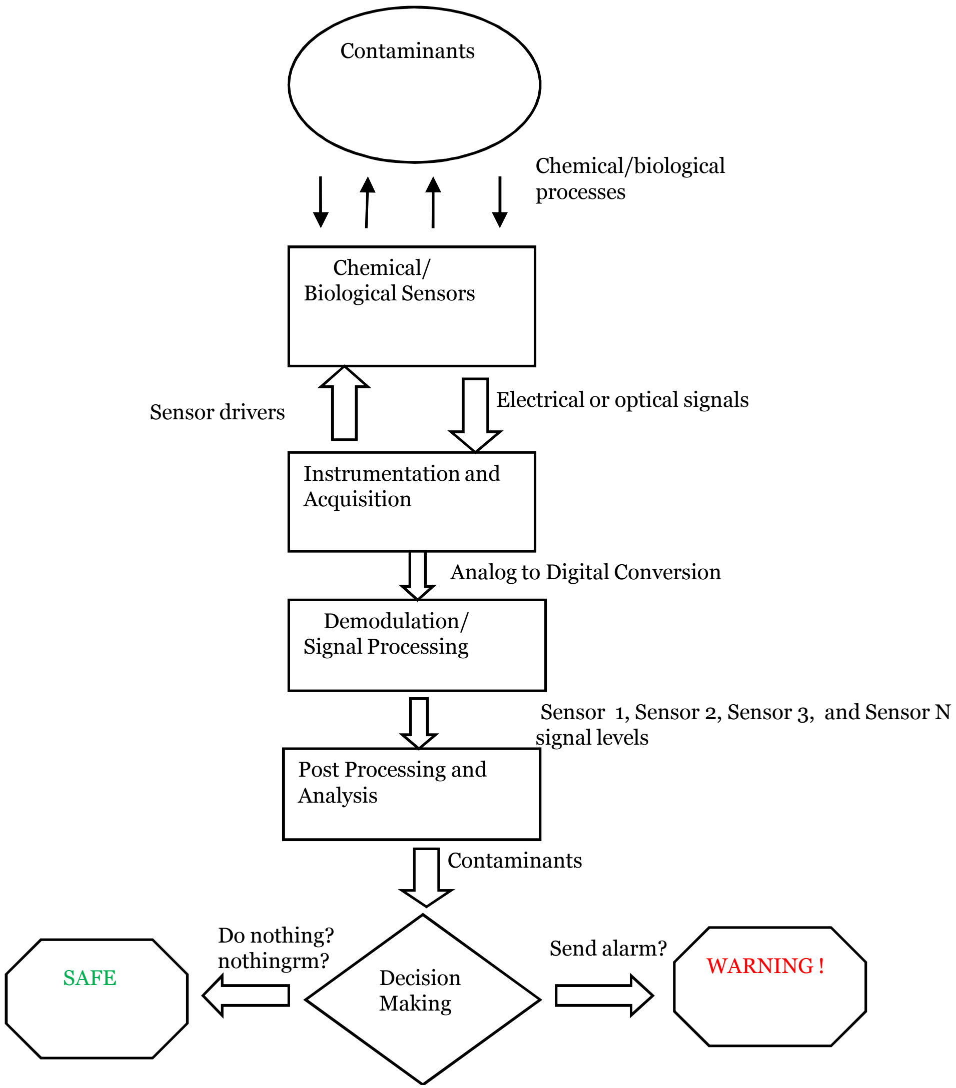
Water security and water monitoring systems



Why Optics-based sensor

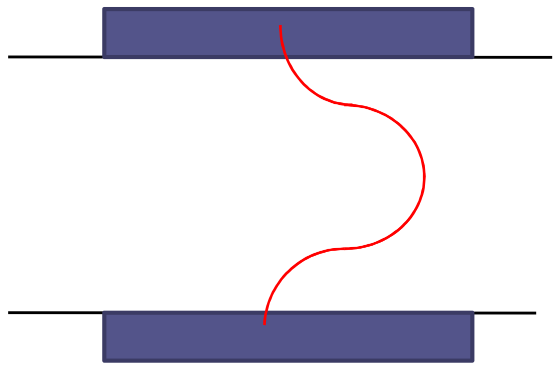
- Fiber Optics sensors represent an exciting class of devices because of
  - Sensitivity and dynamic range
  - Selectivity
  - Lightweight, small size, low cost.
  - Immunity to electric and magnetic fields.
  - Ability to be embedded into other structures.
- The basic operation principle of FOS
  - Light signal changes when exposed to a chemical or physical stimulus
  - Interaction of electromagnetic radiation with matter

Objective

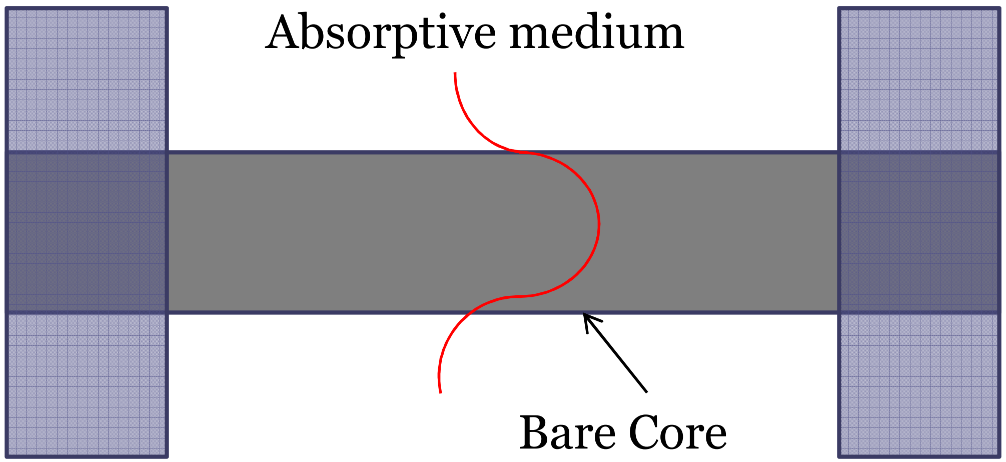
- Monitoring/detection trend
  - Batch sampling technique
    - Insufficient in the case of disasters
    - Online detection system required
- Objective
  - Develop FOS to detect chemical contaminants in-situ.
  - Formulate correlation between response time, concentration of chemical contaminant and change in optical intensity.

Clad Modified Evanescent Fiber Optic (CMEFO) Sensors

- Primarily operates on TIR
- Evanescent field is property of fiber cable
- Evanescent field in cladding region absorbed by sensitive region



Absorptive cladding



Multiple Reflections

- Snell's Law

$$n_c \sin \phi_c = n_d \sin \varphi_d$$

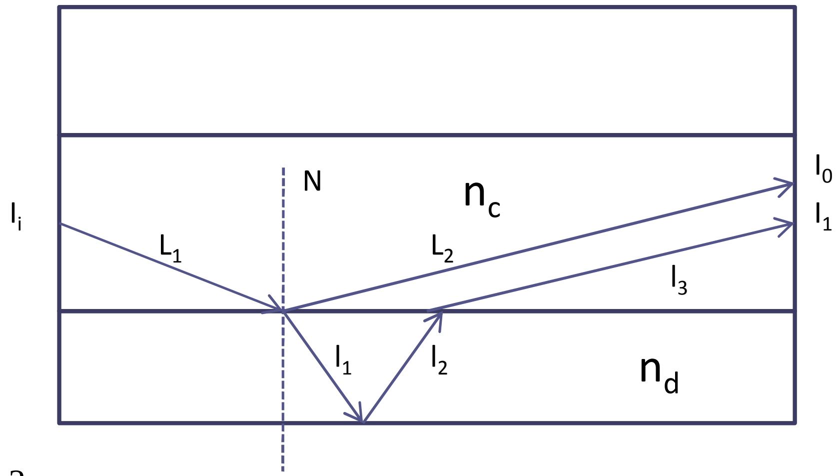
- Fresnel Equations

$$R_s = \left[\frac{\sin(\phi_d - \phi_c)}{\sin(\phi_d + \phi_c)} \right]^2$$

$$T_s = \frac{n_d \cos \phi_d}{n_c \cos \phi_c} \left[\frac{\sin(\phi_d - \phi_c)}{\sin(\phi_d + \phi_c) \sin(\phi_d + \phi_c)} \right]^2$$

- Absorption coef.

$$\alpha_i = k \cdot \kappa_i$$



$$I_o = I_i R \cdot e^{-2\alpha_c (L_1 + L_2)}$$

$$I_1 = I_i T^2 R \cdot e^{-2(\alpha_d (l_1 + l_2) + \alpha_c l_3)}$$

$$I = I_0 + I_1 + \ldots I_N$$

Incoherent source

Absorbance

- Transmission

$$T = \frac{I_{out}}{I_{In}} = e^{-\alpha CL}$$

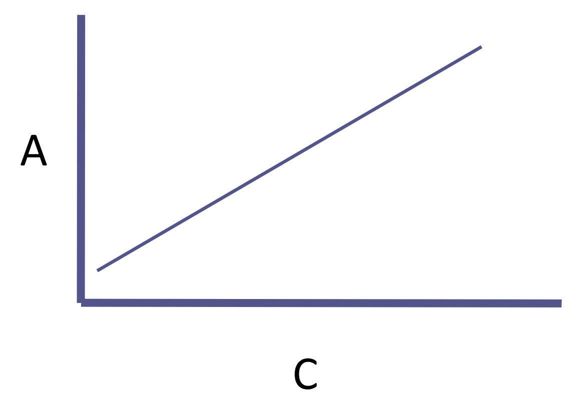
- Absorbance

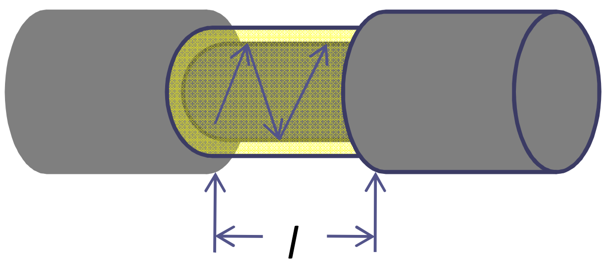
$$A = \log(1/T) = \alpha CL$$

  - Optical Fiber evanescent absorption

$$A = \Gamma \alpha d_p C \left[\frac{l \cdot n_c \sin\theta}{a(n_c^2 - n_d^2 \sin^2\theta)^{0.5}} \right]$$

Absorbance vs C:

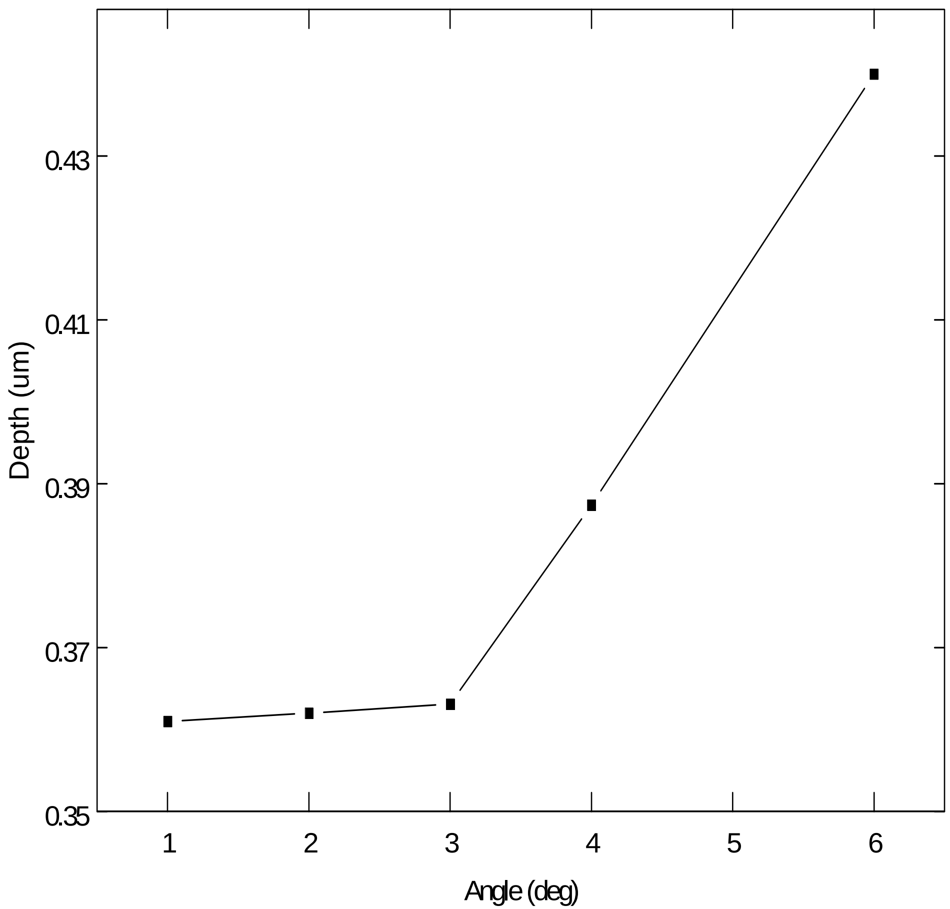




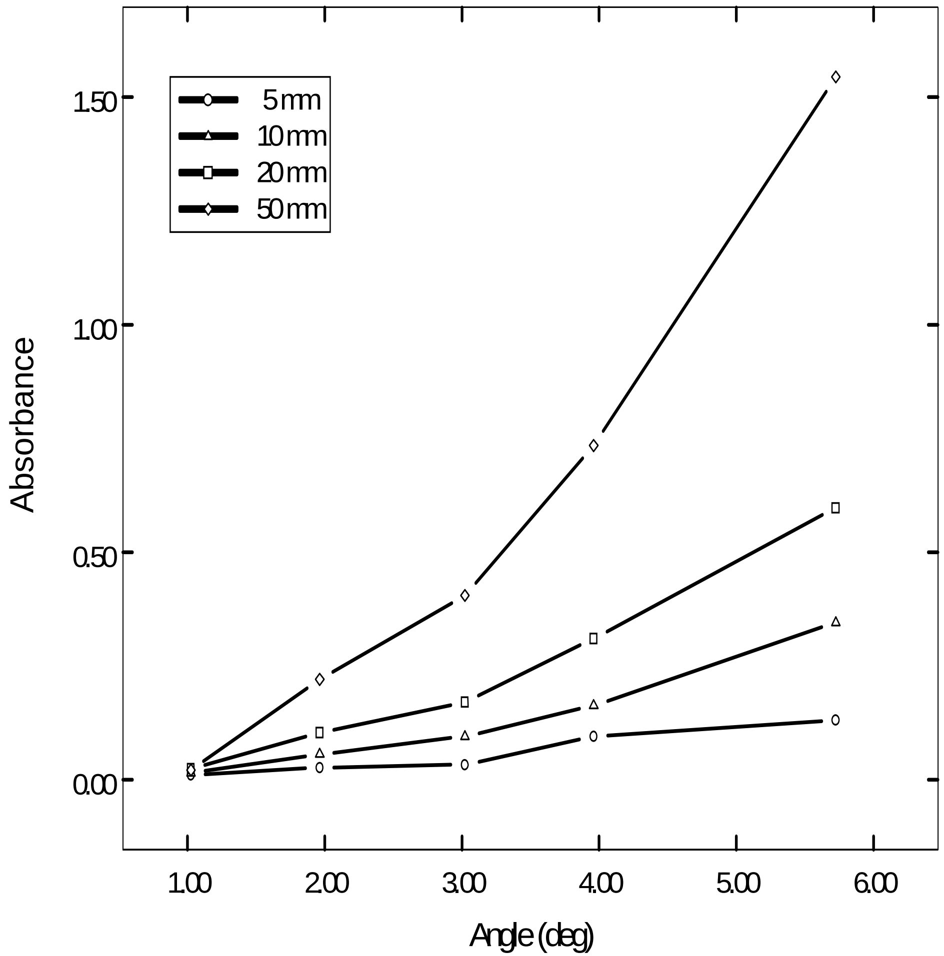
Number of internal reflections

Simulation

Thickness of sensing region=0.4 μm

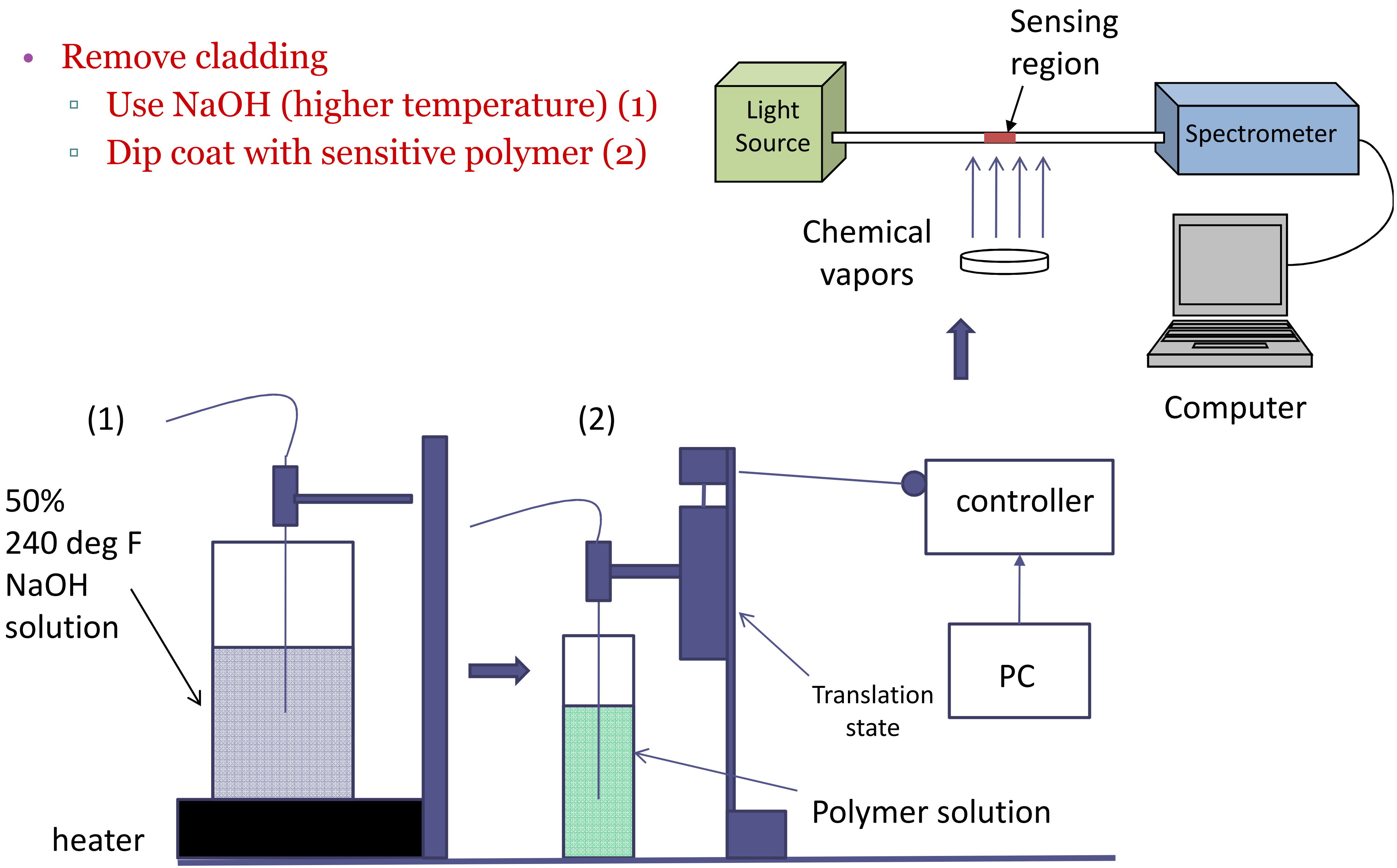


Length of the Sensing region = 35nm



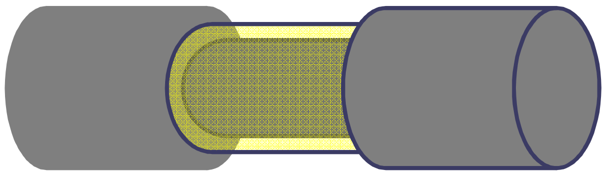
Fabrication of CMEOF Sensors

- Remove cladding
  - Use NaOH (higher temperature) (1)
  - Dip coat with sensitive polymer (2)

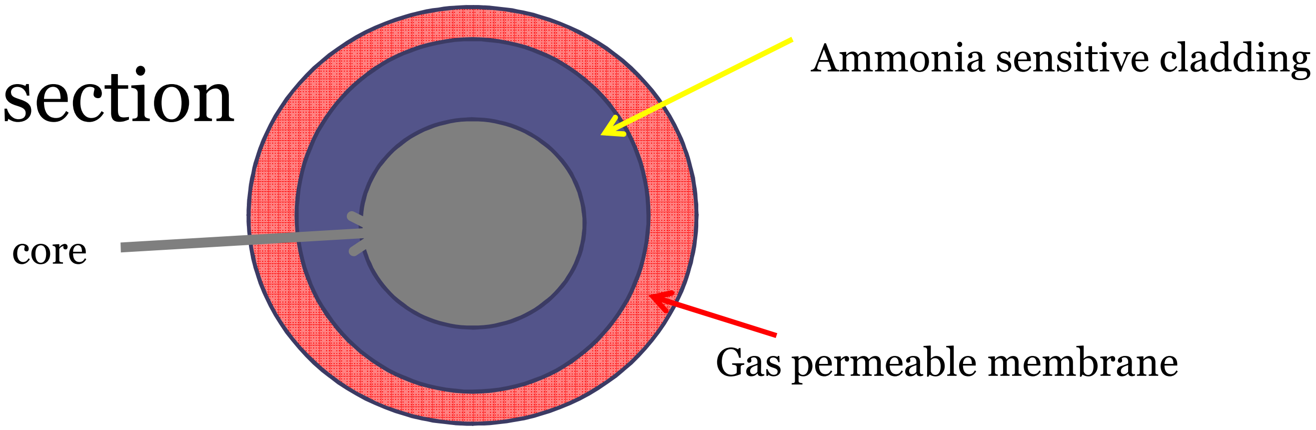


CMEOF Ammonia Sensor

- Water proof sensor design
  - Gas permeable membrane
  - Allows NH_3 gas and blocks solution (ions/cations)



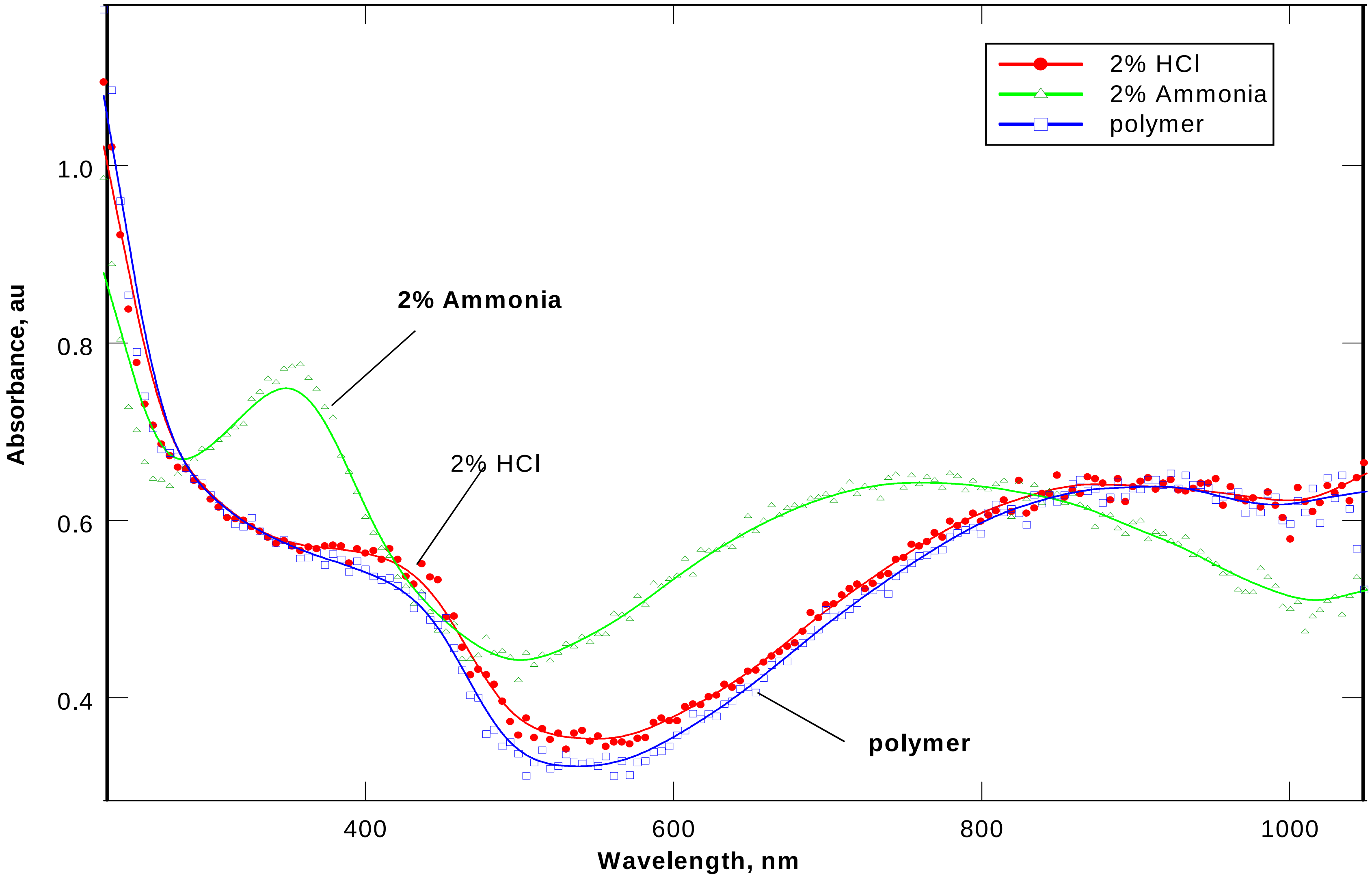
- Cross section



Characteristics of Polyaniline

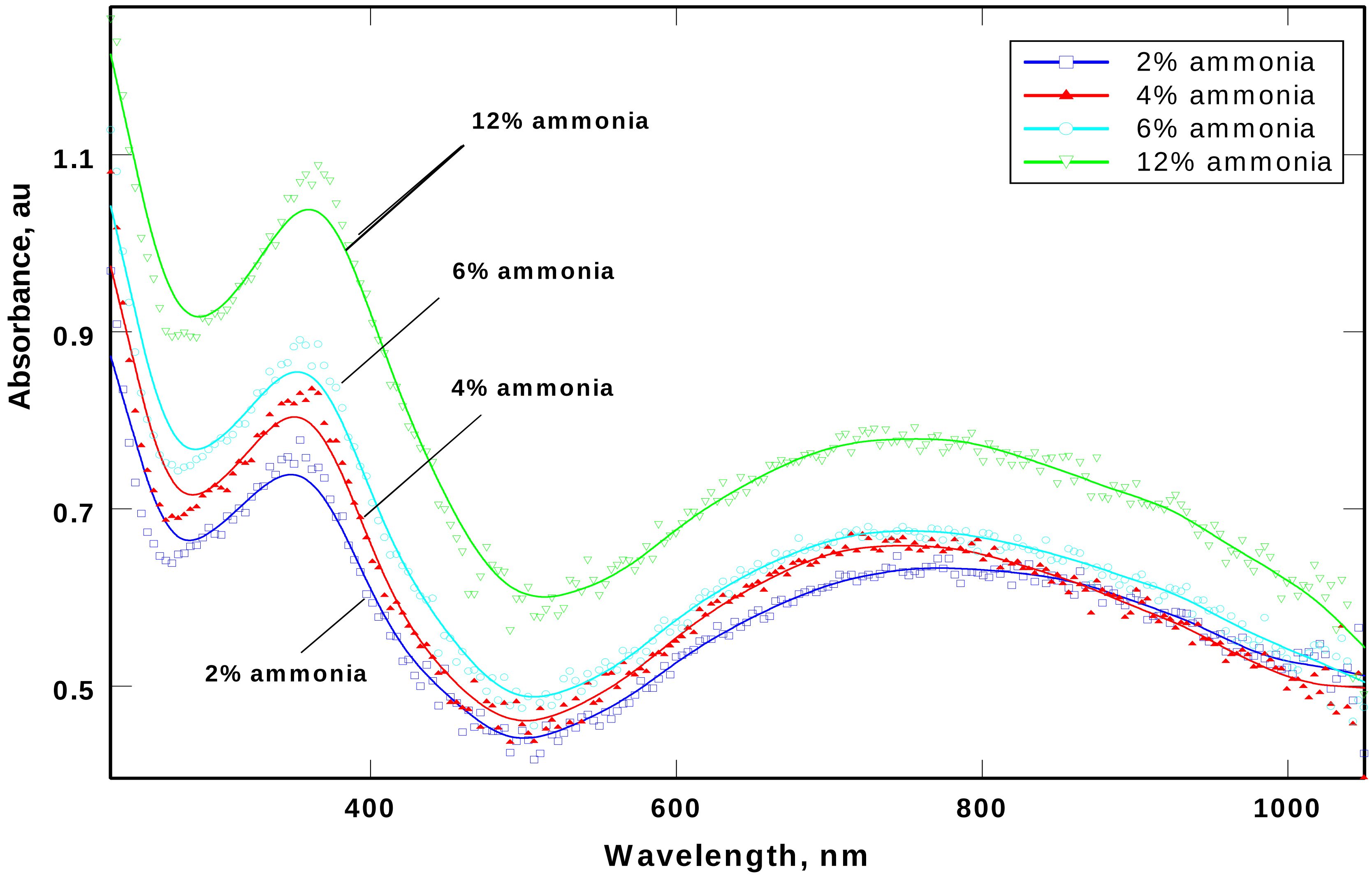
- Polyaniline changes color when exposed to acid/base
  - Polyaniline is blue in color when exposed to Ammonia and green when exposed to Hydrochloric Acid.
  - Ammonia and Hydrochloric Acid can be detected by observing absorbance at various wavelengths
  - Polyaniline is biodegradable and non-toxic.

Results

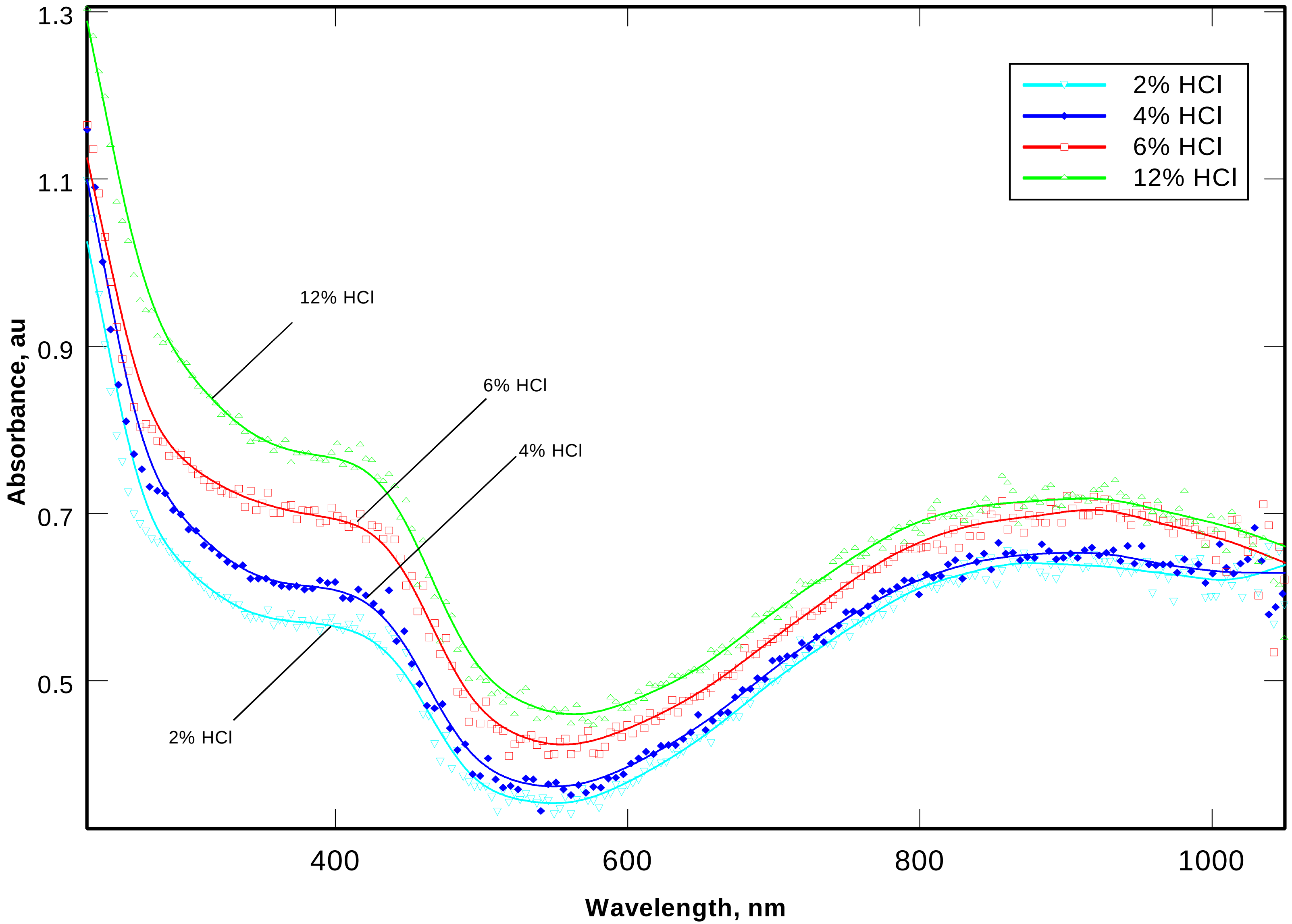


2% HCl
2% Ammonia
polymer
2% Ammonia
2% HCl
polymer
Absorbance, au
1.0
0.8
0.6
0.4
400
600
800
1000
Wavelength, nm

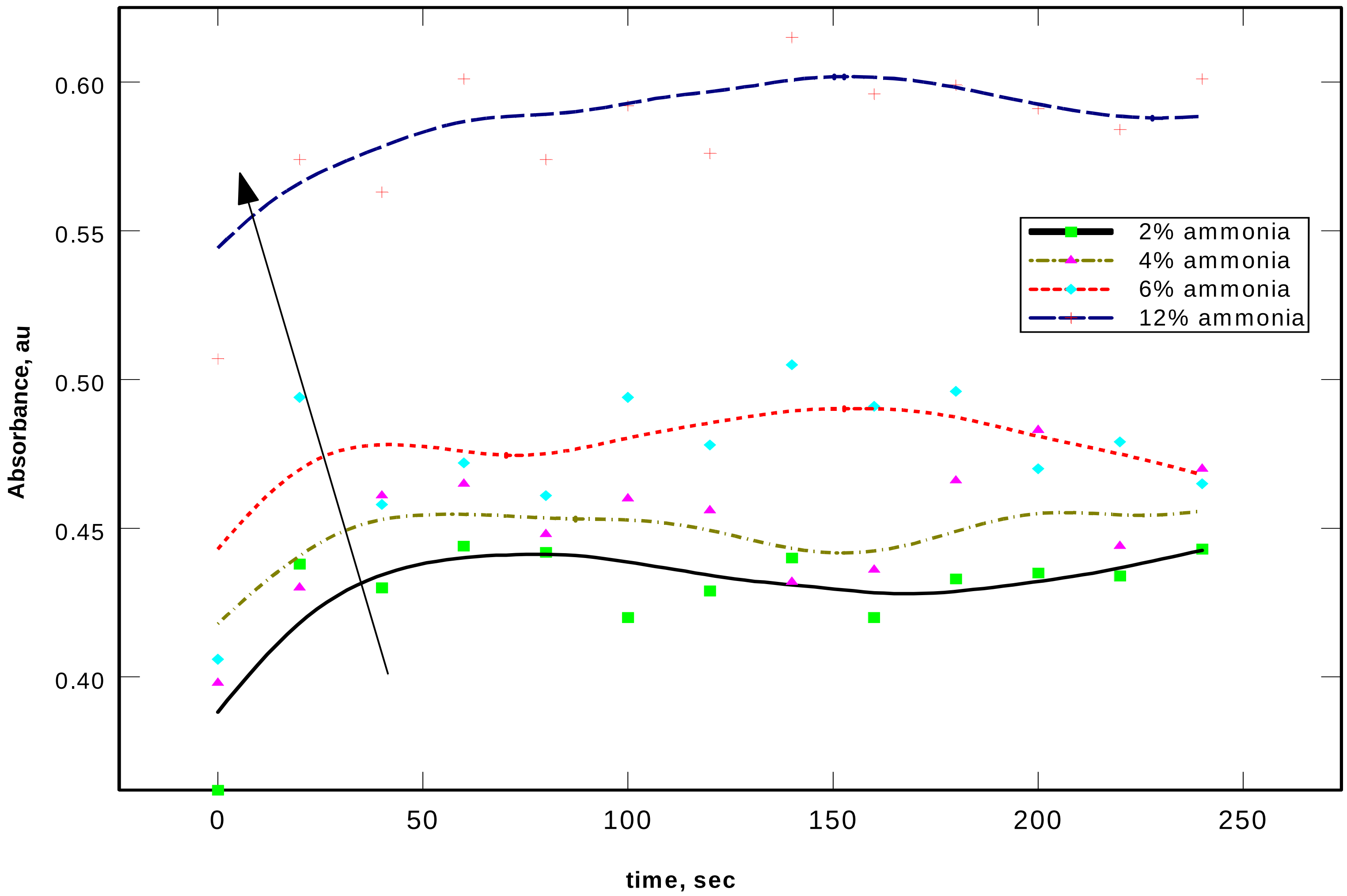
Results (contd.)



Results (contd.)



Results (contd.)



Conclusion

- An optics-based sensor has been developed to detect ammonia and hydrochloric acid
- The sensor showed a rapid color change when exposed to ammonia and hydrochloric acid
- The change in intensity caused by the modified cladding can be studied parametrically which provides insight on variation of intensity with concentration of chemical contaminant