Multi-Element Surface Acoustic Wave (SAW) Sensors for Methane Detection

Daejin Kim[1,2], Jeffrey Culp[1,2], Jagannath Devkota[1,2], Ruishu Wright[1]
[1]National Energy Technology Laboratory, [2]NETL Support Contractor, 626 Cochran Mill Road, Pittsburgh, PA 15236, USA

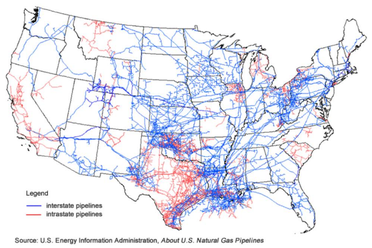
Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

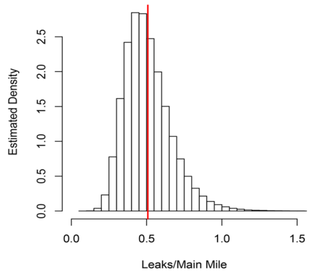
Natural Gas Pipelines in the U.S.

1

(Source: *seekingalpha.com*)



Natural gas pipelines in the U.S.:
305,000 miles (~12 times earth's circumference)



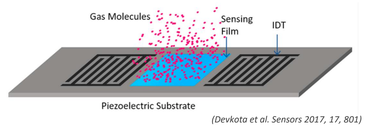
(Source: *Environ. Sci. Technol. 2020, 54, 14, 8958−8967*)

- Estimated **natural gas leak** from distribution pipelines: **0.51 leaks/mile**
- **Development of methane gas sensor**: immediate leak detection → risk mitigation → ensure pipeline integrity → enhance energy security in the U.S.

Surface Acoustic Wave (SAW) Sensor

2

- Surface Acoustic Wave (**SAW**) Sensor:

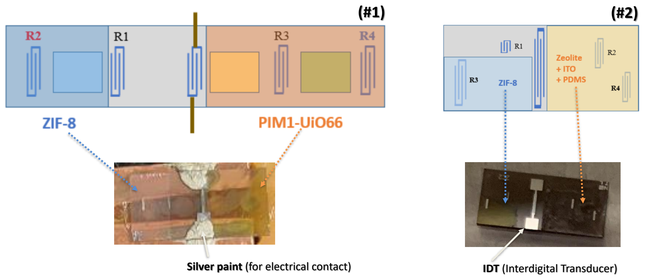


(Devkota et al. Sensors 2017, 17, 801)

radio frequency signal <---> SAW
piezoelectric substrate
(based on **mass change** in the sensing film)

Advantages: - High sensitivity, fast response time, reversibility
- Small size, low cost, wired or wireless modes

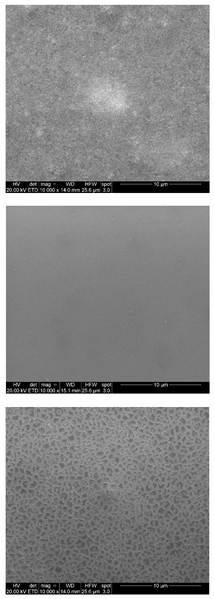
- SAW Sensor Configurations:

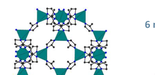


- SAW Sensor Testing Conditions:
  - Test mode: **wireless**
  - Frequency: 430 MHz
  - Humidity: dry and 43% RH
  - Gases exposed: CH_4, CO_2, N_2

Gas Sensing Materials

3



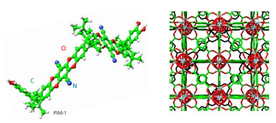


ZIF-8

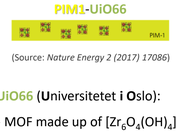
6 membered ring window diameter: **3.4 Å**

(Source: *Nature Comm. 9 (2018) 1429*)

ZIF-8:
- **Z**eolitic **I**midazolate **F**ramework-**8**)
- highly stable sensing material
- For physical gas adsorption



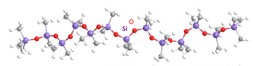
PIM1 (**P**olymer of **I**ntrinsic **M**icroporosity):
- high porosity & flexibility



PIM1-UiO66

(Source: *Nature Energy 2 (2017) 17086*)

UiO66 (**U**niversitetet **i** **O**slo):
- MOF made up of $[Zr_6O_4(OH)_4]$ with 1,4-benzodicarboxylic acid
- high chemical stability

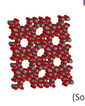


PDMS

(Source: *www.acs.org*)

(Polydimethylsiloxane): hydrophobic polymer

PDMS-ZSM 5



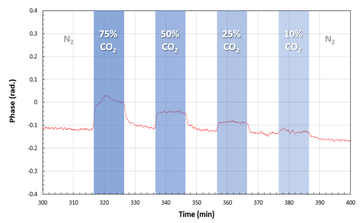
ZSM 5 (**Z**eolite **S**ocony **M**obil–**5**): - aluminosilicate zeolite
- pore range: 0.3-0.6 nm

(Source: *commons.wikimedia.org*)

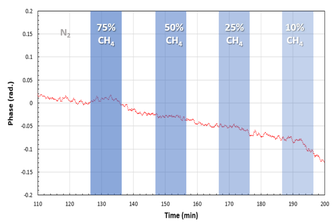
CO_2 and CH_4 Sensing

4

- Configuration #1 (ZIF-8 and PIM1-UiO66)

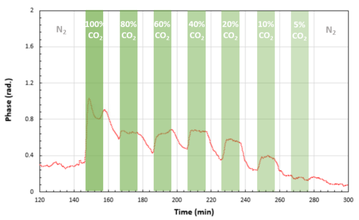


- Shows quantitative CO_2 sensing response.

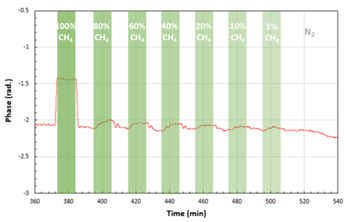


- Shows weak CH_4 sensing response.

- Configuration #2 (ZIF-8 and PDMS-ZSM 5)



- Shows high CO_2 sensing response at different concentrations.

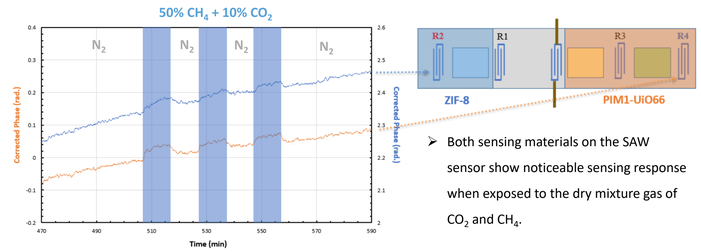


- Shows irreversible CH_4 sensing response.
- Indicates the slow desorption rate of CH_4 from the sensing materials.

Mixture Gas Sensing

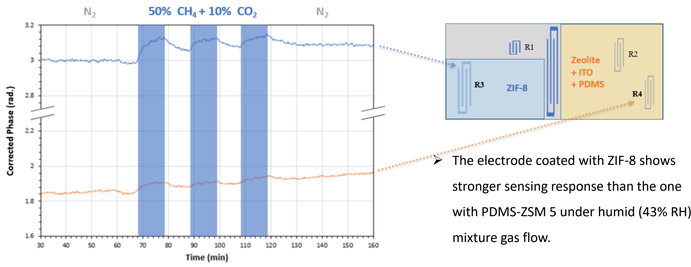
5

- Configuration #1 (ZIF-8 and PIM1-UiO66)



- Both sensing materials on the SAW sensor show noticeable sensing response when exposed to the dry mixture gas of CO_2 and CH_4.

- Configuration #2 (ZIF-8 and PDMS-ZSM 5)



- The electrode coated with ZIF-8 shows stronger sensing response than the one with PDMS-ZSM 5 under humid (43% RH) mixture gas flow.

Conclusion

6

- ✓ Developed the **multi-elements SAW sensors** coated with the different gas sensing materials in different configurations.
- ✓ Demonstrated mixture gas sensing response composed of **50% CH_4 and 10% CO_2** in the **wireless mode**.
- ✓ Needs to improve the CH_4 sensing response by optimizing the coating composition of the sensing materials.

Acknowledgement

7

- ✓ This work was performed in support of the U.S. Department of Energy's Fossil Energy and Carbon Management's Oil & Gas/Natural Gas Infrastructure/Emissions Mitigation Program and executed through the National Energy Technology Laboratory (NETL) Research & Innovation Center's Natural Gas Infrastructure FWP.
- ✓ The authors would like to acknowledge Dr. Ki-Joong Kim at NETL for his contribution to the synthesis of ZIF-8 and ZSM-5.

Disclaimer

8

This work was funded by the U.S. Department of Energy, National Energy Technology Laboratory, an agency of the United States Government, through a support contract with Leidos Research Support Team (LRST). Neither the United States Government nor any agency thereof, nor any of their employees, nor LRST, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.