Towards an integrated on-chip mid-infrared chemical sensing system

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Content

- MIR Sensors
  - Applications
  - Materials (chalcogenides)
  - Devices (spiral)

- MIR Detectors
  - Materials (PbTe)
  - Devices (film, waveguide-integrated, RCE)

- Integrated Photonics Roadmap
Sensors
Applications of Integrated Photonic Sensors
Integrated Photonic Chemical Sensor: A schematic
Sensor platform: Materials selection for MIR

- Finger print region
- Functional group vibrations

<table>
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<th>UV</th>
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<th>NIR</th>
<th>Mid-IR</th>
<th>Far-IR</th>
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<td>1</td>
<td>2</td>
<td>5-10</td>
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- Silica
- Silicon nitride
- Silicon
- Germanium
- Metal oxides
- Halides
- Chalcogenides
Glass–on–Silicon
Chalcogenide Glasses

- Wide IR transparency window
- Tunable optical properties
- Ease of fabrication
ChG methane gas sensor

On-chip sensing of methane gas using MIR absorption

Han, Zhaohong, et al. APL, 2016
On-chip Detectors
PbTe film as a MIR photoconductor

- PbTe photoconductor properties
  - Good responsivity upto 3.5 µm

Integration of PbTe with a waveguide to enable room-temperature operation

Responsivity for thermally evaporated 650 nm polycrystalline PbTe film at -60 °C
PbTe detector integrated with a ChG waveguide

- 1st generation device
  - Discontinuity of thin film
  - Spacer = planarizing layer + index matching layer
  - Complex fabrication

- Novel fabrication process
  - Coupling loss due to index mismatch and step edge?
PbTe integration coupling efficiency analysis

- Thin PbTe layer
- Refractive indices are similar for TM mode
- Coupling efficiency > 94%
  - Good enough

PbTe integration without a spacer is feasible
Waveguide-Integrated Detector

Waveguide integration:
- Noise suppression
- IR photonic circuit

Detector performance
Waveguide-Integrated Detector at RT

- Responsivity (A/W): 1.0
- External quantum efficiency: 58%
- Temperature: Room Temperature

Han, Zhaohong, et al. APL, 2016
**Enhanced Detection: PbTe Detector in a Resonant Cavity**

- Successful low-T fabrication process on Si: $<150 \, ^\circ C$
- Demonstrate 13.4X cavity enhancement
- Peak responsivity = 100 V/W
Resonant Cavity Enhanced IR Detector

- Enhanced detectivity inside a cavity
- Detectivity increases when photodetector size decreases


Packaged Prototype
Packaged integrated detector on a silicon platform

Cross-sectional view of 1 photodetector

Top-down view
Detectors on Si ROIC

Successful fabrication of integrated prototype
Integrated Methane Gas Sensor: Case Study

Oil and Gas – Pipeline leakage monitoring
Joseph De Wolk, Will Wolfe, Preston Kutney, Ozzie Ortiz
Sloan School of Management
Oil and Gas Sensing
MIT Sloan School of management

Requirements:
• 10-200 ppm sensitivity
• High selectivity and low false positive rate
• Low power consumption
Pipeline leak detection with integrated photonic sensors can save billions $$

![Graph showing net savings of $5B over 10 years with a 3-year payback period.](image)

Based on assumptions from California Energy Commission Report
Applications of Integrated Photonic Sensors
Global Photonics Sensors Market

Segmentation and Forecast, 2013 - 2020

Global Photonics Sensors Market is expected to reach $15.2 Billion by 2020

Growing at a CAGR of 16.9% (2014-2020)

Global Photonics Sensors Market by Technology

- Fiber optic technology
- Laser technology
- Biophotonic technology

Global Photonics Sensors Market by Product Type

- Fiber optic sensors
- Image sensors
- Biophotonic sensors
- Other

The comprehensive view on the % share of Type segment (2020)

Global Photonics Sensors Market by Application

- Military
- Homeland security
- Industrial process
- Factory automation
- Civil structures
- Transportation
- Biomedical
- Micro fluidic
- Bio- environmental
- Wind energy turbines
- Other

The comprehensive view on the % share of Application segment (2020)

Top Impacting Factors

- Need for enhanced safety and security solutions
- Better and enhanced alternative for conventional technology
- Lack of industrial technological standards
- Rise in wireless sensing technology
- High initial investment

Europe is expected to be the highest revenue generating region by 2020

North America, Asia Pacific, LAMEA

For More Details See Table of Contents
Where do we go from here?

What direction should the Integrated Photonics industry take?
Integrated Photonic Systems Roadmap 2016: AIM Photonics Academy and iNEMI

Photonic Systems:
- Telecommunications
- LIDAR
- Packaging
- Testing
- Sensors

2016 Roadmap:
Technology, Components, Equipment, Supply Chain

2017 Roadmap:
Photonic integrated circuit packaging and reliability
Summary

- Sensors
  - Applications
  - Materials (chalcogenides)
  - Devices (spiral)

- Detectors
  - Materials (PbTe)
  - Devices (film, waveguide-integrated, RCE)

- Roadmap
Questions?