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

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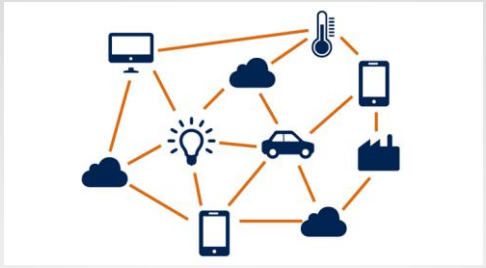
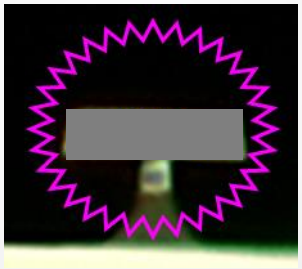
Content

- MIR Sensors
  - Applications
  - Materials (chalcogenides)
  - Devices (spiral)
- MIR Detectors
  - Materials (PbTe)
  - Devices (film, waveguide-integrated, RCE)
- Integrated Photonics Roadmap

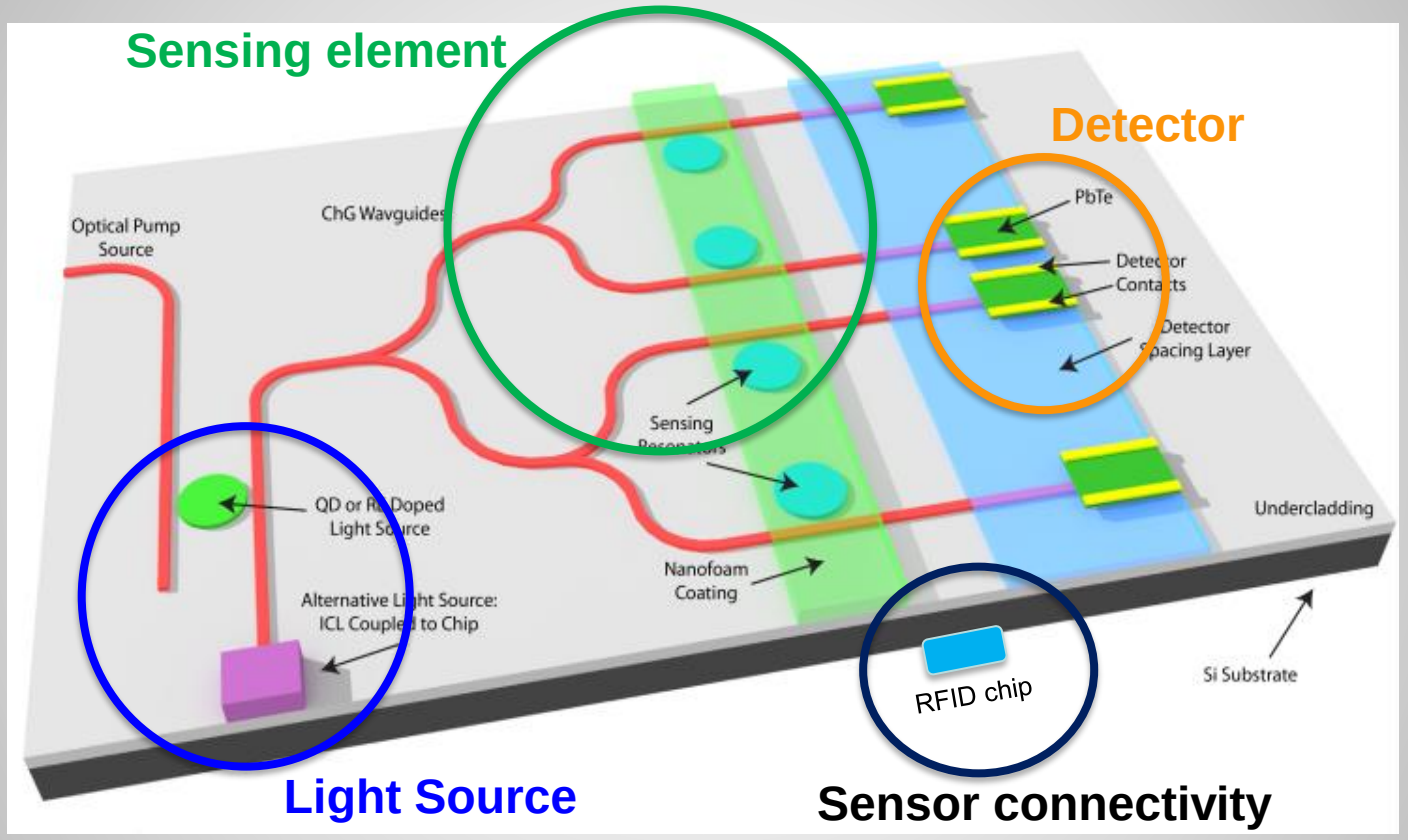
Sensors

Applications of Integrated Photonic Sensors



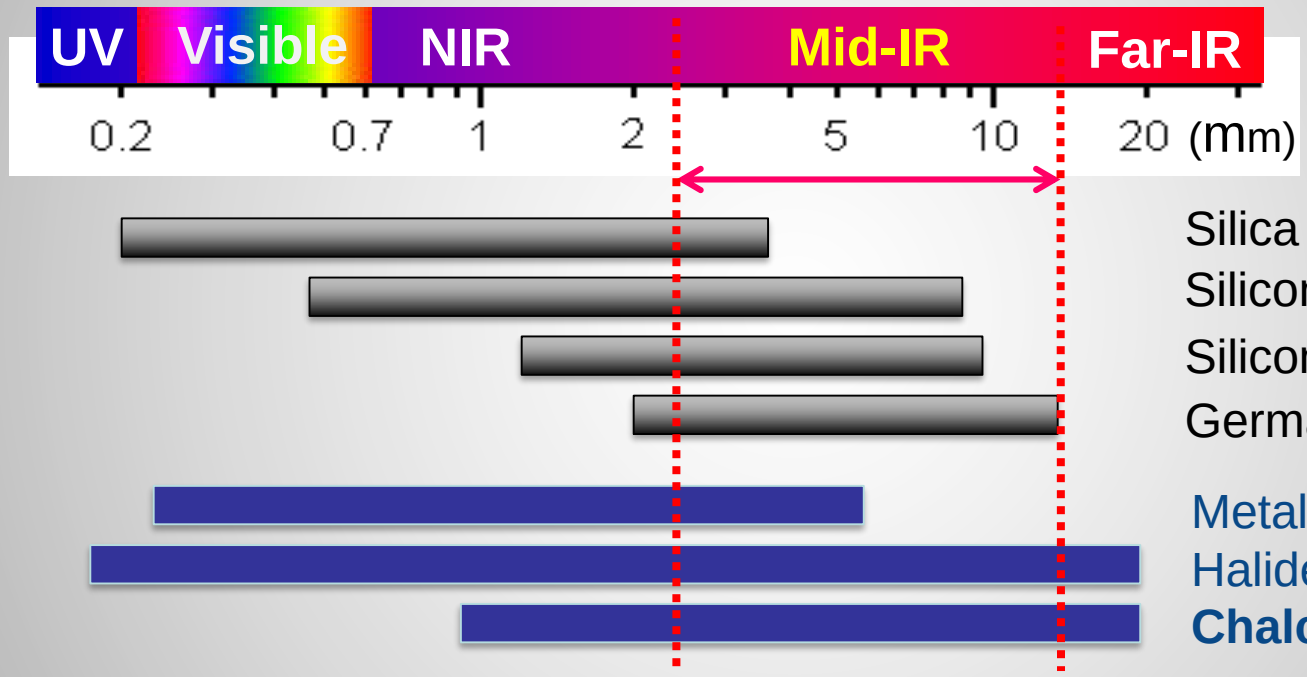


Integrated Photonic Chemical Sensor: A schematic

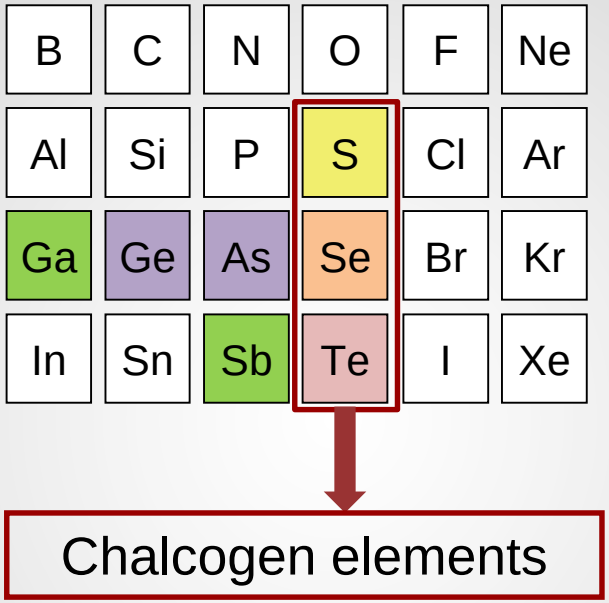


Sensor platform: Materials selection for MIR

- Finger print region
- Functional group vibrations

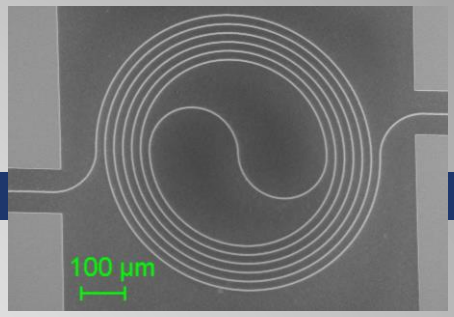


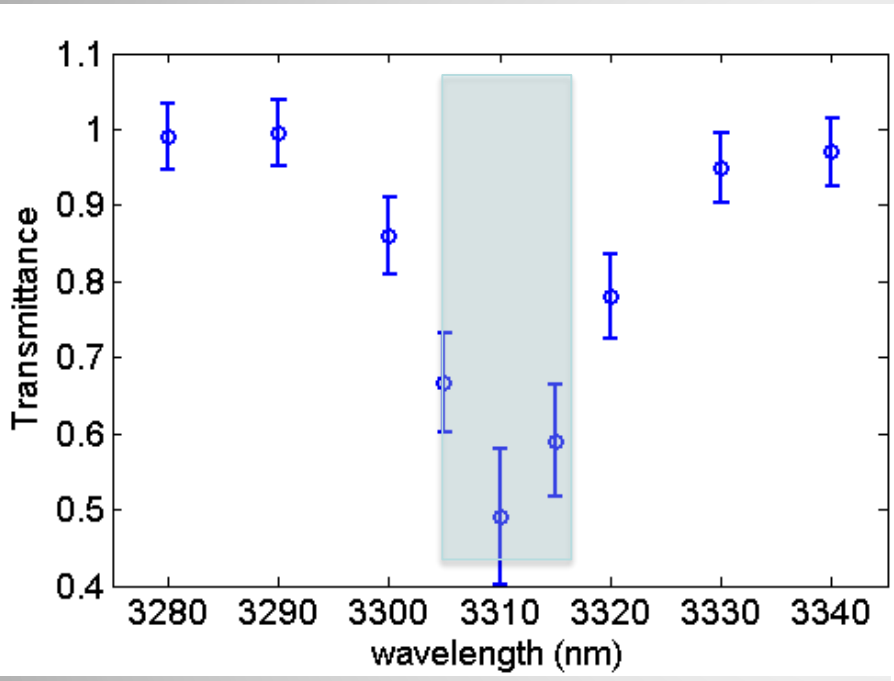
Glass–on–Silicon Chalcogenide Glasses

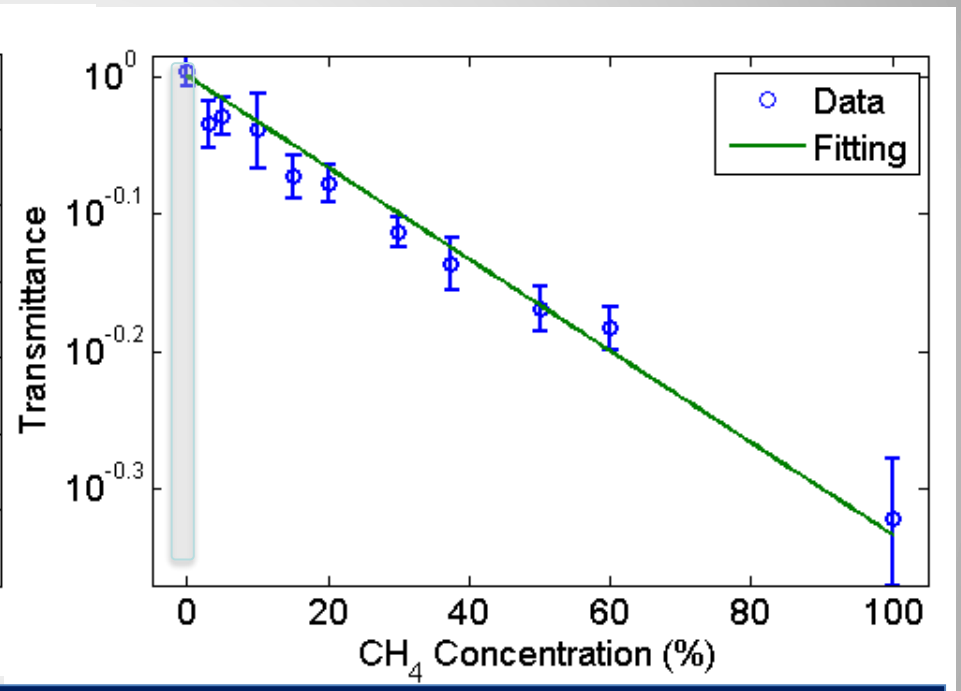


- **Wide IR transparency window**
- **Tunable optical properties**
- **Ease of fabrication**

ChG methane gas sensor







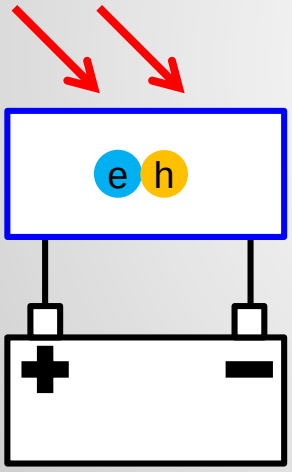
On-chip sensing of methane gas using MIR absorption

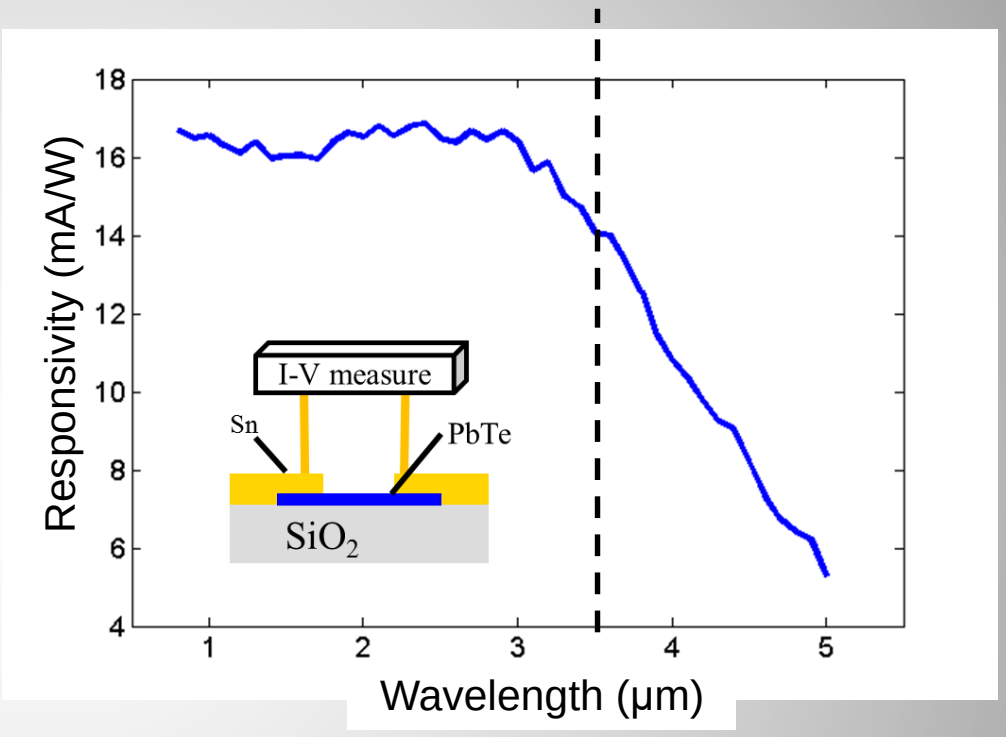
Han, Zhaohong, et al. *APL*, 2016

On-chip Detectors

PbTe film as a MIR photoconductor

- PbTe photoconductor properties
  - Good responsivity upto 3.5 µm



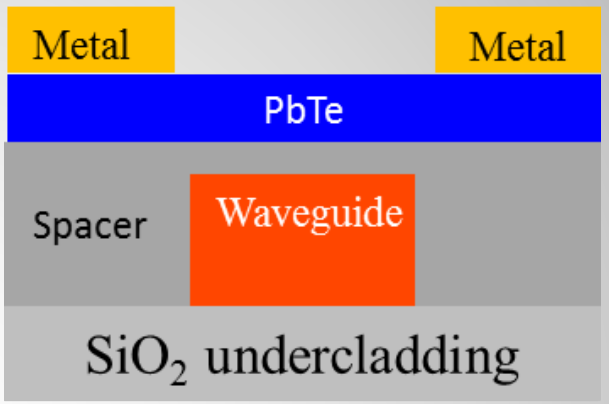


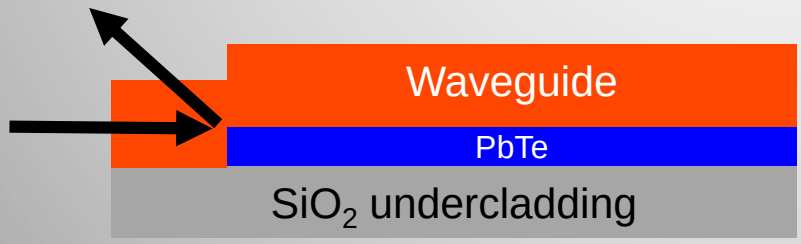
Responsivity for thermally evaporated 650 nm polycrystalline PbTe film at **-60 ºC**

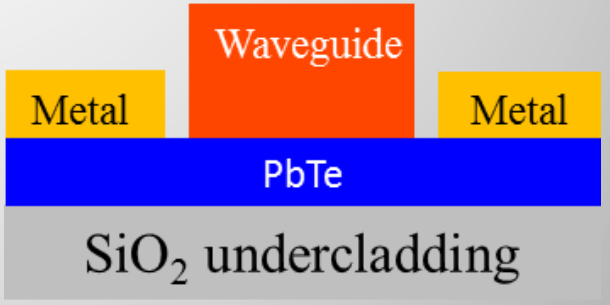
Integration of PbTe with a waveguide to enable room-temperature operation

PbTe detector integrated with a ChG waveguide

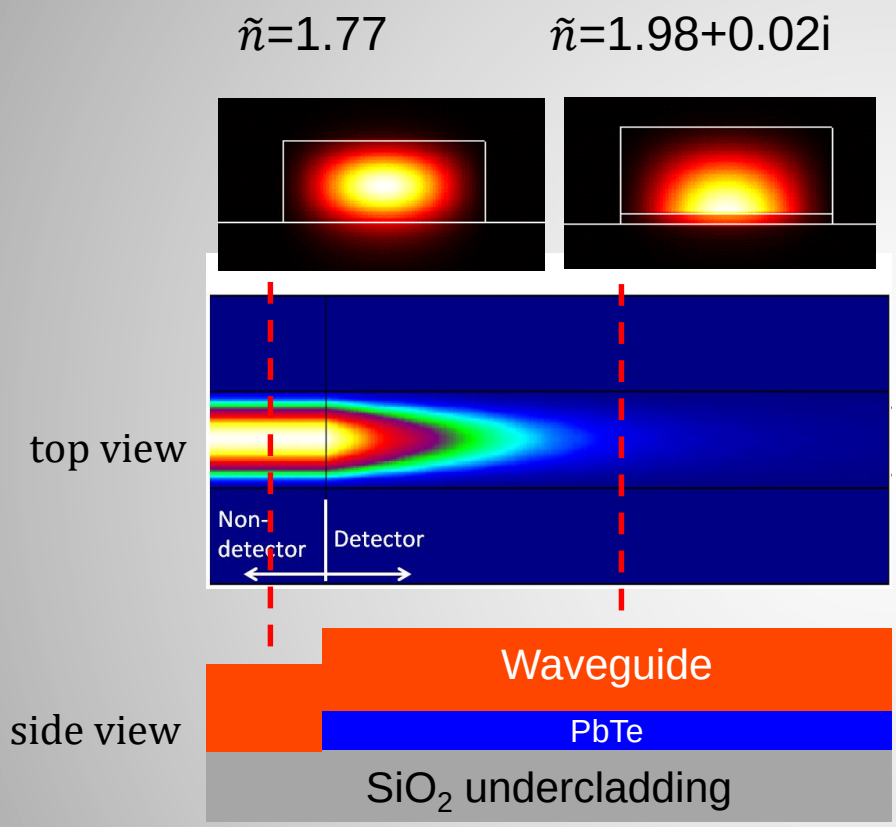
- 1st generation device
  - Discontinuity of thin film
  - Spacer = planarizing layer+ index matching layer
  - Complex fabrication
- Novel fabrication process
  - Coupling loss due to index mismatch and step edge?







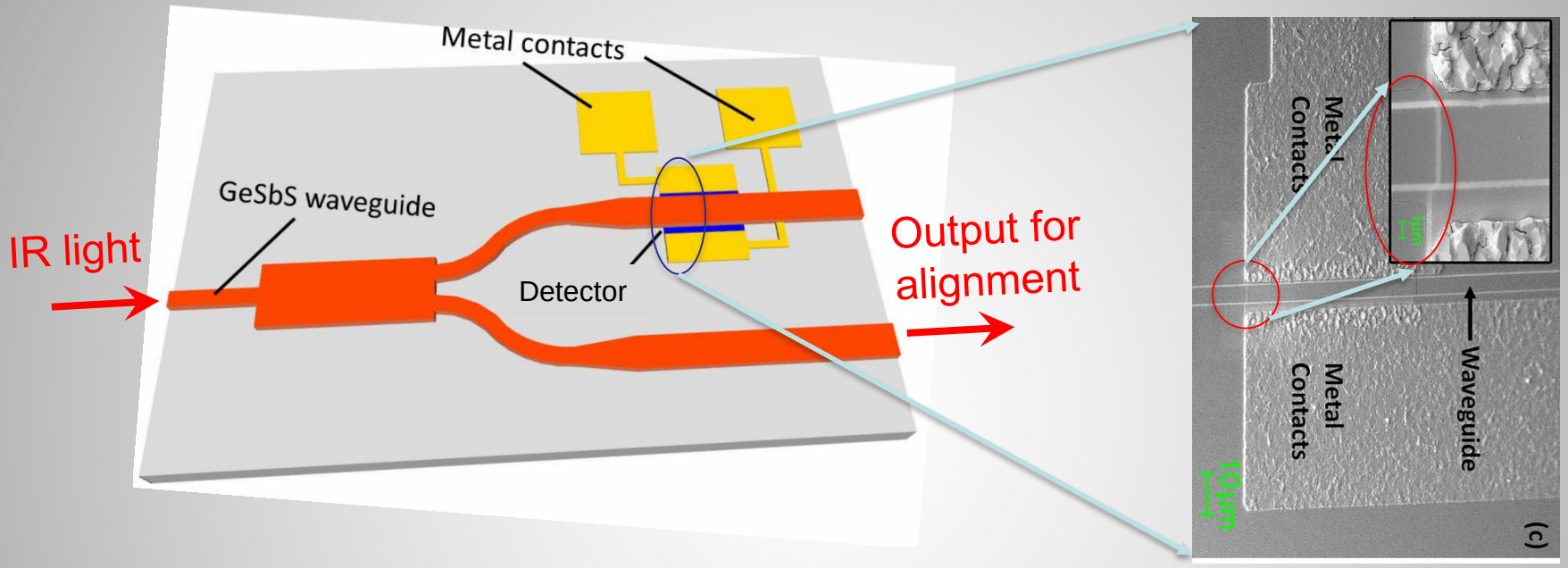
PbTe integration coupling efficiency analysis



- 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

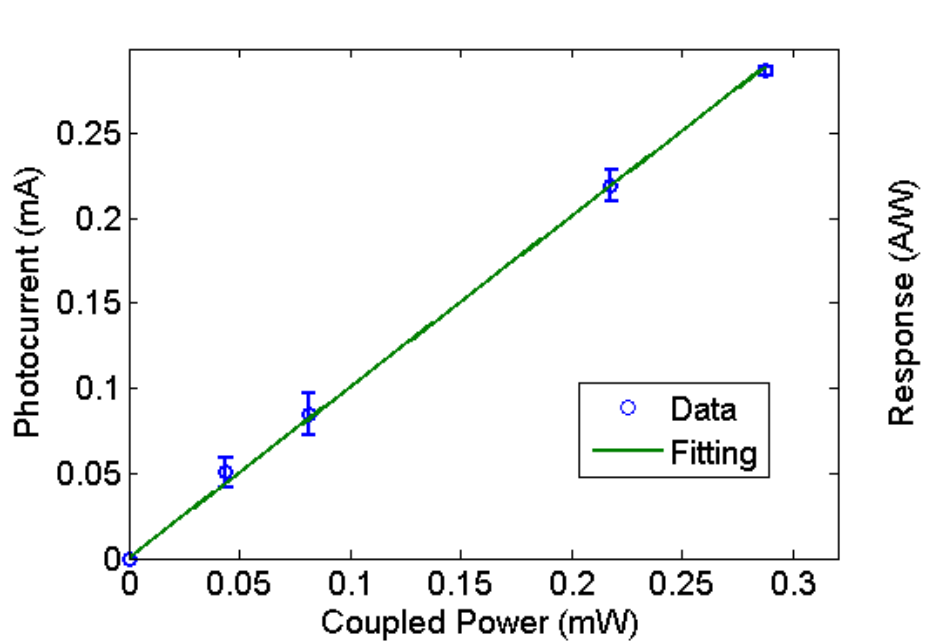


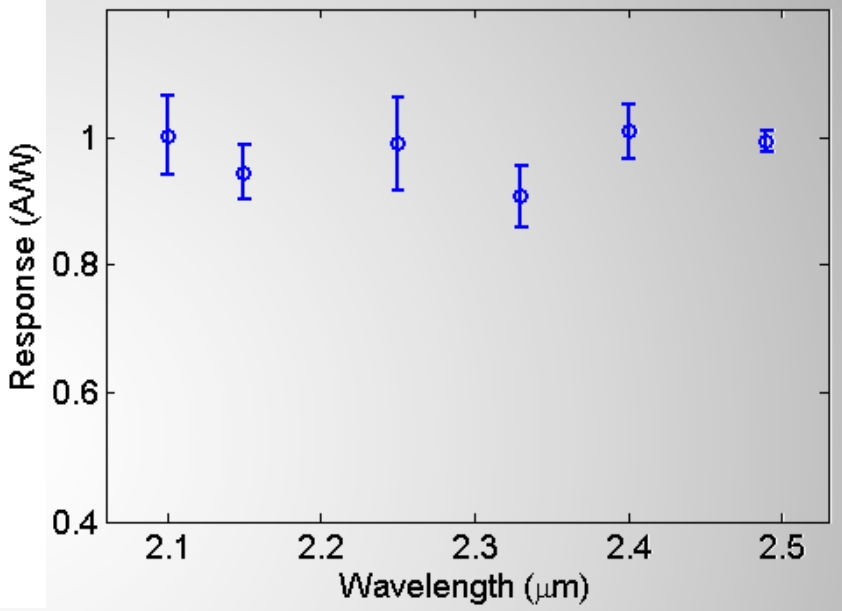
Waveguide integration:

- **Noise suppression**
- **IR photonic circuit**

Detector performance

Waveguide-Integrated Detector at RT

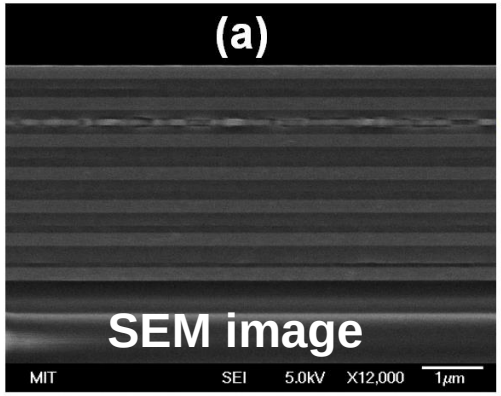


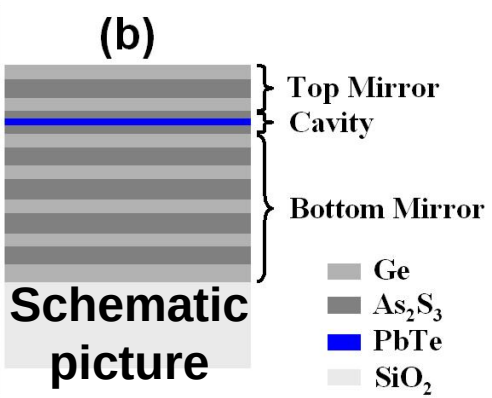


	Waveguide Integrated	Normal Incident
Responsivity (A/W)	1.0	0.017
External quantum efficiency	58%	0.94%
Temperature	Room Temperature	- 60 ºC

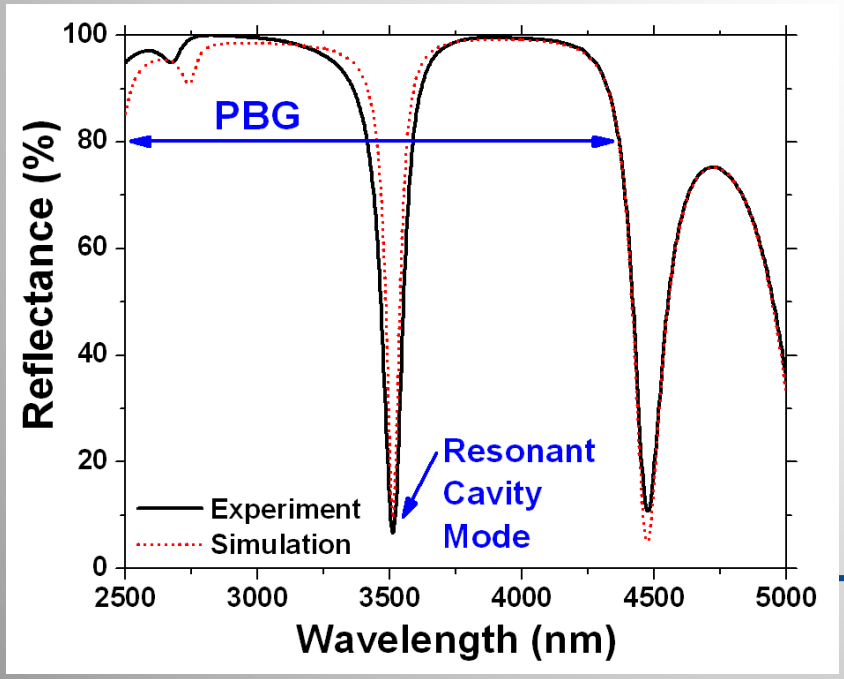
Han, Zhaohong, et al. *APL*, 2016

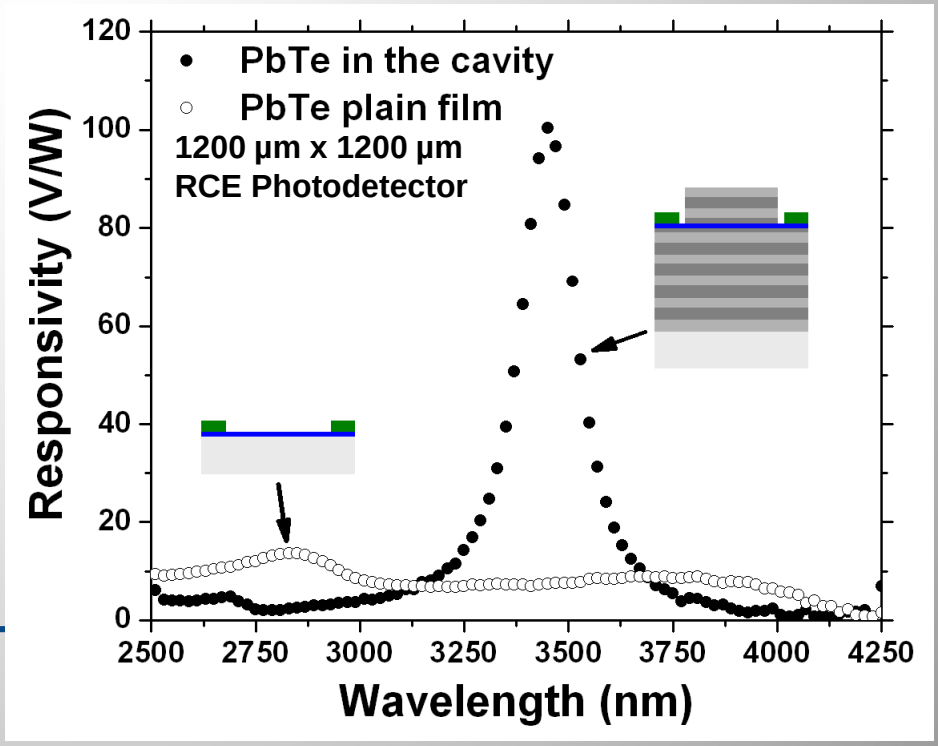
Enhanced Detection: PbTe Detector in a Resonant Cavity



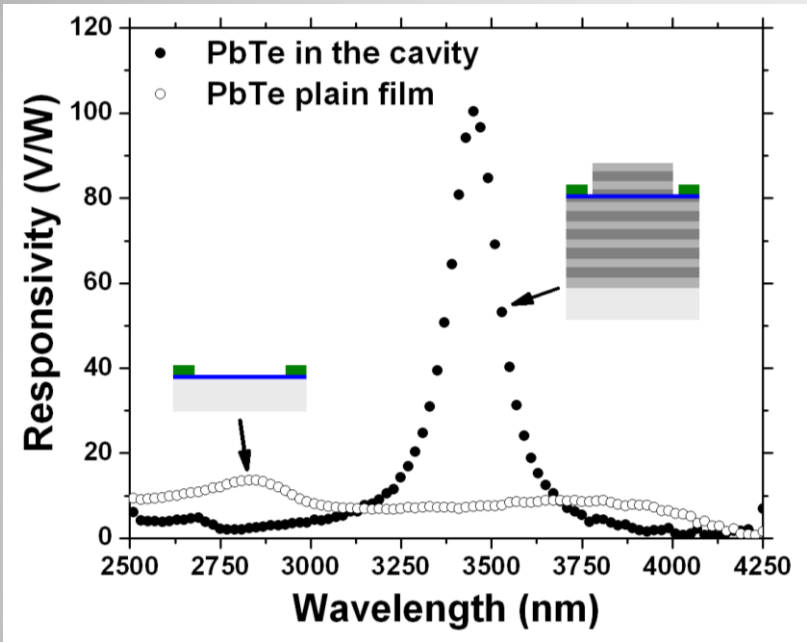


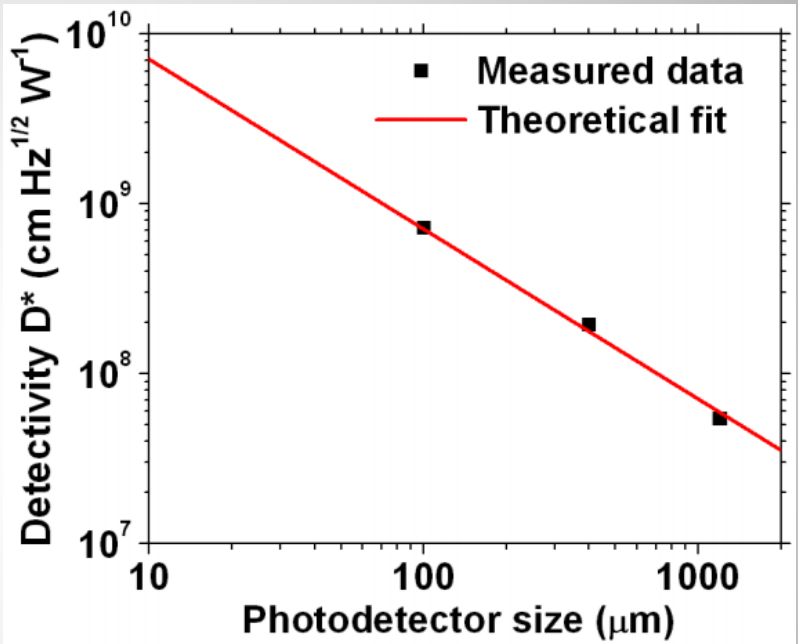
- Successful low-T fabrication process on Si: <150 °C
- Demonstrate 13.4X cavity enhancement
- Peak responsivity = 100 V/W





Resonant Cavity Enhanced IR Detector





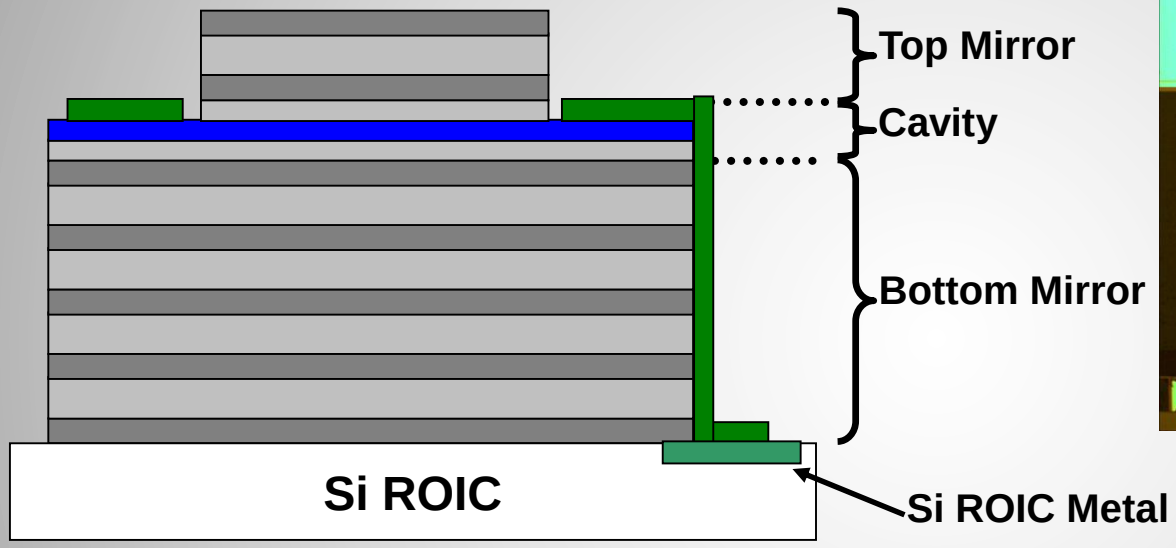
- **Enhanced detectivity inside a cavity**
- **Detectivity increases when photodetector size decreases**

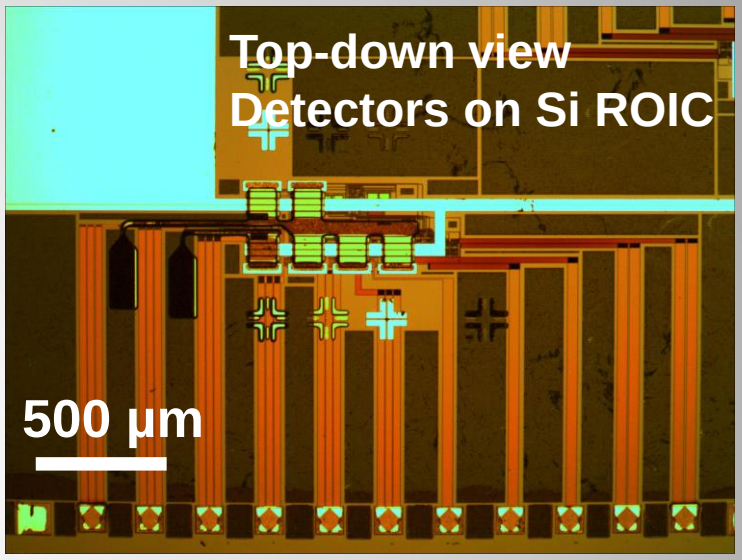
Jianfei Wang *et al.*, *Opt. Express* **18**, 12890-12896 (2010)

Packaged Prototype

Packaged integrated detector on a silicon platform

Cross-sectional view of 1 photodetector





Successful fabrication of integrated prototype

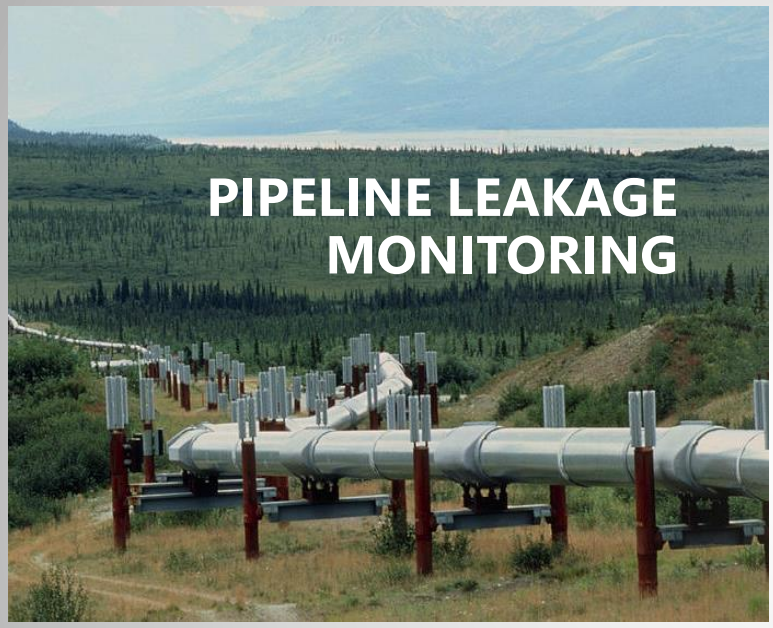
Integrated Methane Gas Sensor: Case Study

Oil and Gas – Pipeline leakage monitoring

Joseph De Wolk, Will Wolfe, Preston Kutney, Ozzie Ortiz
Sloan School of Management

Oil and Gas Sensing

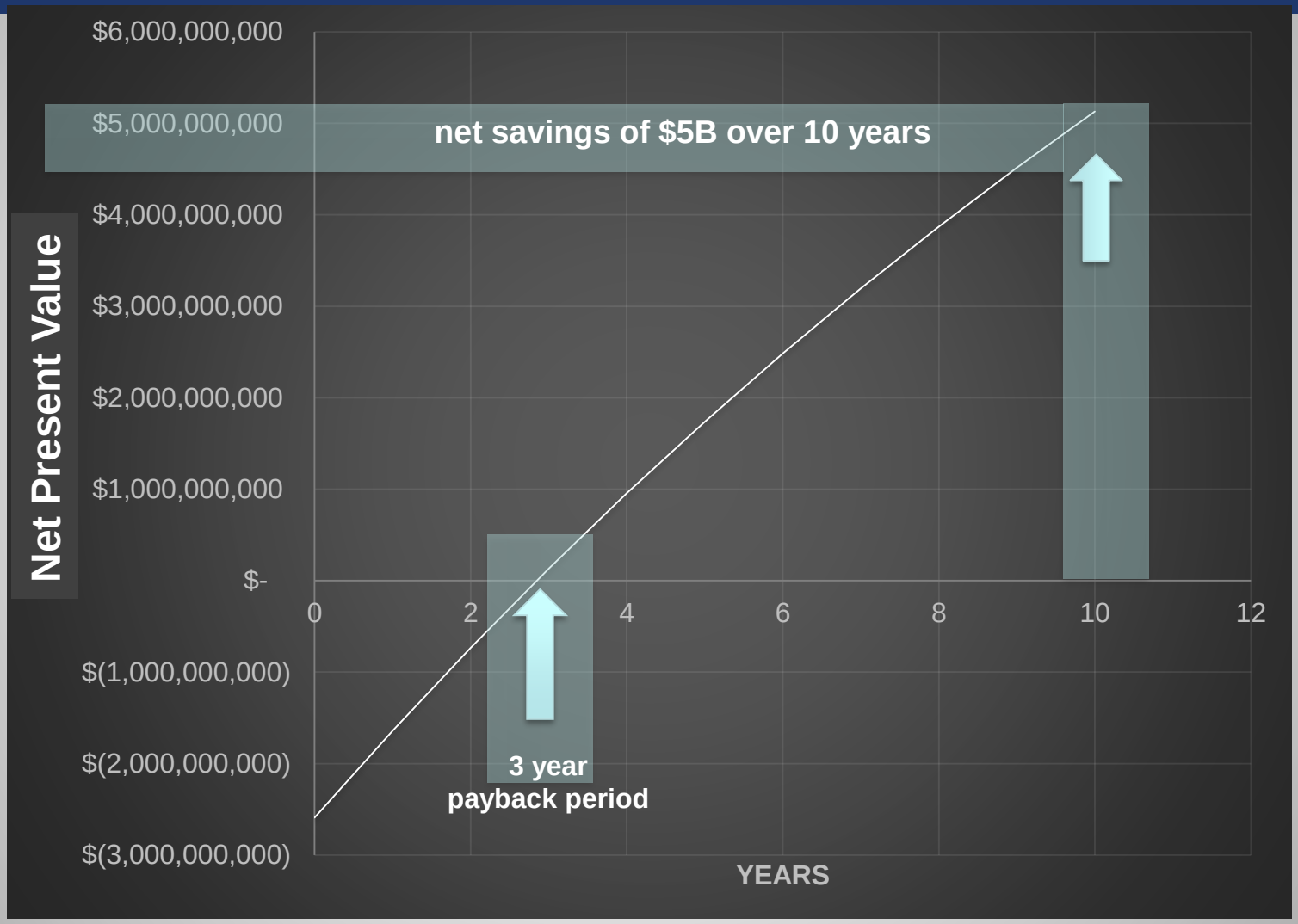
MIT Sloan School of management



Requirements:

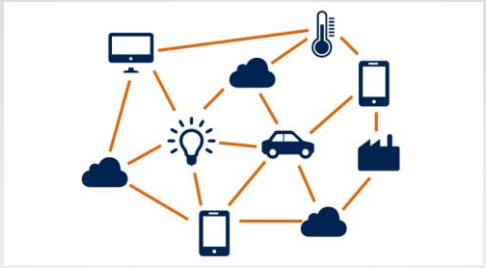
- **10-200 ppm sensitivity**
- **High selectivity and low false positive rate**
- **Low power consumption**

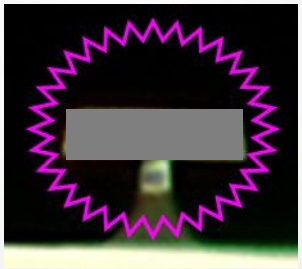
Pipeline leak detection with integrated photonic sensors can save billions $$



Based on assumptions from California Energy Commission Report
Natural Gas Leak Detection Sensor for Widely Deployable Networks" O. Herrera, M. Frish, D. Bamford, M. Laderer. Dec 2015.

Applications of Integrated Photonic Sensors





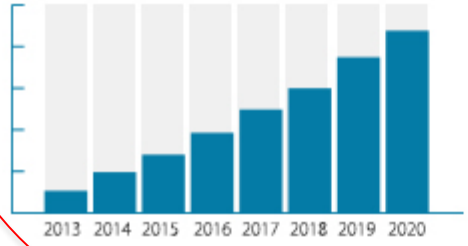
Global Photonics Sensors Market

Segmentation and Forecast, 2013 - 2020

https://www.alliedmarketresearch.com/photonics-sensor-market

Global Photonics Sensors Market

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

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

For More Details See Table of Contents

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

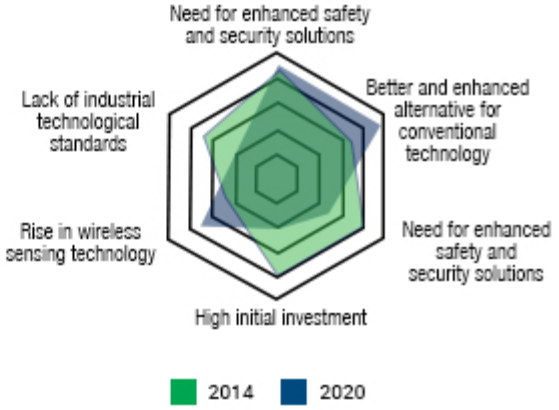
The comprehensive view on the % share of Application segment (2020)

Global Photonics Sensors Market by Geography

Europe is expected to be highest revenue generating region by 2020

North America, Asia Pacific, LAMEA

Top Impacting Factors



Where do we go from here?

What direction should the Integrated Photonics industry take?

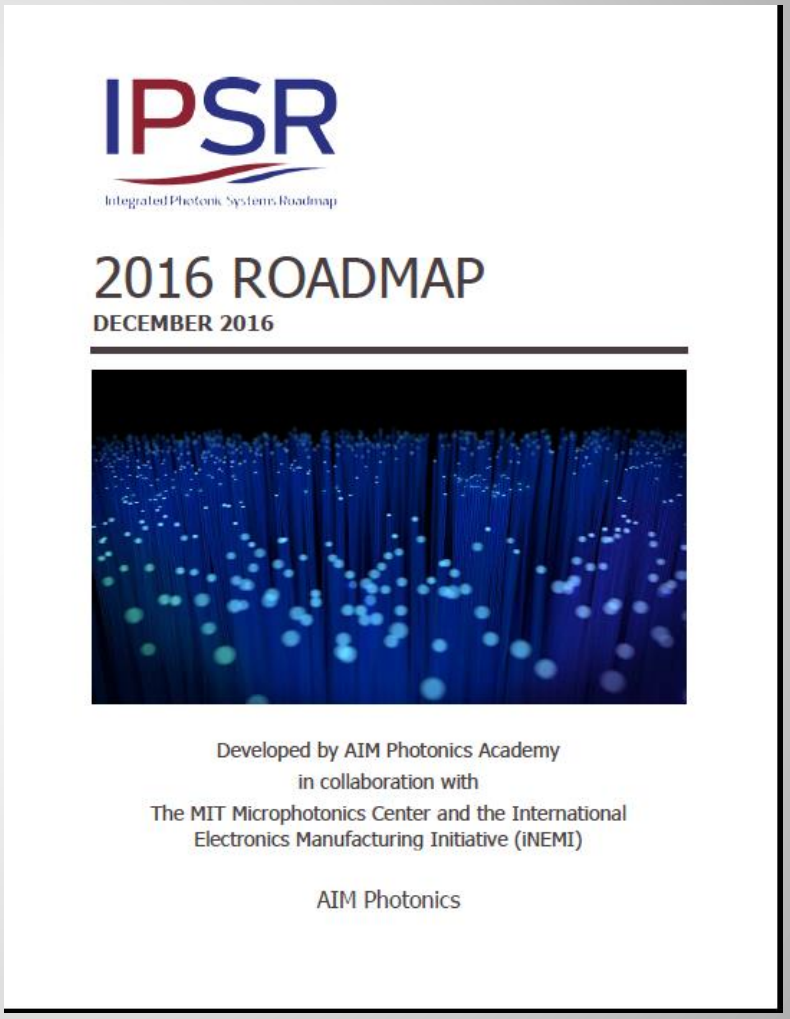
Integrated Photonic Systems Roadmap 2016: AIM Photonics Academy and iNEMI

Photonic Systems:

- Telecommunications
- LIDAR
- Packaging
- Testing
- **Sensors**

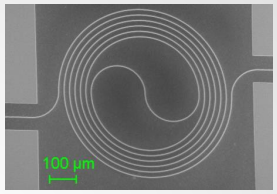
2016 Roadmap: Technology, Components, Equipment, Supply Chain

2017 Roadmap: Photonic integrated circuit packaging and reliability

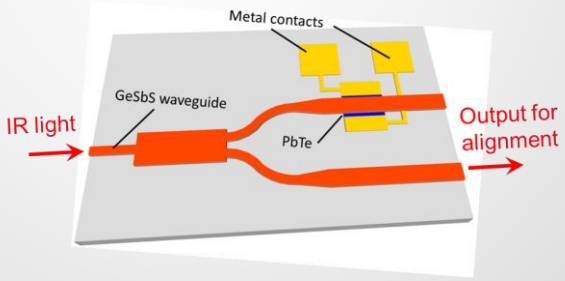


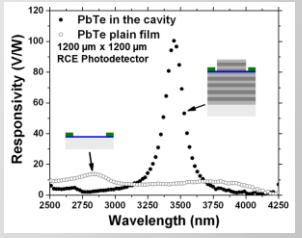
Summary

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



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





- Roadmap

Questions?