DEVELOPMENT OF A SOLO SPECTROSCOPY GAS SENSOR IN THE MID-IR

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EMERGING TECHNOLOGIES WORKSHOP

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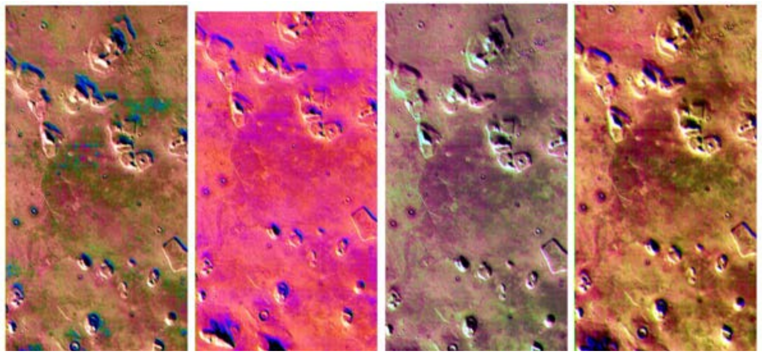
Space-based Spectroscopy

- Main spectroscopic analysis areas
  - Hyperspectral imaging of earth
    - Imaging of Amazon for deforestation
    - Imaging of ice caps
    - Military uses
  - Spectroscopy of the moon / Mars

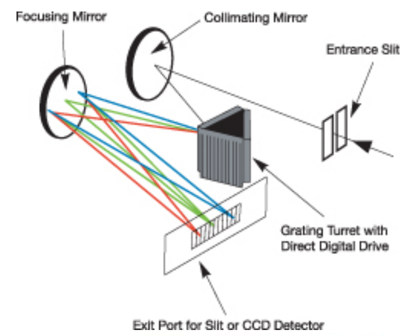


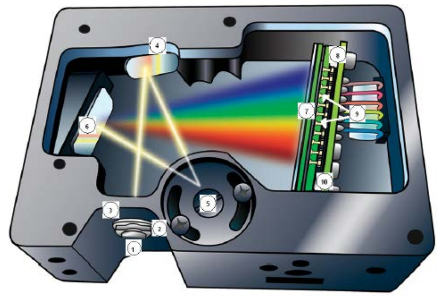
Spectroscopy in Space

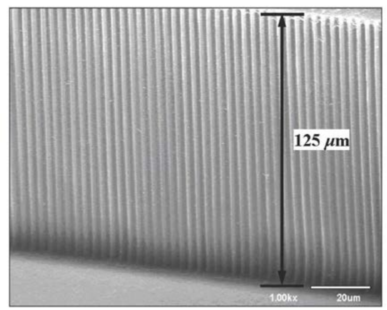
- Current and planned solutions are not ideal
  - Heavy payload
  - Most have moving parts
  - Do not span entire spectral range or do not have high resolution
  - Relatively high power consumption
  - Degree of temperature control
  - Lack of versatility / dynamic reconfiguration
  - Scan speed limits pixel size

What is the problem we are trying to solve?

- Current spectrometers have multiple components
  - Alignment issues
  - Expensive to manufacture
  - Optical effects – loss of photons / stray light
  - Miniaturisation difficult – spectral resolution suffers as size of spectrometer is decreased



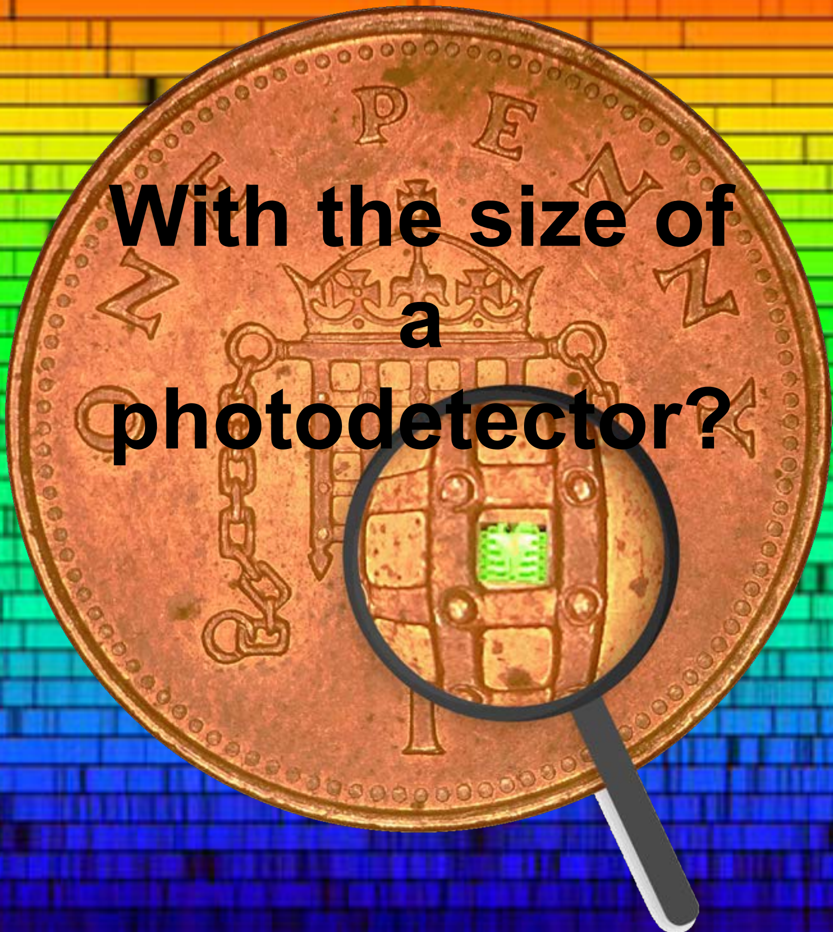




What if you could combine

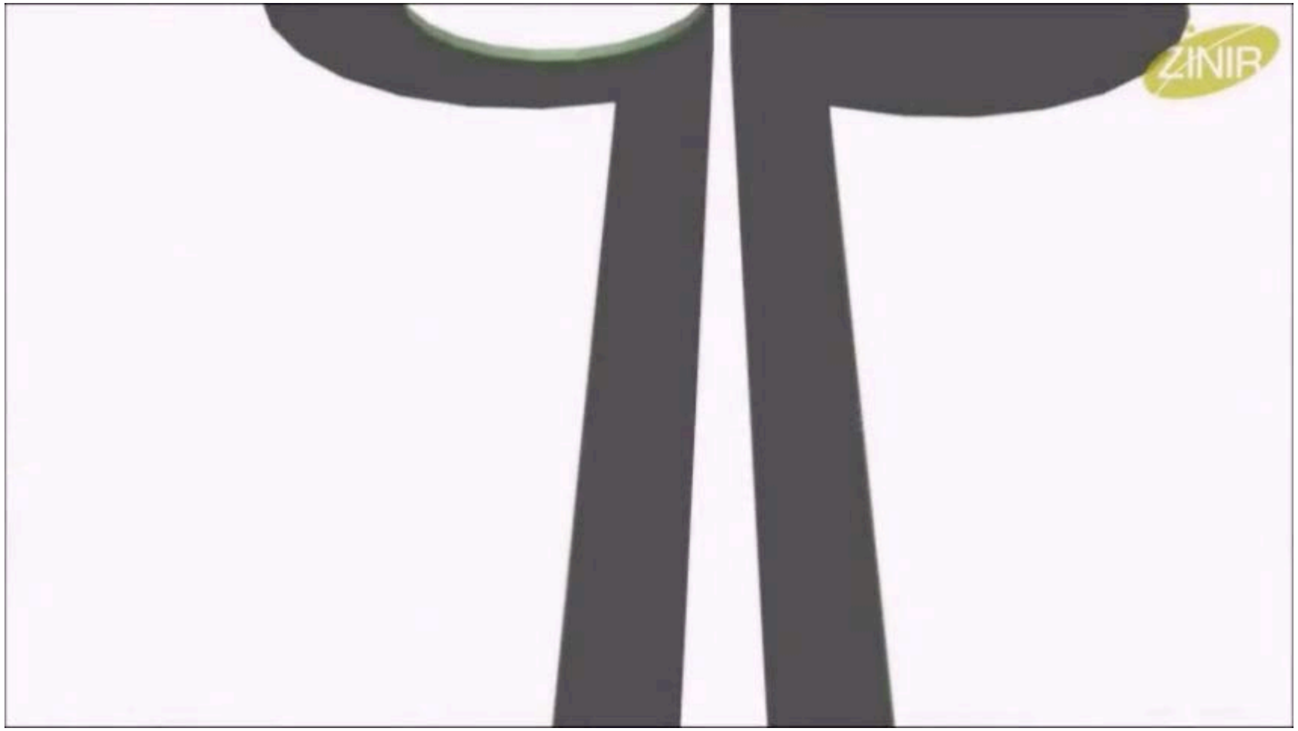
The spectral resolving capability of a spectrometer…

With the size of a photodetector?



Background image credit: NASA

A monolithic chip-based spectrometer

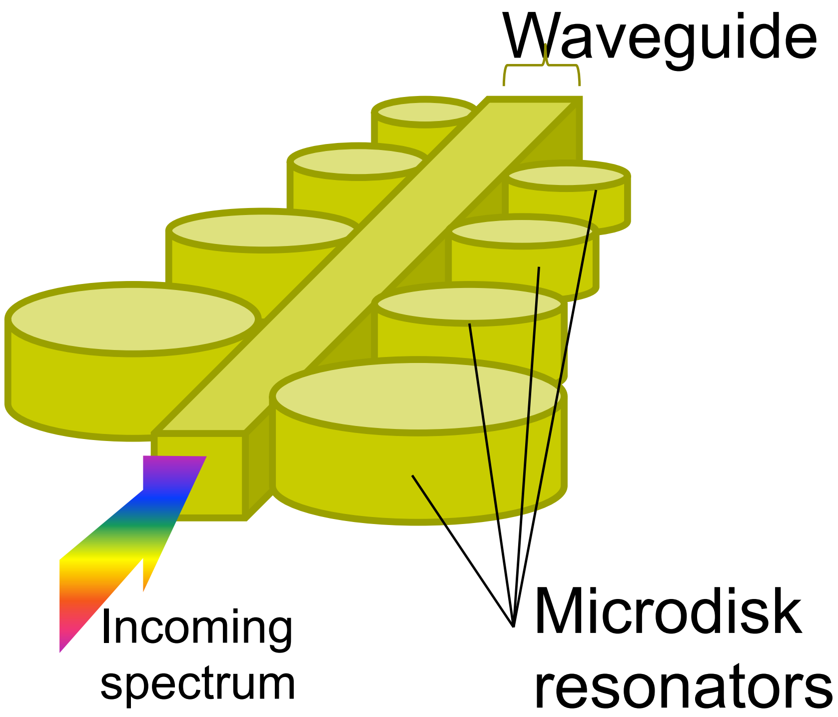


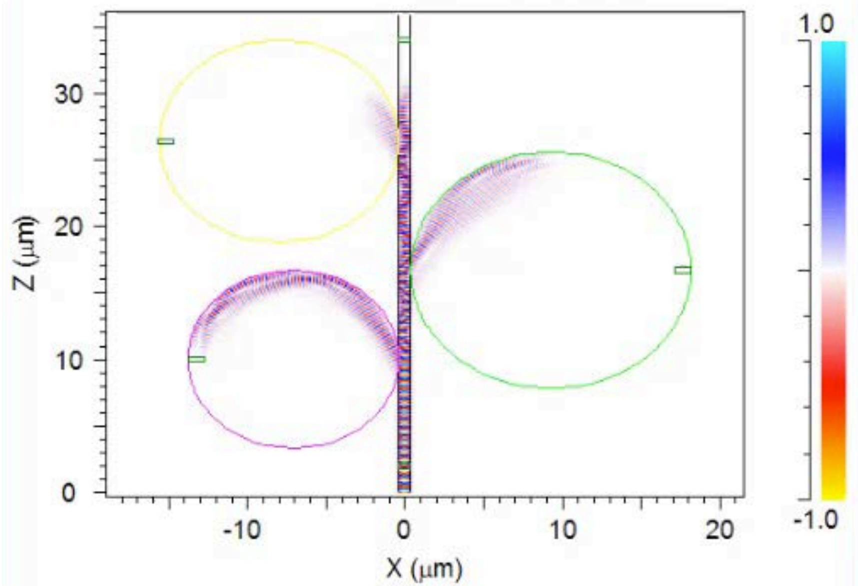
Broadband light travels down the central waveguide

Differently sized microdisk resonators pick out specific wavelengths

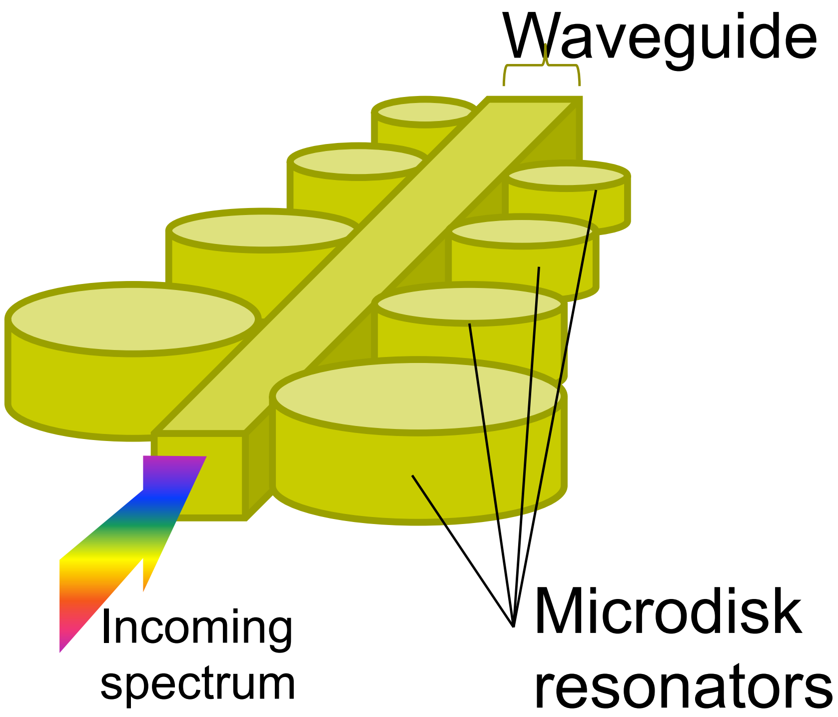
Each resonator is a separately addressable photodiode

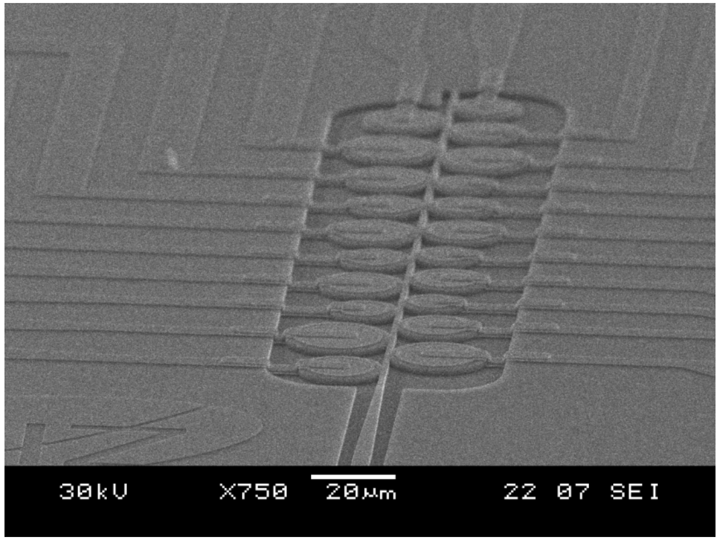
Our solution: Resonant Detector Array



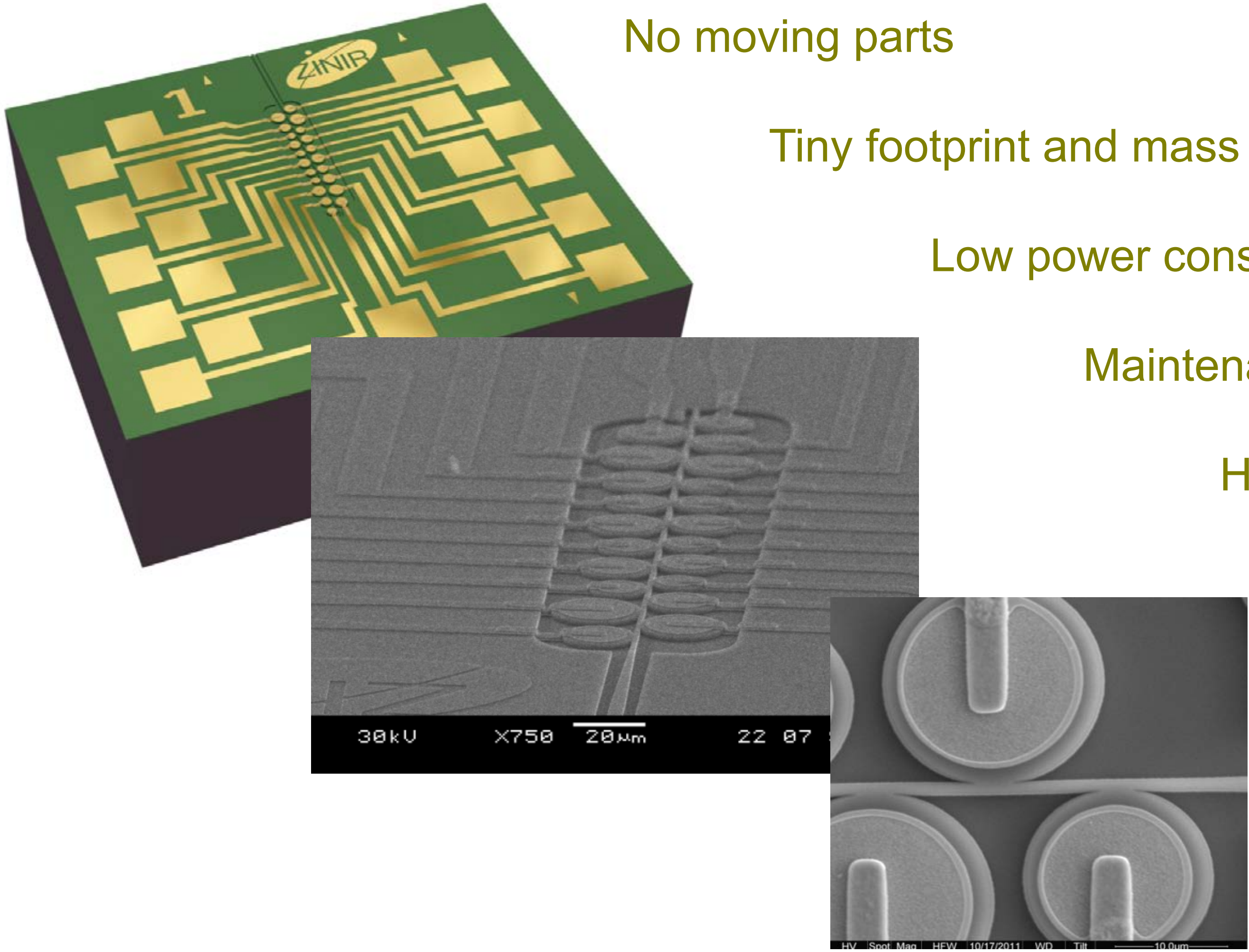


Our solution: Resonant Detector Array





Solo
Spectroscopy™



No moving parts

Tiny footprint and mass

Low power consumption

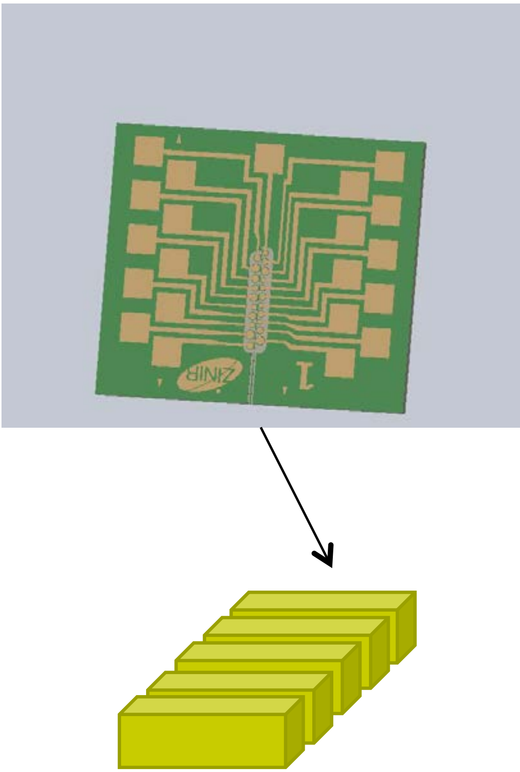
Maintenance - free

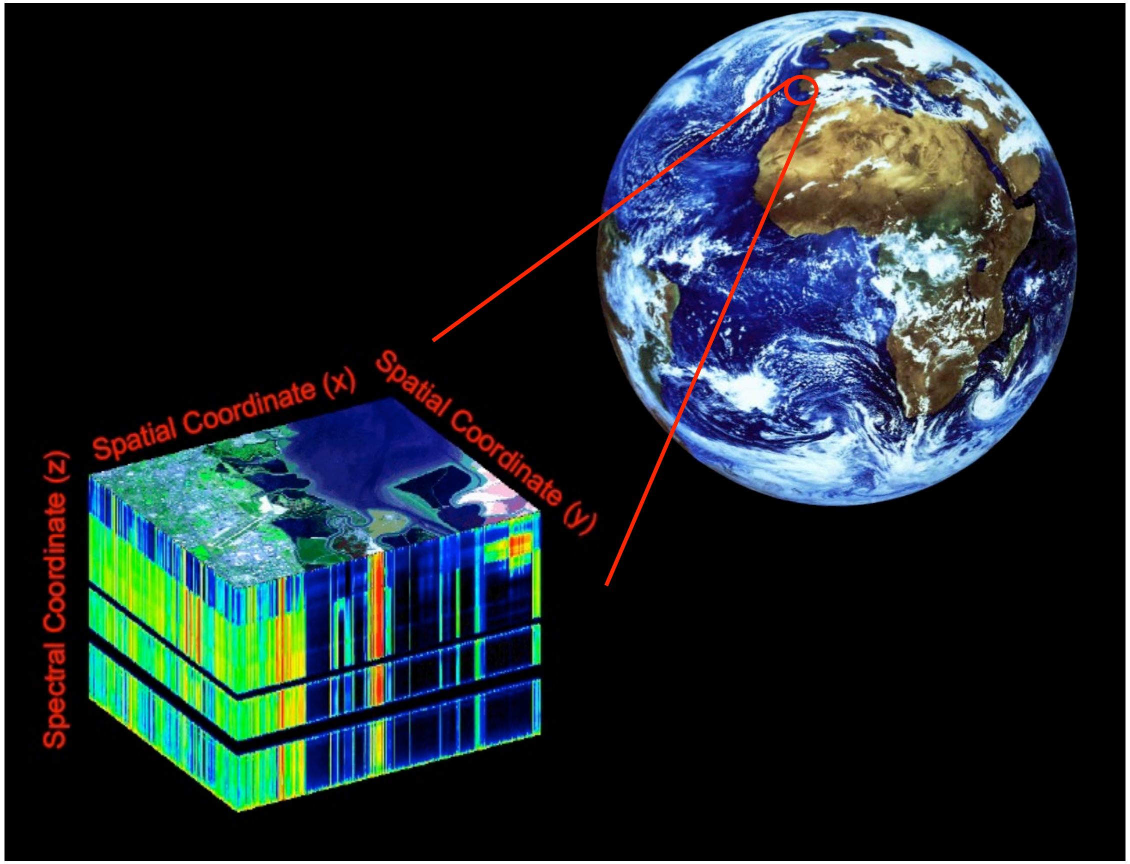
High volume manufacture

Different spectroscopy approaches

	Czerny Turner rotating grating	Grating and detector array	MEMS grating based	FTIR	Plasmon Filter based	Solo
Single component	✘	✘	✘	✘	✘	✓
High spectral resolution	✓	✓	✘	✓	✘	✓
Low mass (<500grams)	✘	✘	✓	✘	✘	✓
No moving parts	✘	✓	✘	✘	✓	✓
Low temperature sensitivity	✘	✘	✘	✘	✘	✓
Inexpensive manufacturing	✘	✘	✘	✘	✓	✓
Very small footprint (<10cm^3)	✘	✘	✓	✘	✓	✓
Spectral features adjustable by end user in real time	✓	✓	✘	✓	✘	✓

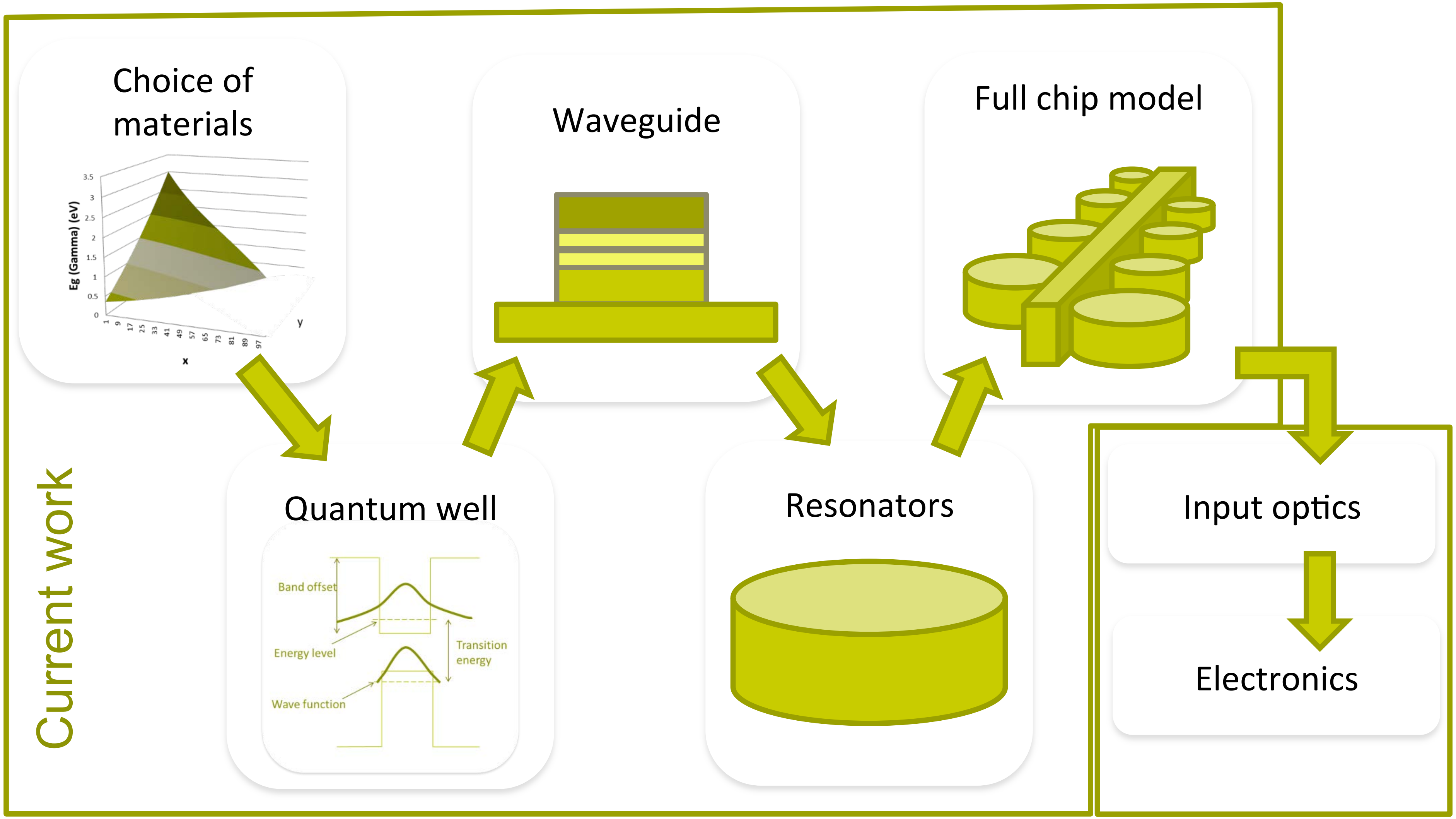
Arrays for hyperspectral imaging





Chip approach allows for relatively straightforward linear arrays

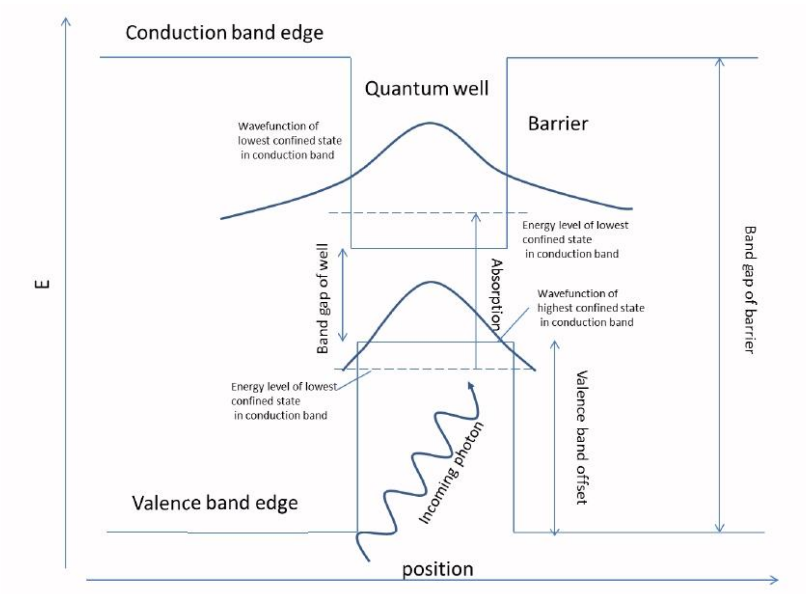
Design: Electronic and Optical Parameters



Approaches

Shorter wavelengths

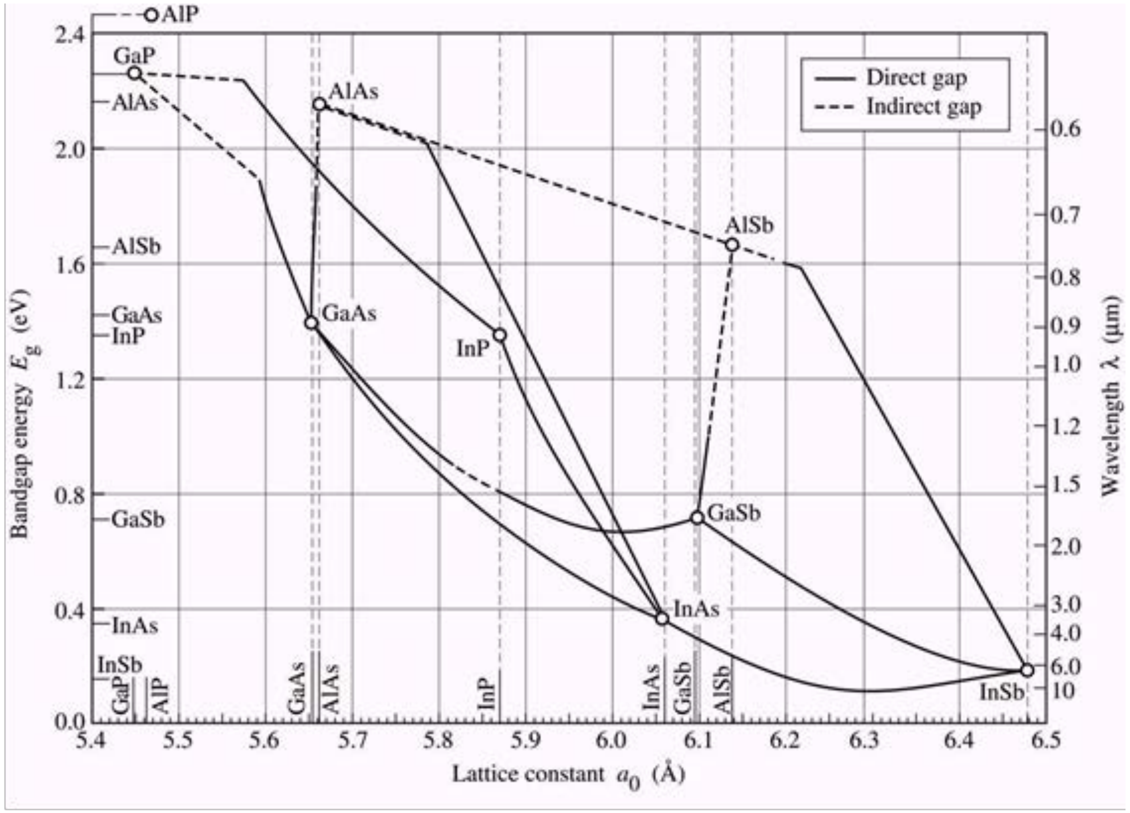
- Interband approach



Longer wavelengths

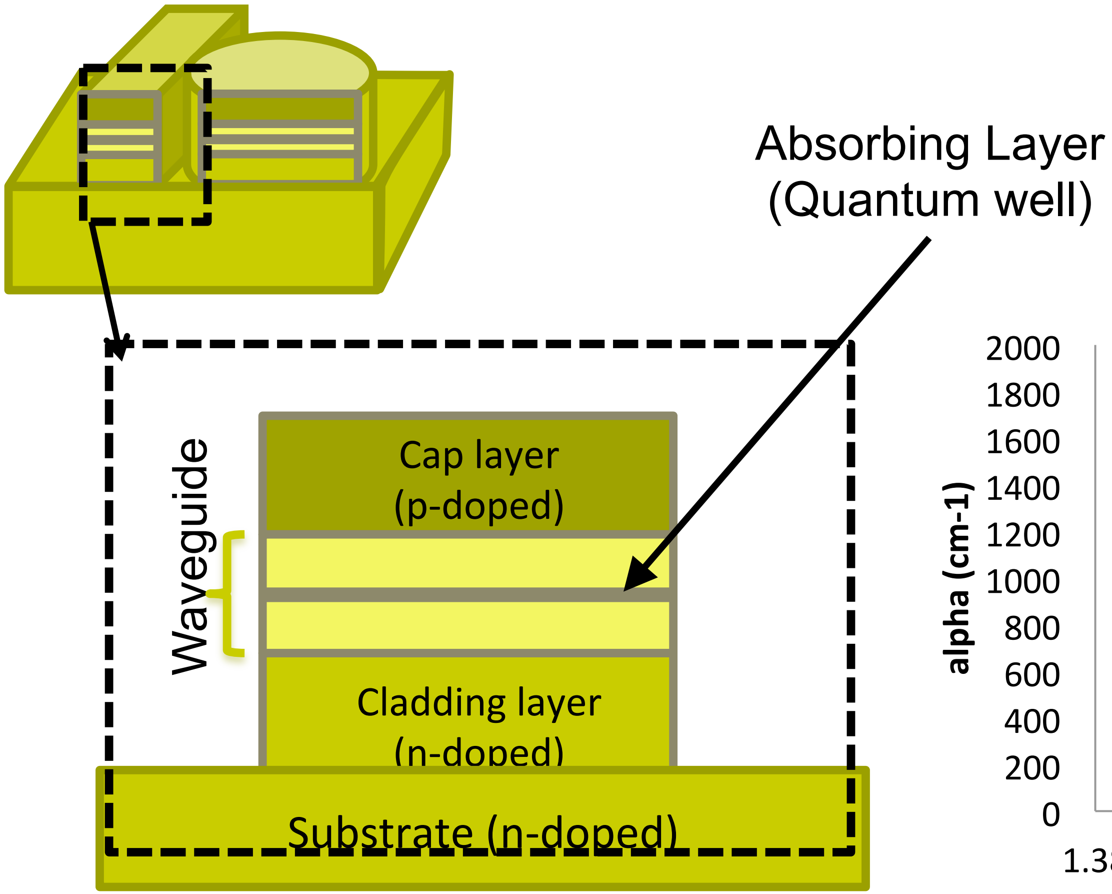
- Intraband approach

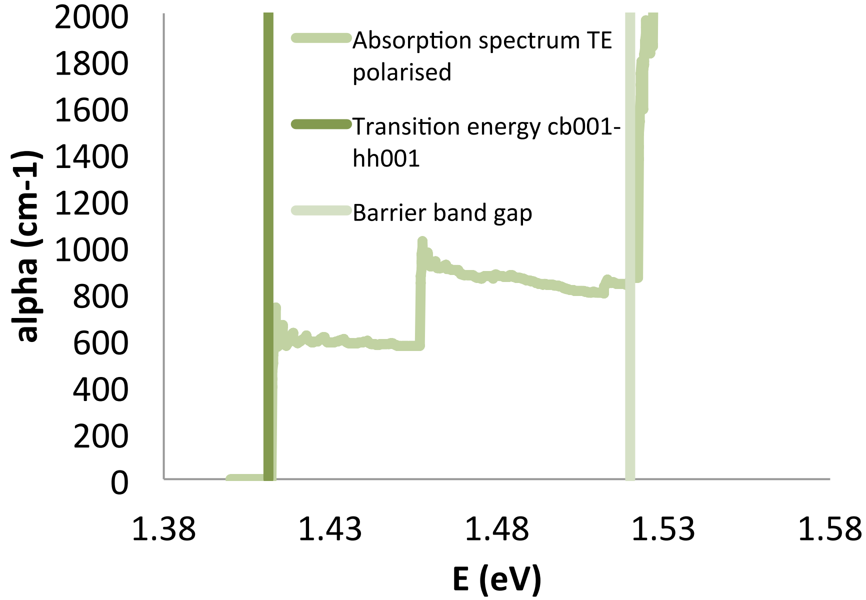
Interband devices – exploit range of III-V semiconductors



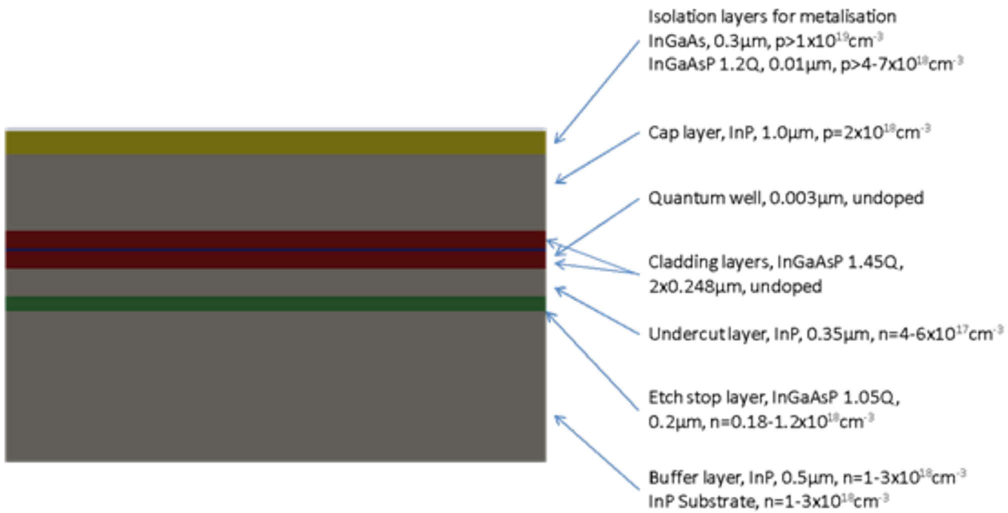
- InGaAs(P)/InP:
  - 1200-1700 nm range.
  - Direct band gap
  - Well-established material system commonly used in telecommunications device applications.
  - Applications in this range include gas sensing, e.g. CO_2.
- InGa(As)Sb/GaSb:
  - 2000-3000 nm range.
  - Direct band gap
  - Material used for mid-infrared lasers
  - Tolerances are more favourable due to the large feature size

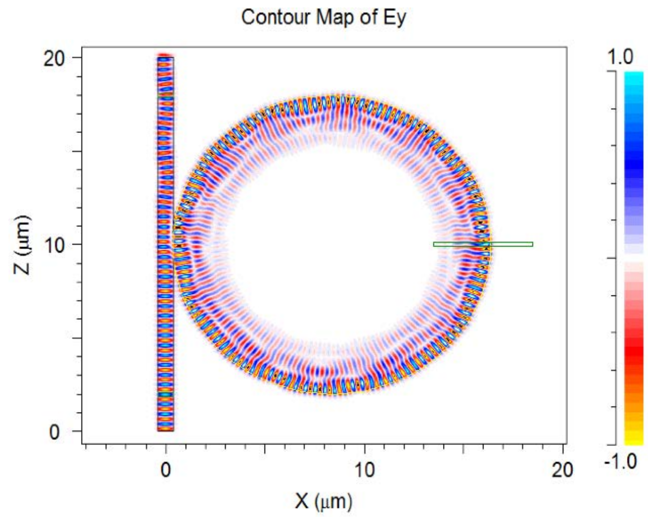
Layer structure: quantum well

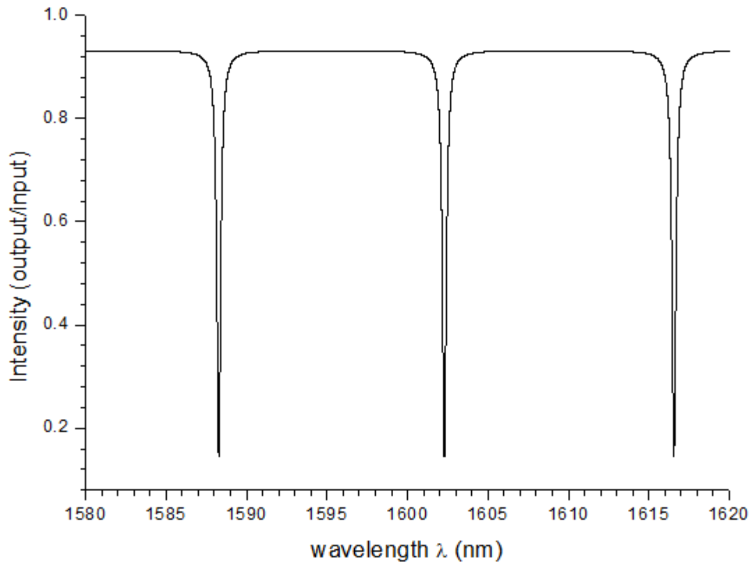




The 1600nm chip (interband)

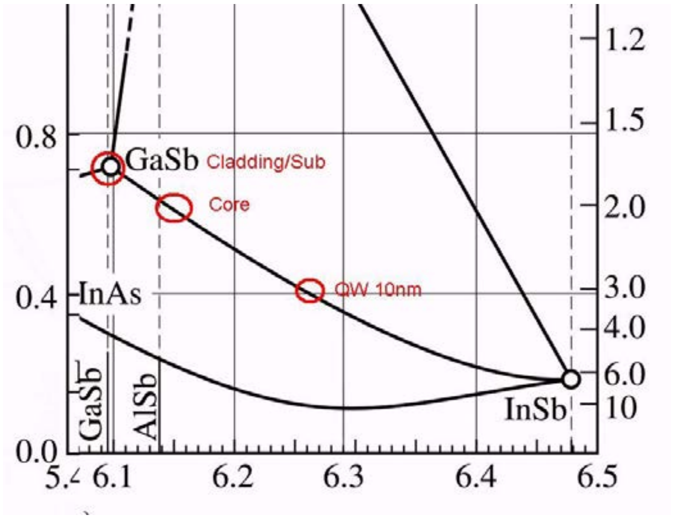


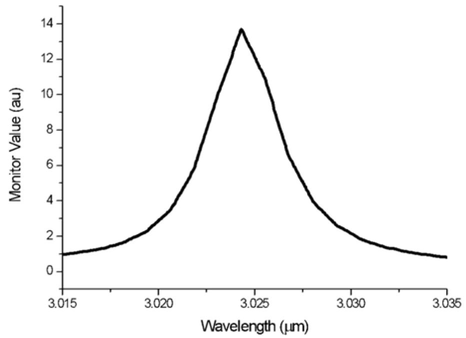


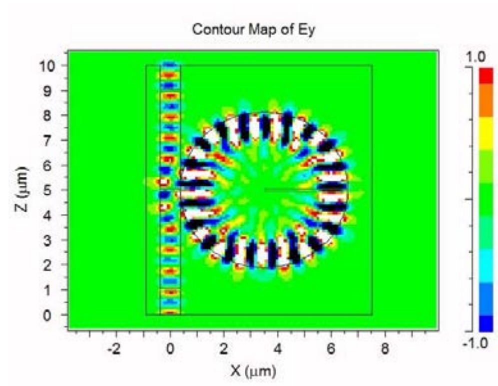


The InGaAsP/InP system provides a good solution for a system operating around 1600nm benefitting from mature telecomms device semiconductors

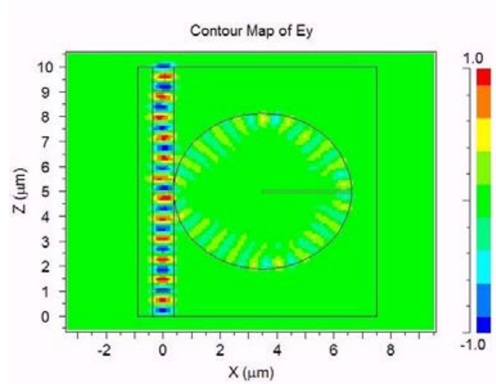
Extending to longer wavelengths (λ=3µm chip (interband)







On resonance

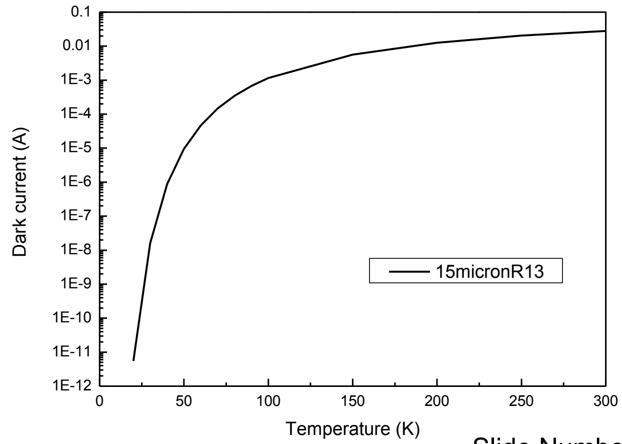


Off resonance

- $In_xGa_{1-x}Sb$ system grown on GaSb
- 10nm thick QW
- 3um disk radius
- Strong resonance observed close to 3um with linewidth of 4.6nm

Issues going to even longer wavelengths

- Interested in feasibility of using Solo concept out to 15.0µm
- Issues:
  – Non-radiative carrier recombination increases as wavelength increases (Auger processes)
  – Difficulty of obtaining high quality material (leads to defect-related recombination)
  – Cost/availability of materials
  – Thermal noise / dark current



Approaches

Shorter wavelengths

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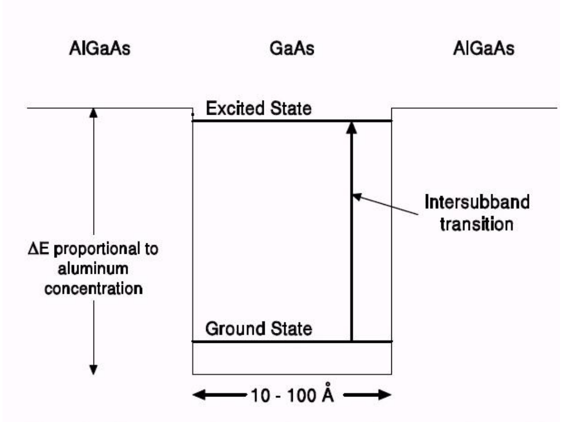
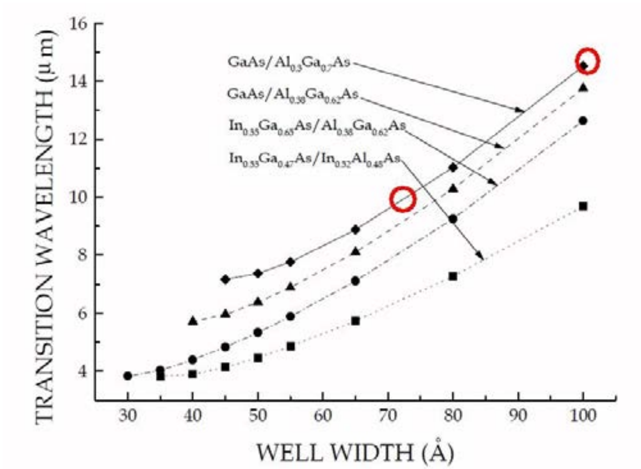
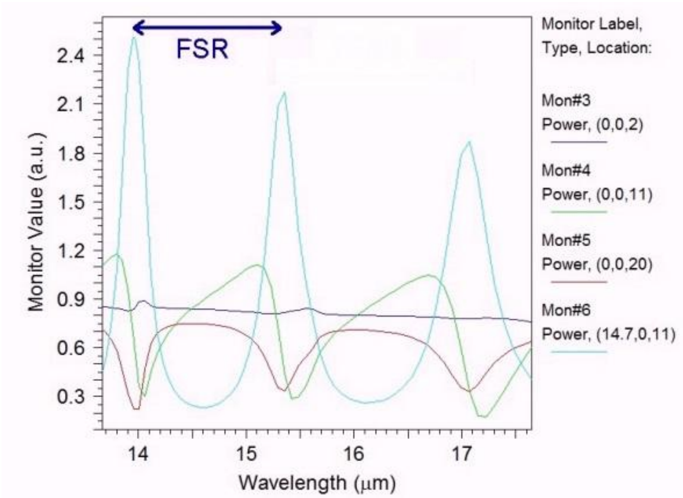
Longer wavelengths

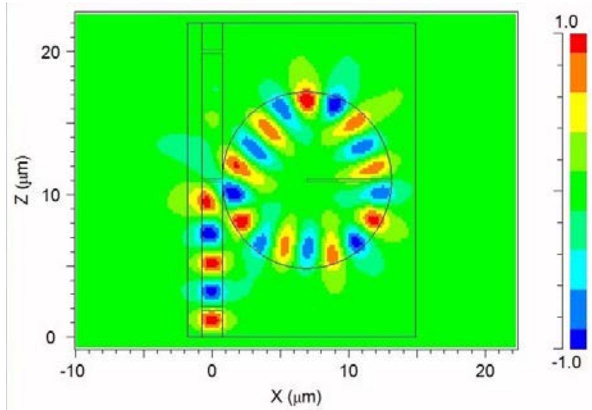
- Intraband approach





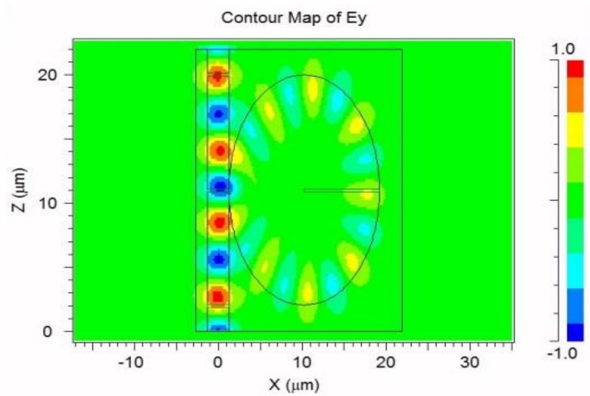
Exploiting quantum confinement control for long wavelength operation15µm chip (intraband)





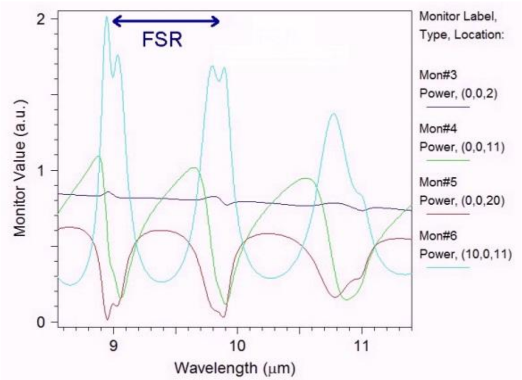
On resonance

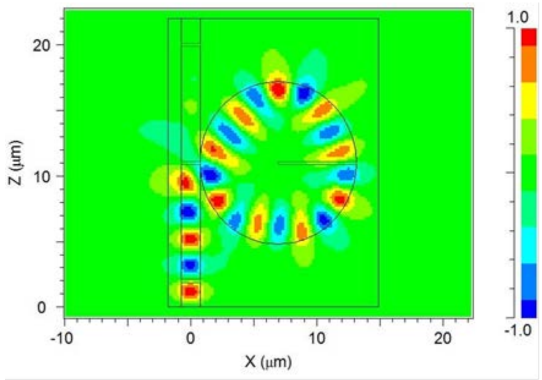
- 25 x GaAs 10.8 nm QWs separated by 50 nm AlGaAs barriers
- Disk radius 6µm
- Resonant linewidth of 300 nm
- Large FSR of 1400 nm



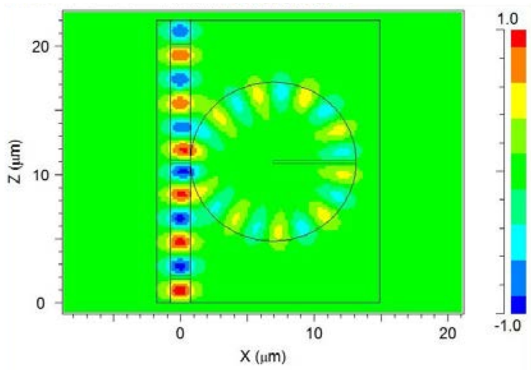
Off resonance

10µm design (intraband)





On resonance

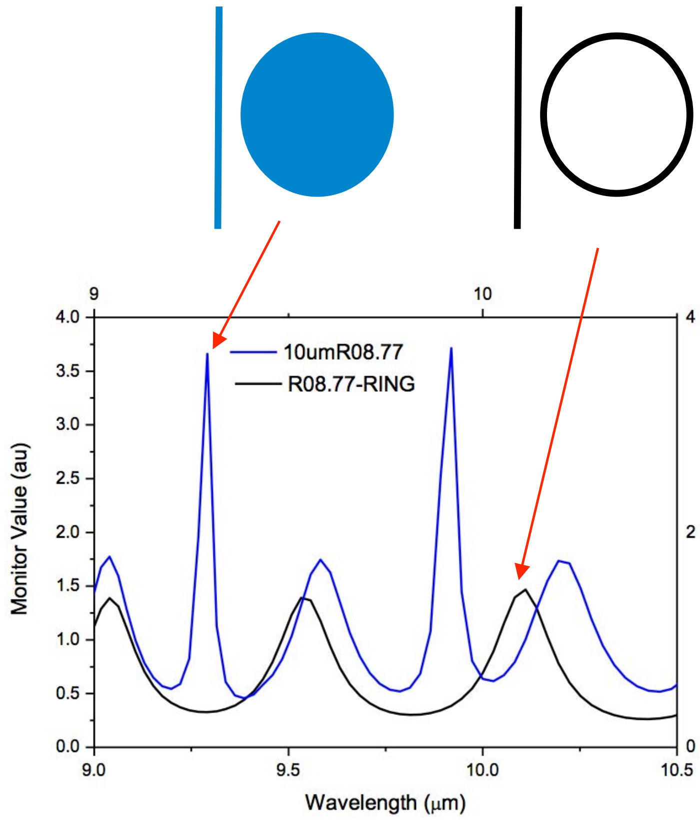


Off resonance

- A waveguide structure containing 25x GaAs 7.35 nm QWs separated by 50 nm AlGaAs barriers
- Disk radius 6µm
- Resonant linewidth of 206 nm
- FSR of 900 nm
- Initial characteristics look promising

Removal of parasitic modes: ring and other geometries

- Preliminary investigation of disk versus ring geometry.
- The ring provides a method of mode exclusion, to be explored in future work together with other geometries



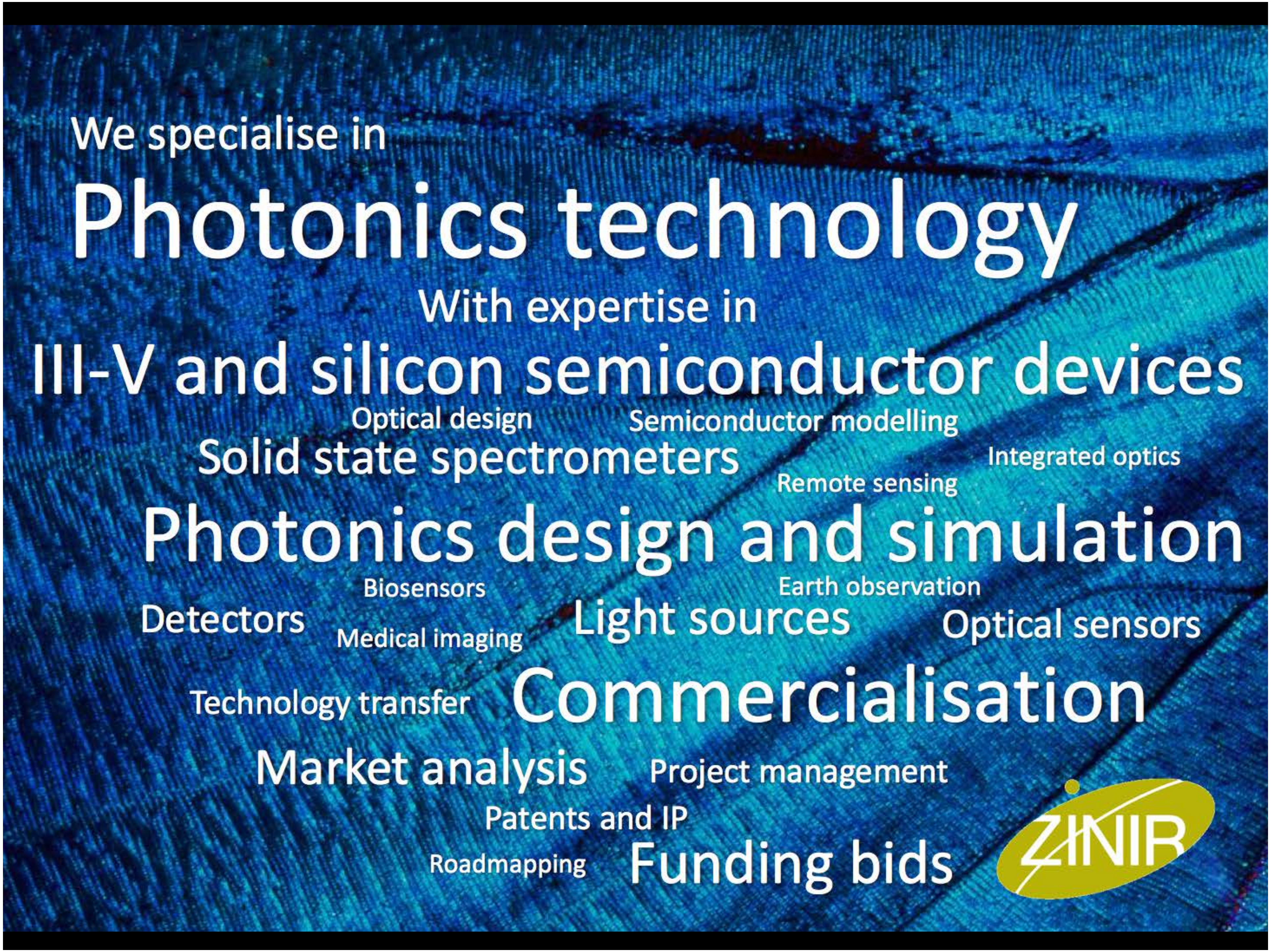
Summary

- Solo spectrometer approach offers a monolithic solution for spectroscopy in the optical domain
- The approach may be applied across a broad wavelength range through choice of an appropriate semiconductor alloy (up to 3000nm in principle)
- The use of an intraband approach extends the operating window significantly with 15um achievable with a GaAs/AlGaAs system
- Future work will focus on detailed device design and prototype manufacture

Sensitivity – signal current

Target Wavelength (µm)	Responsivity (A/W)
1.6	7.70
3.0	5.23
10.0	12.65
15.0	11.63

Calculated resonator responsivities assuming 100% IQE and all absorbed power leads to carrier generation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