Australian Academy of Science
National Nanotechnology Research Strategy

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Outline

- **AAS-NNRS**: “Sustainable agriculture and food security” is one of the top five opportunities for Nanotechnology: Typical examples, (1) airborne sensors for precision-monitoring of crops, and (2) in-field sensors for monitoring contamination, food authentication, quality, process control, etc.

- **One example**: UWA research group facilities, areas of expertise, and current research directions in MEMS, and IR materials and technology for IR spectroscopy/imaging

- **Motivation, overview, operating principles, and developed optical MEMS technologies** for NIR/SWIR multi-spectral infrared sensors (spectrometer-on-a-chip)

- **Current and future projects on large-area MEMS-based tunable filters** for multi-spectral 2-D IRFPA imaging applications and extending operating range to Vis/NIR and LWIR wavelengths
WACSOM Facilities

- 6 academic staff, 10+ postdoctoral research fellows, 20+ PhD students
- Riber 32P MBE HgCdTe semiconductor growth with spectroscopic ellipsometry
- 200 m² clean room
- Full device fabrication technology
  - Wet processing, photolithography, RIE, ICPRIE, PECVD, ICPCVD, E-beam and thermal deposition, RTA, bonding & packaging, 4-wave reactive sputtering
- Full characterisation facilities
  - spectral responsivity, IV, CV, noise, SEM/TEM/AFM/SLM, magneto-transport up to 16T, DLTS, DCXRD, optical profilometer, IR ellipsometry, etc
- Extensive system design and modelling
  - Synopsis, Cadence, Sentaurus, Altera & Cyprus Tools, ZEMAX, XFDTD, CoventorWare, ANSYS, ABAQUS, etc
WACSOM Areas of Expertise

- HgCdTe IR detectors (from MBE growth to sensor modules)
- Micro Electro-Mechanical Systems (MEMS)
- Semiconductor materials characterisation: e.g. mobility spectrum analysis, scanning laser microscopy, etc
- GaN and SiC-based High Power/Temperature materials, devices & technology
WACSOM Formal Linkages in IR Technology with Non-University Govt Labs and Industry (past 10 years)

- US: NRL, Raytheon, NVESD, DARPA, AFRL, DRS, Goodrich (now UTC), Agilent Technologies, Teledyne
- EU: Fraunhofer IAF (Freiburg, Germany), Selex Galileo (Southampton, UK)
- Aust: DSTO, Raytheon Australia, Agilent Technologies, GRDC
- Focused primarily on HgCdTe, InAs/GaSb T2SLs, and Optical MEMS
- Linkages have included joint patents, direct research grants, joint research funding, licensing agreements, research contracts, etc
WACSOM HgCdTe MBE Growth

- In-doped n-type; As and vacancy doped p-type
- MBE grown CdTe passivation and HgTe/CdTe superlattices
- Multi-layer devices fabricated on MBE materials
8 × 8 detector array packaged in LCC carrier

**HgCdTe detector array**

**Fanout**

**Double layer photoresist for In bump fabrication**

- Mirror finished surface
- IR
- Converted n-type
- p-type HgCdTe
- CdZnTe
- ZnS/CdTe
- Au/Cr
- In/Cr
- Au
- Sapphire
Motivation:

IR spectral information:

- Imaging: Improved target ID in clutter with lower false alarm rates
- Spectroscopy: Chem/bio sensing (food, agriculture, biomedical, defence & security, IEDs, environmental, etc)
Long-Wave InfraRed Multi-Spectral Imaging
Key to Detecting Targets in Deep Hide:
Similar for detecting weeds, crop stress, or foliage

The sum of a hundred narrow band images in the band of 8-12 μm

The difference of two narrow bands, one at ~9.7 μm and one at ~8.3 μm

Although two bands work, the bands vary with time and environment:

Require adaptive IRFPAs

• We want to avoid generating the so-called “Hyperspectral Cube”

• How to do “on-the-fly” spectral and spatial processing??
Reconfigurable Multi-Function Sensing

Many Sensor Functions Can Be Combined into One **Adaptive** Day/Night EO Sensor
Applications in Meat Industry: In-line process control (faecal contamination, spoilage, etc)

FIG. 2. Typical FT-IR absorbance spectra from pre- and postspoilage chicken. Also shown is the Pearson correlation coefficient (R) between the FT-IR absorbances (in experiments 1 and 2) and the log_{10}(TVC). The asterisks indicate peaks that are attributable to amide I (1,640 cm\(^{-1}\)), amide II (1,550 cm\(^{-1}\)), and amine (1,240 and 1,088 cm\(^{-1}\)) vibrations.

Rapid and Quantitative Detection of the Microbial Spoilage of Meat by Fourier Transform Infrared Spectroscopy and Machine Learning

David J. Ellis,\(^1\) David Broadhurst,\(^1\) Douglas B. Kell,\(^1\) Jem J. Rowland,\(^2\) and Royston Goodacre\(^1\)

APPLIED AND ENVIRONMENTAL MICROBIOLOGY, June 2002, p. 2822–2828
Food, Precision Agriculture

• **Why?**
  - Real-time IR spectroscopy for food & agricultural applications
    - Wine, wheat protein & moisture, soil analysis, etc
  - To replace lab-based wet chemical analysis

• **What is needed?**
  - Low-cost, field-portable NIR/SWIR multispectral sensor with reduced SWaP
  - Control electronics and optical design
  - Database of experimental measurements of IR spectra
  - Chemometrics data analysis
Motivation (microspectrometer):

Bench-scale FTIR spectrometer
- High precision and accuracy over very wide spectral range
- Expensive
- Bulky
- Fragile

Microspectrometer
- Limited spectral resolution and tuning range
- High speed (extremely low mass)
- Potentially low cost due to standard IC processing technology
- Mechanically robust (low mass)
- Dramatically reduced SWaP
Specifications for field-portable stand-off chem/bio sensing in complex media

• Not so important:
  – Spectral resolution and tuning range is not critical
    • 20-50nm resolution for NIR/SWIR (uncooled)
    • Max spectral tuning range of one octave matches detector technology: NIR, SWIR, MWIR, LWIR

• Important:
  – Sensitivity, speed, high optical throughput
  – Compatibility with 2-D multi-spectral imaging arrays
  – Internal wavelength calibration
  – Low cost

• Essential:
  – Mechanical robustness, reproducibility, stability, reliability
  – Dramatically reduced SWaP
Specifications for field-portable stand-off chem/bio sensing in complex media

A possible spectral filter – Fabry Perot

• A simple example – a soap film

From http://www.exploratorium.edu/imagery/misc_stills.html
What are MEMS

- **Micro Electro Mechanical Systems**
  - Micro-scale mechanisms
  - Can generate motion on the micro-scale
  - Driven Electrically
  - Fabricated using same processes as IC technology

http://www.memx.com

http://www.princeton.edu/mae/people/faculty/soboyejo/research_group/research/mems/

How Does it Work?

- Spectral filters created by separating mirrors a distance 'd'
- Filter tuned by moving top mirror and changing cavity length ‘d’
- Mirror moved electrically
Principle of Operation

- Transmitted light is detected with a broadband detector

Detector output is proportional to the area under this curve.
Principle of Operation

- Transmitted light is detected with a broadband detector

Voltage is increased to change the transmitted wavelength
Principle of Operation

- Transmitted light is detected with a broadband detector.
Principle of Operation

• Transmitted light is detected with a broadband detector
Principle of Operation

- Transmitted light is detected with a broadband detector.
Principle of Operation

- Transmitted light is detected with a broadband detector
Principle of Operation

- Transmitted light is detected with a broadband detector

A range of tuning voltages are used to determine the incident spectrum.
IR/MEMS Time Line

1990
HgCdTe infrastructure development of material, detector & packaging technology

1996
Development of Fabry-Perot MEMs filters

Early 2004
Detectors with thin film Fabry-Perot Filters

Late 2004
Photodiodes with TF-FP Filters

Early 2005
Tuneable Photodiodes with TF-FP MEMS Filters

2007
Tuneable arrays of Photodiodes with Fabry-Perot MEMS Filters

R & D partners: (US, EU & Aust.)
Defence industry
Govt Labs
Universities

Start-up & IP commercialization:
Food & Agriculture (with GRDC)

Applications & end-users:
Food & agriculture
Defence & security

New directions: (US, EU & Aust.)
LWIR, VIS/NIR
Large area 2-D

PhD’s

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School of Electrical, Electronic and Computer Engineering
The University of Western Australia
Measured displacement and SWIR transmittance

Displacement measured using optical profilometer

- Measured displacement
- Fixed-fixed beam analytical model
- From transmittance data
Hybrid approach: 
Single-element SWIR spectrometer on a chip

InGaAs SWIR Detector on TEC
Measured SWIR spectral data demonstrates tuning from 2425 nm to 1620 nm (≈ 900 nm)

Demonstrated close to theoretical performance for 3-layer mirrors:
- 50 nm linewidth with low tuning voltage (< 25 V)
- Extinction ratio > 120 @ 2000 nm
- Widest reported tuning range for a MEMS-based tunable Fabry-Perot filter
WACSOM capabilities in optical MEMS for multi-spectral IR sensors & imaging arrays

• Tuneable IR sensors based on MEMS in the SWIR (1.6 - 2.5 µm) and MWIR (3 - 5 µm) using the same materials/mirror technology, with near-theoretical performance in SWIR: wide tuning range of 900nm using < 25 V, linewidth ~50 nm (3-layer mirrors), extinction ratio > 120, switching speed < 50 microsec)

• Currently finalising IC chip design for internal wavelength calibration, and developing prototype portable SWIR microspectrometer instrument and commercialisation plan for chemometric sensing in food & agriculture (with GRDC)

• Currently investigating materials & technologies for extension into VIS/NIR and LWIR wavelength ranges, and developing very large-area (multi-mm x multi-mm) tuneable filter technologies for large format 2-D focal plane adaptive imaging arrays (for airborne remote sensing)
THANK YOU