Sensors for Food Quality Safety: Detection and Characterization

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Key Collaborators

- Penn State
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  - Vet Sci: Chobi Debroy, Ali Demirci, Bhushan Jayarao
  - Chem/Materials: David Allara, Carlo Pantano
- Purdue University
  - Bindley Biosciences Center
  - Depts.: ABE, Food Sciences, Vet Sciences, Chemistry
  - Mike Ladisch, Cris Staiger, Garth Simpson, Sophie Liverve, Peixuan Guo, Kinam Park
- IUPUI Cancer Center (Drs. Nakshatri, Sledge, MD)
- Mayo Clinic (Robert Jenkins, MD)

Several Others ….

Assessment of Food Quality and Safety Parameters

Handled

Processed

Stored

Packaged

More than 90% of foodborne illnesses are attributed to bacteria and 6 of these cause over 50% of the illnesses

Bacteria	Cases	Death	Dose
E. coli O157:H7	725,000	400	10^1 to 10^2
Salmonella	$3.8 * 10^6$	4,000	10^4 to 10^7
C. jejuni	$4.0 * 10^6$	511	400 to 10^6
L. monocytogenes	1,767	485	400 t0 10^3
S. aureus	$1.0 * 10^6$	1210	> 10^6
C. perfringens	10,000	100	> 10^8

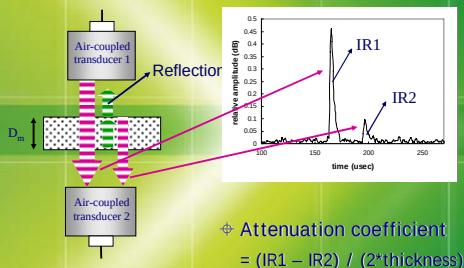
Non-Contact Ultrasound Imaging

Foreign object & internal disorder detection in cheese using Non-contact ultrasound imaging

- Detection
  - Fragments: minimum 3×3 mm²
  - Cylindrical objects: 1.5 mm in diameter
  - Cracks and sporadic porosities

Cho et al. (2000-2004)

Attenuation coefficient measurement



- Attenuation coefficient
  = (IR1 – IR2) / (2*thickness)

NCU Imaging system

- To obtain NCU image
  Non-contact air instability compensation transducer
  Sample
  X
  Y
  X-Y position system
  NCU unit

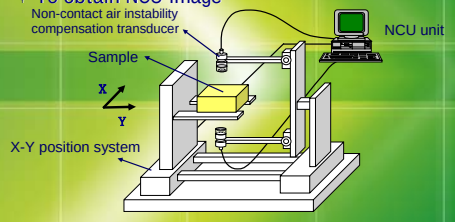
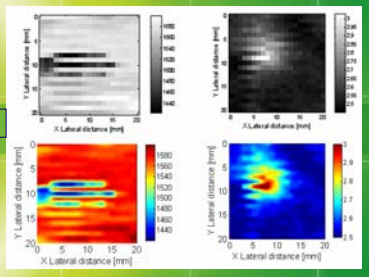


Image processing

raw

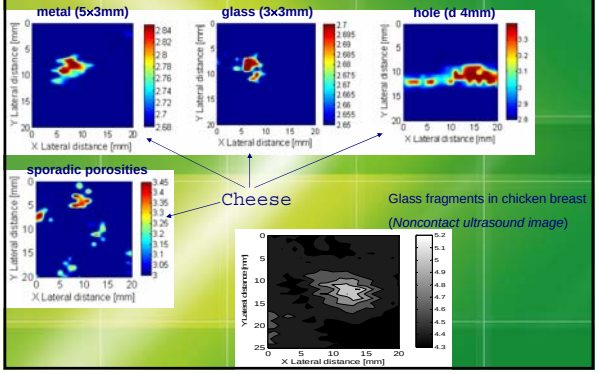
Glass fragment

processed



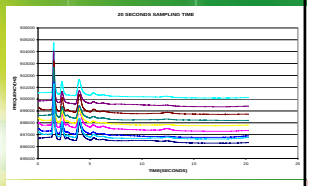
velocity relative attenuation

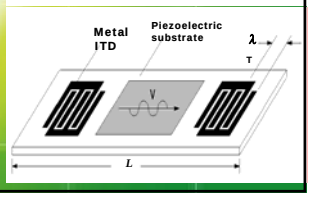
Foreign object & internal disorder



Food Quality – Non contact

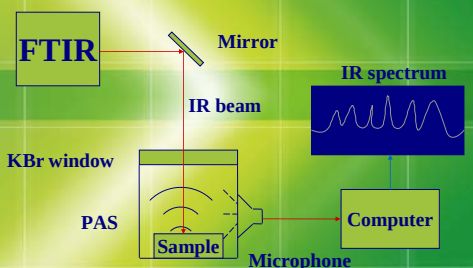
Znose
- Honey authenticity
- Honey adulteration
- Wine classification
- Apple quality



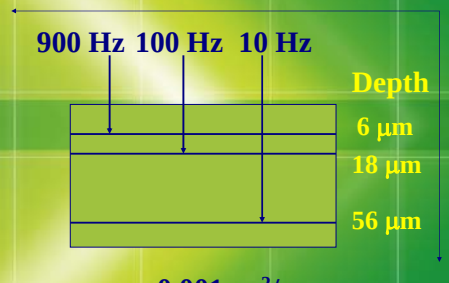


Znose – abundant Literature

Diagram of FTIR-PAS

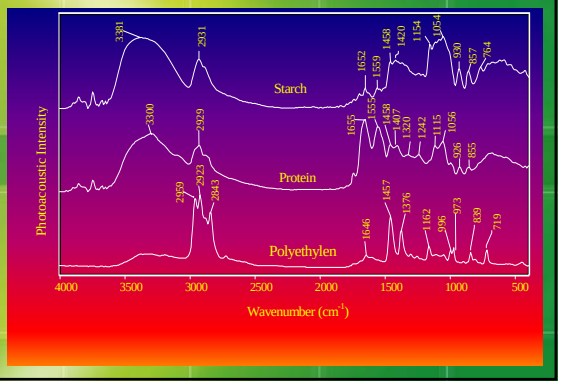


Phase modulation frequencies



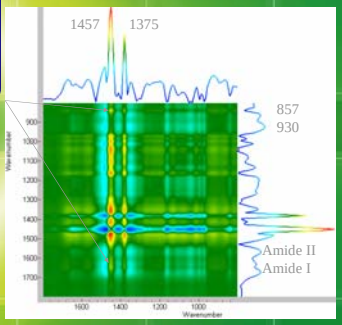
$\alpha = 0.001 cm^2/s$

Rapid-scan FTIR-PAS spectra of protein, starch, and polyethylene



Asynchronous G2D correlation FTIR-PAS spectra of three-layer polyethylene/starch/protein

Red color indicate polyethylene is above protein and starch



Fourier transform Raman spectroscopy

- A near-infrared (1064 nm) laser is used as a probed beam to overcome the fluorescence effect
- There is no sample preparation
- Raman spectrum is complementary to infrared spectrum

Direct determination of microorganisms on Food and package

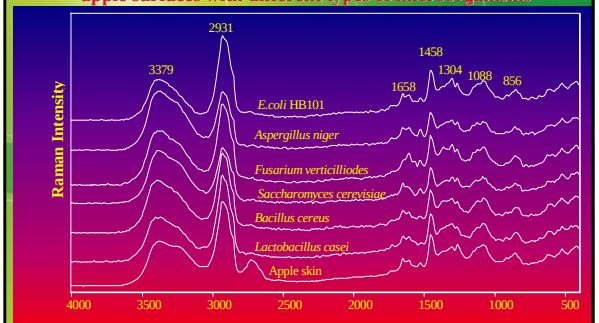
Materials & Methods

Material: fungi (*Aspergillus niger* and *Fusarium verticilliodes*), yeast (*Saccharomyces cerevisiae*), bacteria (*Bacillus cereus, Lactobacillus casei,* and *E.coli* (HB101, DH5α, JM107, JM101, K12, O157:H7)), and apple

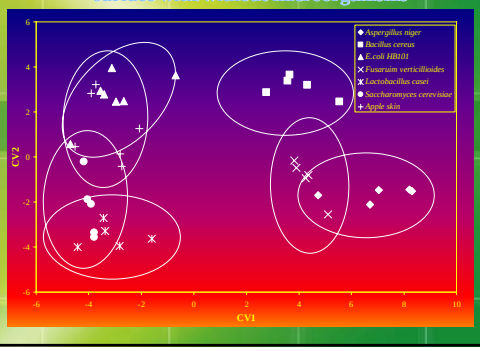
Instrumentation: FTIR-PAS and FT-Raman

Data Analysis: Canonical variate analysis

FT-Raman spectra of uncontaminated apple and contaminated apple surfaces with different types of microorganisms



Discriminant canonical variate analysis based on the first two canonical variates from the spectra of whole apple surface with/without microorganisms



Differentiation of microorganisms in a cocktail of pathogens

Bacteria

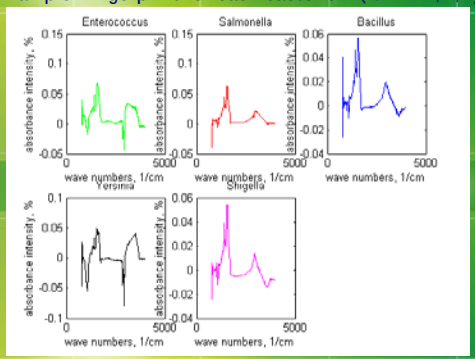
1. *E. coli* O157:H7
2. *Salmonella* Enteritidis
3. *Bacillus cereus*
4. *Yersinia enterocolitis*
5. *Shigella boydii*

Testing and validation of the algorithm

- 3 out of 5 bacteria were used to make 10 possible combination of mixtures:

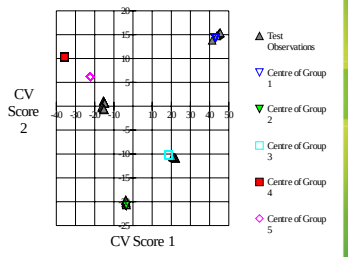
m1: 1,2,3; m2: 1,2,4; m3: 1, 2, 5; m4: 1,3, 4; m5: 1, 3, 5; m6: 1,4,5; m7: 2,3,4; m8: 2, 3, 5; m9: 2 ,4, 5; m10: 3,4,5

Example 'fingerprint' of each bacterium (for m2: 1, 2, 4)



Spectra after background interference removed

Discriminant analysis *(m1: 1+2+3)*



Bacteria present
1. *E. coli* O157:H7
2. *Salmonella*
3. *Bacillus*

Bacteria not present
4. *Yersinia*
5. *Shigella*

100% accurate prediction for this application !

Concept has been extended to a cocktail of up to 12 pathogens in apple juice

Food Safety — Biosecurity

Characterization
Detection

Spectroscopy ⟺ *Biosensors*

- FTIR
- Raman
- *Confocal-Raman*

- *Single particle*
- *IR flim based*
- *Biomimetic*, SPR

Nanoscale methods

Chemistry, Physics, Engineering

Single molecule methods

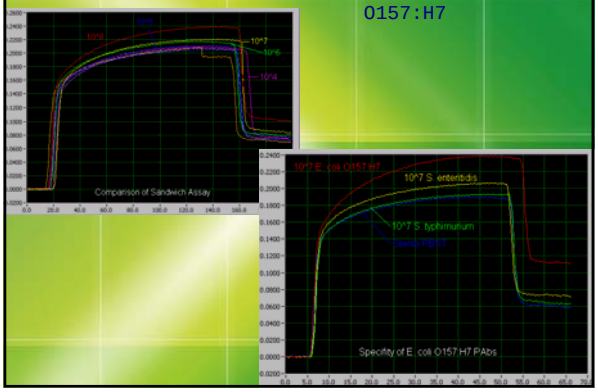
SPR based pathogen detection

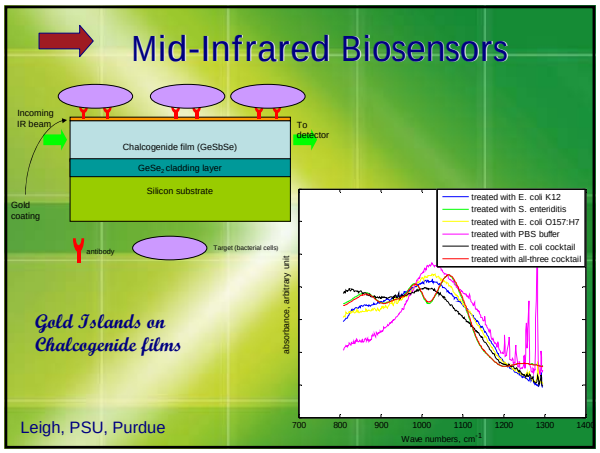
- Sensor surface setup
- Flush
  - Ethanol → D.Water → HCl → NaOH → D.Water
- SAM Activation
  - EDC & NHS mixture
- Ab Immobilization
  - Ab in SA
- Establish baseline: PBST
- Inject Ag: Ags in PBST
- Dissociation: 20 mM NaOH
- Establish baseline: PBST
- Reuse the chip

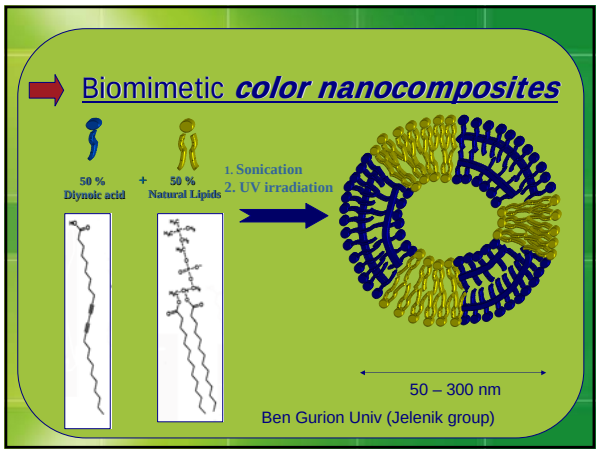
Assay Development

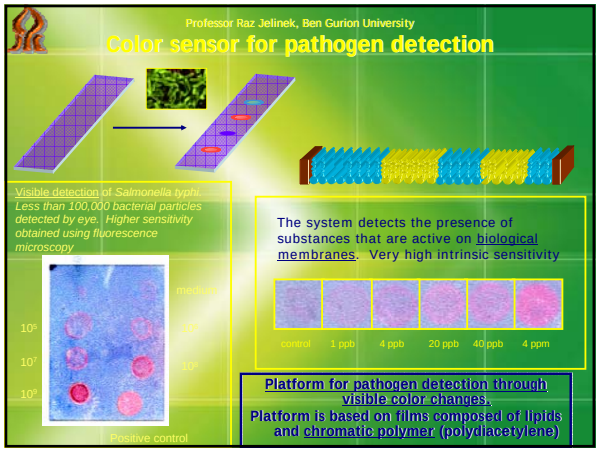
Sensitivity and Specificity

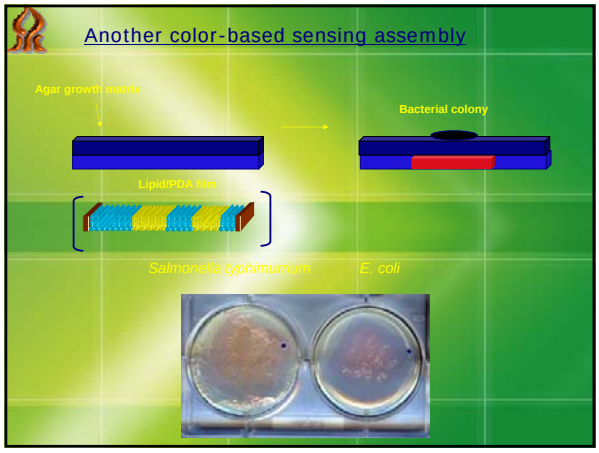
O157:H7



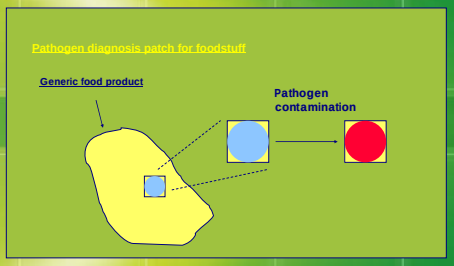

Mid-Infrared Biosensors
Incoming IR beam
To detector
Chalcogenide film (GeSbSe)
GeSe2 cladding layer
Silicon substrate
Gold coating
antibody
Target (bacterial cells)
Gold Islands on Chalcogenide films
Leigh, PSU, Purdue
absorbance, arbitrary unit
treated with E. coli K12
treated with S. enteriditis
treated with E. coli O157:H7
treated with PBS buffer
treated with E. coli cocktail
treated with all-three cocktail
700
800
900
1000
1100
1200
1300
Wave numbers, cm-1


Biomimetic color nanocomposites
50 % Diynoic acid
+
50 % Natural Lipids
1. Sonication
2. UV irradiation
50 – 300 nm
Ben Gurion Univ (Jelenik group)

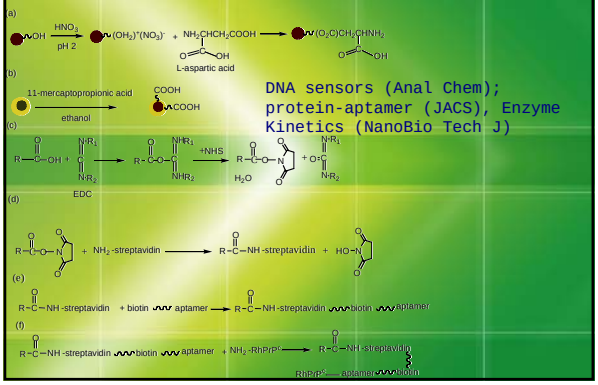

Professor Raz Jelinek, Ben Gurion University
Color sensor for pathogen detection
Visible detection of Salmonella typhi. Less than 100,000 bacterial particles detected by eye. Higher sensitivity obtained using fluorescence microscopy
medium
10⁸
10⁷
10⁶
Positive control
The system detects the presence of substances that are active on biological membranes. Very high intrinsic sensitivity
control
1 ppb
4 ppb
20 ppb
40 ppb
4 ppm
Platform for pathogen detection through visible color changes.
Platform is based on films composed of lipids and chromatic polymer (polydiacetylene)


Another color-based sensing assembly
Agar growth matrix
Bacterial colony
Lipid/PDA film
Salmonella typhimurium
E. coli

Possible sensor products



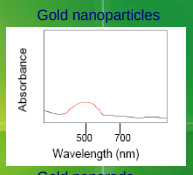
Nanoparticle-based sensors



Rod shaped gold nanoparticles have unique optical properties

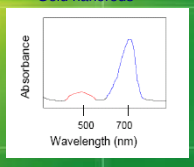
Au nanoparticles

The red axis represents spherical shaped gold nanoparticles and appears at about 500nm.

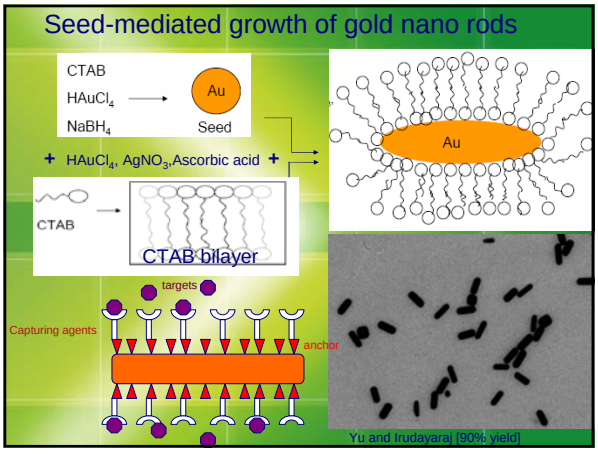


Au nanorods

The green axis represents rod shaped gold nanoparticles and appears at 600nm or above depends upon the aspect ratio of the rods



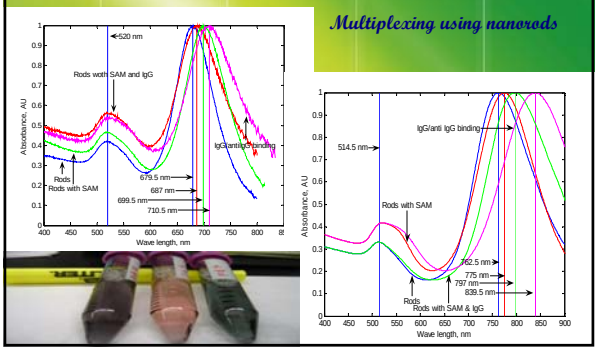
Seed-mediated growth of gold nano rods



Functionalization and Target detection

Probe: human IgG; Target: goat anti-human IgG

Multiplexing using nanorods



Bioaffinity Sensors

S + R ⟶ SR

- *Receptor R*
  - *Dye*
  - *Lectin*
  - *Enzyme*
  - *Apoenzyme*
  - *Antibody*
  - *Receptor*
  - *Transport system*
- *Chemical signal S*
  - *Protein*
  - *Saccharide*
  - *Harmone*
  - *Substrate*
  - *Antigen*
  - *Substrate analogue*

Transducers

- Thermistors [Thermometric indication]
  - A change in enthalpy due to enzyme-catalyzed reaction
  - One reaction step and no final product

An enzyme attached thermistor is dipped in a sample

Enzyme : Glucose oxidase, Urease, Trypsin

Substrate : Glucose, Urea, Cholesterol

- Electrochemical Transduction
  - Potentiometric
  - Amperometric
  - Conductometric

Selected Biosensors (sugars)

Analyte	Principle	Life(d)	Range(mM)	Application
Glucose	Ampero	20	0.2-2.8	cocoa
Glucose	pH-electrode		< 8g/l	On-line
Maltose	Ampero	7	0.03-2.5	Brewer's yeast frem
Lactose	Ampero	50	0.002-3	milk

Other Examples

Analyte	Principle	Life(d)	Range(nM)	Application
Citrate	Ampero	18-21	0.001-1.0	juices
Fatty acids	Ampero	10	0.1-1.2	oils
Tryptophan	Ampero	90	0.025-1.0	E.Coli (culture)
Lysine	chemuLum	60	0.01-1	

Questions in Development

- Market
- Alternate methods and cost
- Sensitivity and Specificity
- Sample matrix – is this changing?
- Measurement conditions
- Application – in/at/on/off -line
- Measurement range, time, life

Thank you