Optical spectroscopy and biosensors for investigation of biomolecules and their interactions

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Optical Biosensors for Environmental Monitoring. Food Safety, and Security

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Content

Content:

- Overview of harmful analytes that concern food quality control, examples of specific implementations
- Security, possible means for spatial mapping of the presence of chemical that can serve as warfare agents
- Environmental monitoring of contaminations in water, soil and similar environments
- Examples with information on requirements of legal bodies.

Date: June 14th

Food Control

Food Control

- **Detection of Pathogens**
  Microbial contamination of food products can cause infectious diseases to arise in both humans and animals (*Escherichia Coli* O157:H7, *Listeria monocytogenes*…)

- **Detection of Toxins**
  Microbial contamination can lead to the presence of toxins (Ochratoxin in wine, aflatoxins in milk…)

- **Detection of Pesticide Residues**
  Due to the widespread use of pesticides in agriculture results in the passive consumption of these molecules within our food products (atrazine,…).

- **Detection of Drug Residues**
  Animals are often treated with various veterinary medicines, ingestion of these medications in meat and dairy products (tetracyclin, sulfamethazine).

See e.g. overview in S. Balbinot et al. Trends in Food Science & Technology 111 (2021) 128–140129

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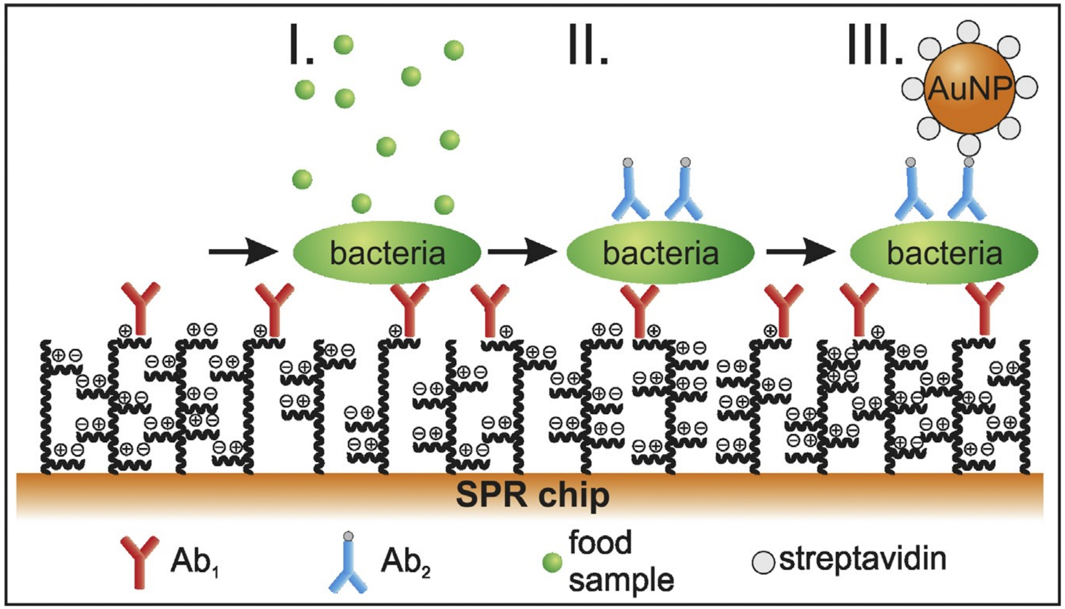
Food Taster

A head chef or food taster sampling dishes in *Feast of Bartolomeo Colleoni in honor of Christian I of Denmark*, attributed to Romanino (1467)

Roman poisoner Locusta

SPR Biosensor for Direct Detection of Bacterial Pathogens



http://dx.doi.org/10.1016/j.bios.2016.01.0400956-5663

i) rapid, specific, and sensitive
ii) require minimum sample preparation
iii) robust and cost-effective, thus enabling use in the field.

SPR Biosensor for Direct Detection of Bacterial Pathogens

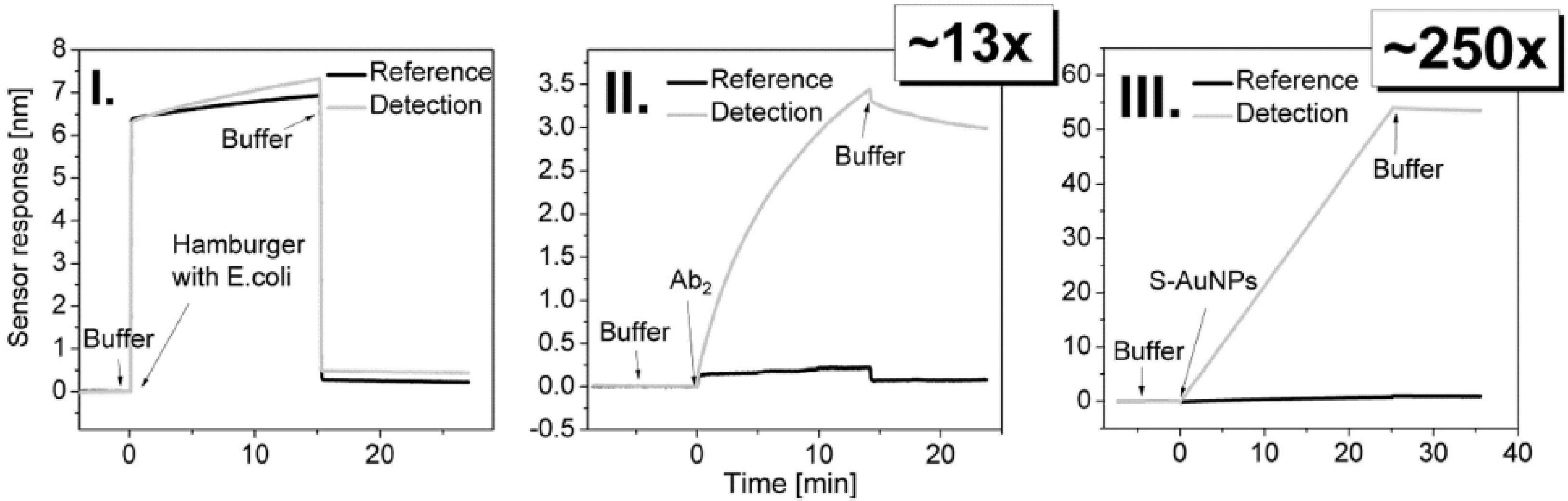


Fig. 2. Typical SPR sensorgrams obtained for the detection of *E. coli* O157:H7 (7.5×10^5 CFU/mL) in hamburger sample for each step of the detection assay as depicted in Scheme 2. The sensor response enhancement is given in the boxes.

http://dx.doi.org/10.1016/j.bios.2016.01.0400956-5663

Example of sensor kinetics for the direct (I) and amplified (II, III) detection in homogenized food sample.

SPR Biosensor for Direct Detection of Bacterial Pathogens

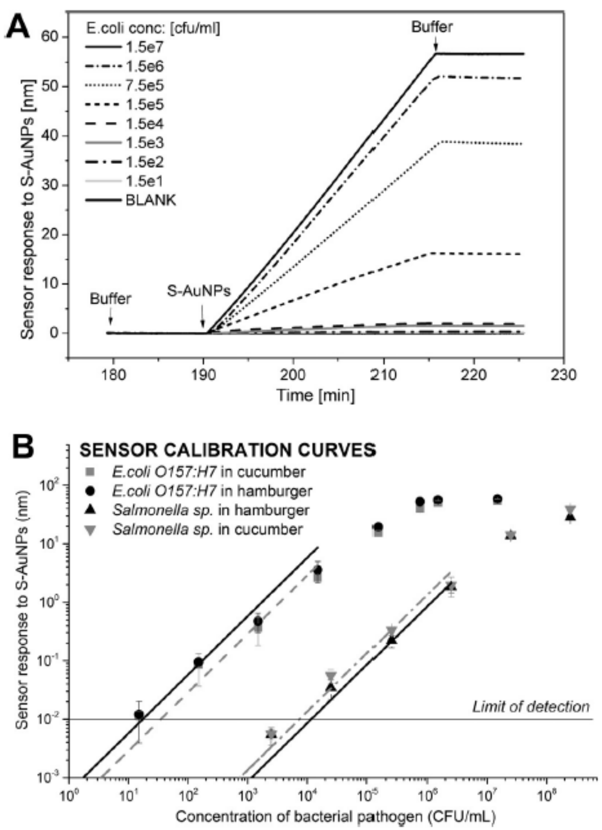


Fig. 3. (A) SPR sensor response to the binding of S-AuNPs in step (III) of the assay for the detection of *E.coli O157:H7* in cucumber sample. (B) Calibration curves for *E. coli* and *Salmonella sp.* in both hamburger and cucumber samples.

- Limit of detection should approach low CFU/mL (depending on analyte and the regulation requirement)
- CFU – colony forming units refering to common culturing-based method.
- Drawback of not possible discrimination of viable pathogens (not killed ones).

http://dx.doi.org/10.1016/j.bios.2016.01.0400956-5663

SPR Biosensor for Detection of Aflatoxin M1

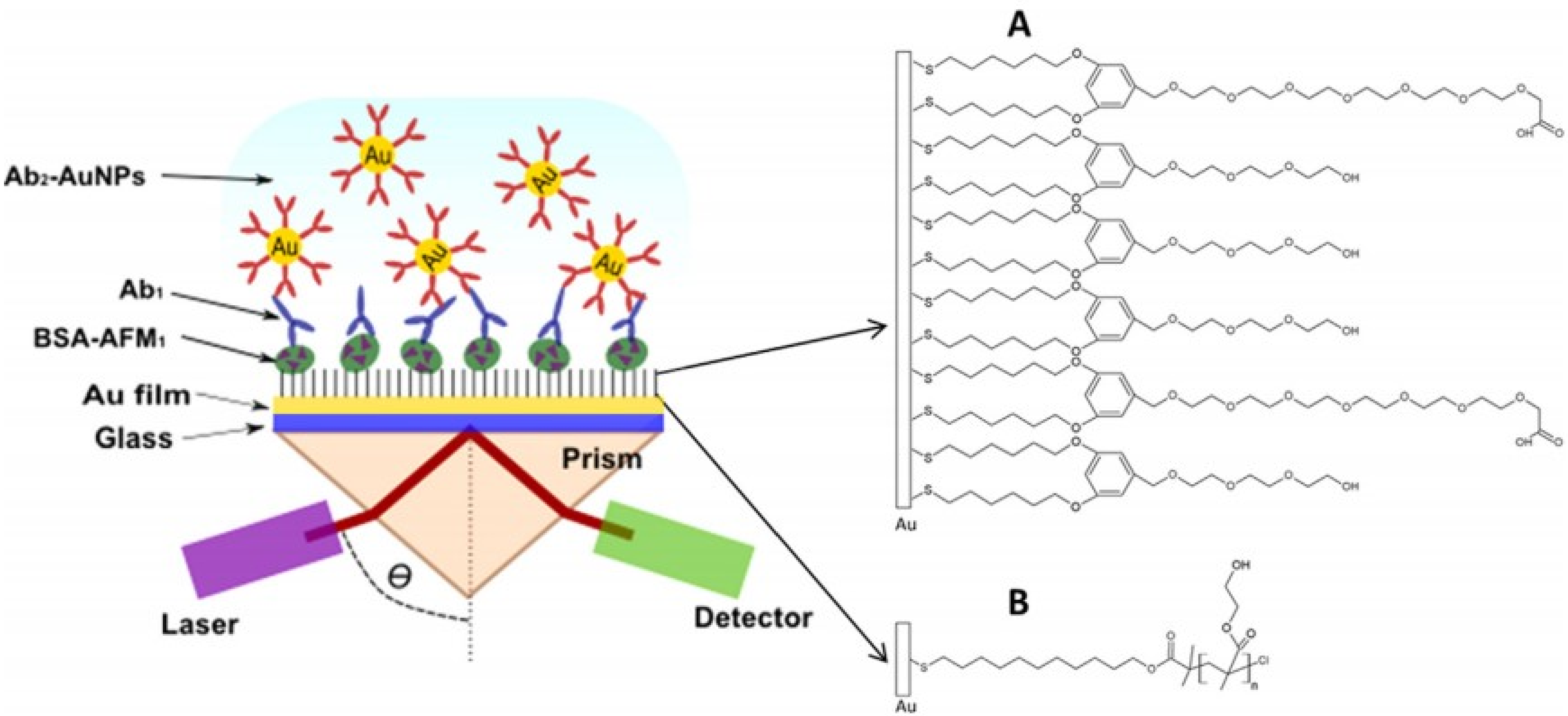
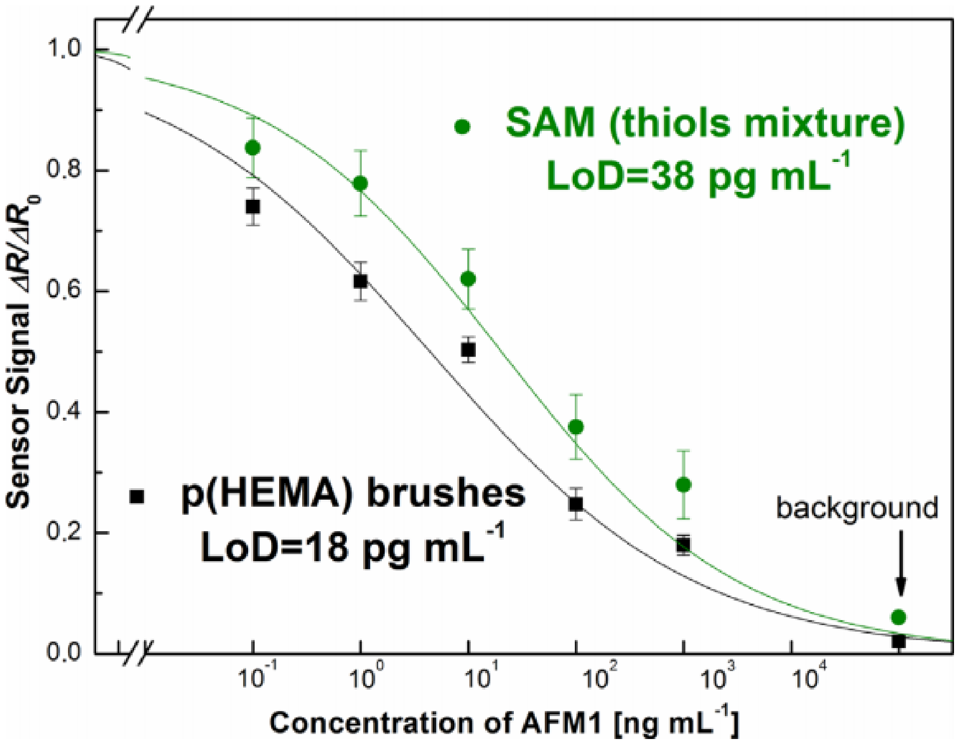


Fig. 1. The scheme of the optical setup and sensor chip with different surface architecture (A) mixed SAM and p(HEMA) brushes (B).

https://doi.org/10.1016/j.bios.2016.02.061

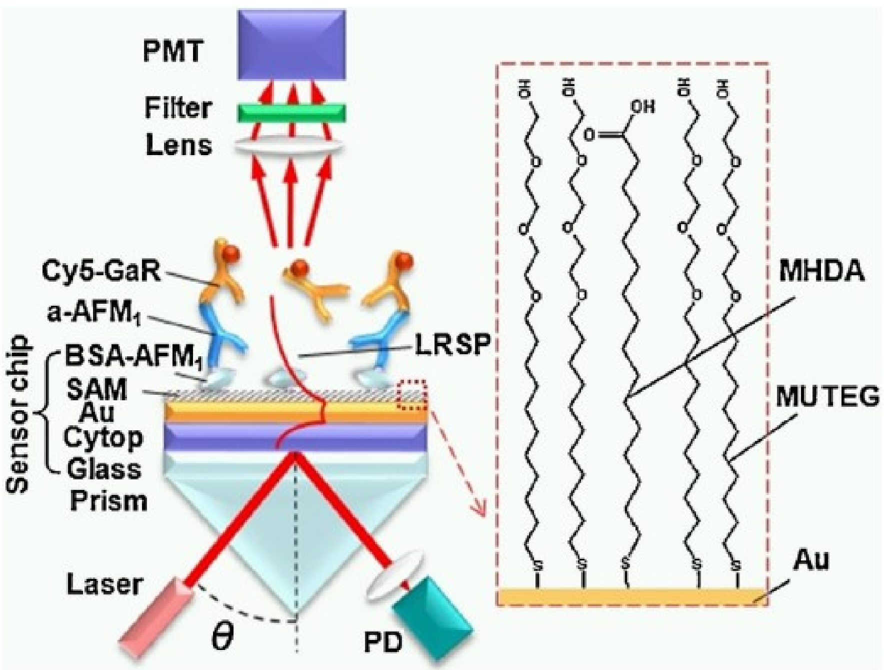
SPR Biosensor for Detection of Aflatoxin M1

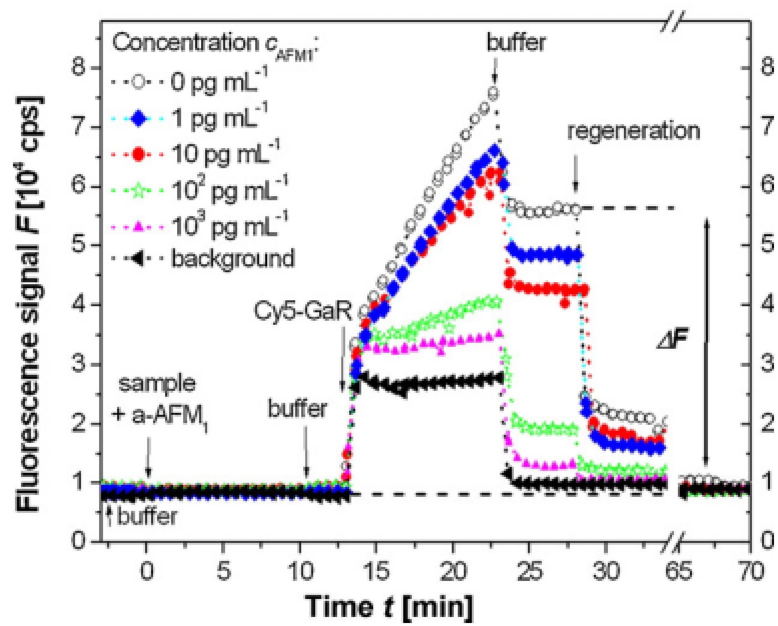


- The European Commission stipulates a maximum permissible level of 50 ng/L for AFM1 in milk and dried or processed milk products (in 2016).
- Detection perfomed in fat-free milk samples.

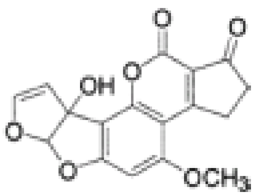
https://doi.org/10.1016/j.bios.2016.02.061

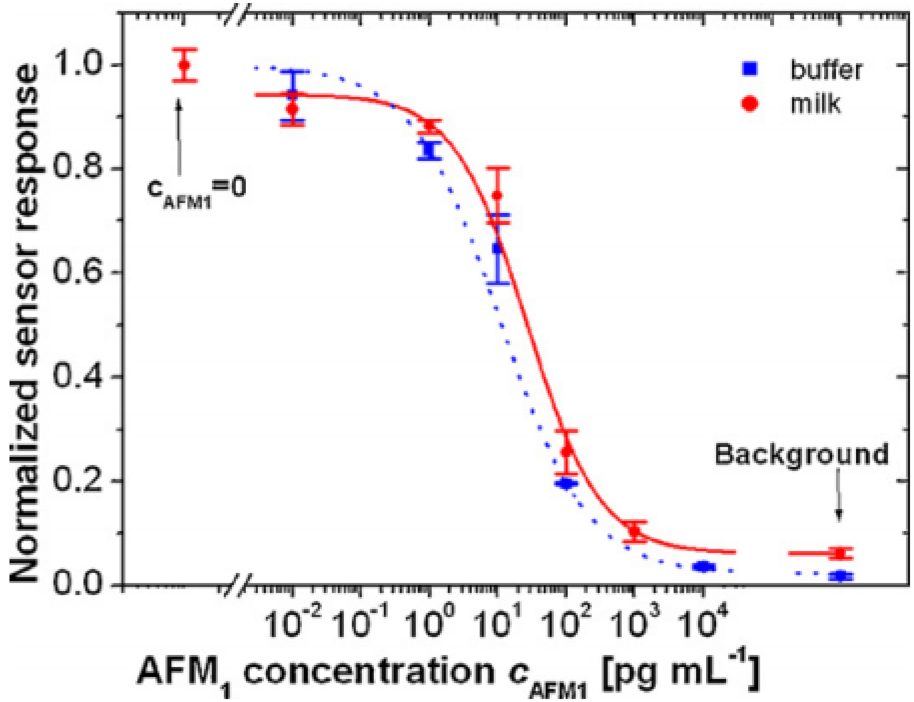
SPFS Biosensor for Detection of Aflatoxin M1





SPFS Biosensor for Detection of Aflatoxin M1





- Limit of detection at sub-pg/mL levels.
- Pursued in the context of portable devices to be installed to lorries collecting milk from local farmers.

Authentication of Milk – Buffalo vs Cow

- Tools for rapid screening of adultarization of milk products (e.g. mixing of expensive buffalo milk with cheaper cow milk).

- PCR-based tests are complemented with simpler ones based on biosensors.

DOI 10.1007/s13594-011-0008-7

https://www.factssa.com/news/buffalo-milk-is-it-a-safe-alternative-for-cows-milk-allergic-consumers/

Security

Biosensors for Biological Warfare Agents

Table 2. Optical biosensors and bioassays for biological warfare agents assay.

Analyte	Principle	Specific Material in Biosensor	Limit of Detection	Other Specifications	Reference
2,6-dipicolonic acid—a marker of *Bacillus anthracis*	The modified dots interacted with 2,6-dipicolonic acid; it resulted in change of fluorescence color	Manganese-doped carbon dots with ethylene diamine and ethylenediamine tetraacetic acid with bound Eu^{III}	0.1 nmol/L	Results within 1 min	[57]
DNA from *Bacillus anthracis*	Photonic sensor immobilized single stranded DNA; interaction with DNA from sample causes resonant wavelength shift	Photonic crystal sensor with total-internal-reflection modified with DNA	0.1 nmol/L	Results within 1 h	[58]
DNA from *Francisella tularensis*	Optical inteferometry using DNA probes	Long-period fiber gratings	1 ng	Results within 20 min	[59]
Francisella tularensis and ricin	Optical inteferometry using immobilized antibodies and antibodies labeled with alkaline phosphatase—the enzyme finally caused a deposition of insoluble crystals, which was measured by the interferometry	Bio-layer interferometry based on fiber optic biosensors and standard 96-well microplates	10^4 CFU/mL for *Francisella tularensis* and 10 pg/mL for ricin	Results within 17 min	[60]
Botulinum toxin A	Botulium toxin converting fluorogenic peptide containing SNAP25 precursor located on graphene oxide, fluorescence resonance energy transfer is measured	Graphene oxide modified with a peptide	1 fg/mL	Selective for light chain of Botulinum toxin A	[63]
Botulinum toxin A	Botulium toxin convert fluorogenic peptide containing SNAP25 precursor, fluorescence is measured by CCD photodetector	Fluorogenic peptide	1.25 nmol/L	Assay of 16 samples contemporary	[64]

Materials 2019, 12, 2303; doi:10.3390/ma12142303

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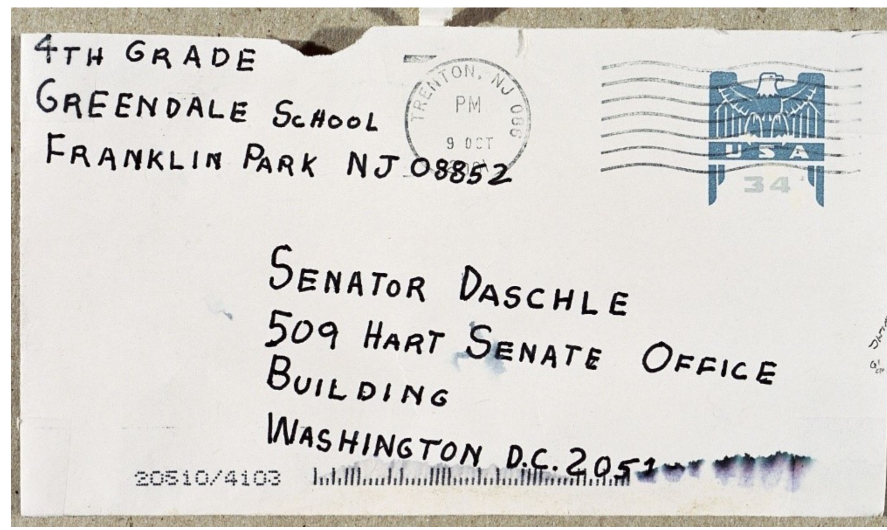
(Bio) Terrorism

- Raised concerns after sarin attach in Tokyo 1995, anthrax-contaminated letters sent in the US 2001,…

https://www.x-rayscreener.co.uk/terrorism/tokyo-subway-attack/



https://en.wikipedia.org/wiki/2001_anthrax_attacks#/media/File:Anthrax_Envelope_to_Daschle.jpg

On Site Detection of TNT

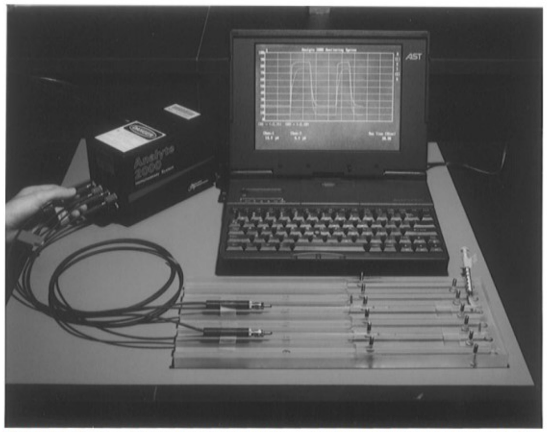


FIGURE 1. Analyte 2000 portable fiber optic biosensor. This portable sensor is capable of monitoring four optical probes simultaneously.

Fiber Optic Biosensor

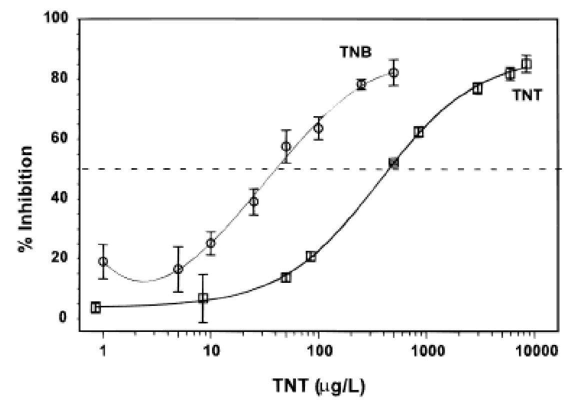
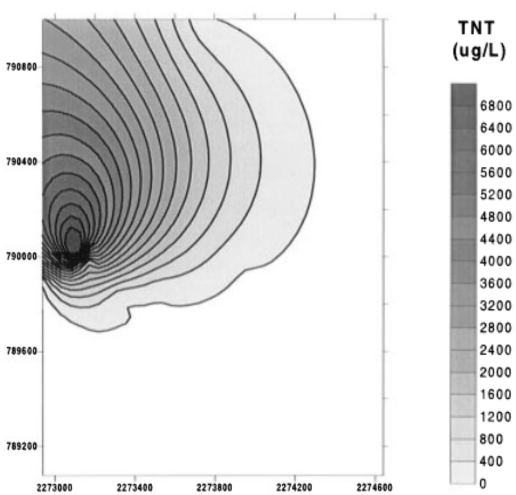


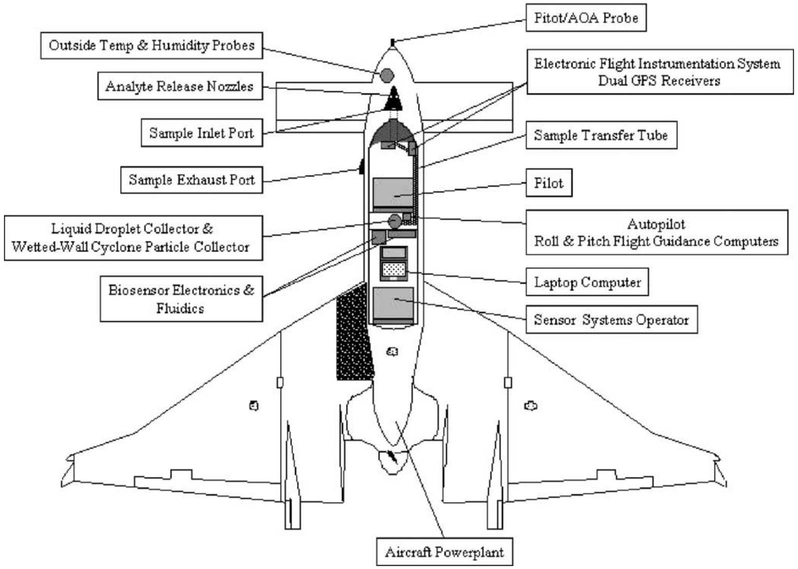
FIGURE 2. TNT and TNB standard curves for groundwater from Umatilla Army Depot. Standards were prepared in groundwater (85%) from Umatilla Army Depot. A minimum of three samples on different probes were tested for each concentration.



- Fluorescence immunosensor used for rapid detection and spatial mapping of TNT in ground water
- Additional works pursued in the context of searching of marine mines, based on leakage of TNT.

Ligler, Environ. Sci. Technol.1997,31,837-841

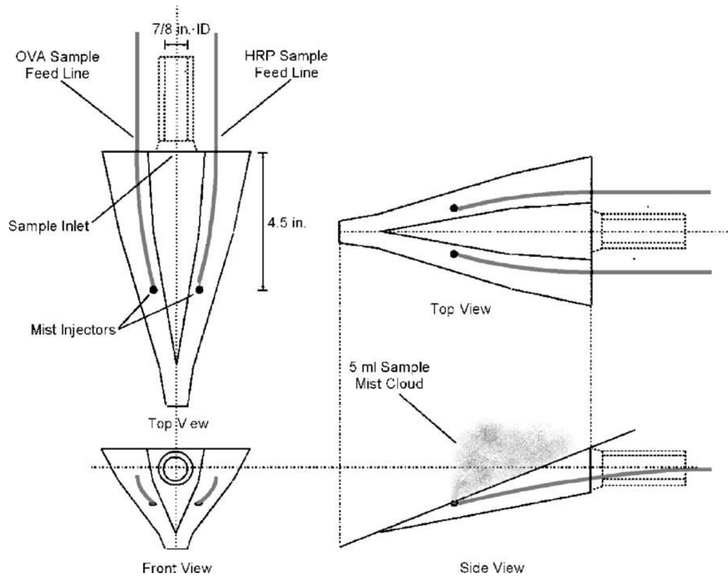
Airborne Analyte Detection of Aircraft-Adapted SPR Biosensor

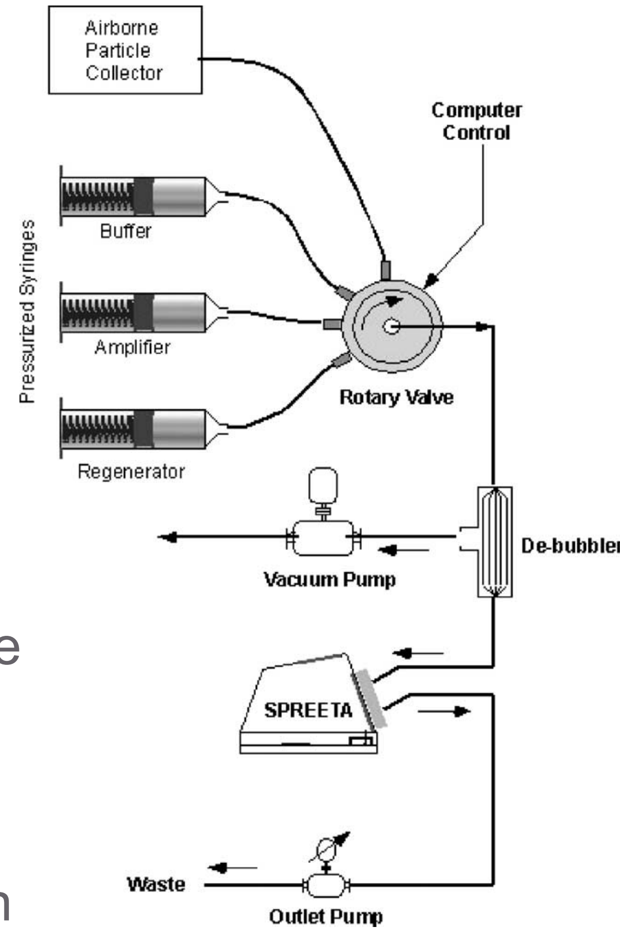


- 3D spacial mapping of the presence of airborne harmful analytes
- Integrated rapid SPR biosensor to aircraft with modules for air collection and liquid condensate delivery to the sensor.

Furlong group, Sensors and Actuators B 104 (2005) 237–248

Airborne Analyte Detection of Aircraft-Adapted SPR Biosensor





- Ovalbumin and HRP were used as a mode analyte representing toxic compounds.
- Demonostrated detection of artificially made clouds through which the plane then was navigated.

Furlong group, Sensors and Actuators B 104 (2005) 237–248

Legionella Pathogen

- Legionnaires’ disease and the less severe form, Pontiac fever, are the two most frequent presentations of legionellosis.
- Case-fatality rates of legionellosis, primarily Legionnaires' disease, fall in the range of ~10 - 50%.

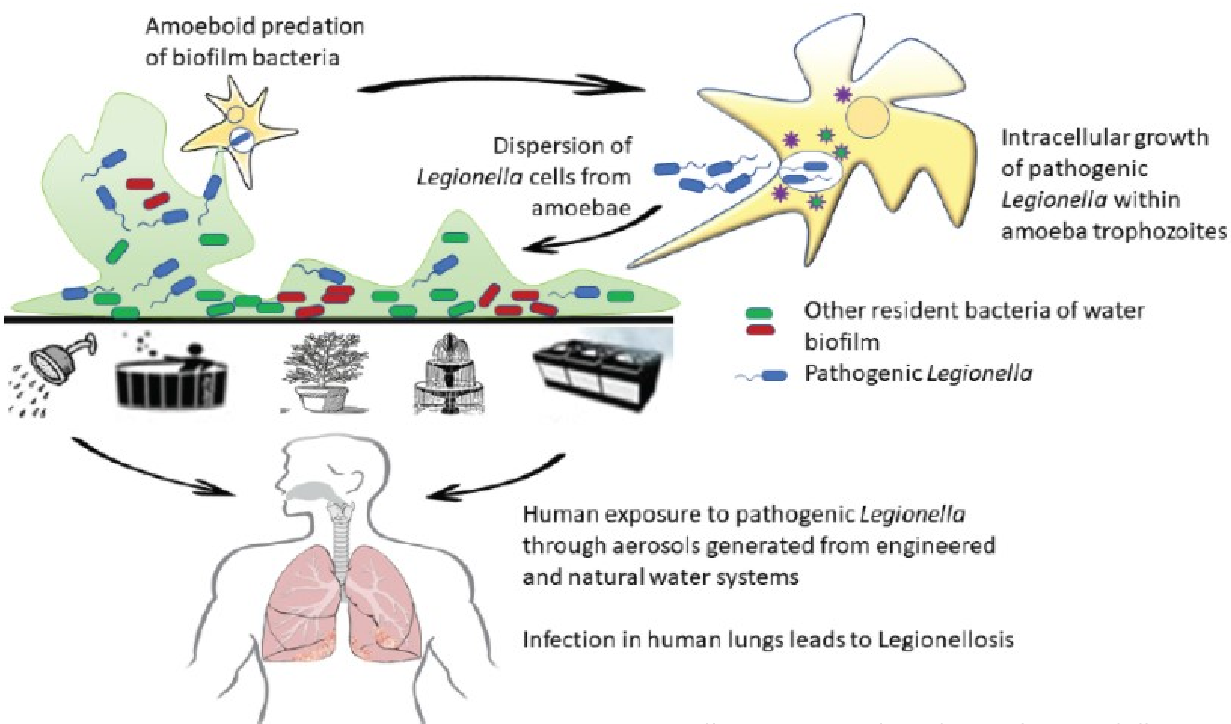
Table 1
Concentrations of *Legionella* found in common water sources.

Source	*Legionella* concentration				Reference
	Total Bacteria (genome units L^{-1})		Culturable Bacteria (CFU L^{-1})		
	Minimum	Maximum	Minimum	Maximum	
Cooling towers	NA	NA	1.2×10^6	1.0×10^7	[142]
	NA	NA	1.0×10^5	1.2×10^9	[143]
	6.3×10^2	2.5×10^6	NA	NA	[120]
Drinking water	NA	NA	1.0×10^2	1.3×10^4	[144]
	NA	NA	3.0×10^6	9.0×10^8	[142]
	NA	NA	5.0×10^3	4.0×10^4	[145]
	NA	NA	4.0×10^1	9.5×10^5	[146]
	1.2×10^4	1.1×10^8	NA	NA	[139]
	1.0×10^4	2.3×10^6	NA	NA	[147]
	3.9×10^3	1.0×10^4	5.2×10^3	7.3×10^3	[124]
	8.1×10^2	3.2×10^5	7.9×10^1	1.5×10^4	[148]
Drinking water distribution system	3.0×10^3	3.2×10^8	NA	NA	[148]
	8.5×10^1 (mean)	5.9×10^3	NA	NA	[133]
	1.3×10^2	5.7×10^3	<50 (LOD)	NA	[149]
Decorative fountains	NA	NA	NA	3.0×10^6	[73]
	NA	NA	3.1×10^3	4.1×10^4	[74]
Hot tubs	1.0×10^3	6.1×10^7	2.5×10^2	3.5×10^5	[150]

http://dx.doi.org/10.1016/j.buildenv.2017.06.024

Legionella Pathogen

- Concern in large buildings with central ventilation system, cooling towards, water sources…



https://www.nap.edu/read/25474/chapter/4#59

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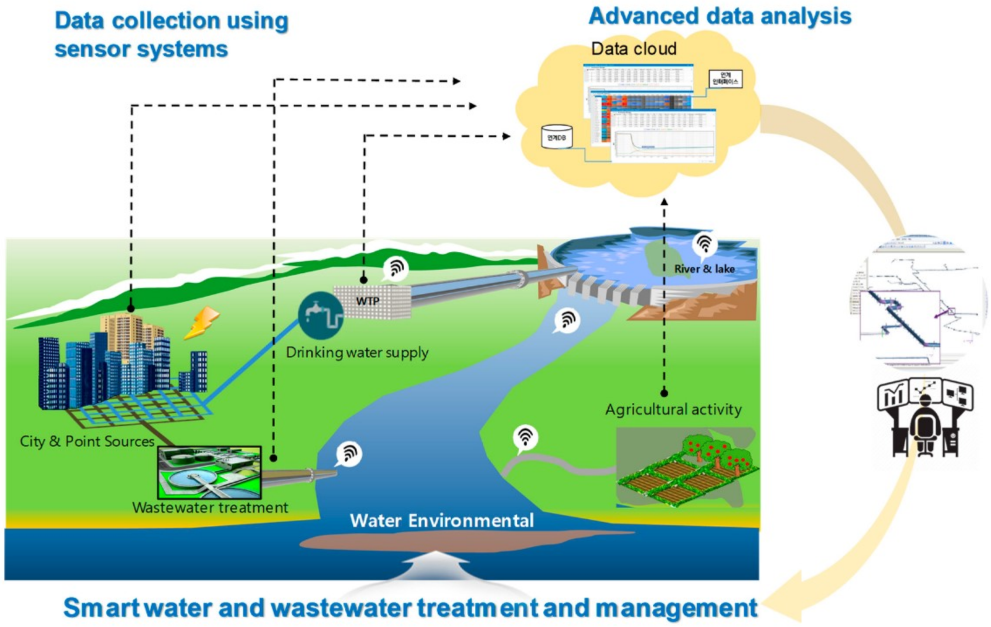
Environmental Monitoring

Environmental Monitoring of Released Analytes and Contamination

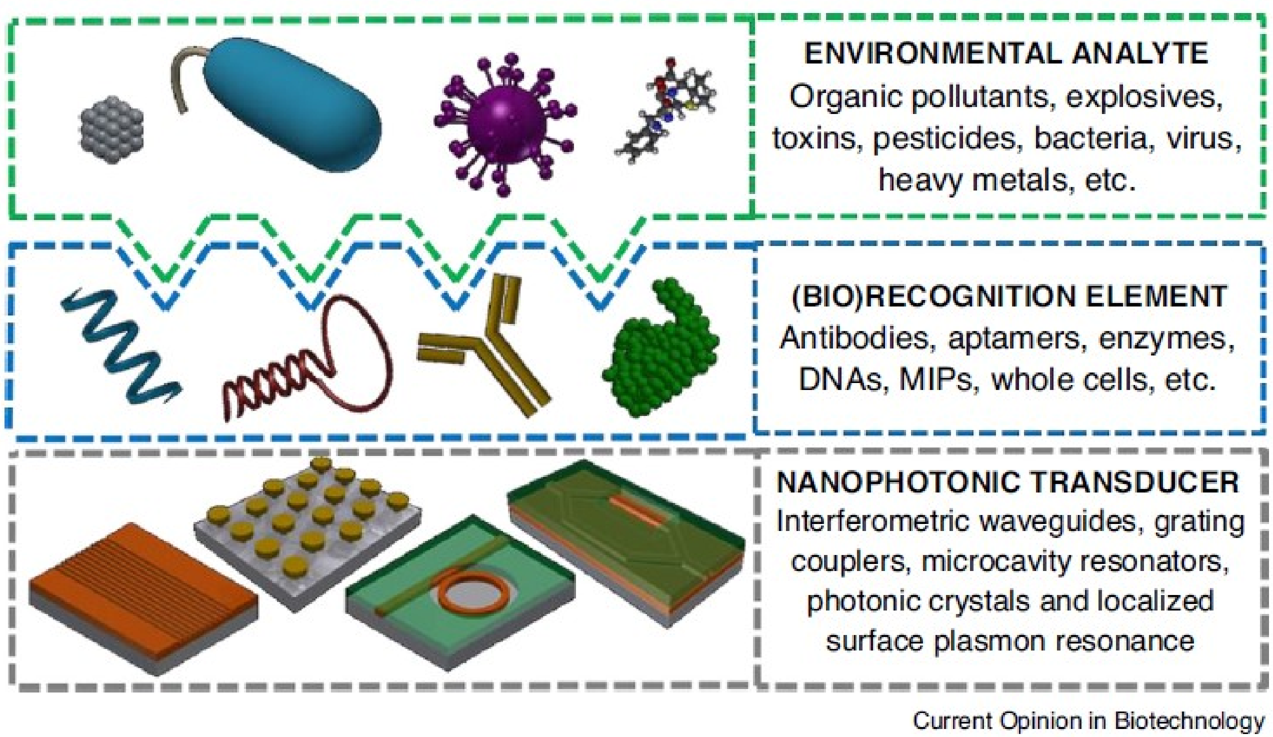
- Monitoring of water sources, waste water, soil contamination.
- Most commonly bacteria, bacterial toxins, or heavy metals are detected. Additional targets include aquatic toxins, pesticides, industrial byproducts, antibiotics, and pharmaceuticals.
- Linked to previous topics - antibiotic resistance development, endocrine disrupting compounds to sweet water fish…



https://doi.org/10.3390/w12020510

Optical Biosensors For Environmental Monitoring

- Early warning systems, need of automatized portable systems for environmental surveillance.



http://dx.doi.org/10.1016/j.copbio.2017.03.016

Optical Biosensors For Environmental Monitoring

Table 3

Recent results of microcavity resonator biosensors for environmental monitoring

Recognition element	Analyte	Matrix	LOD	Reference
Aptamer	Hg^{2+}	Buffer	~1 ng/mL	[31], 2016
Glutathione	Pb^{2+}	Pure water	10 pg/mL	[32], 2014
Ab	2,4-Dinitrophenol	Buffer	NA	[33], 2014
AChE enzyme	Parathion-methyl	Buffer	10 pg/mL	[34], 2008
Ab	Ricin and saporin	Buffer	200 pM (~12 ng/mL) (ricin)	[35], 2013
Modified odorant-binding proteins	DMMP (precursor of Sarin)	Air	6.8 ng/mL	[36], 2014
Aptamer	Aflatoxin M1	Buffer	NA	[37], 2015
Phage protein	*S. aureus*	Buffer	5×10^6 CFU/mL	[38], 2016
Ab	*E. coli*	Buffer	10^5 CFU/mL	[39], 2008
Ab	*Bean pod mottle virus*	Buffer and complex leaf extracts samples	10 ng/mL	[40••], 2012
Ab	M13 bacteriophage	Buffer	2.3×10^3 PFU/mL	[41], 2008

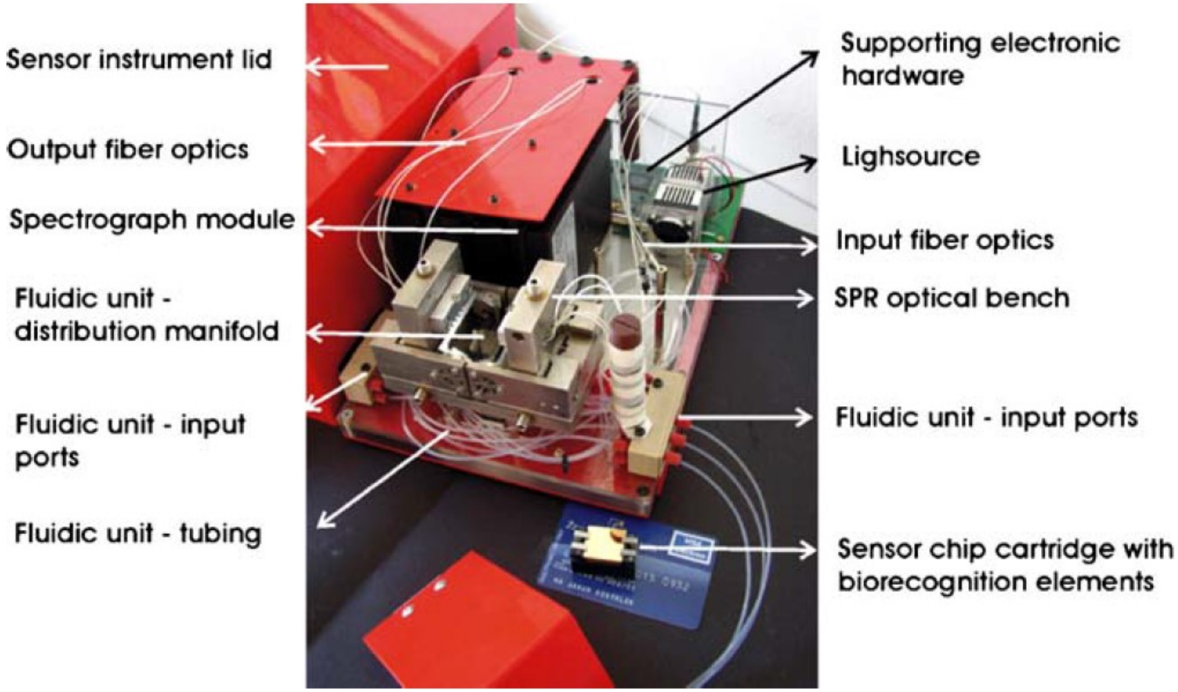
www.sciencedirect.com

Current Opinion in Biotechnology 2017, **45**:175–183

http://dx.doi.org/10.1016/j.copbio.2017.03.016

Optical Biosensors For Environmental Monitoring

- Need of integration of all key components to a functional device.



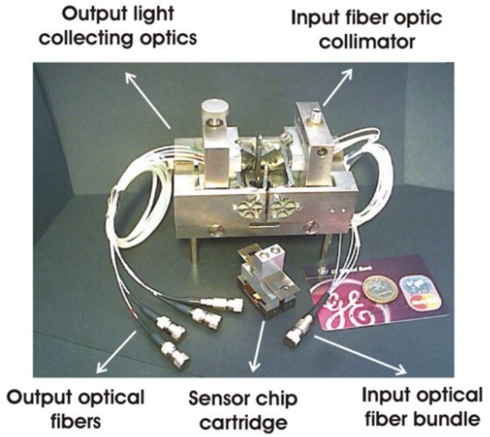
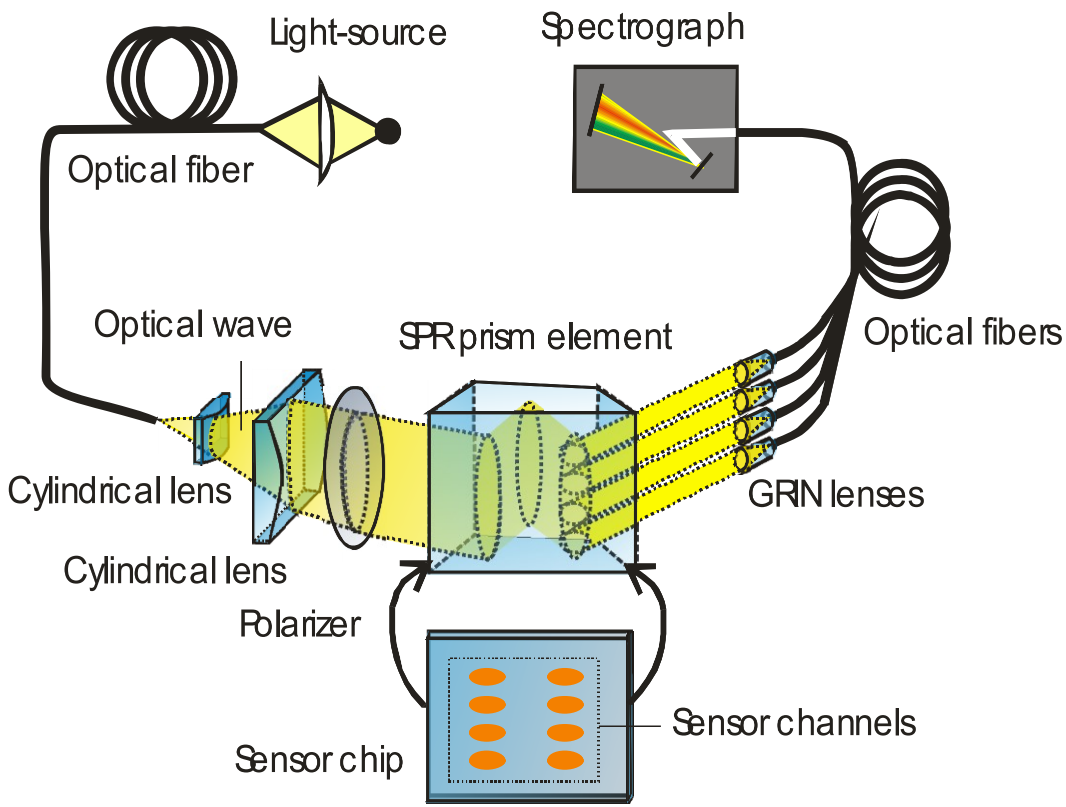


Fig. 8 Portable SPR sensor system developed at the Institute of Radio Engineering and Electronics, Prague with SPR optical platform, fluidic unit, temperature stabilization, and supporting electronic hardware

DOI 10.1007/5346_019

Multichannel SPR Biosensors



- Example of wavelength division multiplexing of sensing channels combined with the using of multiple optical beams.

J. Dostalek, H. Vaisocherova, J. Homola, Multichannel Surface Plasmon Resonance Biosensor with Wavelength Division Multiplexing, Sensors and Actuators B, 108 (2005) 758-764.

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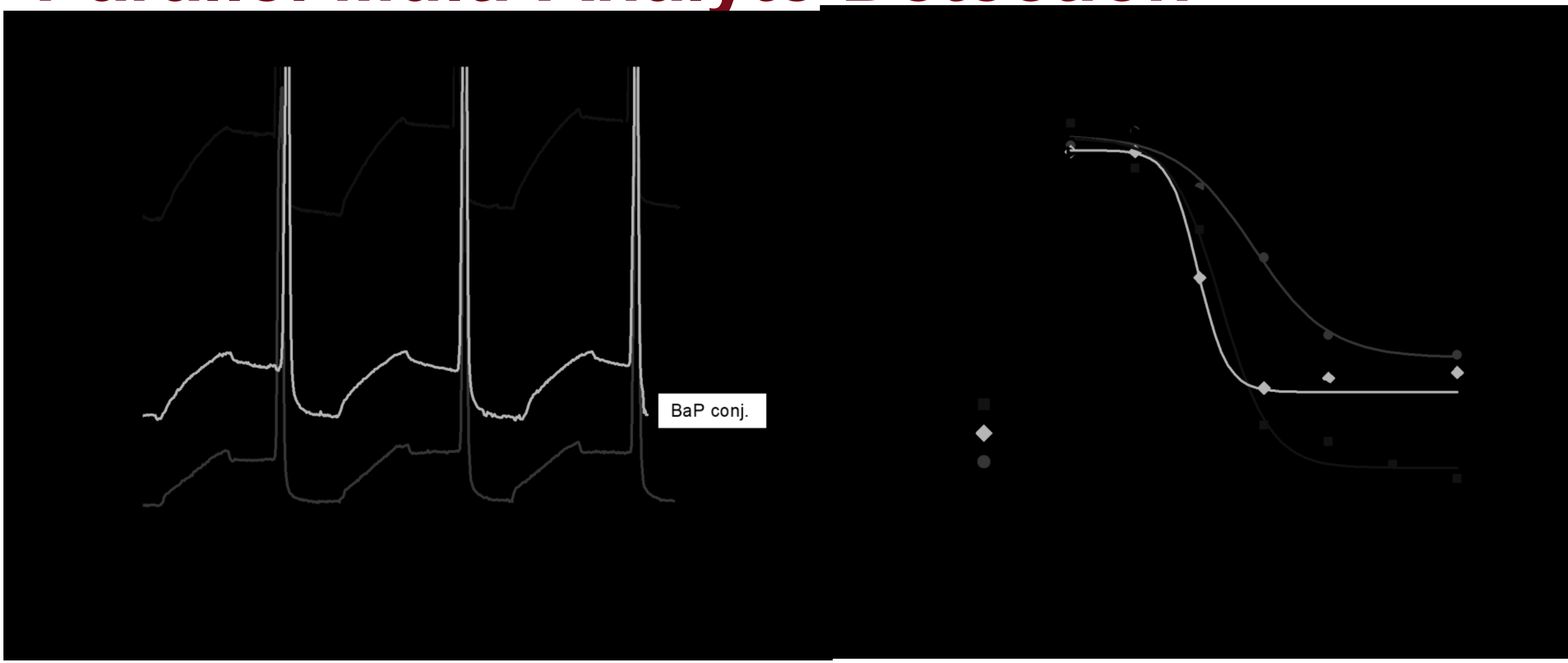
Parallel Multi-Analyte Detection

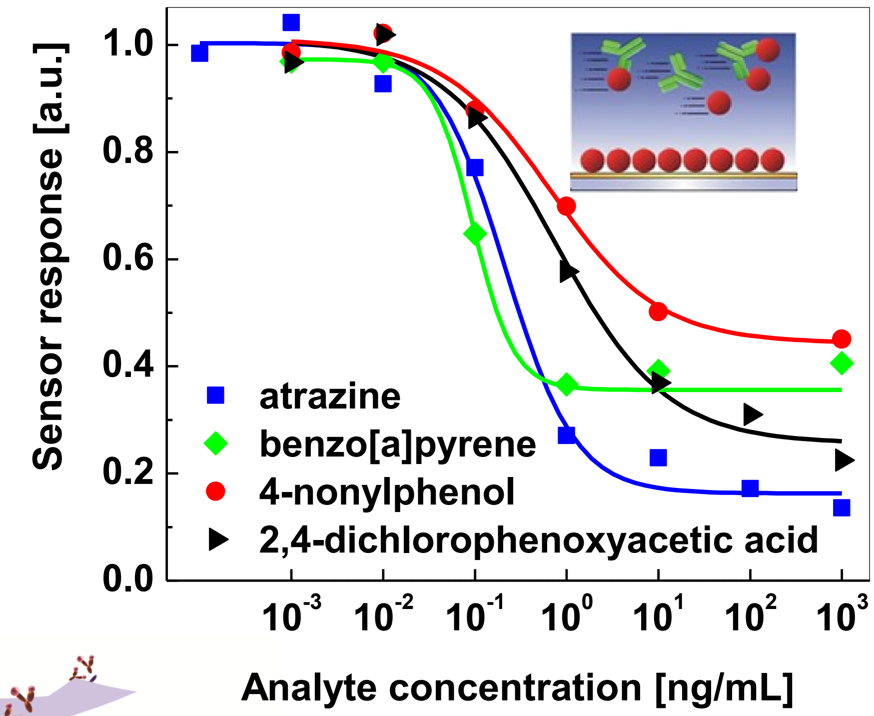


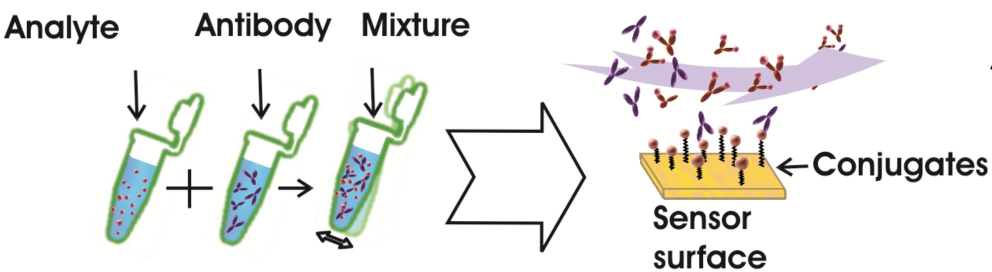
- Parallel detection of multiple analytes in the analyzed sample enabled by the multichannel SPR biosensor instrument.

J. Dostalek, J. Pribyl, P. Skladal, J. Homola, Multichannel SPR biosensor for detection of endocrine disrupting compounds, Analytical and Bioanalytical Chemistry, (2007) 389:1841-1847

Example of Inhibition Assay

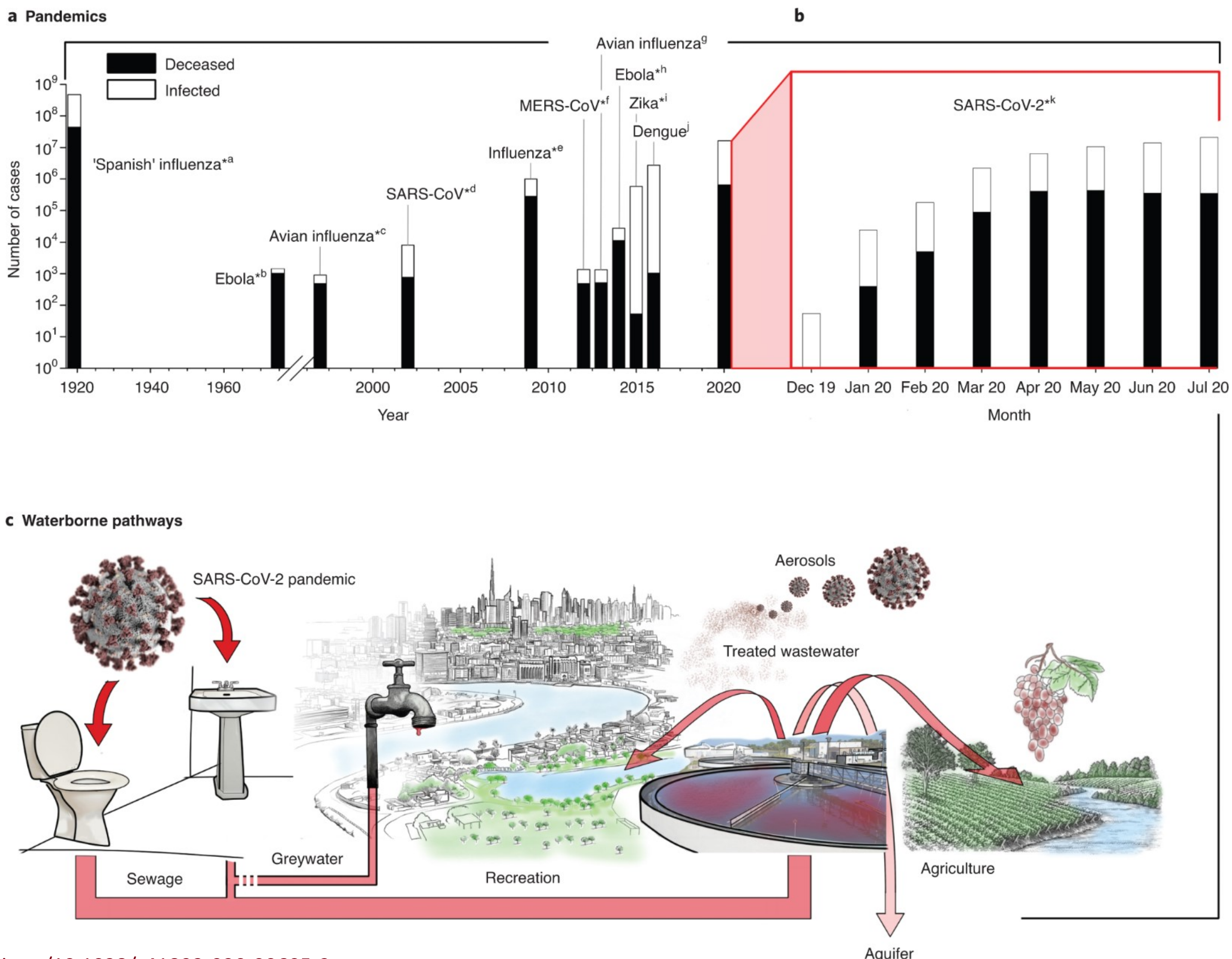
Atrazine – pesticide with molecular weight of 0.2 kDa. Too small to be detected directly and thus inhibition or competitive assays are used.





Dostalek, J. Pribyl, P. Skladal, J. Homola, Multichannel SPR biosensor for detection of endocrine disrupting compounds, Analytical and Bioanalytical Chemistry, (2007) 389:1841-1847

Interlinked Topics



https://doi.org/10.1038/s41893-020-00605-2

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- How can I submit an official comment on proposed regulations?
- Where can I see the text of actual regulations?

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