Achievements and Challenges in Environmental Sensing

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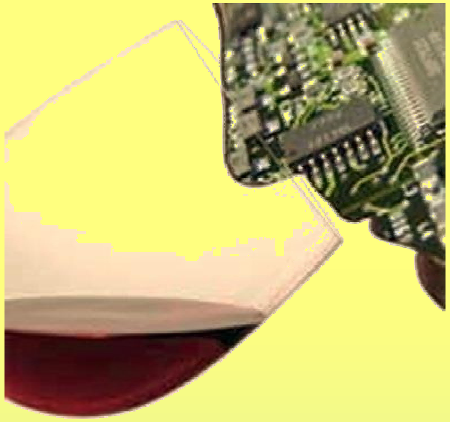
Panel Conclusions

- Main challenges in environmental sensing are molecular sensors
- Namely such sensors let to achieve low cost and low power consumption in various applications, including IoT (smart cities, etc.)
- Progress in sensor interfacing and readout is connected with a changing of traditional sensor output's informative parameters as voltage and current) to frequency-time informative parameters



Is it possible to bring metal oxide E-noses to every-day application, in environmental measurements?

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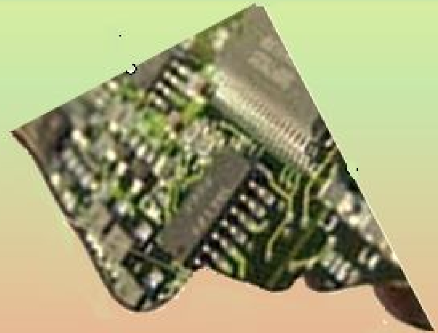
Major perception of E-noses appearance

There is no working devices of such a type around



Major challenges in E-nose development*

Drift of sensor system

Limited selectivity

Instability of operation

Solution

Automatic add-training

* A. Loutfi, S. Coradeschi, G. K. Mani, P. Shankar, J. B. B. Rayappan, *Electronic Noses for Food Quality: A Review*, Journal of Food Engineering, 144, 2015.

Add-training is indispensible

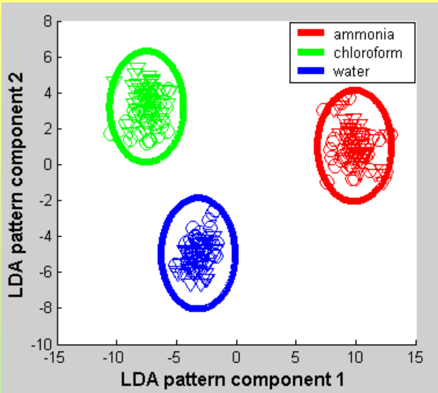
Three time scales of the odor recognition system change in ambient air:

1. **Primary variations** (concentration, daytime air, etc. variations): **1 – 2 days**;
2. **Regular variations** (object change, week day air variations, etc.): **1-2 weeks**;
3. **Drift** (season change, sensor ageing): **months, years**.

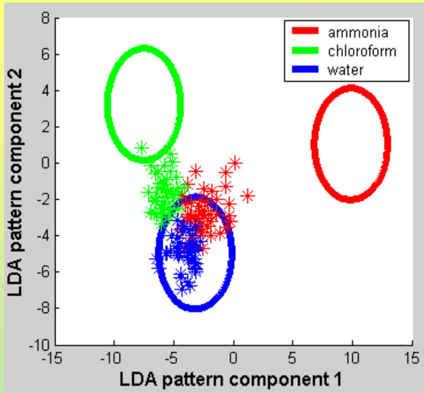
Three stages of the model add-training

1. **Initial model building** (many expositions a day);
2. **Model completion** (few expositions a day);
3. **Continues add-training** (dropping exposition frequency, from one a day to one per couple of months).

Initial model building: separation is perfect

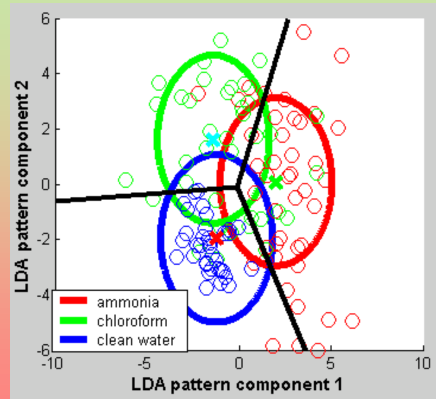


Further exposures slip out



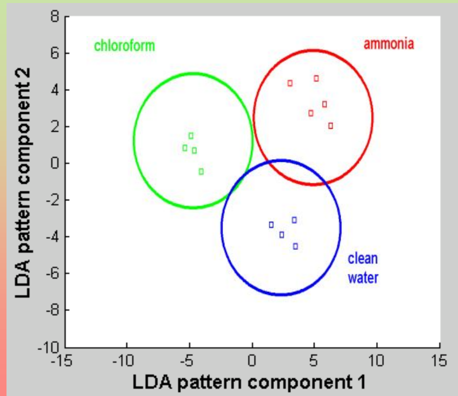
Are taken into training set

Aging: separation becomes insufficient

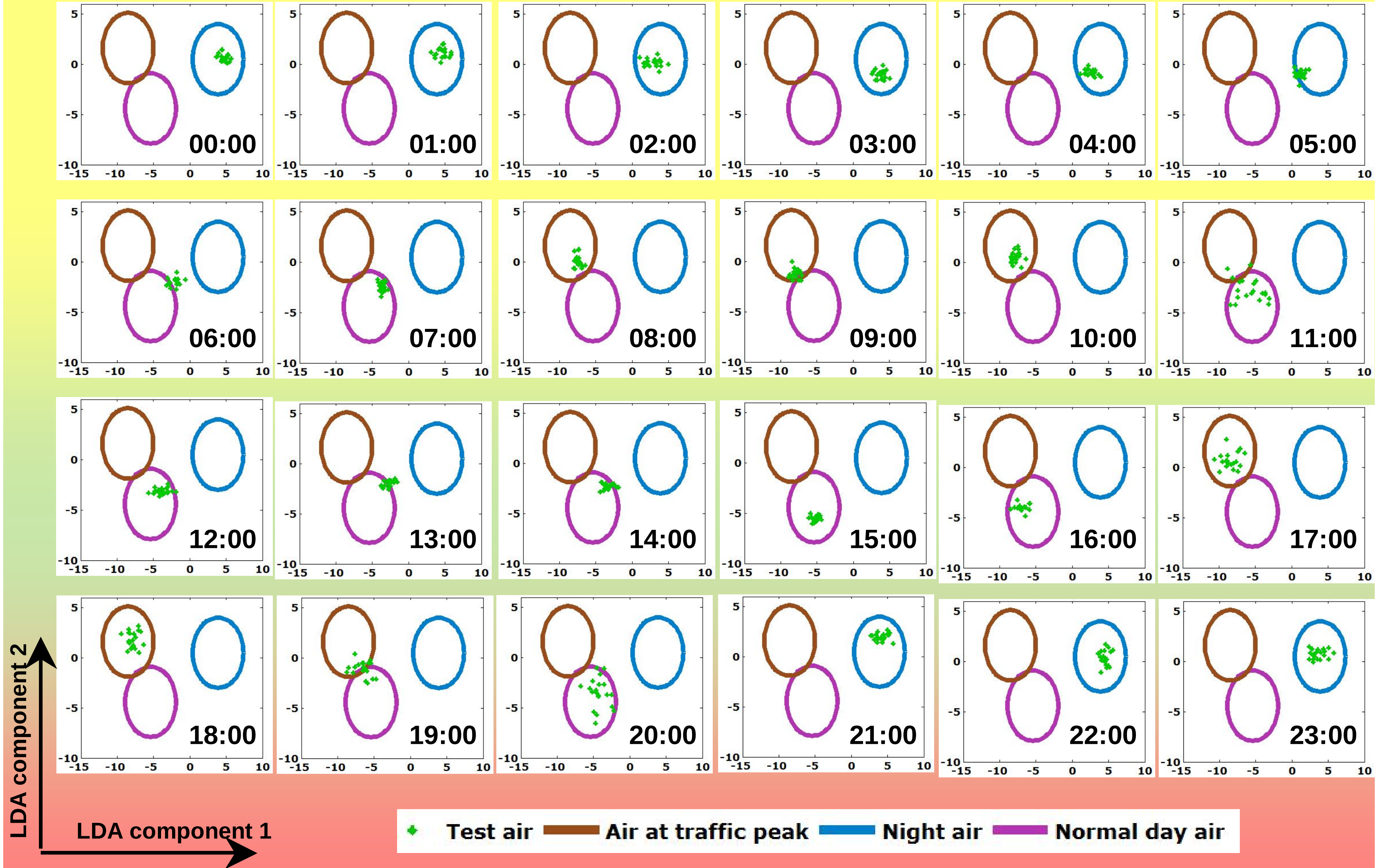


Withdrawal of obsolete training data

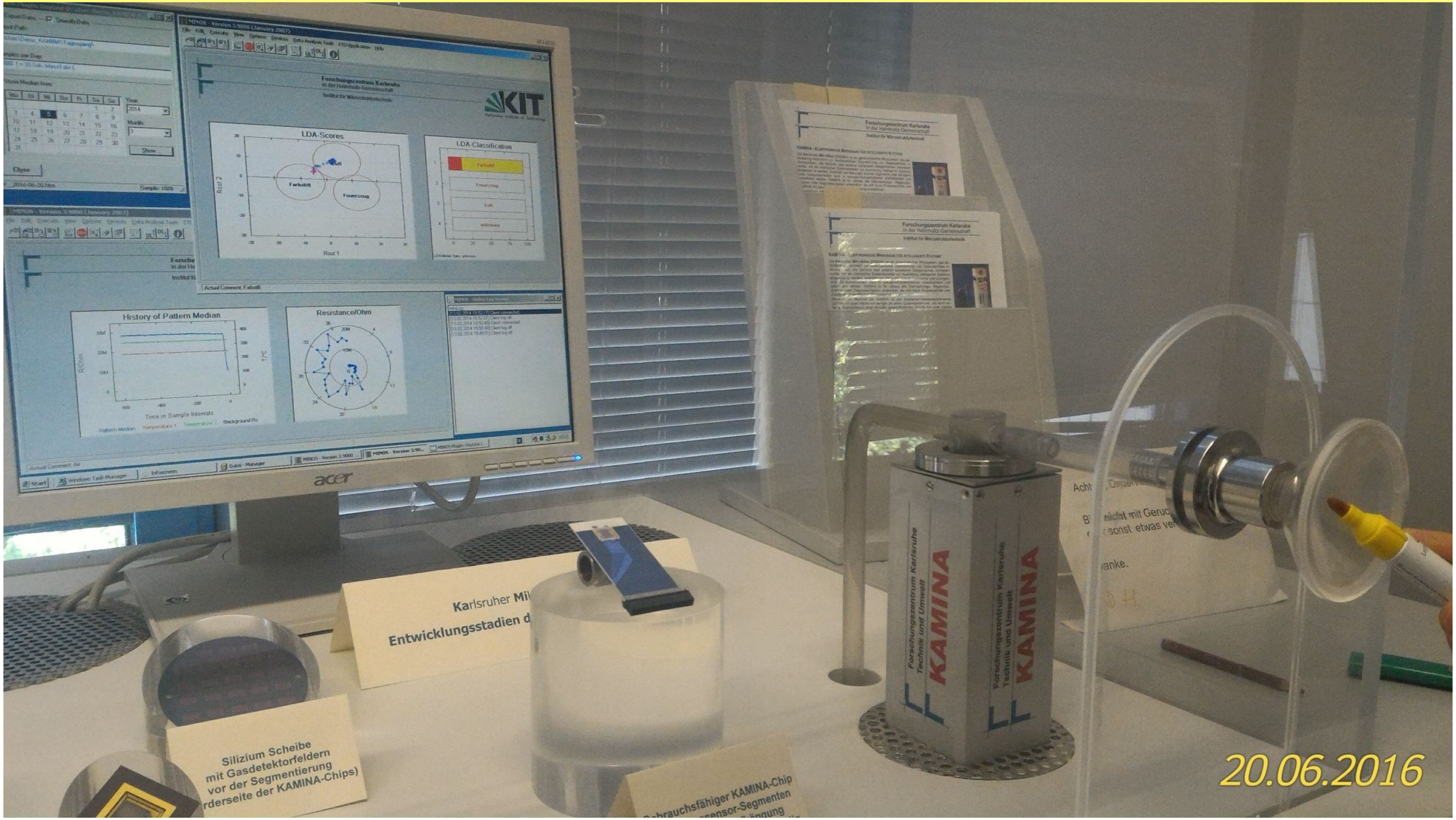
Work model: separation is optimal



Example: Environmental air monitoring with metal oxide sensor array following proper training



Example: A MO gas sensor array operates for 15 years in a continuous mode to demonstrate 100% recognition of smells of lighter, felt-tip pen and ambient air. Add-training: one exposure every 2 months.



Conclusions

1. The future and broad usage belong to molecular-group-specific noses similar to the biological ones.

2. The metal oxide E-noses, as other non-molecular-specific noses, have their niche for application.

3. It is already certain that the existing E-noses can be used for a "simple" long-term application: tracing of expressed pollutions, discrimination of distant odors. This is achieved using the add-training.

4. It is still the main challenge: to get really working industrial E-noses for such simple applications.

5. MO E-noses won't take their place in the market without demonstrative, long working really useful applications. The letter should be established using unprofitable fund raising.

6. It is known that MO E-noses can discriminate very slightly differing odors, such as required for classification e. g. of wine sorts. But it still must be proven, whether long-term applications of this kind are feasible – specifically, using the add-training.

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Achievements and Challenges in Environmental Sensing

Electrochemical sensors

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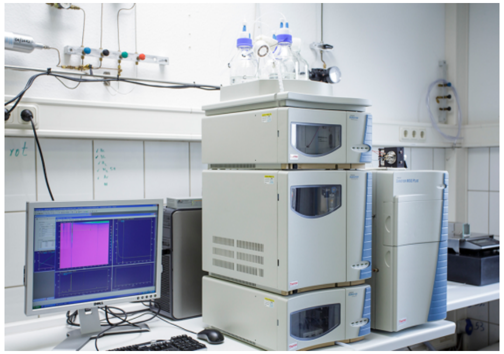
Environmental analysis with (electro-) chemical sensors I

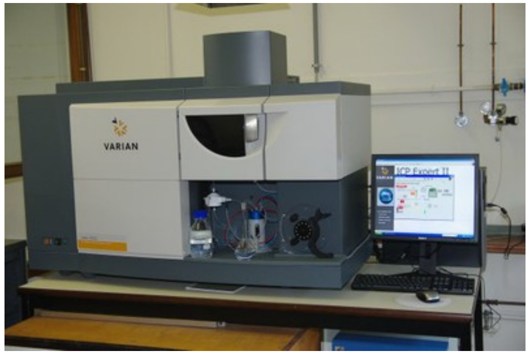



Environmental analysis with (electro-) chemical sensors II

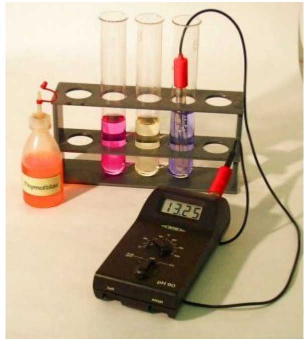


Expensive laboratory analysis using costly equipment





On-site measurements using sensors



Requirements on [(electro)chemical] sensors as an alternative to other analytical tools

* High selectivity and sensitivity
* Low detection limit
* Low signal noise
* no hysteresis
* short response times
* long life-time
* sterilisability
* inexpensive production
* …

Requirements for environmental sensing (electrochemical sensors):

Detection possibilities

No sensors for sulfate and phosphate and other environmentaloly relevant species available

Detection limits

Sensors must become better (exception: pH glass electrode)

Cross sensitivity

Often much too high

Long-term stability

Often too much calibration cycles necessary

Multi component analysis

Often too much calibration cycles necessary

…

Miniaturisation

All solid state sensors

Planar sensors

…

Applications of Acoustic Resonance Spectroscopy for Sensor Devices

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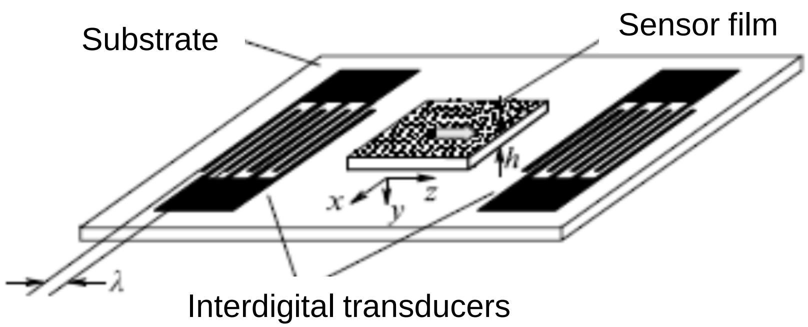
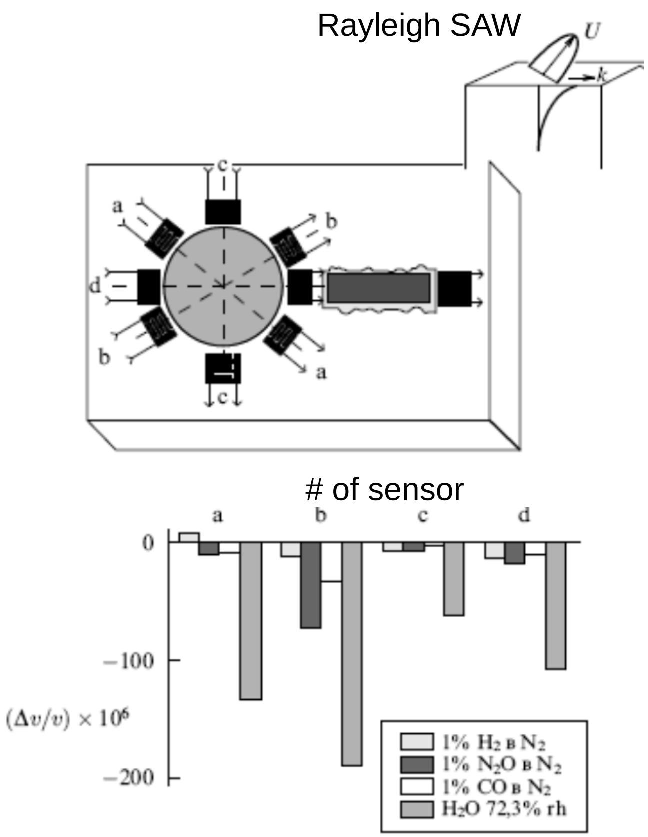
SENSORDEVICES 2016, July 24 - 28, 2016, Nice, France

Gas acoustic sensors



SAW based single channel gas sensor

sensitive to surface massloading



Integral array of SAW sensors

exploit substrate anisotropy

sensitive to different gas absorption

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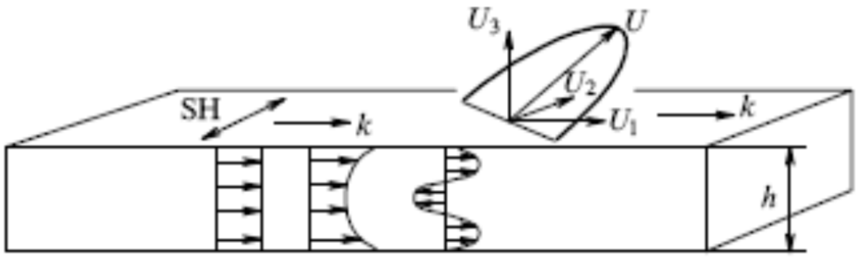
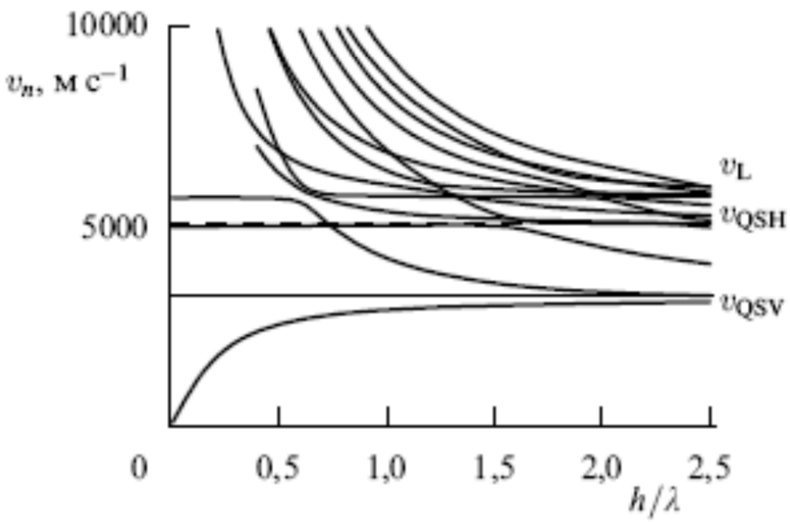
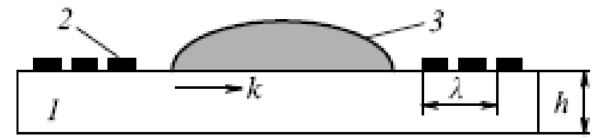
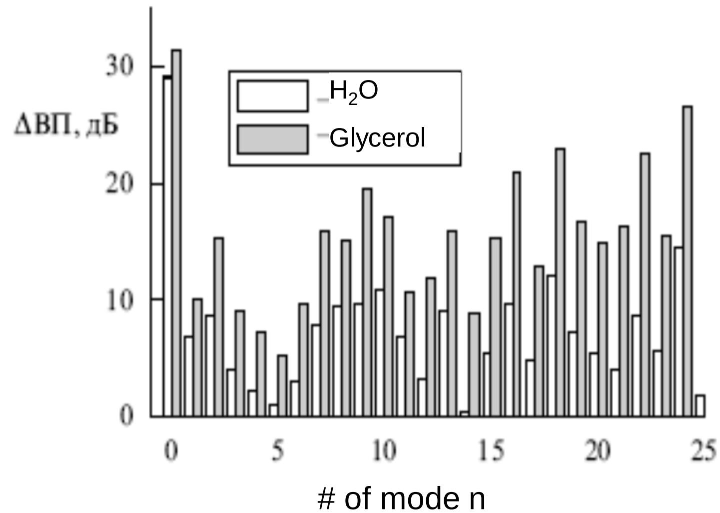
Liquid acoustic sensors

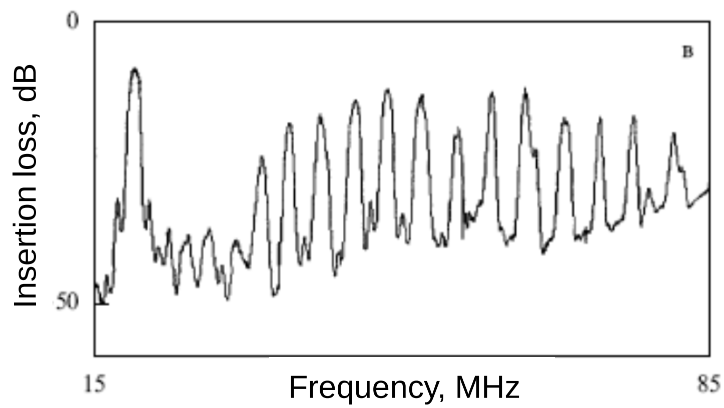
Plate acoustic waves (different modes)











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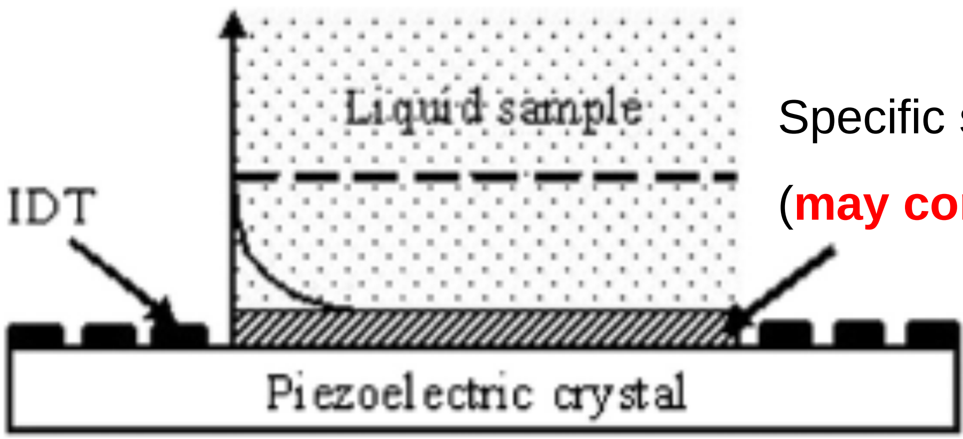
Bacterial cell acoustic sensors



Specific sorbent film

(**may completely absent !**)

Schematic view of acoustic wave liquid sensor

Ultrasonic acoustic waves propagating in thin piezoelectric plates with free faces are used for bacteria detection in micro-litre liquid samples deposited on one of the plate surface. The limits of the detection at normal conditions are as low as 0.04% for highly diluted rich cultural Luria–Bertani broth (LB-media) in distillate water, 0.07% for bacterial cells in distillate water, and 0.6% for bacterial cells in LB-media.

For all analytes the most probable detection mechanism is the change in liquid conductivity.

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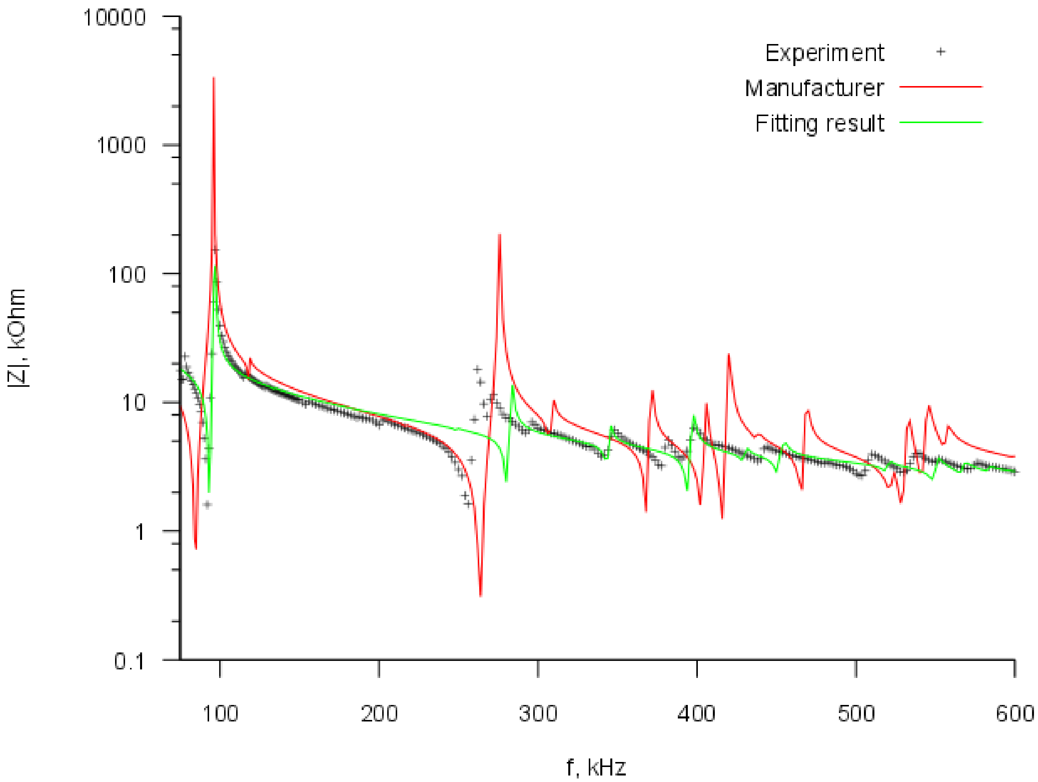
Identification of acoustic properties of materials:

acoustic spectroscopy approach



$$\begin{pmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ D_1 \\ D_2 \\ D_3 \end{pmatrix} = \begin{pmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 & 0 & 0 & d_{31} \\ s_{12}^E & s_{11}^E & s_{13}^E & 0 & 0 & 0 & 0 & 0 & d_{31} \\ s_{13}^E & s_{13}^E & s_{33}^E & 0 & 0 & 0 & 0 & 0 & d_{33} \\ 0 & 0 & 0 & s_{55}^E & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 & d_{15} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{66}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & d_{15} & 0 & \varepsilon_{11}^T & 0 & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 & 0 & \varepsilon_{11}^T & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 & 0 & 0 & \varepsilon_{33}^T \end{pmatrix} \times \begin{pmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \\ E_1 \\ E_2 \\ E_3 \end{pmatrix}$$

Clarification of material constants sets allows more accurately modeling the newly created sensors

A. A. Teplykh. Work supported by RFBR (project # *16-07-00984-a*)