ZEOLITE-BASED QUICK-RESPONDING SENSORS FOR RESPIRATORY RATE MONITORING

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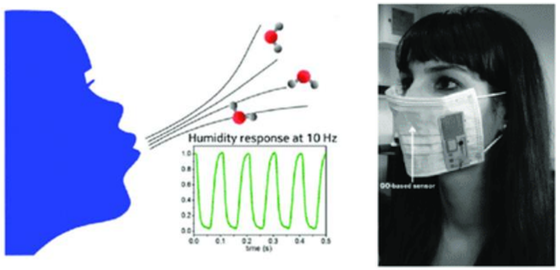
RESPIRATORY RATE MONITORING

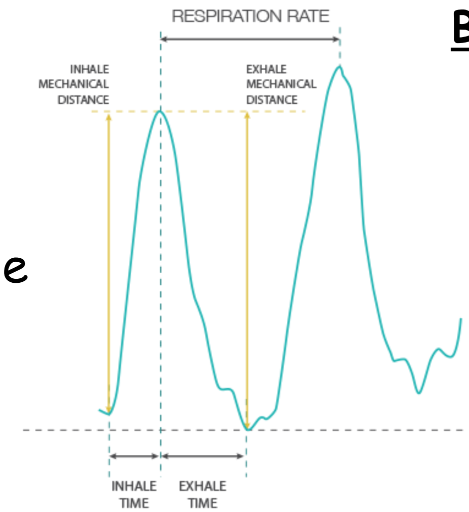
Respiratory rate and other breath parameters, relevant for medicine and sport monitoring, can be determined by detecting the water vapor content in the exhaled air.



Wearable breath sensors

CHARACTERISTICS OF THE REQUIRED WATER SENSOR

Sensitive and quick-responding water sensors are required to get high-resolution breathing patterns, containing reliable physiological information useful to establish health condition.



Breath sensor application fields:

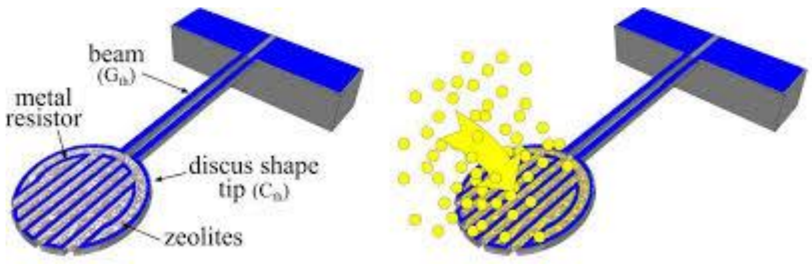
- Medical diagnosis (sleep apnea, asthma, chronic obstructive pulmonary diseases, etc.)
- Personal spirometry
- General anaesthesia
- Sport monitoring
- Space engineering

ZEOLITE-BASED WATER SENSORS

Zeolites have been used for the fabrication of chemical sensors for different substances (e.g., water, ethanol, formaldehyde, etc.)

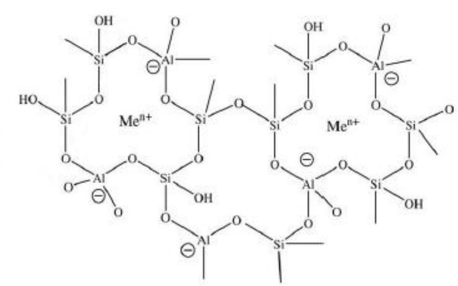
<u>Zeolite sensor characteristics:</u>

- High selective
- Robust
- Thermally stable
- Inexpensive



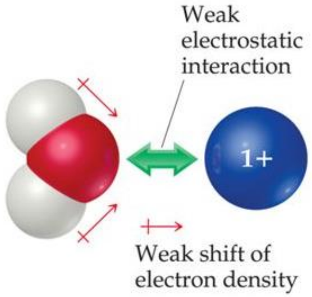
SENSITIVITY OF WATER SENSORS BASED ON CLINOPTILOLITE

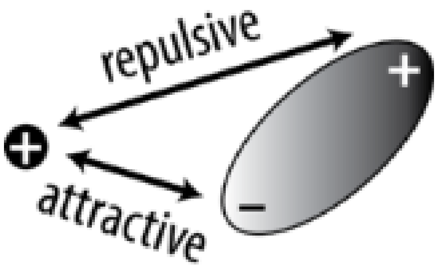
Natural clinoptilolite is a high siliceous zeolite able to experience relevant conductivity changes by exposure to humidity, consequently sensitive water sensors can be based on it.

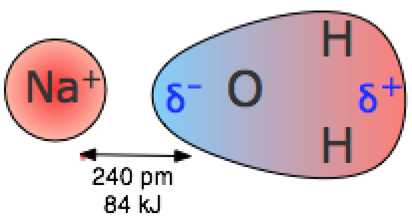


POTENTIAL QUICK RESPONSE OF ZEOLITE SENSOR

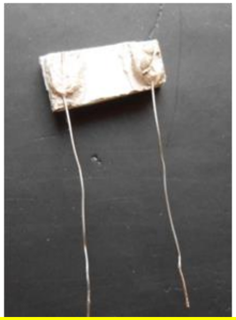
Owing to intensive electrostatic interaction between cations and the water dipole momentum, electrical sensors based on the zeolite surface conductivity should have a prompt response and therefore be potentially useful for breath rate monitoring.



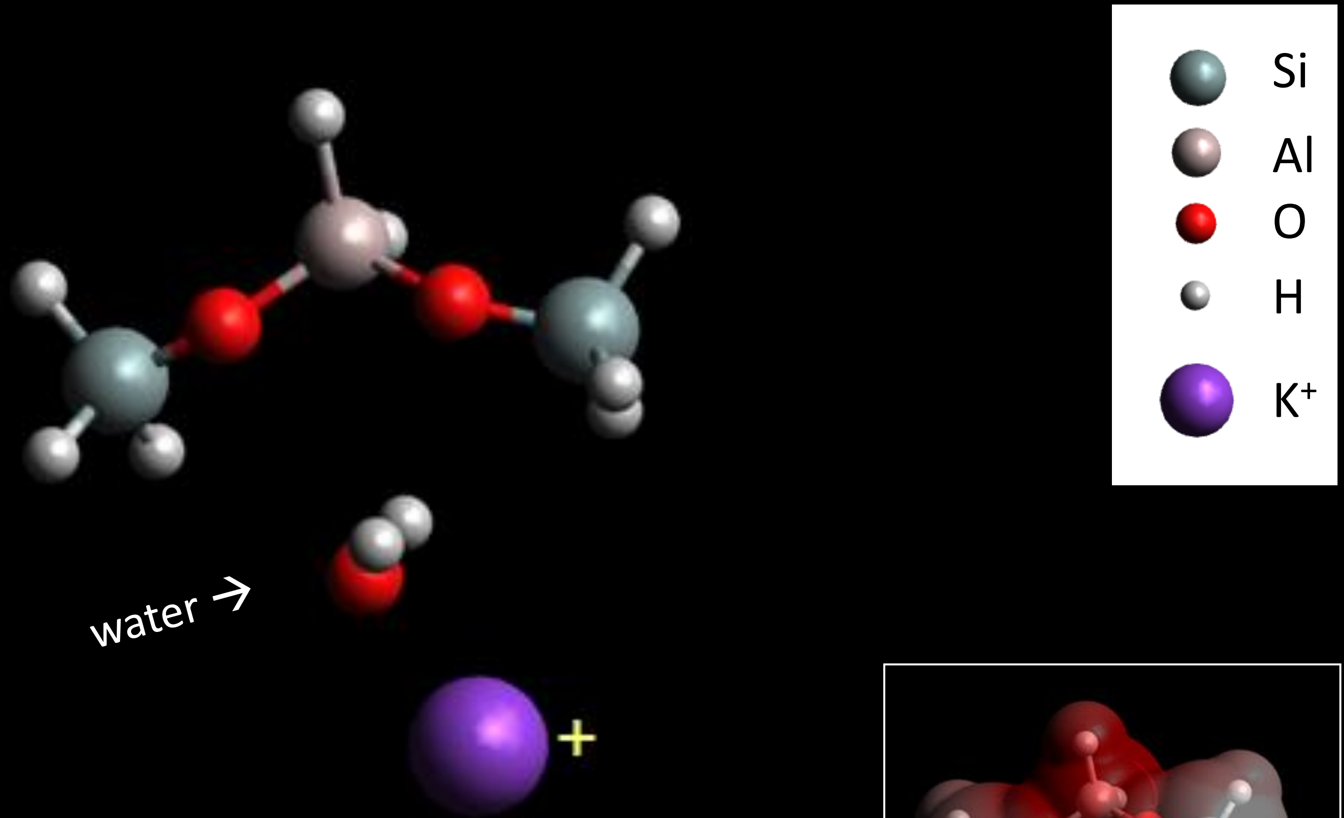


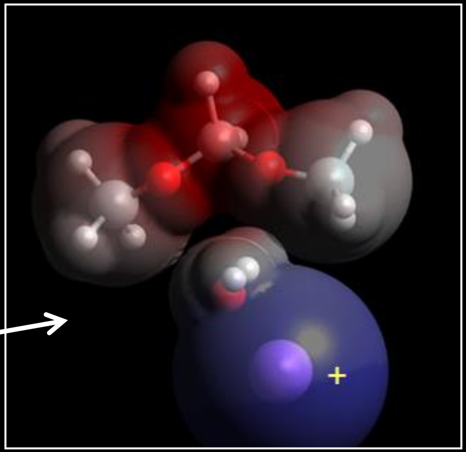


The electrical measurement must involve the sample surface to avoid a slow mass-transport control (diffusion) during the adsorption process.



Clinoptilolite sample





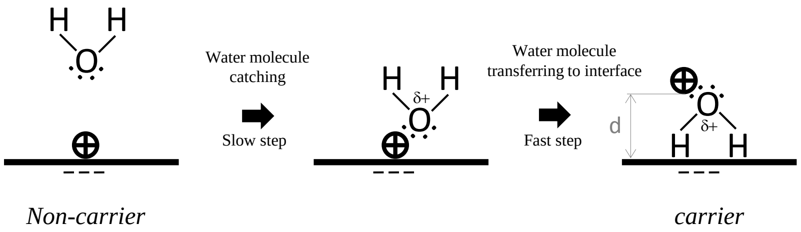
Schematic view of the atomic arrangement of the cation (K^+) inside the zeolite. Water molecule shields electrostatically the cation, favoring its mobility.

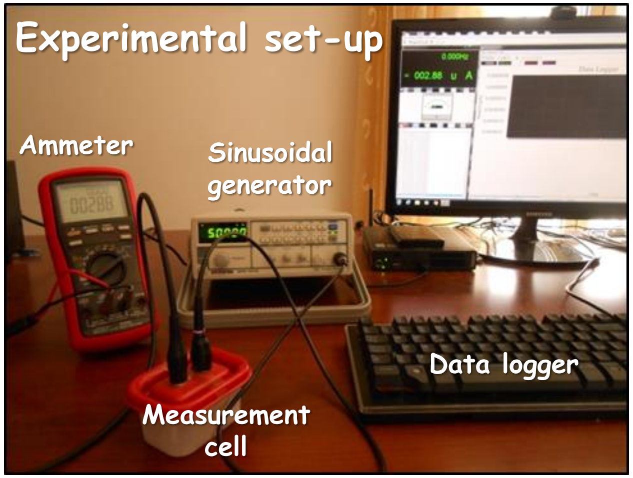
KINETIC ANALYSIS OF ZEOLITE-BASED WATER SENSOR

A kinetic evaluation of the water adsorption/desorption process allows to establish the possibility to use natural clinoptilolite as sensor for respiratory rate monitoring.

ELECTRICAL METHOD USED TO STUDY WATER ADSORPTION

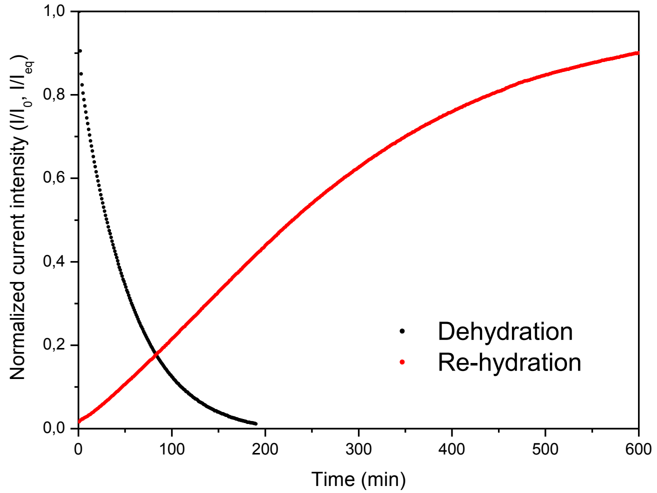
Since hydrated-cations are involved in the electrical transport while dry-cations are not, the adsorption/desorption rate can be investigated by time-resolved current intensity measurements (I is directly proportional to the hydrated-cations concentration). The clinoptilolite sample surface was biased by an a.c. voltage (sinusoidal signal, 5kHz) and true-RMS current intensity was measured by a digital multimeter during the adsorption/desorption process.



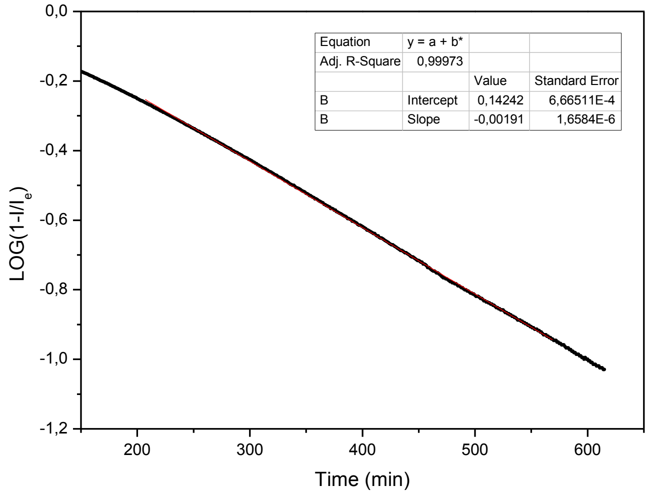


DETERMINATION OF THE WATER ADSORPTION SPECIFIC RATE

The kinetic analysis of the adsorption process based on time-resolved current intensity data shows a pseudo-first-order kinetic behavior (Lagergren model) with a specific rate (k) of $0.00586 min^{-1}$.



Temporal evolution of the normalized current intensity during dehydration and re-hydration.



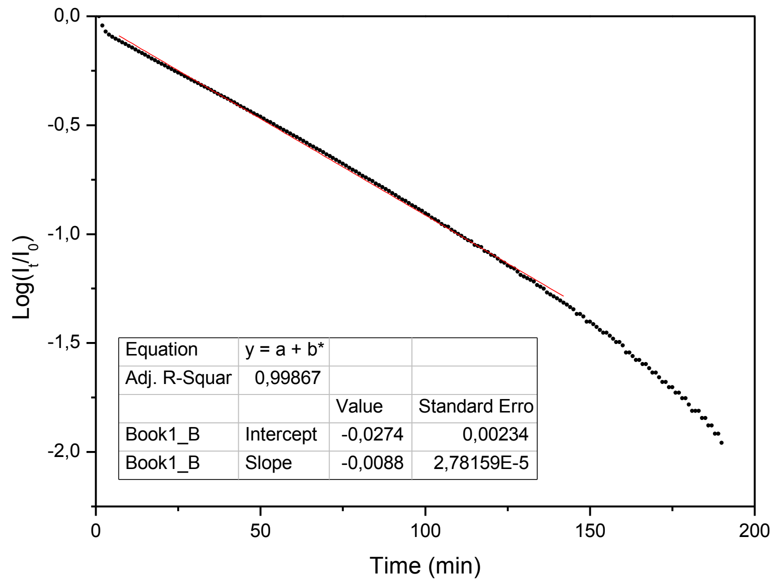
Fitting of the current intensity data by the pseudo-first-order model of Lagergren.

$$log\left(1-\frac{I_t}{I_{eq}}\right)=log\left(1-\frac{Q_t}{Q_{eq}}\right)=-\frac{k}{2.303}\cdot t$$

Lagergren model

WATER DESORPTION KINETICS

The same electrical method can be used to study the kinetics of the process of water desorption from the surface of the clinoptilolite sample.

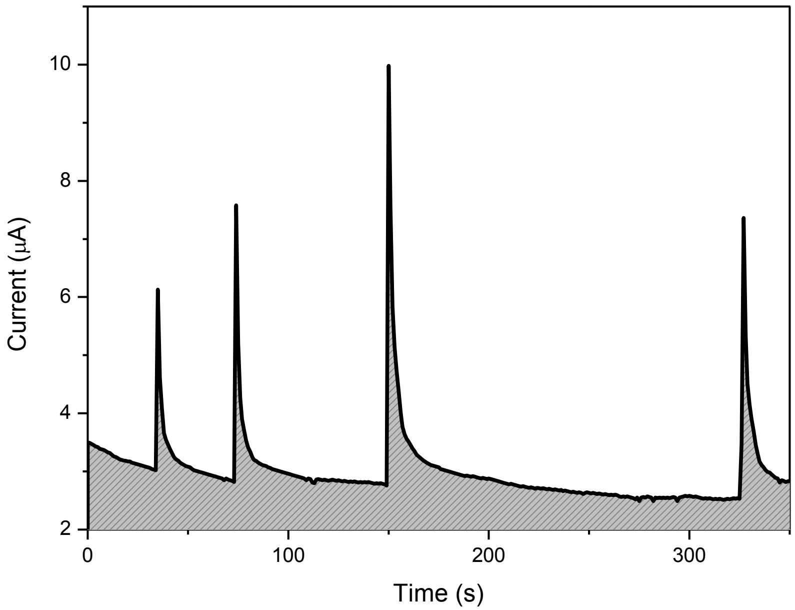


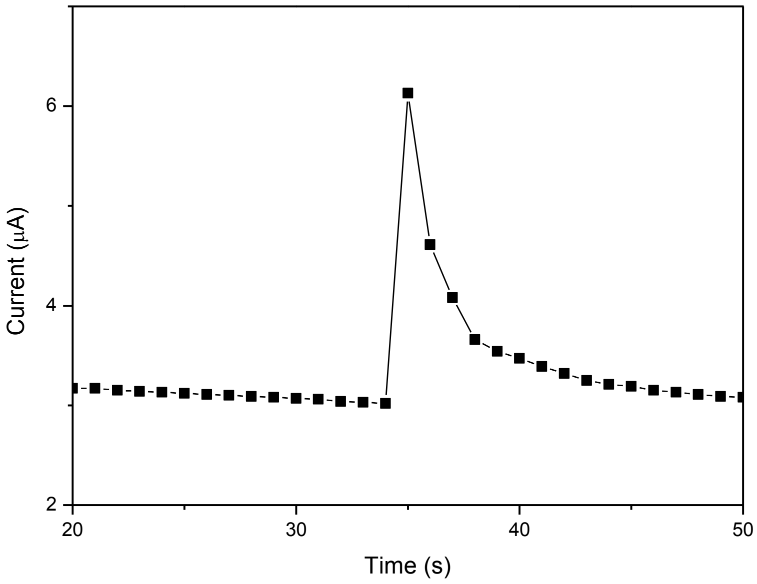
$$\log\left(\frac{Q_t}{Q_0}\right) = -\frac{k'}{2.303}\cdot t$$

Behavior of the relative current intensity logarithm during water desorption from a natural clinoptilolite sample.

HUMAN BREATH PATTERN

The human breath pattern exactly corresponds to the temporal evolution of the current intensity.





CONCLUSIONS

- ✓ Water sensors based on clinoptilolite are potentially useful to monitor breath rate.
- ✓ An electrical approach has been used to study the response rate of clinoptilolite based sensors.
- ✓ Owing to the high silicon content, clinoptilolite-based sensors are very sensitive to water molecules.
- ✓ Zeolite sensor response is fast enough to allow their use as breath sensor.
- ✓ Water adsorption follows a Lagergren kinetic model (pseudo-first order) with a specific rate of 0.00586min^{-1}.
- ✓ Water desorption follows a first-order kinetics.