CPK Automotive
Member of the Heinzmann Group

Engine Emission Management

CPK Automotive

NO_x-Sensor for Emission - and Immission - Measurement

PEMS 2021 Virtual Conference

11. + 12. March 2021

Riverside, CA

Agenda

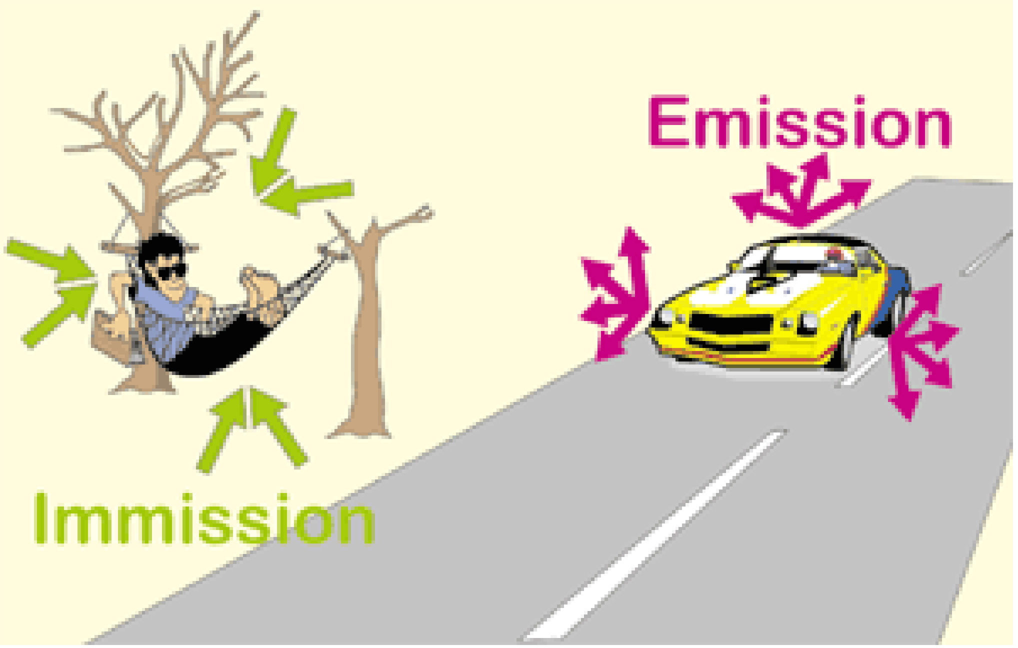
1 Introduction dosimeter principle

2 NO_x sensor design

3 Test results

4 NO_x sensor architecture

5 Summary & next steps



- Immission measurement

  => low concentrations (ppb-range)

- Emission measurement

  => higher concentrations (ppm-range)

Typical NO_x concentration of Diesel exhaust	
engine out, raw	500ppm
but …	
tailpipe post SCR System	< 10ppm

1: Introduction dosimeter principle

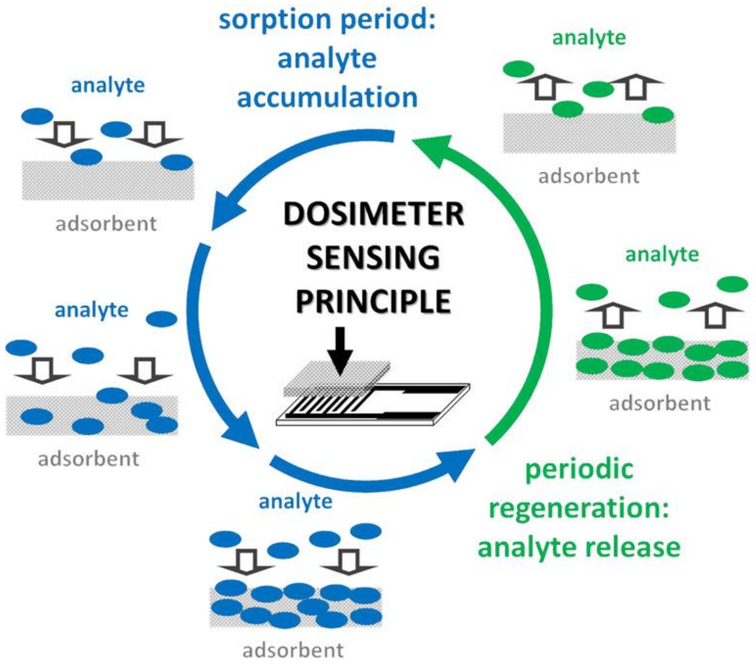


Fig. 1: Operation principle of a dosimeter-type gas sensing device with a sensitive layer as an adsorbent

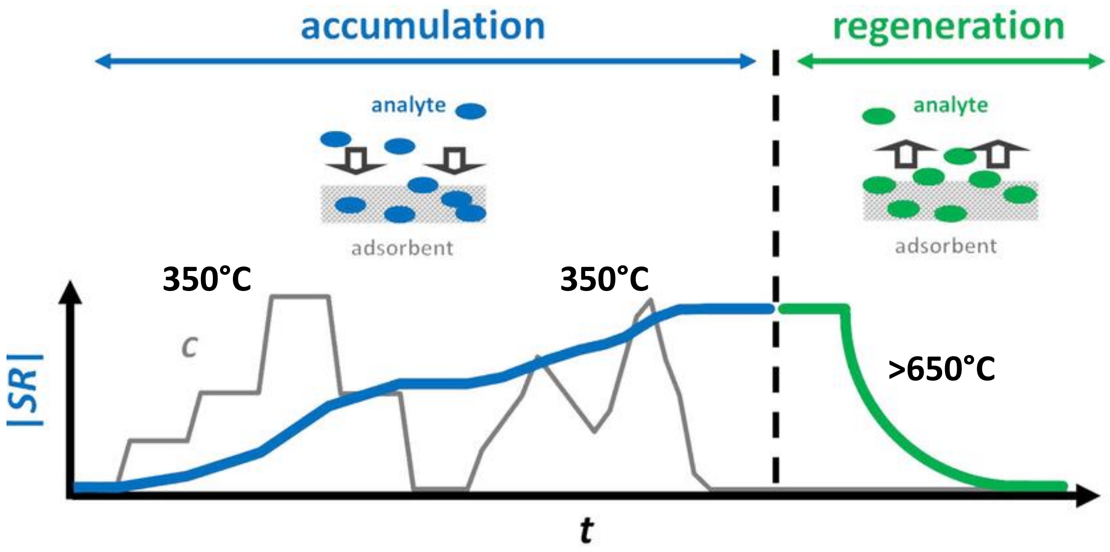


Fig. 2: Sensor response (SR) during accumulation phase with concentration (c) and regeneration phase

Source: Doctor´s thesis I. Marr, Materialien für dosimeterartige Gassensoren zur Detektion im ppm- und im Sub-ppm-Bereich, Bayreuth, 2016

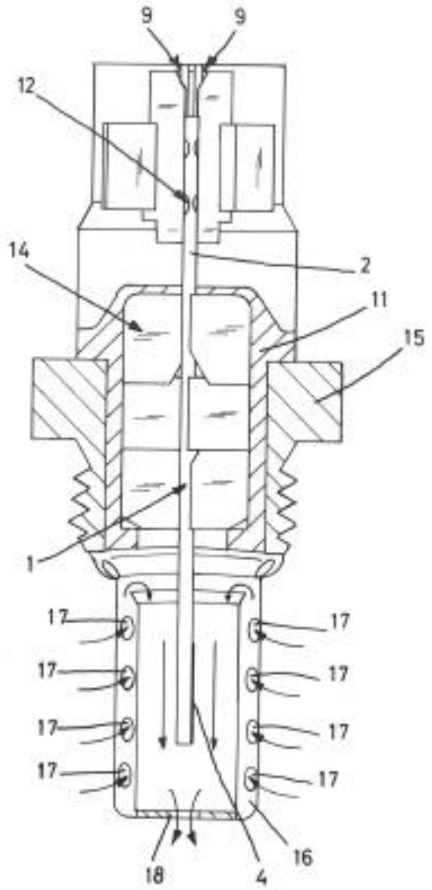
Requirements for NO_x-storage materials:

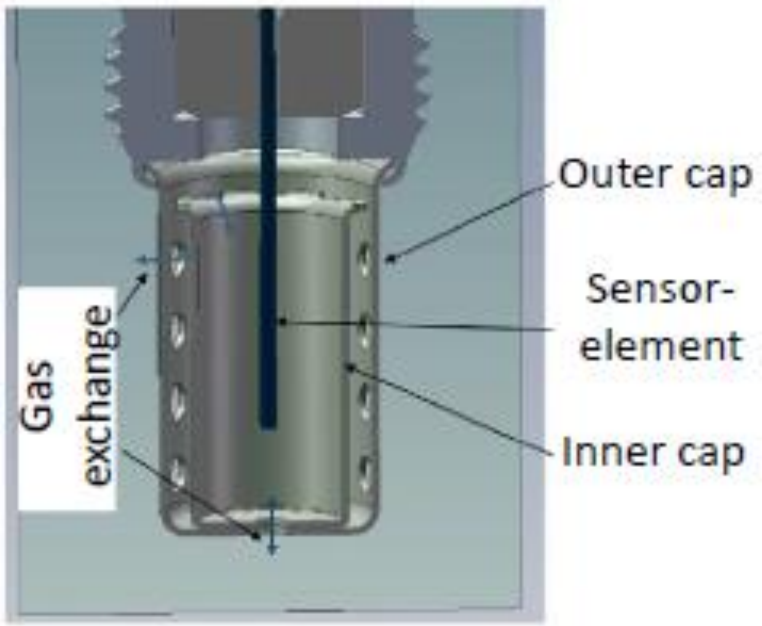
- **Selective storage of NO_x**
- Sufficient holding capability
(strong interaction between NO_x and storage material)
- Change of **at least one electrical measuring signal** when NO_x molecules get stored
Signal must be proportional to NO_x load of storage material
- Load of storage material must not influence the adsorption of the NO_x molecules
- An actively initiated regeneration of storage material and measuring signal must be possible

=> **Potassium permanganate** was found to fulfill the requirements best

Source: Doctor´s thesis I. Marr, Materialien für dosimeterartige Gassensoren zur Detektion im ppm- und im Sub-ppm-Bereich, Bayreuth, 2016

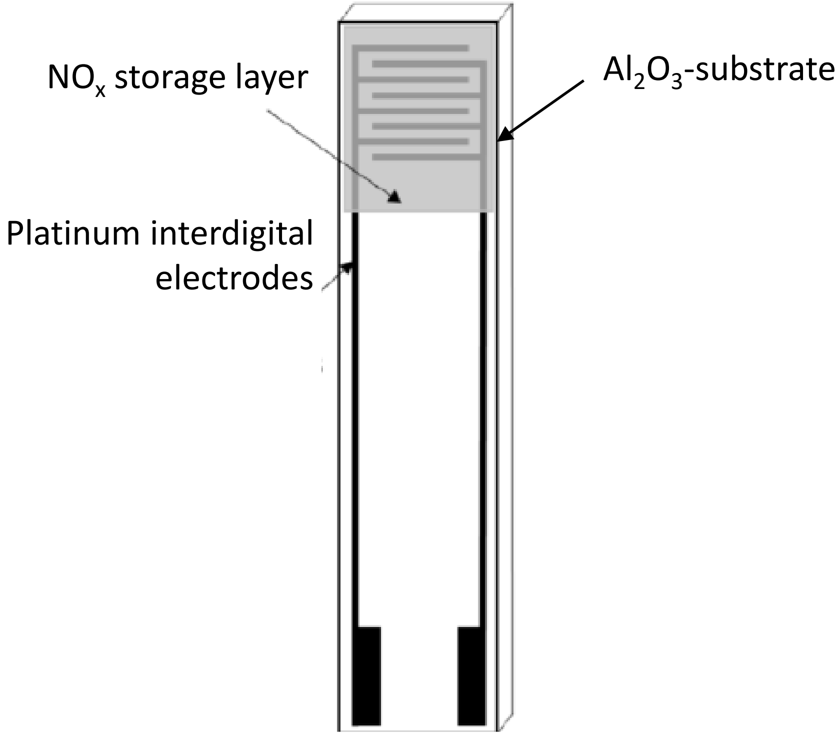
Sensor design used for testing





2: NOx sensor design

Frontside

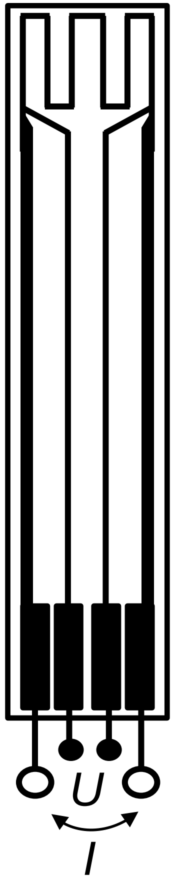


$R = |\underline{Z}| / \cos(\varphi)$

Impedometric sensor response

Supply alternating voltage with frequency from 1 Hz … 10 MHz

Rearside



Heater to keep sensitive layer at constant temperature

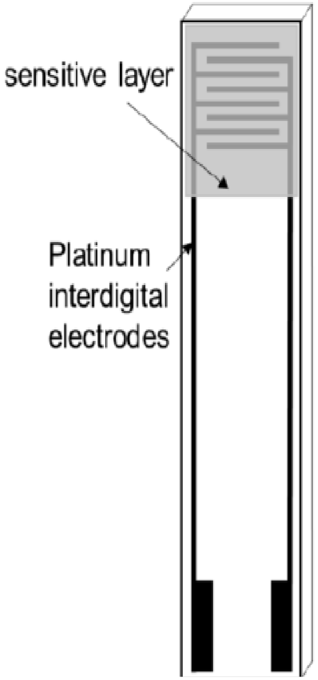
Operating temperature for dosimeter mode
350 °C

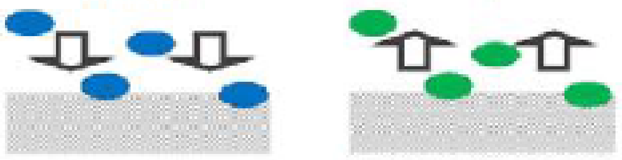
(Immission measurement ppb range)

Measurement of heater current and measurement of heater voltage to control heater

$R_H = U / I$

Same sensor design operated at higher temperature shows gas sensor behavior





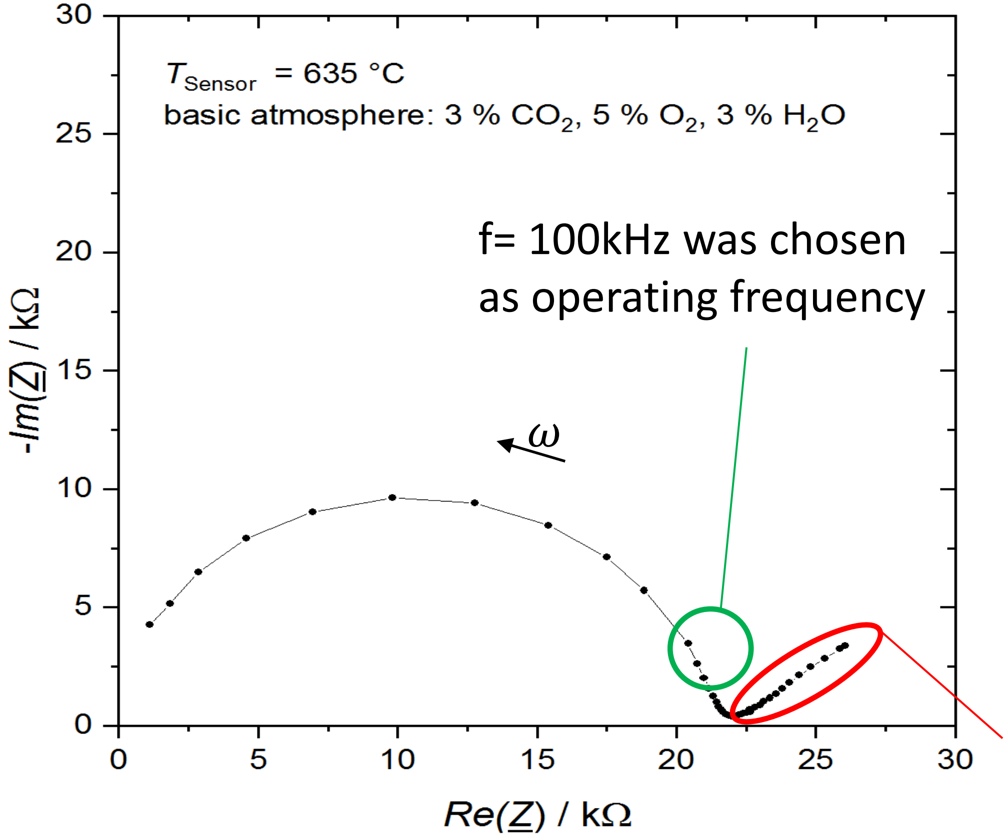
Equilibrium between adsorption and desorption of NO_x molecules @ 650°C

Gas sensor behavior

Operating temperature for
gas sensor mode
650 °C

(Emission measurement ppm range)

Impedometric sensor response (Nyquist diagram)



Equivalent circuit R II C: $\underline{Z} = \frac{R}{1+j\omega CR}$

Determination of electrical conductibility with **alternating current method:**

System is stimulated by **sinusoidal alternating voltage** with amplitude U_o and angular frequency ω.

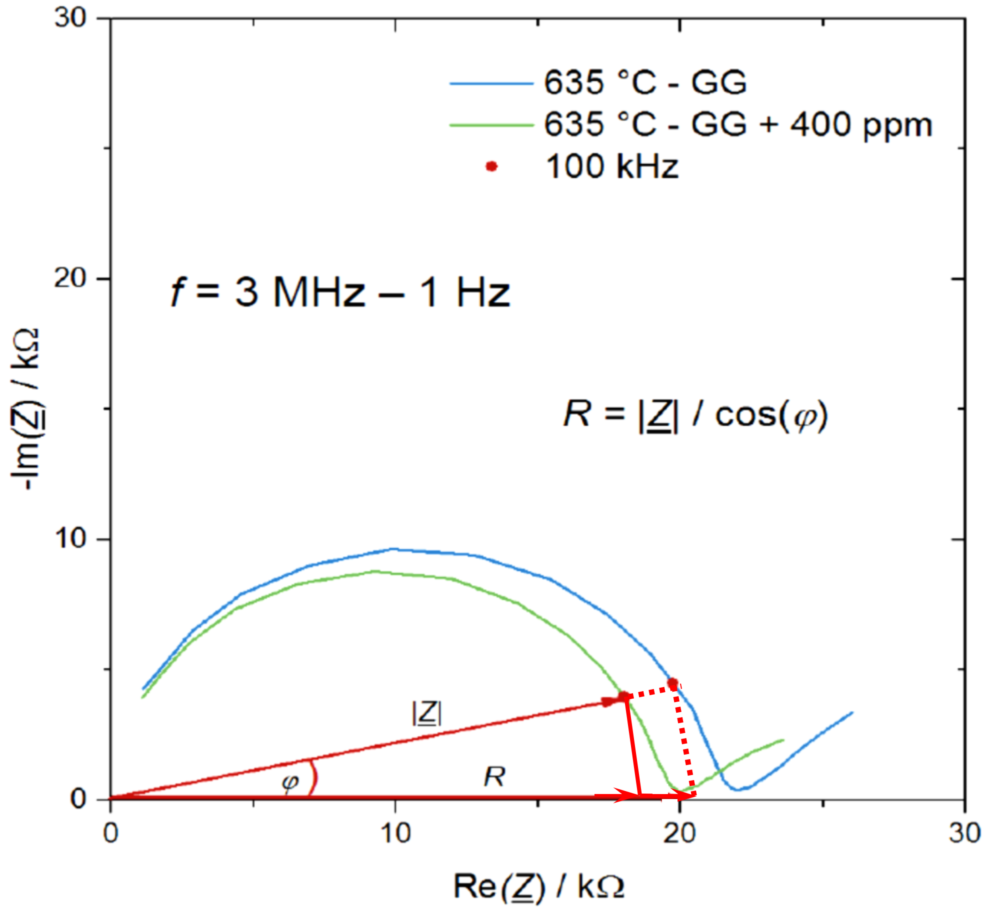
$$(U = U_0 . \sin(\omega t))$$

System answer is an **alternating current signal** with amplitude I_o and **displacement angle** $\boldsymbol{\varphi}$.

$$(I = I_0 . \sin(\omega t + \boldsymbol{\varphi}))$$

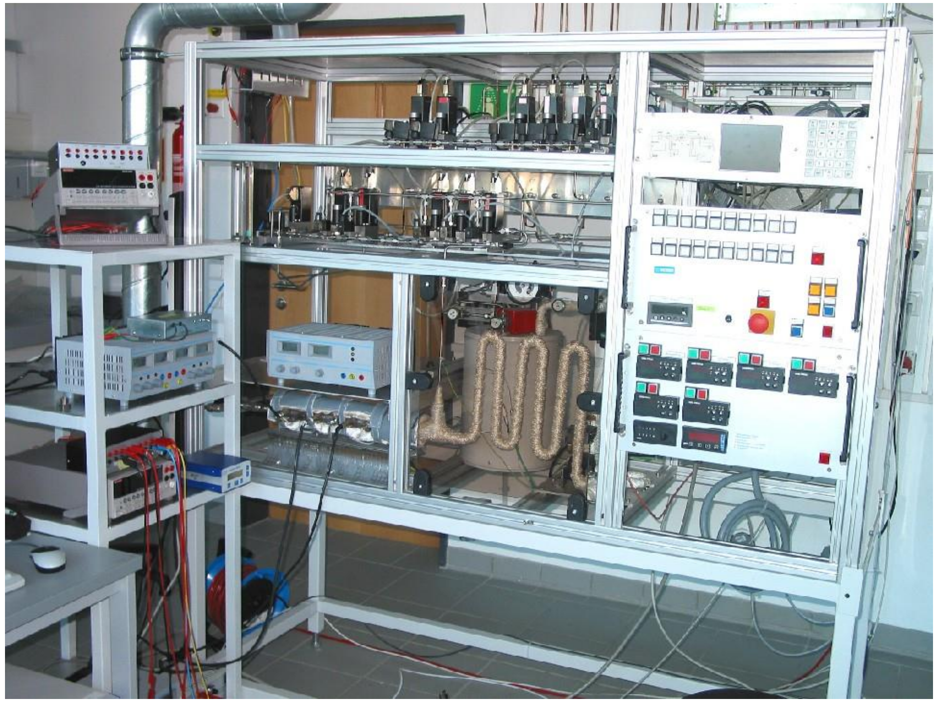
Operating frequency
as high as needed
to stay away from electrode effects

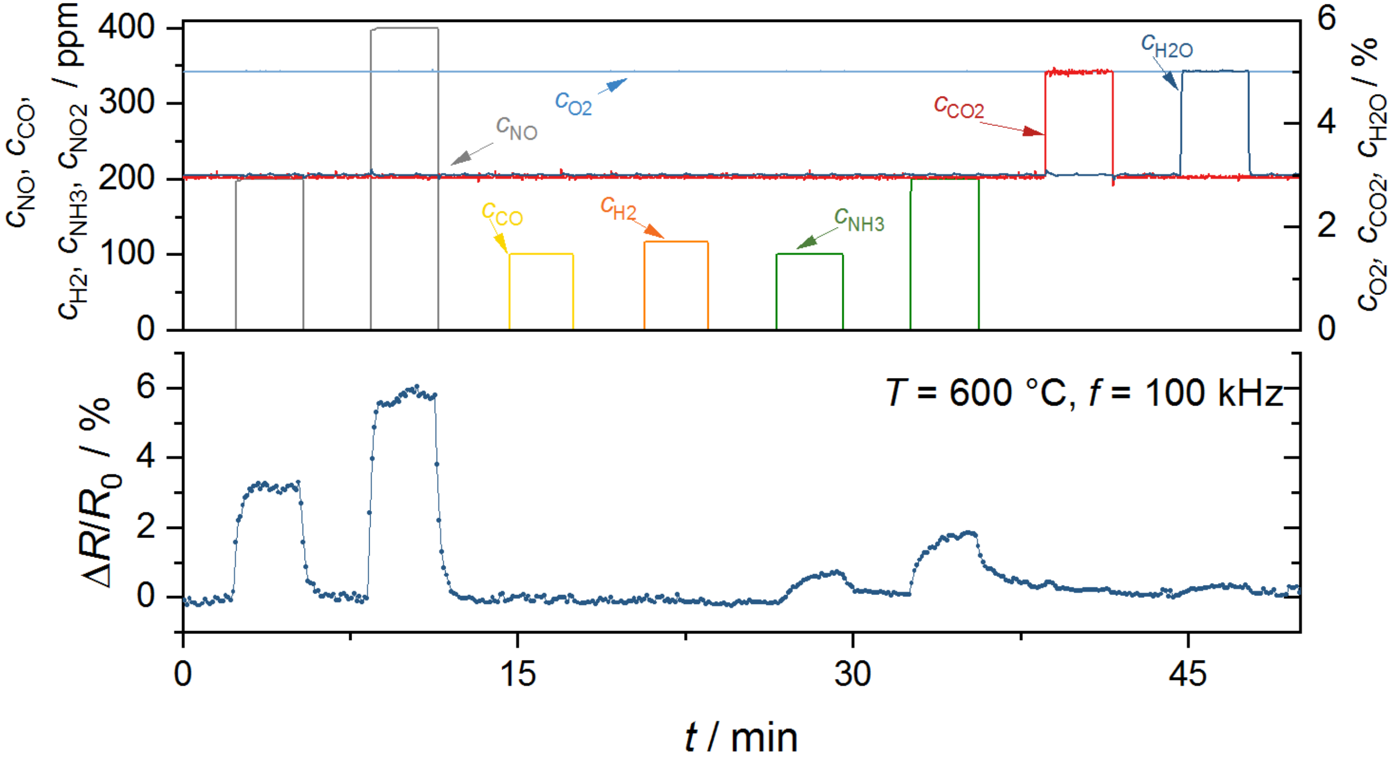
Nyquist diagram with and w/o NO concentration



- Operating temperature 635°C (gas sensor behaviour)
- Basic gas atmosphere (GG) contents of N_2, O_2, CO_2 and H_2O
- **Semicircle describes conductivity of NO_x sensitive layer over frequency.**
  (Resistance decreases with increasing NO_x concentration)

Gas reactor testing with synthetic exhaust



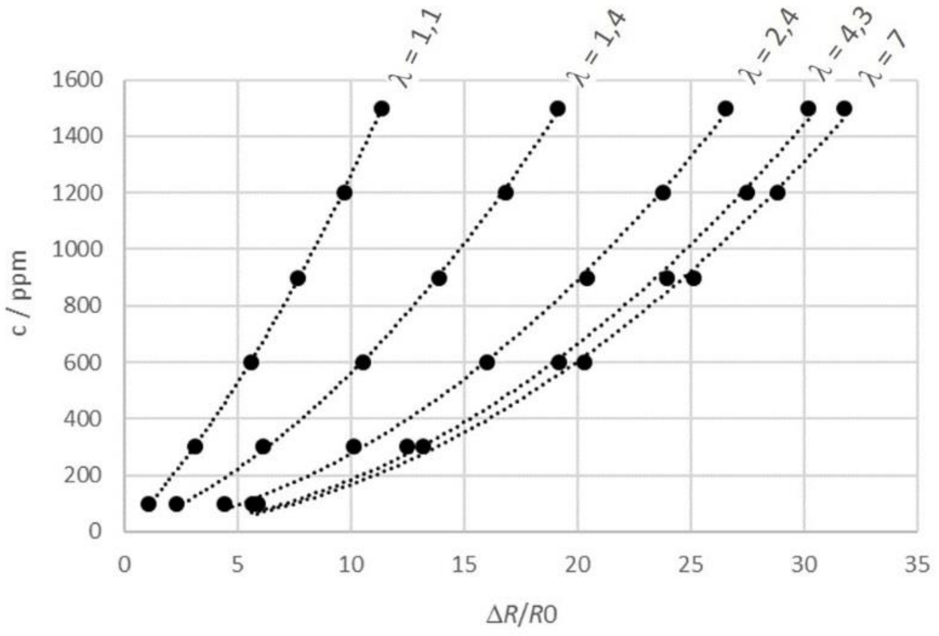


Base gas atmosphere

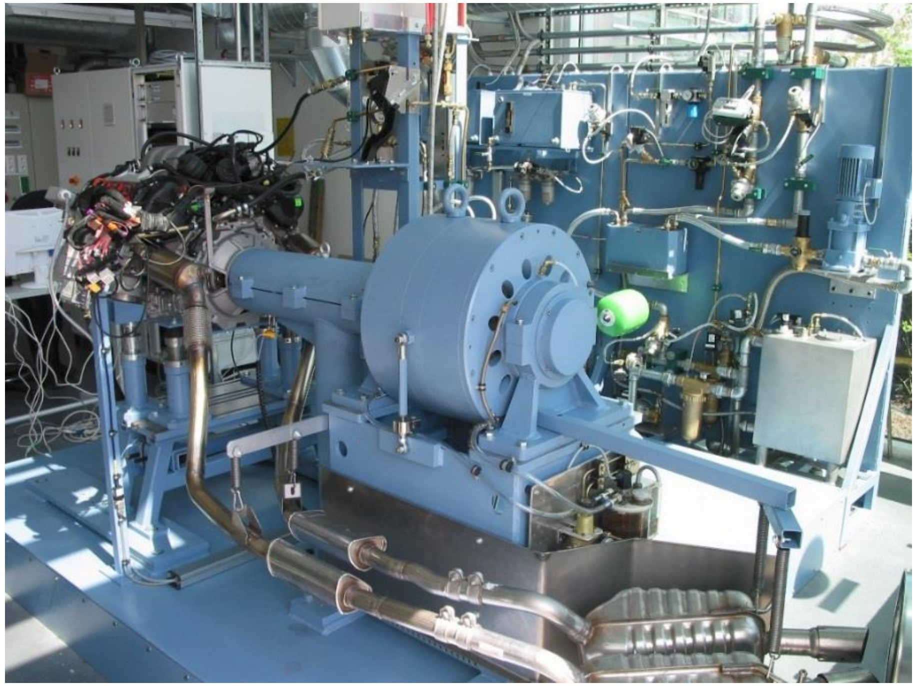
3% CO_2, 5% O_2, 3% H_2O

NO_x dependence on oxygen content (Lambda)

- Lab tests showed dependance of NO_x-values on Lambda-values (residual oxygen in exhaust gas)
- **=> Integration of O_2-measurement into NO_x sensor to adjust measurement values in electronics**



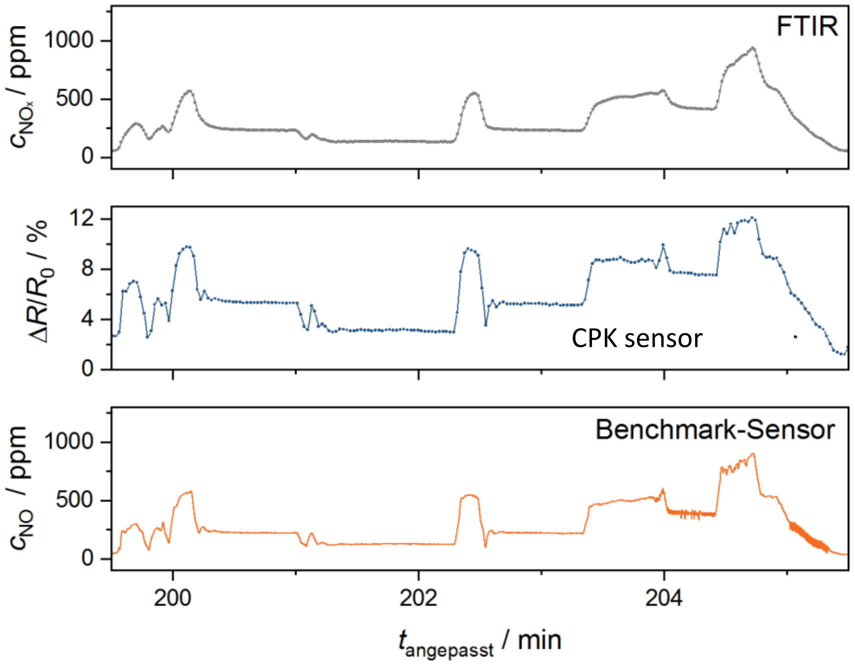
Characteristic curve of NO_x sensor in dependence of Lambda, measured in synthetic exhaust



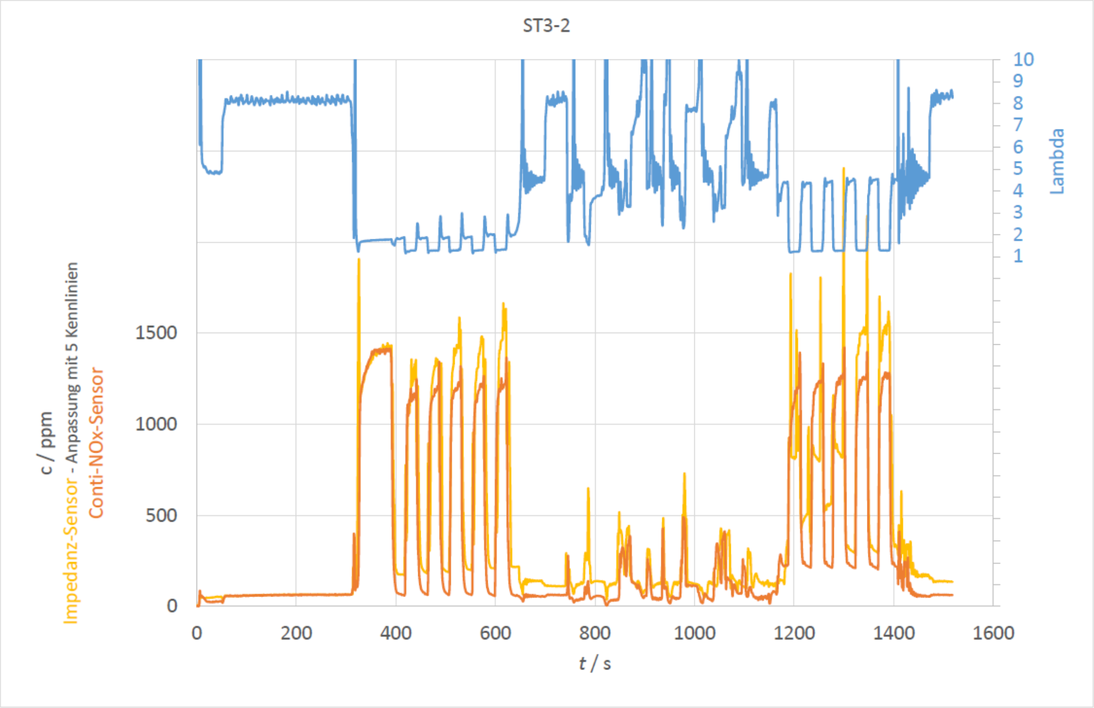
Test setup with comparison of:

- NO_x sensor sample
- Engine dyno FTIR device
- Benchmark NO_x sensor

Initial test on engine testbench



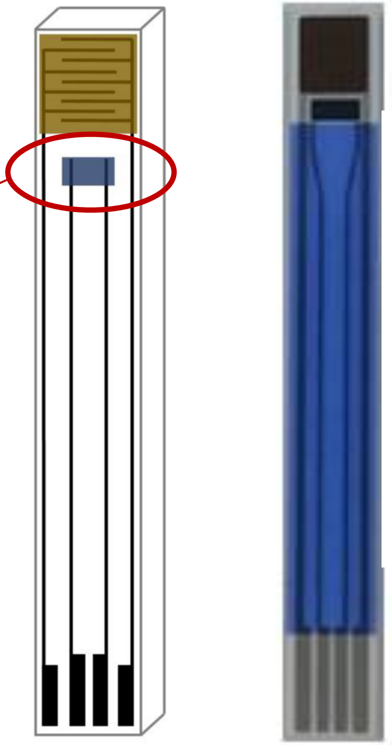
Comparison NO_x measurement on engine test bench



Comparison O_2 corrected value of Impedancesensor with benchmarksensor during variation of O_2 concentration

Oxygen sensitive layer integrated in sensor design and electronics

O2 sensitive layer



Heater-Control

Impedance Analysis (NOx)

µProcessor

CAN-interface

Resistance Analysis (O_2)

Summary

Patents pending

- Simple sensor design allows **cost effective production in thickfilm technology**
- Sensor can be **operated @ 350°C as a dosimeter**…
  - Immission measurement (ppb-range)
- … and @ **650°C as a gas sensor**
  - Emission measurement (ppm-range)
- NOx-signal dependence on oxygen content **requires integration of O_2 measurement**

- The sensor element with the NO_x sensitive layer including electronics and as well …
- … the NO_x sensor electronics (analysis elements, μ processor, heater ...) have to be industrialized

5: Summary II

	Impedance based NOx Sensor		Commercial NOx Sensor
Functional material	Potassium Manganate		Zirconium Oxide
Function	Dosimeter principle	Sensor principle	Sensor principle
Operational Temperature	350°C	650°C	800°C
Measurement range	5ppm +/- 10%	1500ppm +/- 10%	1500ppm +/- 10%
Suitable for ultra low NOx requirements	**+**	**-**	**-**
Resistance to exhaust flow impurities e.g. silicates	**+**	**o**	**-**

Thank you for your attention!

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