European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

WGs and MC Meeting at Cambridge, 18-20 December 2013

Action Start date: 01/07/2012 - Action End date: 30/06/2016

Year 2: 1 July 2013 - 30 June 2014 (*Ongoing Action*)

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EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

EuNetAir
European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

COST is supported by the EU Framework Programme

European Science Foundation — ESF provides the COST Office through a European Commission contract

Towards sensitive air quality monitoring exemplified by the field effect sensor platform

From chemical interactions to electrical transduction

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Outline

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- FET sensor signal transduction – overview
- FET transducer design
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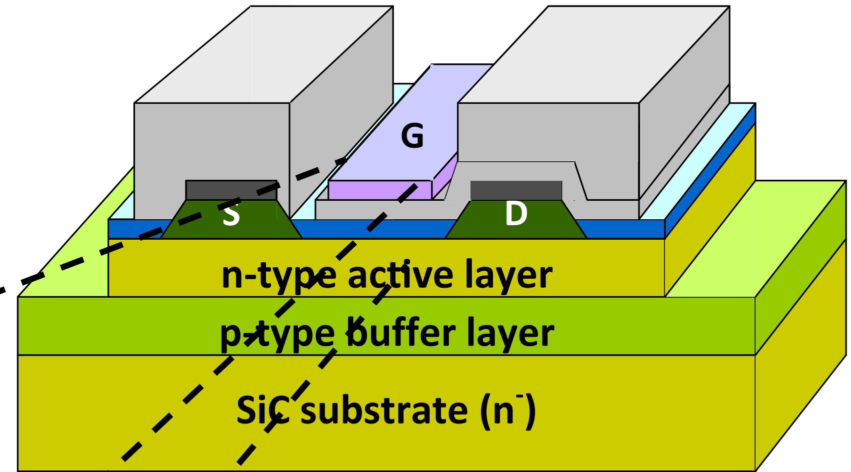
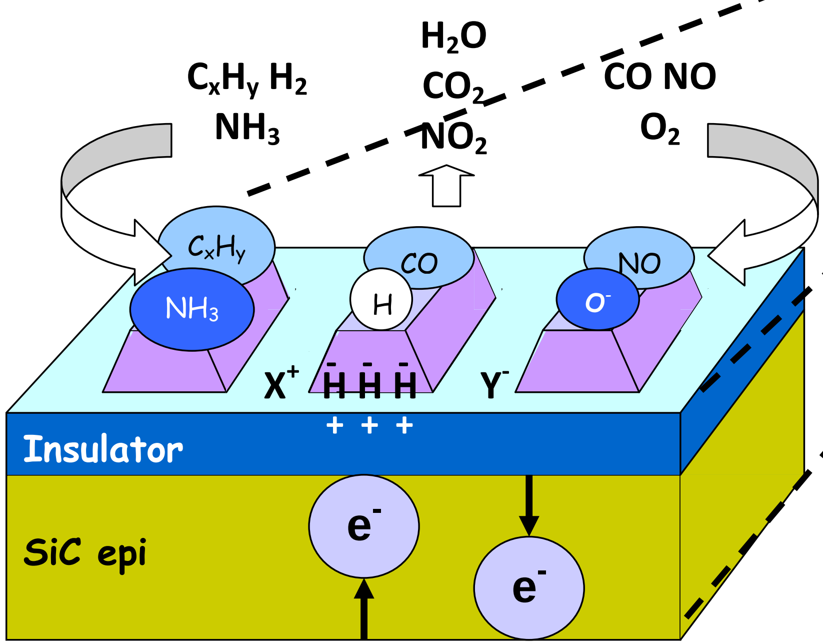
  - ➢ Influence of gate length
- FET operation
  - ➢ Influence of gate bias
- FET materials design – chemical interactions
  - ➢ Influence of gate insulator
  - ➢ Influence of gate structure
  - ➢ Influence of gate material
- Example

Overview – Field effect sensor technology

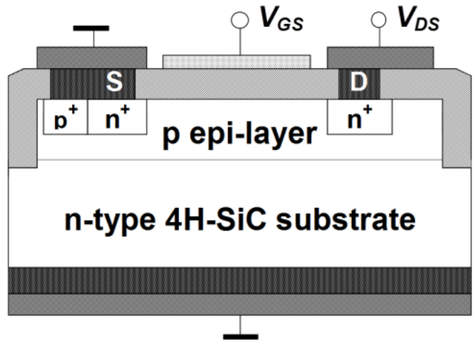
Adsorption and chemical reactions on the gate of field effect transistor devices changes the gate-to-substrate electric field and thus the channel conductance





Silicon carbide promising for high temperature operation and applications involving a corrosive environment due to its wide bandgap and chemical inertness

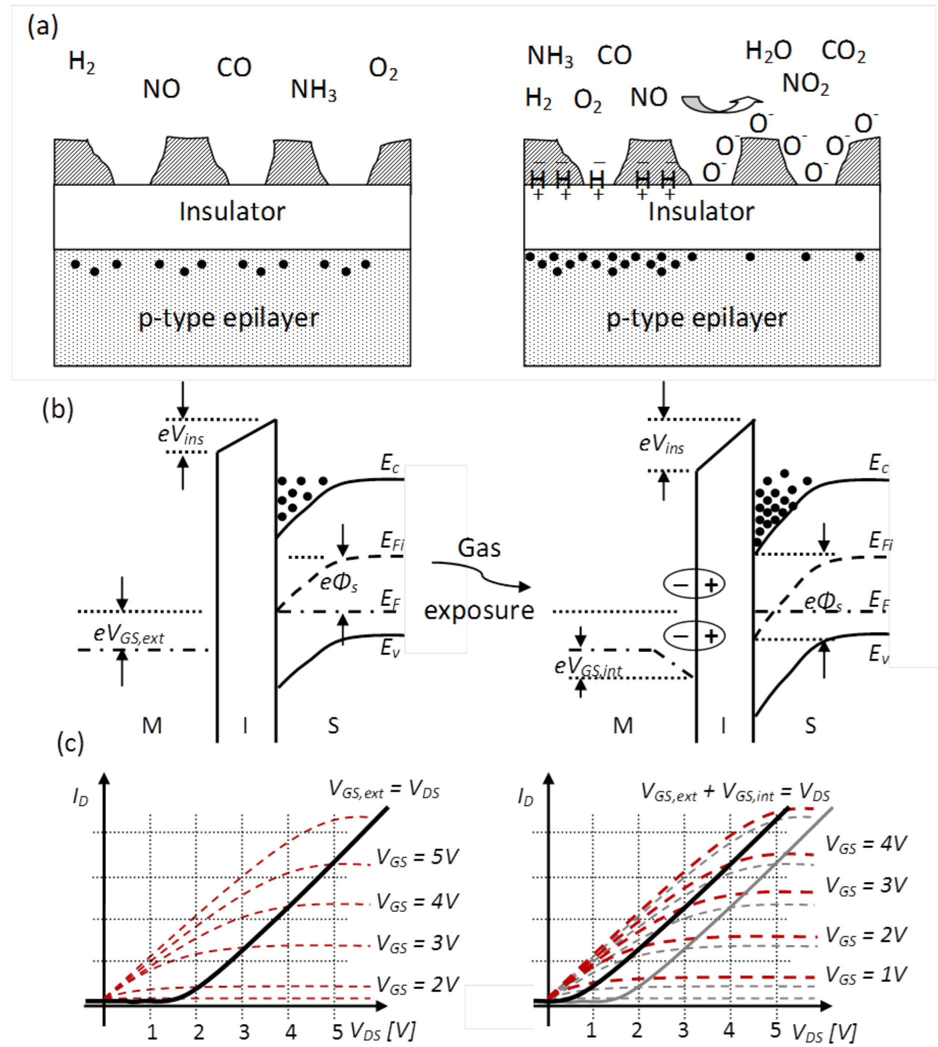
Overview – FET sensor signal transduction



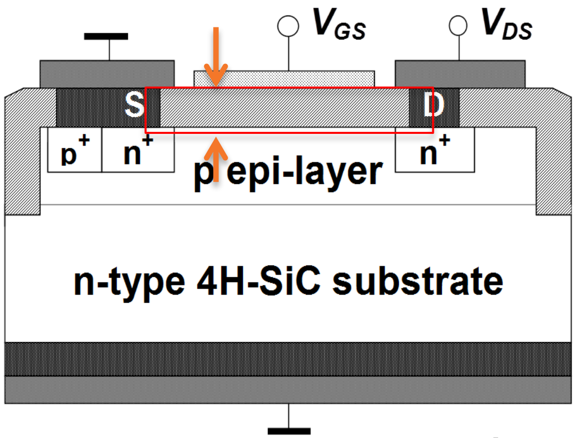
$$I_{D,sat} = \frac{W\mu_n\varepsilon_{ins}}{2Ld_{ins}}[V_{GS} - V_T]^2$$

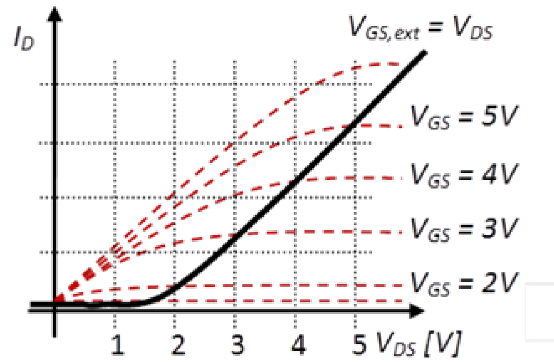
$$V_T = \frac{2d_{ins}[eN_a\varepsilon_s\Phi_F]^{½}}{\varepsilon_{ins}} - \frac{Q_{SS}d_{ins}}{\varepsilon_{ins}} + \Phi_{ms} + 2\Phi_F$$

$$g_{m,sat} = \frac{\partial I_{D,sat}}{\partial V_{GS}} = \frac{W\mu_n\varepsilon_{ins}}{Ld_{ins}}[V_{GS} - V_T]$$



FET transducer – influence of device type

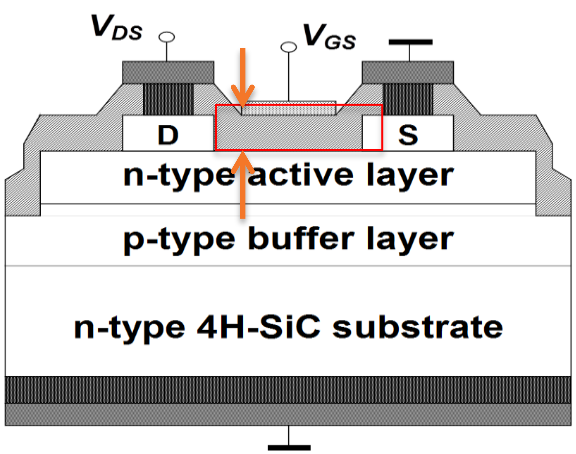


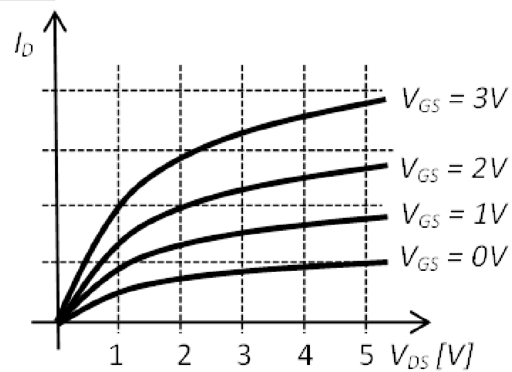


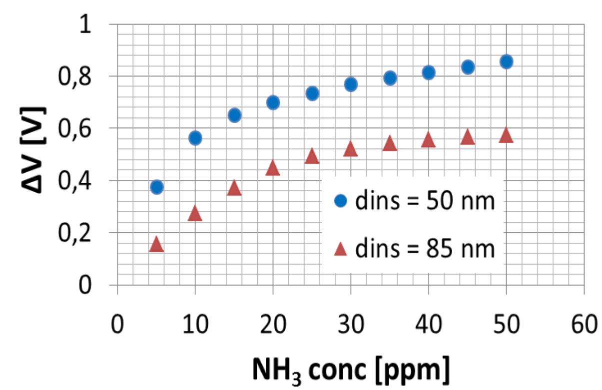
Low gate-to-substrate field
=>
thin gate dielectrics

Enhancement type

$$g_{m,sat} = \frac{\partial I_{D,sat}}{\partial V_{GS}} = \frac{W \mu_n \varepsilon_{ins}}{L d_{ins}} [V_{GS} - V_T]$$

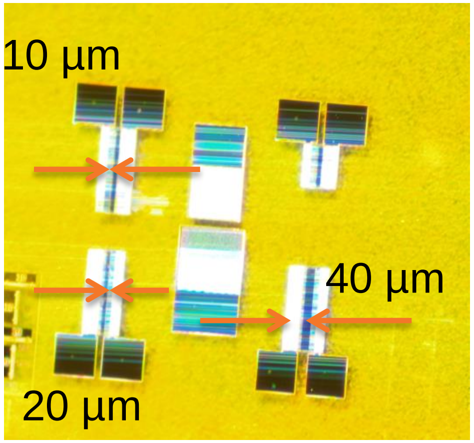


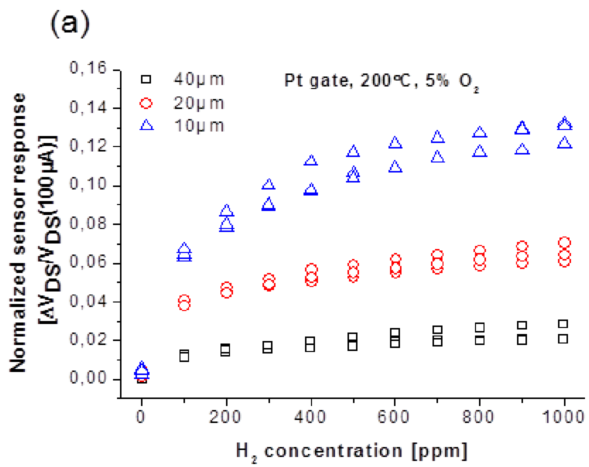


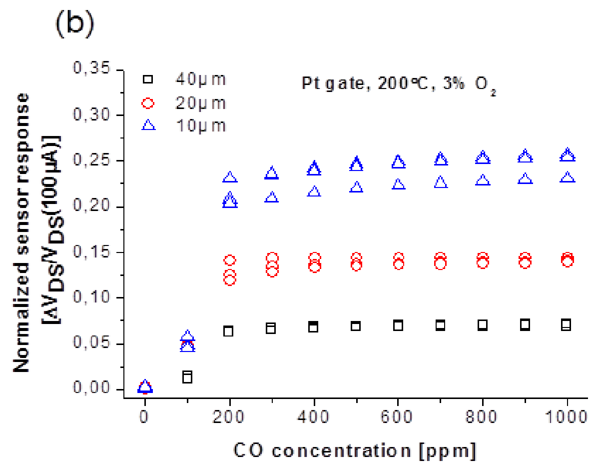


Depletion type

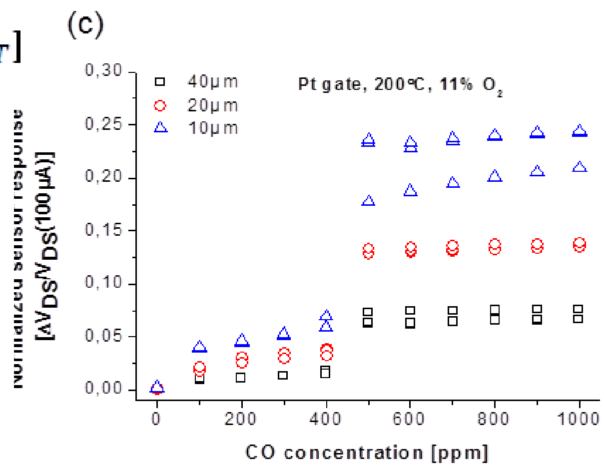
FET transducer – influence of gate length

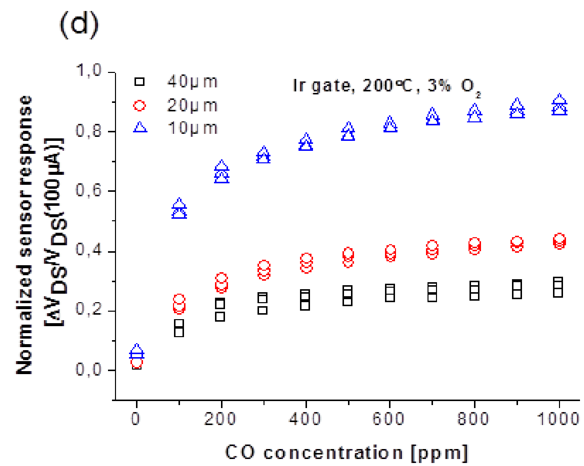






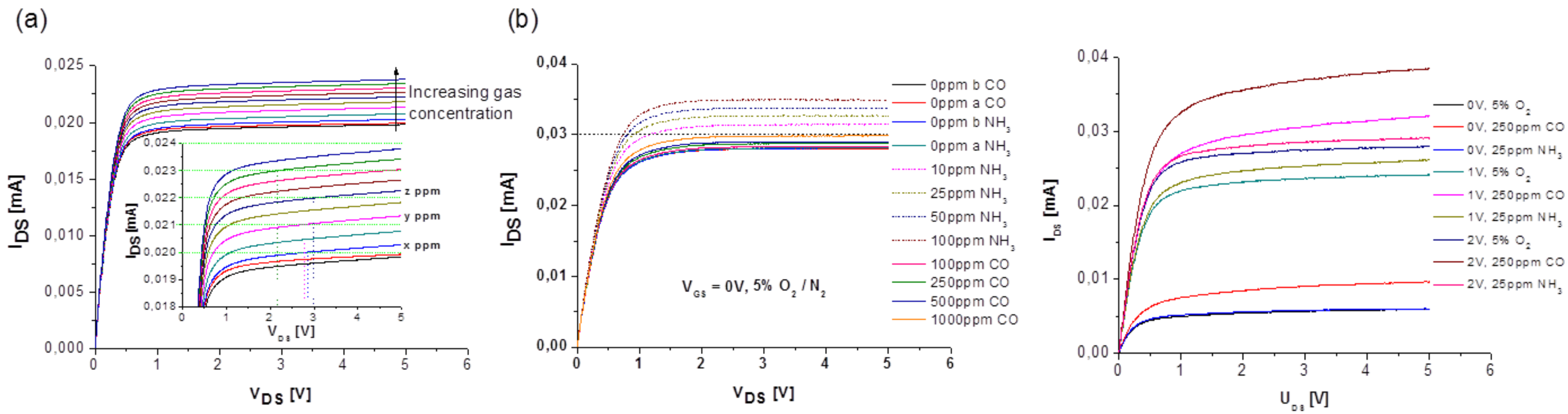
$$g_{m,sat} = \frac{\partial I_{D,sat}}{\partial V_{GS}} = \frac{W \mu_n \varepsilon_{ins}}{L d_{ins}} [V_{GS} - V_T]$$

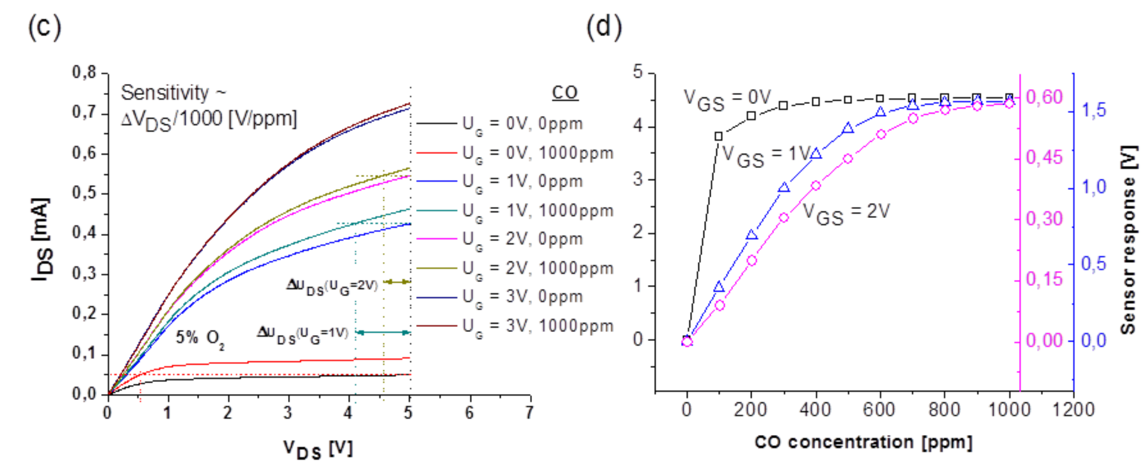




The wider or shorter the gate the more sensitive to V_{GS} changes

FET transducer – influence of gate bias





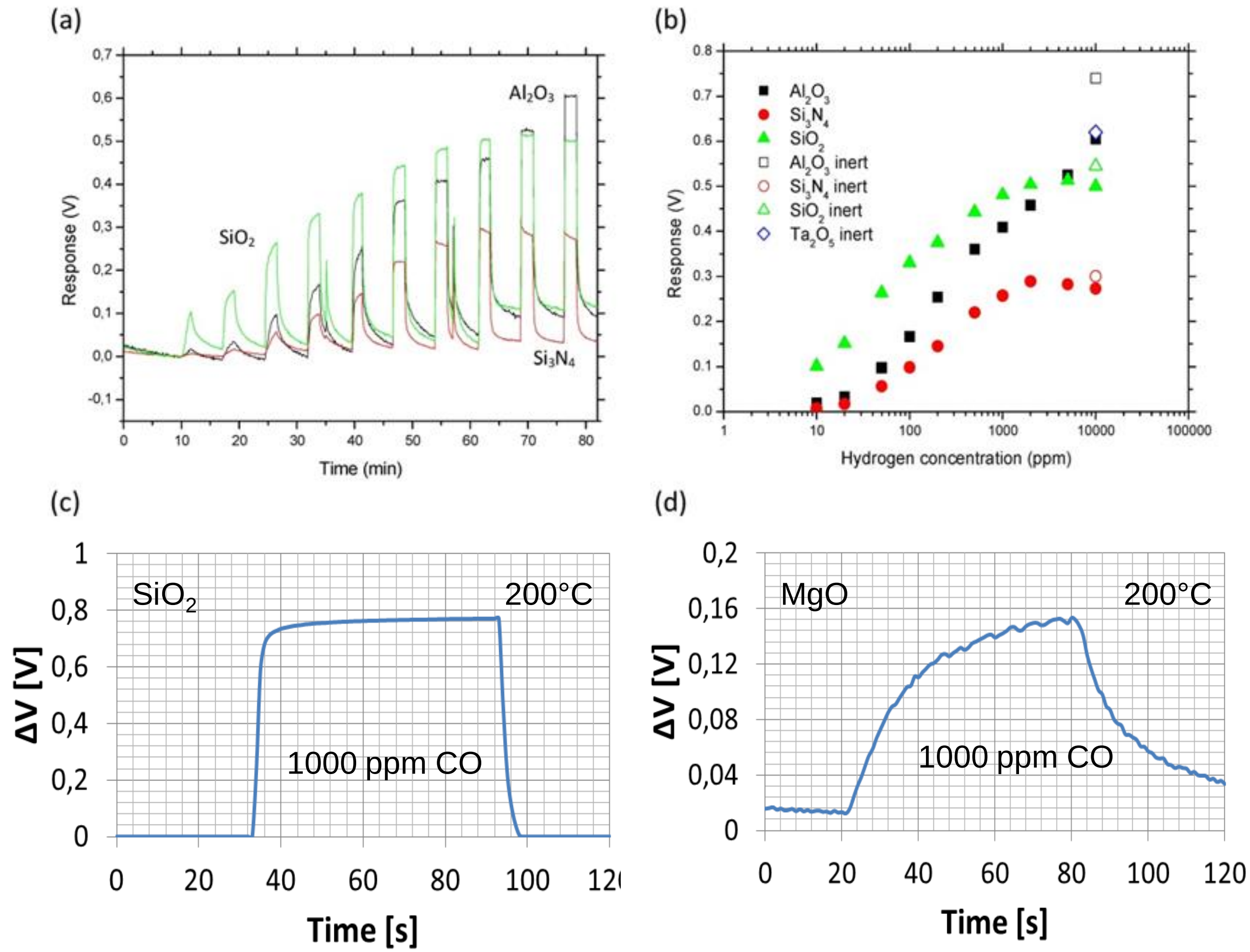
Enhanced sensitivity to different substances can be gained by the choice of gate bias.

$$g_{m,sat} = \frac{\partial I_{D,sat}}{\partial V_{GS}} = \frac{W \mu_n \varepsilon_{ins}}{L d_{ins}} [V_{GS} - V_T]$$

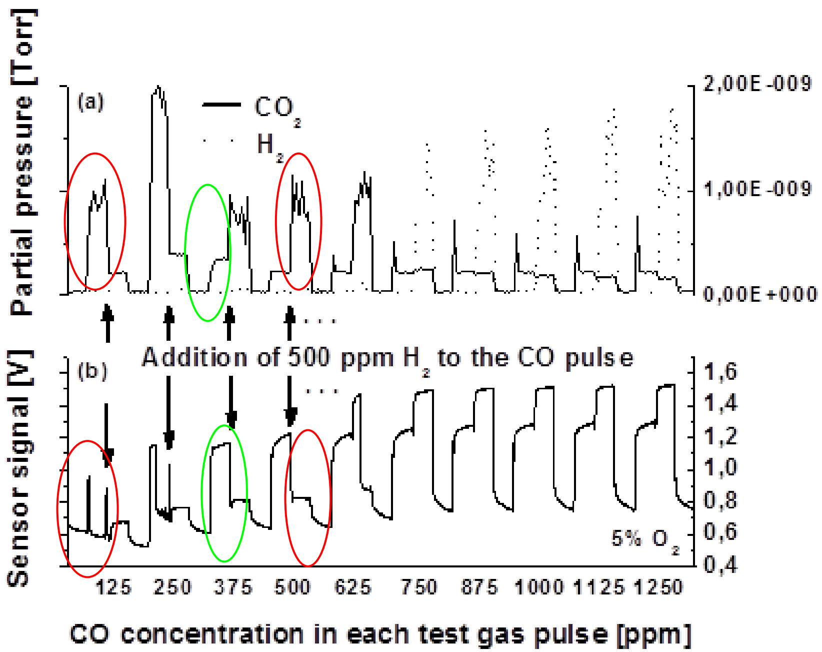
Materials design – influence of gate insulator

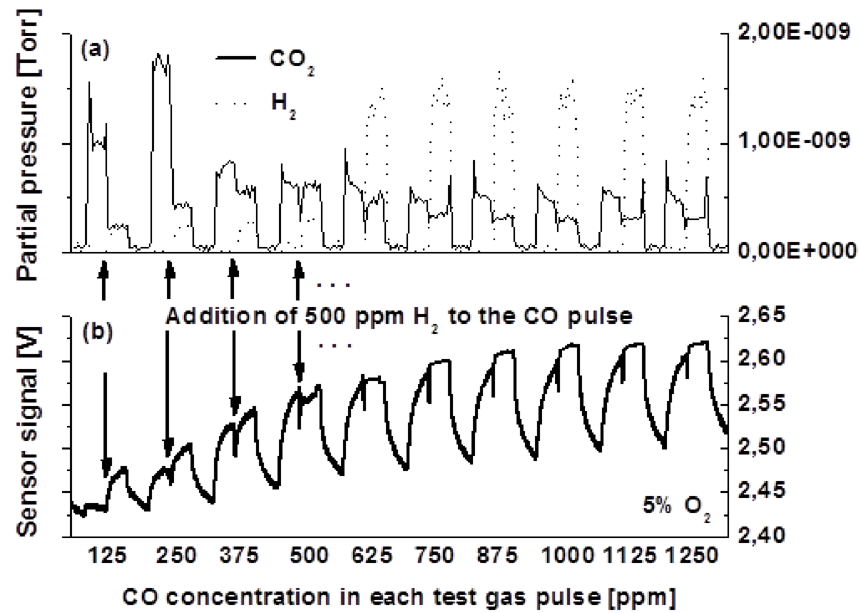
Depending on the density of adsorption sites, the enthalpy of adsorption and its dependency on coverage, different insulator materials/ surfaces exhibit different dynamic ranges for the gas response

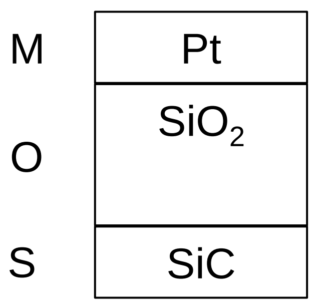
$$\Delta V_{int} = n_H \cdot p/\varepsilon$$

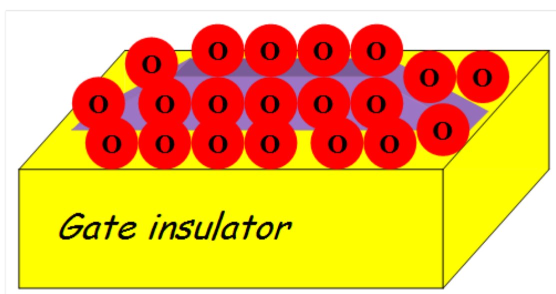


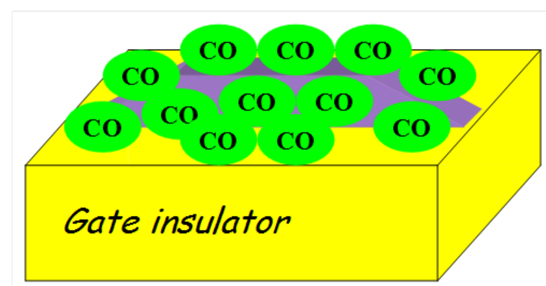
Materials design – influence of gate stack

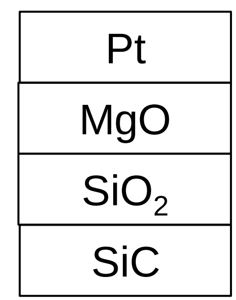








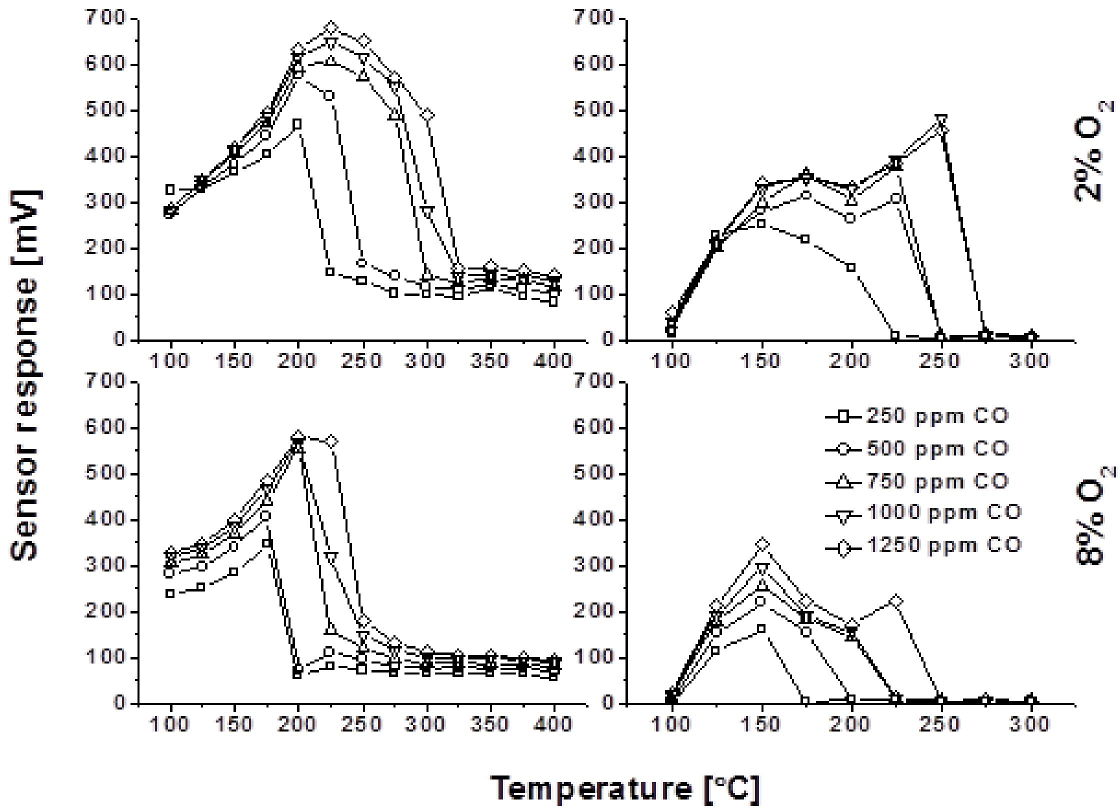


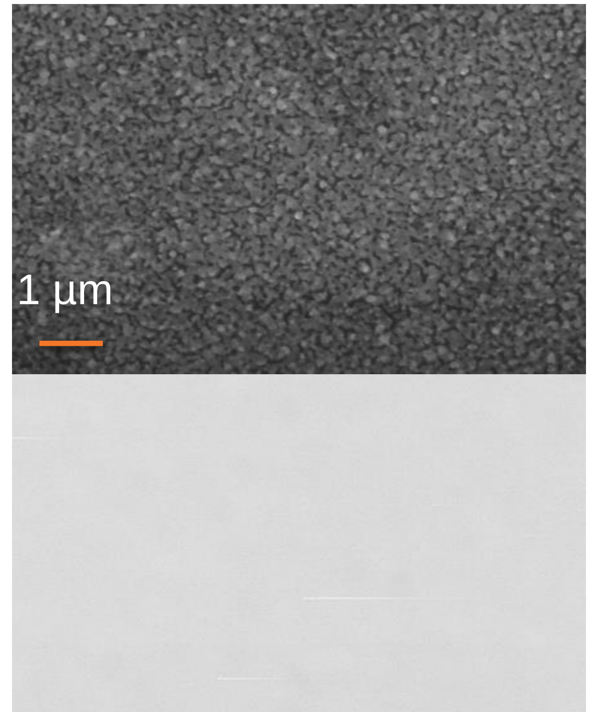


Materials design – influence of gate structure

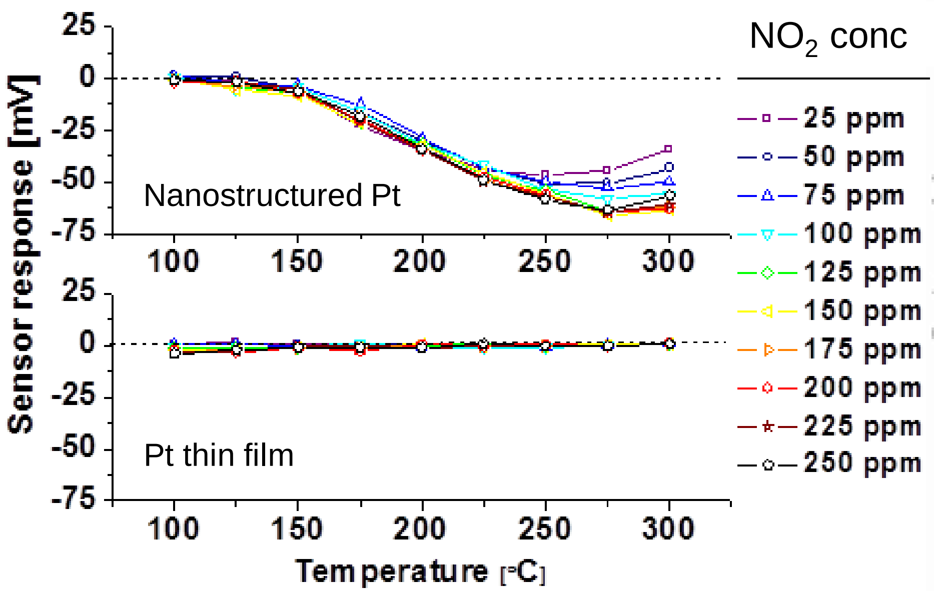
Nanostructured Pt

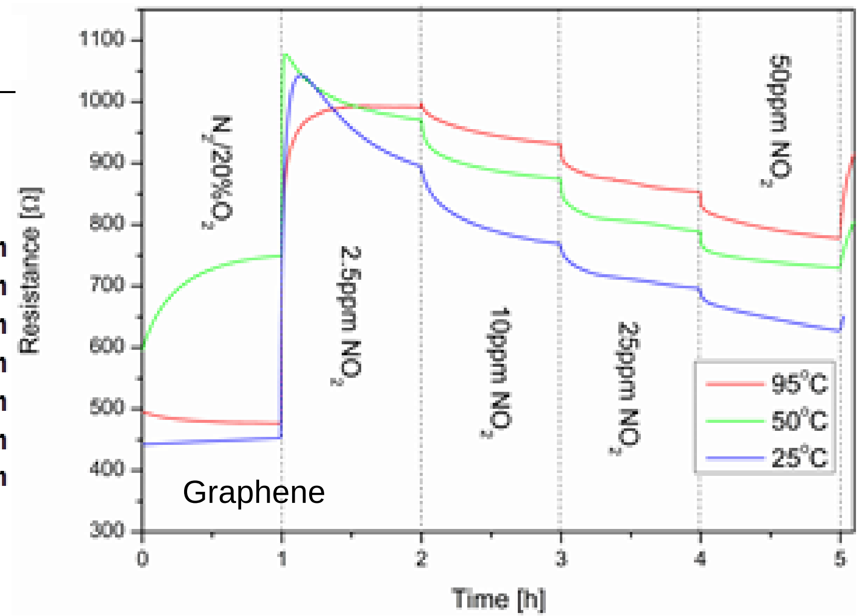
Pt Thin film





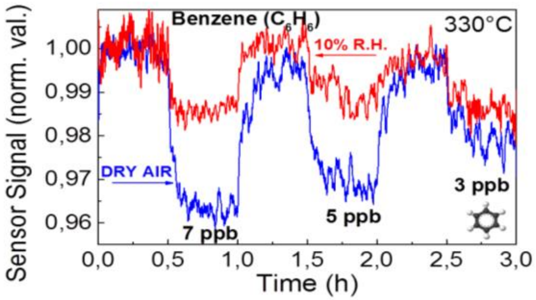
Materials design – influence of gate material



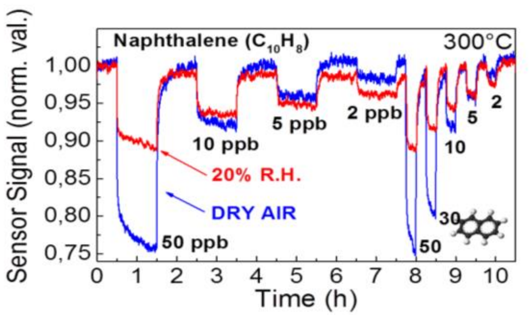


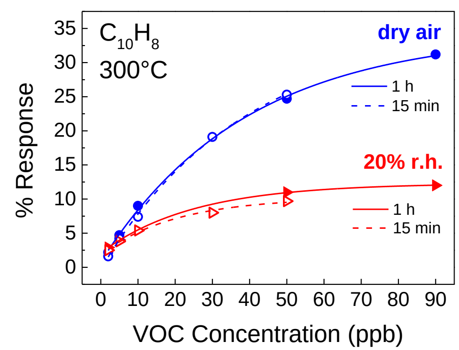
Comparison of the changes in sensor signal upon NO_2 exposure between nanostructured Pt, thin film Pt and graphene at low operation temperatures

Example

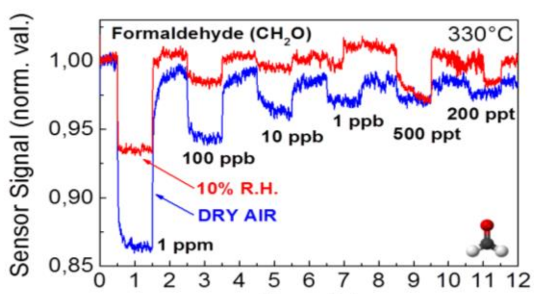


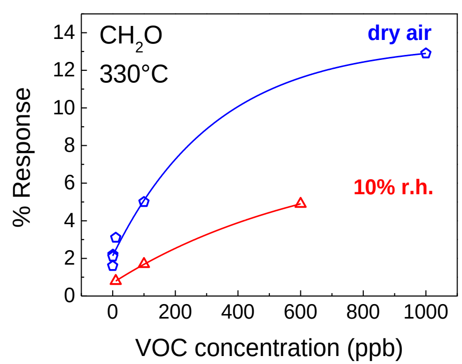
Highly sensitive sensor devices under development for VOC measurements for indoor air quality monitoring applications in cooperation with Saarland University, Germany, to be continued in the EU FP7 project SENSIndoor





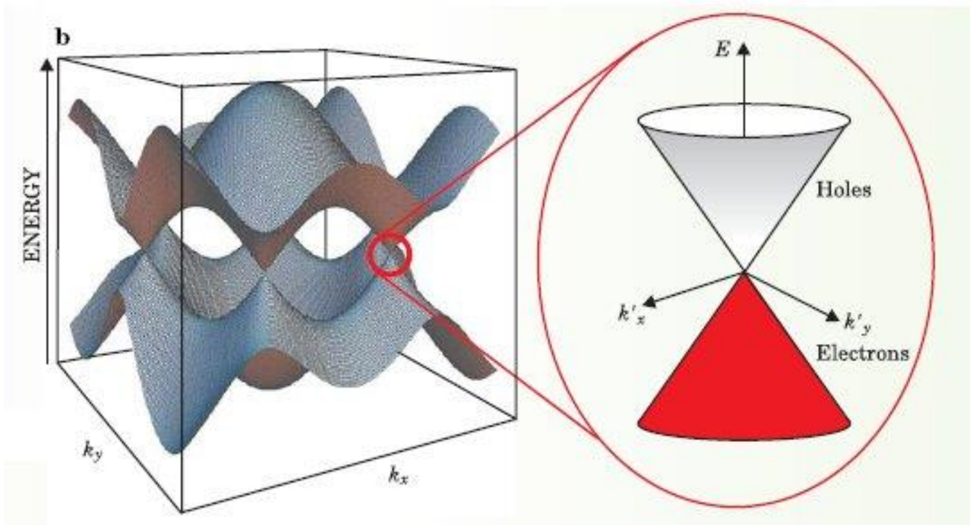
Measurements performed by Donatella Puglisi and Christian Bur at Saarland University, Laboratory for Measurement Technology

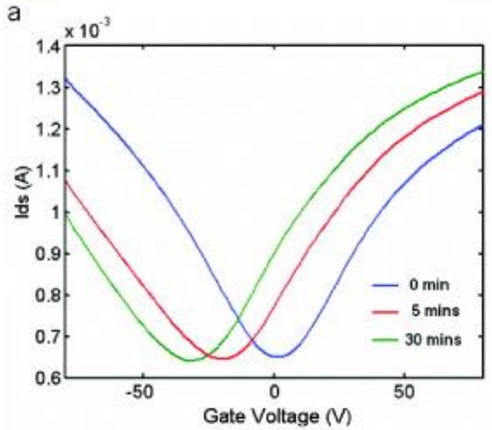


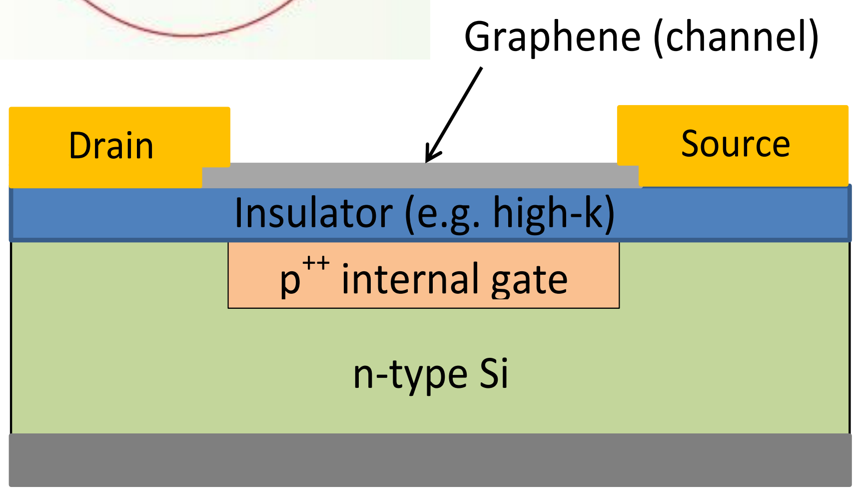


Example

Gate bias tuning of a graphene channel field effect device to adjust the sensor to operate at the Dirac point to ensure highest possible sensitivity to NO_2 under all conditions







Thank you for your attention!