Optimization of GaN based pH-Sensors for monitoring of bioreactions

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Goals

- development of a GaN-based integrated sensor system for fast physical, chemical, and biological analysis
- AlGaN/GaN-heterostructures for measuring pH-values of different fluids for various applications
- optimization of the open gate heterostructures in order to achieve a sensitiv sensor device
- integration and testing of integrated sensors in biological measurement setups
- characterization of biological reactions by continuously pH-measurement

Principle of operation

- fluidic sensor based on an open gate HEMT-structure
- manipulation of the electron concentration in the 2-dimensional electron gas by changing the surface potential
- surface potential is changed by chemical reactions at amphoteric surface sites (site dissociation theory)
- measuring the drain current at constant reference potential or the reference potential at constant drain current with a calibrated sensor give the pH-value of the solution
- pH-difference is also derived from analysing the shift of the transfer characteristic measured by a calibrated sensor

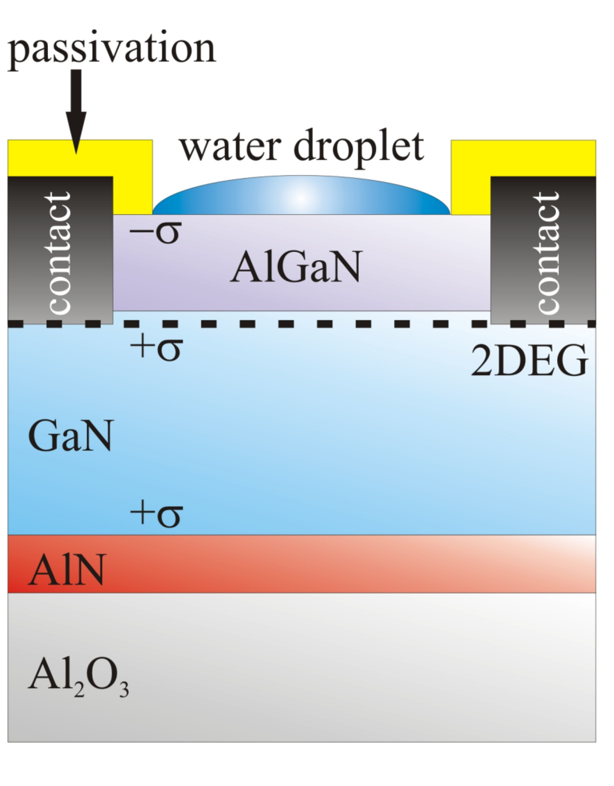

Fig.1: Open gate transistor.

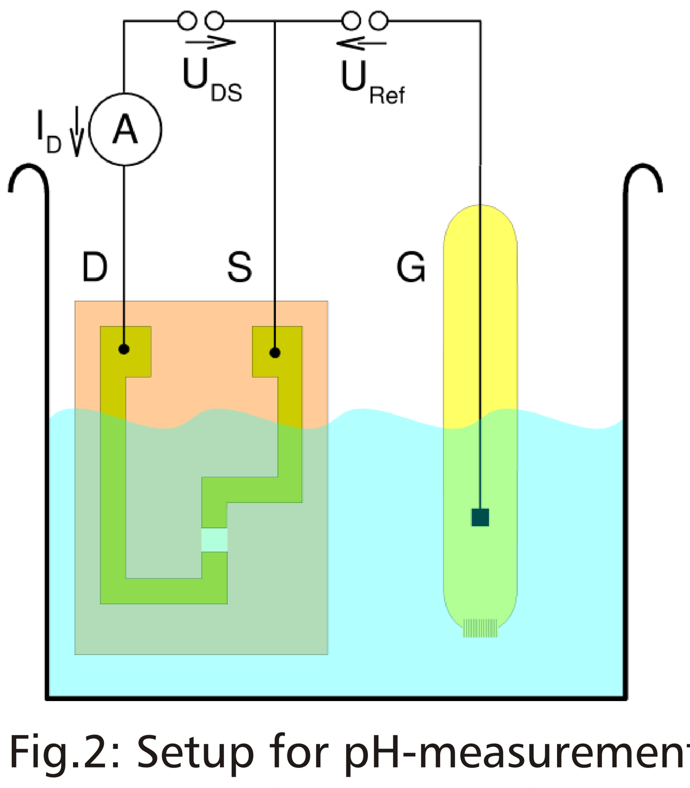

Fig.2: Setup for pH-measurement with Ag/AgCl-reference electrode to apply a "gate potential".

Influence of Al-content and barrier thickness

- theoretical calculation were done by simulating AlGaN/GaN-heterostructures with different Al-content and barrier thickness
- CV-characteristics were measured to characterize and optimize the sensor structures
- onset of 2-DEG depletion should be at low negative voltages, because the change of surface potential, caused by aqueous solutions, is in this range

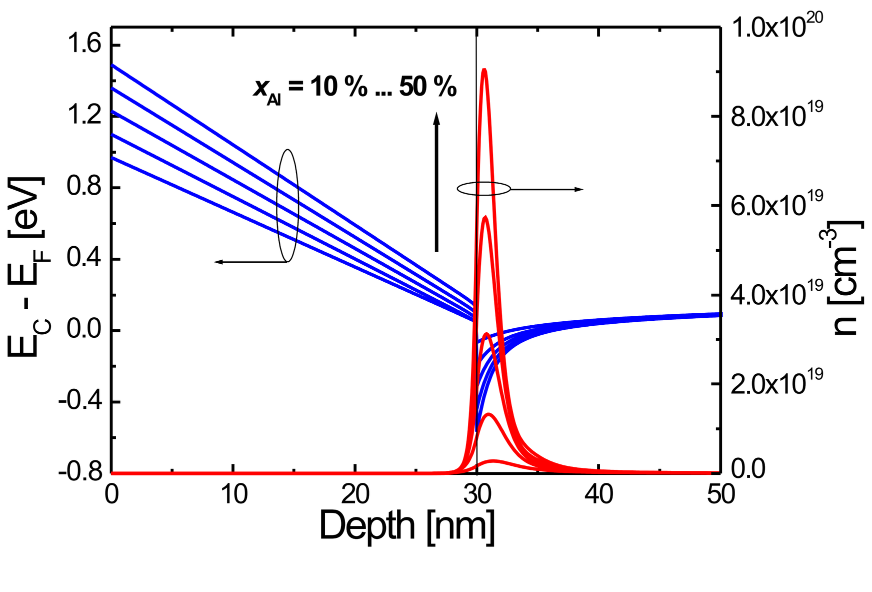

Fig.3: Calculation of band model and electron concentration of AlGaN/GaN-heterostructures with different Al-content.

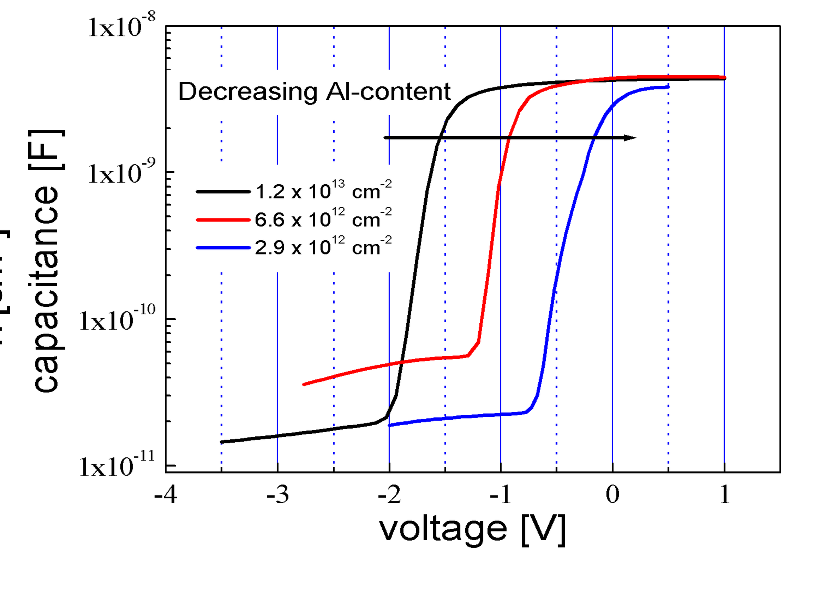

Fig.4: Measured CV-charcteristic of heterostructures with decreasing Al-content and calculated electron concentrations.

pH-measurements

- various structures were characterized by constant current/potential measurement

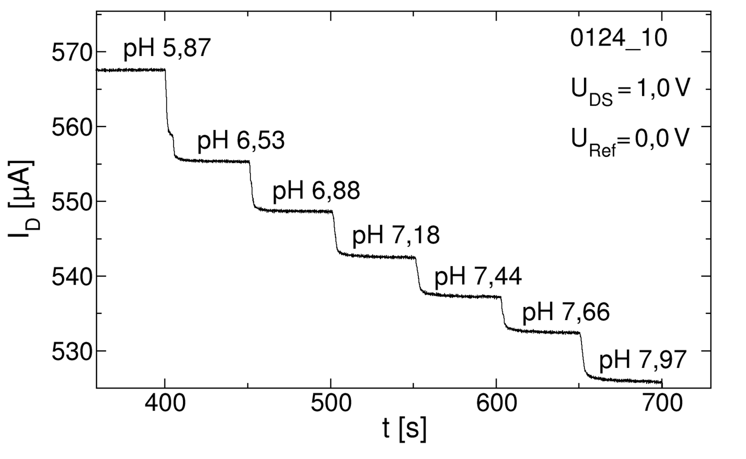

Fig.5: pH-dependent current at constant reference potential.

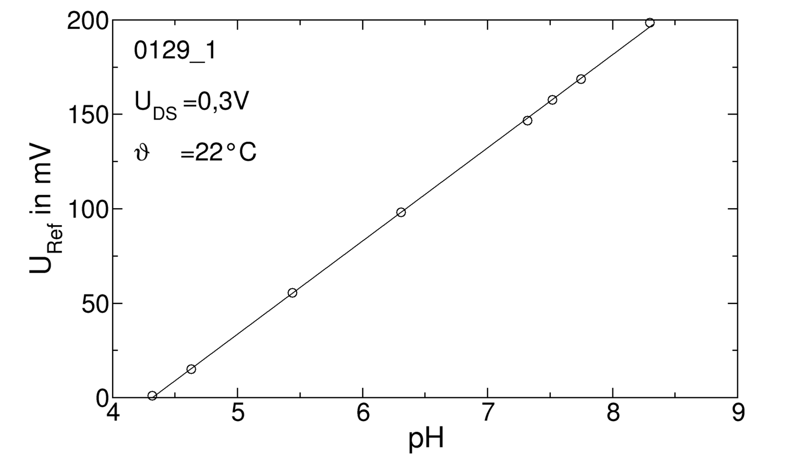

Fig.6: Linearity of pH-response at constant current.

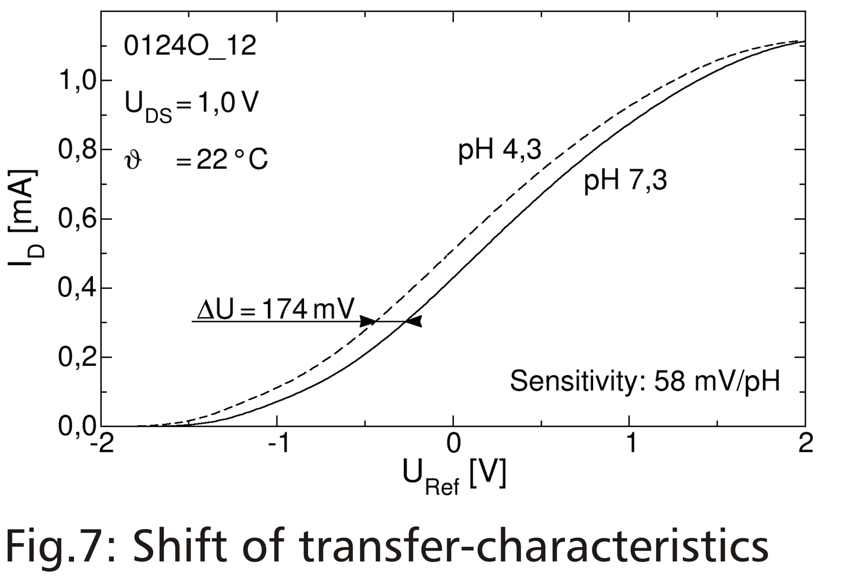

Fig.7: Shift of transfer-characteristics by changing the pH-value.

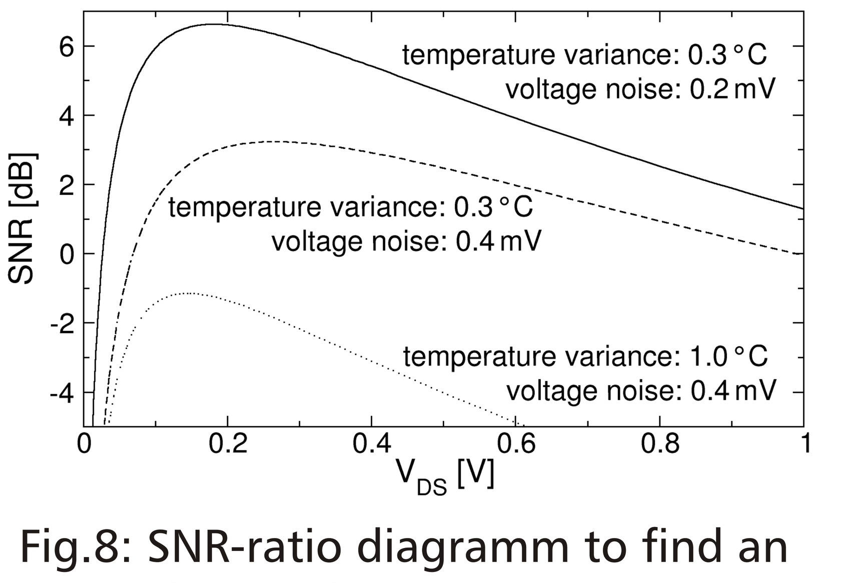

Fig.8: SNR-ratio diagramm to find an optimal operating point.

Passivation layers

- testing of fluorocarbon layers, glas layers, and solder stop resists to protect the metallization against electrochemical decomposition

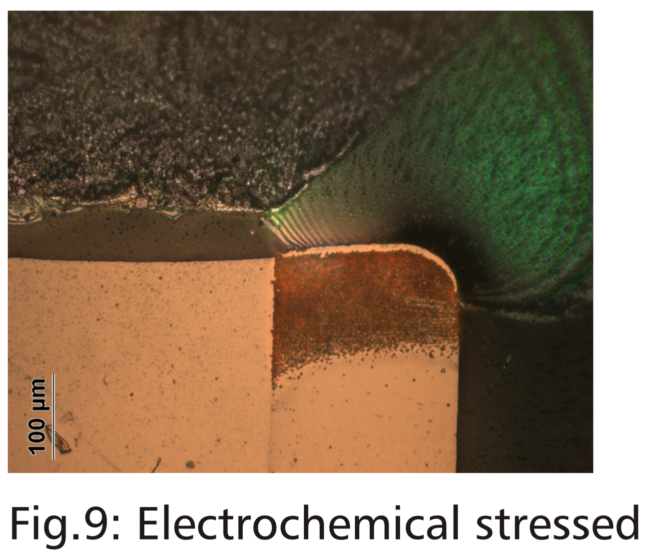

Fig.9: Electrochemical stressed passivation layer.

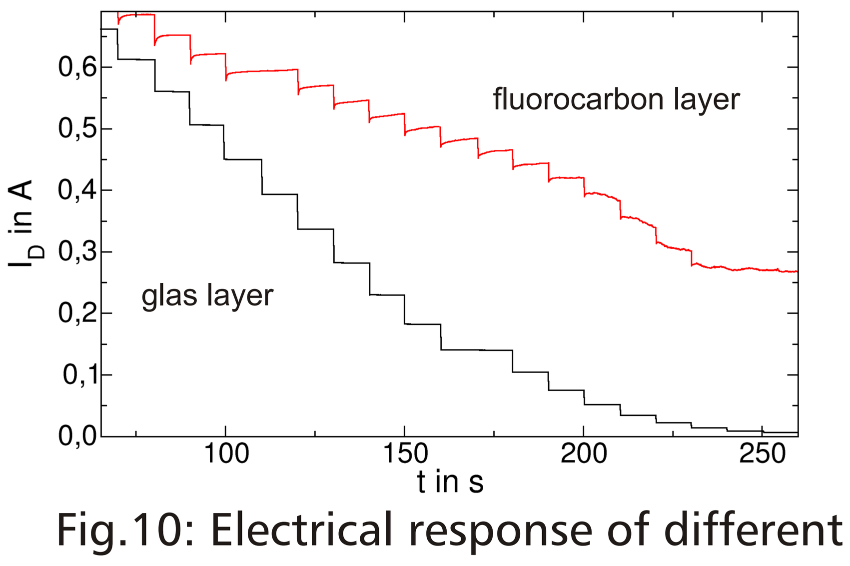

Fig.10: Electrical response of different passivations.

Biological measurements with GaN based pH-sensors

- continuously measurement of pH-value in enzymatic reactions, e.g. histone deacetylasen (HDAC), to identify new inhibitors
- integration of GaN-based sensors in cell bioreactors to measure pH-value close to the liver cells (HEPG2)

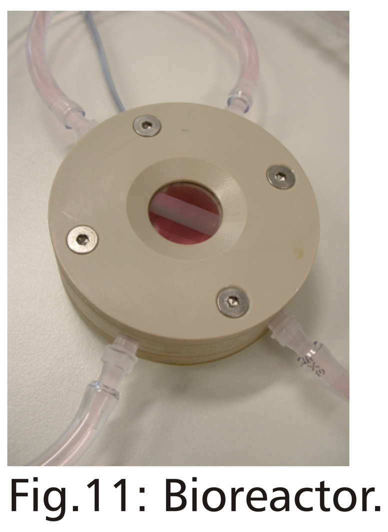

Fig.11: Bioreactor.

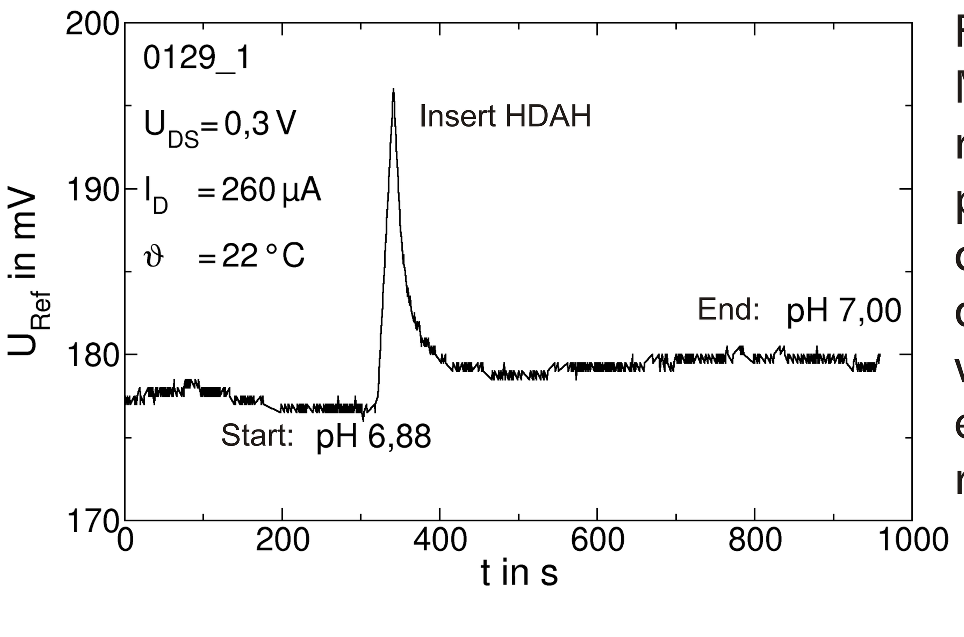

Fig.12: Monitoring the reference potential in order to determine pH-value during enzymatic reactions.

Summary

- $Al_xGa_{1-x}N$/GaN-based heterostructures with a barrier thickness of around 12 nm and x = 0.25 are well suited for pH-measurements
- pH-sensors show a sensitivity of around 58 mV/pH
- solder stop resist protects the metallization of sensor structure during measurements in electrolyts
- pH-value of an enzymatic assay (HDAC) were continuously measured to identify inhibitors or desired mutant enzyme
- AlGaN/GaN-heterostructures were integrated to a cell bioreactor to measure pH-value close to the cells

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