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Publication Date
2007-10-10

Peer reviewed
A High-Performance Micromachined Amperometric Nitrate Sensor for Environmental Monitoring

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Introduction: Why a Micromachined Amperometric Nitrate Sensor?

- Nitrate is a major contaminant in ground water: cause human health risks (e.g., methemoglobinemia)
- Nitrate-sensor applications: In situ nitrate monitoring, environmental science/engineering research, and precision farming

Electrochemical Methods

- Nitrate-sensor requirements
  - Inexpensive, small, remotely operable, and large detection range (0.1 µM to 1 mM)
- Electrochemical techniques meet the requirements
  - High sensitivity (0.1 – 1 µM) and good dynamic range (1-10 mM)
  - Relatively simple operation
  - Easy miniaturization
  - Low power consumption

Working Principle: Amperometric Detection of Nitrate

- Electrochemical reaction on the sensing electrode and measured current is dependent to nitrate concentration
  \[ \text{NO}_3^- + H_2O + 2e^- \rightarrow \text{NO}_2^- + 2OH^- \]
- Proposed electrochemical system: NaOH electrolyte, Ag working electrode, Ag/AgCl reference, and Pt counter electrode.
- Double-step chronocoulometry: less noise and minimize O2 interference

Nitrate Analysis

- High sensitivity: 2.47 A s\(^{1/2}\) / (V\(^{1/2}\)·M·cm\(^2\)) better than other electrochemical system
- Low detection limit: ~4 µM
- Wide dynamic range: ~4 to 10000 µM
- Interference: PO\(_4\)\(^3-\), Ca\(^2+\), and Sr\(^2+\) shows significant interference (20% signal distortion)

Micromachined Nitrate Sensor: Design, Fabrication, Experimental Results, and Summary

- High sensitivity (0.1 ~ 1 µM)
- Low detection limit: ~4 µM
- Wide dynamic range: ~4 to 10000 µM
- Interference: PO\(_4\)\(^3-\), Ca\(^2+\), and Sr\(^2+\) shows significant interference (20% signal distortion)

Improvement in Sensor Reliability

- Sensor performance
  - Linear up to 500-2000 µM
  - Detection limit: ~75 µM
  - r\(^2\)=0.99 linearity

Experimental Data (Chip 41)

- Calibration curves of a micromachined sensing chip for nitrate standards
- Calibration Curves of a Micromachined Sensing Chip for Nitrate Standards

Toward Field-deployable Stand-alone Nitrate Sensor

- LABVIEW-based automatic nitrate sensing and calibration
  - LABVIEW control valves manifold, potentiostat and peristaltic pumps
  - Automatic sensor calibration from 0 to 1000 µM
  - Uninterrupted continuous sensing (adjustable time interval)

- Palm-sized sensor-interface board with microprocessor, wireless capability, and built-in potentiostat is being developed
  - 8 bit µcontroller, SOS operating system, valve and pump control circuitry
  - Can replace bulky, expensive, power-hungry potentiostat
  - MICA 2 daughter board for wireless telemetry

- Donnan-dialysis-based sample processor (filtration unit)
  - Nitrate-specific anion-exchange membrane would improve selectivity to groundwater that contains many ionic species
  - Numerical simulation and experimental analysis making progress

Future Work

- Groundwater testing and comparison with conventional bench-top analysis techniques
- Field test (Palmdale site, Merced river etc.)