Diode Laser Based Trace Gas Sensors for Semiconductor Process Monitoring

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Summary

The development of compact, robust diode laser based gas sensor that are potentially more effective than presently available monitoring instruments and their application to precise, real-time monitoring and quantification of process gases (such as HCl, NH3, and HF) used in semiconductor manufacturing will be reported. Critical manufacturing steps include chemical vapor deposition and plasma etching [1] and also the monitoring of internal clean room air quality, as well as external plant emissions at parts-per-billion (ppb) levels. This becomes particularly important as device feature sizes approach the 100 nm level and below, where extremely thin films are required and variations in process gas concentrations will significantly impact integrated circuit (IC) device yields. Several recent advances in enabling technologies that include commercially available telecommunications laser diodes, optical fiber technology (beam delivery, couplers, and amplifiers), and novel digital signal processing (DSP) techniques will be utilized in sensor based laser absorption spectroscopy.

Three types of gas sensor architectures are being studied: near infrared distributed feedback (DFB) diode lasers for overtone spectroscopy, mid-infrared spectroscopic sources based on difference frequency generation (DFG), and quantum cascade lasers for direct absorption of ro-vibrational transitions of fundamental molecular absorption bands. Details of extractive NH3 monitoring by all three techniques will be described.
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1. Wide Range of Gas Sensor Applications
   - Chemical Analysis and Industrial Process Control
   - Semiconductor Industry
   - Urban and Industrial Emission Measurements
   - Industrial Plants
   - Combustion Sources
   - Automobiles
   - Rural Emission Measurements
   - Agriculture
   - Environmental Monitoring
   - Atmospheric Chemistry
   - Volcanic Eruptions
   - Spacecraft and Planetary Surface Monitoring
   - Crew Health Maintenance & Life Support
   - Medical Applications

2. Existing Methods for Trace Gas Detection
   - Non-Dispersive Infrared Spectroscopy
   - Flame Photometry
   - Electrochemical Sensors
   - Gas Chromatography
   - Oceanic
   - Mass Spectrometry
   - Gas Chromatography
   - Dispersive Spectroscopy
   - Laser Spectroscopy

3. Diode Laser Based Trace Gas Detection Methods
   - Overline Laser Spectroscopy
   - III-V Semiconductor Diode Lasers
   - Tunable Infrared Diode Laser Absorption Spectroscopy
   - Lead salt diode lasers
   - Mid-Infrared diode lasers
   - QC DFB Lasers
   - DFG Based Laser Spectroscopy
   - BPM and QPM NLO Materials
   - Two Diode Laser based Pump Sources

4. Laser Source Requirements for Spectroscopy
   - Source
   - Sensitivity
   - Linearity
   - Multicomponent
   - Beam Quality
   - Directionality
   - Response
   - Rapid Data Acquisition

5. \( \text{NH}_2 \) line data @ 1-2 \( \mu \)m

6. \( \text{NH}_2 \) line selection in the near-IR

7. Fiber-coupled Ammonia Gas Sensor

8. Diode Laser Based Molecular Absorption Monitor

9. Schematic of \( \text{NH}_2 \) Gas Sensor

10. \( \text{NH}_2 \) Absorption Spectrum @ 3 \( \mu \)m

11. HCI HITRAN Transmission Spectrum

12. Summary
   - Diode Laser Based Trace Gas Sensors
     - Compact, portable, robust (alignment insensitive)
     - High sensitivity (10^-13) and selectivity (46 MHz)
     - Fast data acquisition and analysis
     - Suitable for trace gases: \( \text{HCl}, \text{HNO}, \text{HCO}, \text{CO}, \text{NO}, \text{NO}_2, \text{SO}_2, \text{so} \ 2-6 \) species of \( \text{N}_2 \), \( \text{O}_2 \), \( \text{H}_2 \)
   - Applications in Trace Gas Detection
     - Indoor process control and emissions analysis
     - Environmental monitoring: \( \text{HCl}, \text{CO}, \text{CO}_2, \text{CH}_4, \text{N}_2 \text{O}, \text{NO}, \text{NO}_2 \)
   - Future Directions
     - State-of-the-art fiber lasers and amplifiers
     - Cavity enhanced spectroscopy
     - Longer and IR wavelengths beyond 1 \( \mu \)m with orientation patterns of DFG and grating based lasers