Diode Laser Based Trace Gas Sensors for Semiconductor Process Monitoring

F. Tittel, D. Leleux, H. Tanaka, R. Claps, F. Englich, M. Erdelyi
Rice Quantum Institute
Rice University
Houston, TX, USA

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, NH_3, 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 NH_3 monitoring by all three techniques will be described.

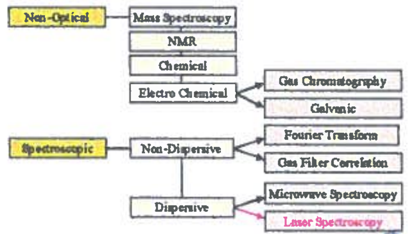
Diode Laser Based Trace Gas Sensors for Semiconductor Process Monitoring

F. K. Tittel, D. Leleux, R. Claps, F. Englich & T. Harman
Rice University, Houston TX, USA
fkt@rice.edu
http://www.ruf.rice.edu/~lasersci/

1 Wide Range of Gas Sensor Applications

- Chemical Analysis and Industrial Process Control
  - Semiconductor Industry
- Urban and Industrial Emission Measurements
  - Industrial Plants
  - Combustion Sources
  - Automobile
- Rural Emission Measurements
  - Agriculture
- Environmental Monitoring
  - Atmospheric Chemistry
  - Volcanic Emissions
- Spacecraft and Planetary Surface Monitoring
  - Crew Health Maintenance & Life Support
- Medical Applications

2 Existing Methods for Trace Gas Detection



3 Diode Laser Based Trace Gas Detection Methods

- Overtone 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

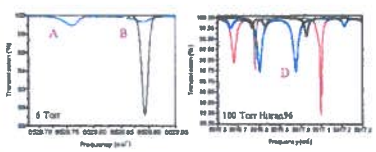
4 Laser Source Requirements for Spectroscopy

SOURCE	REQUIREMENTS
•Power	•Sensitivity
•Line Width	•Specificity
•Tunable	•Multi-gas Components
•Beam Quality	•Directionality
•Response	• Rapid Data Acquisition

5 NH_3 line data @ 1-2 µm

	Linestrength x 10^{21} cm/mol	Frequency cm^{-1}	Wavelength nm	Reference
A	2.33	6528.76	1531.68	M. Webber, D.S. Baer, R. Hanson, Appl. Opt. to be published
B	1.24	6528.89	1531.65	M. Webber, D.S. Baer, R. Hanson, ibid
C	1.54	6548.79	1526.99	[illegible]
D	8.62	5016.98	1993.23	Hitran96 database

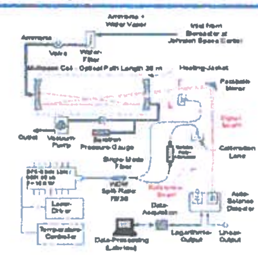
6 NH_3 line selection in the near-IR



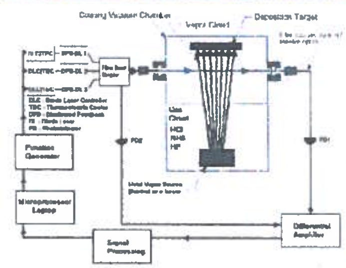
- 300 ppm NH_3 measured experimentally
- 10 % CO_2

- 1 ppm NH_3
- 2% H_2O
- 1% CO_2

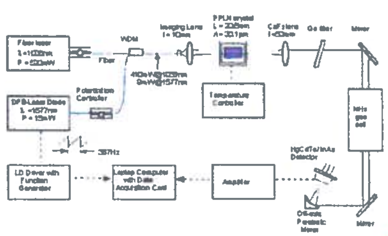
7 Fiber-coupled Ammonia Gas Sensor



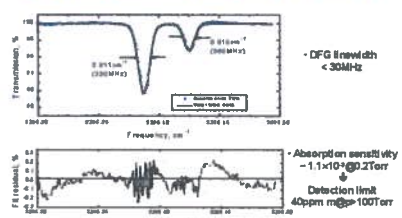
8 Diode Laser Based Molecular Absorption Monitor



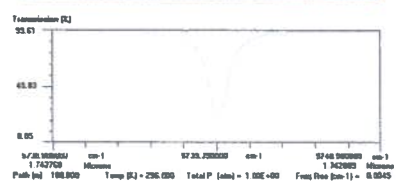
9 Schematic of NH_3 Gas Sensor



10 NH_3 Absorption Spectrum @ 3 µm



11 HCl HITRAN Transmission Spectrum



12 Summary

- Diode Laser Based Trace Gas Sensors
  - Compact, tunable, robust (alignment insensitive)
  - High sensitivity ($<10^{-4}$) and selectivity (<60 MHz)
  - Fast data acquisition and analysis
  - Detected trace gases: NH_3, HCl, H_2CO, CH_4, NO_2, N_2O, CO_2, CO, NO, H_2O, SO_2, isotopic species of $^{12,13}C$, $^{16,17,18}O$, $^{35,37}Cl$
- Applications in Trace Gas Detection
  - Industrial process control and chemical analysis
  - Environmental monitoring: H_2CO, CO, CH_4 (NASA, NCAR, NOAA, EPA)
- Future Directions
  - State-of-the-art fiber lasers and amplifiers
  - Cavity enhanced spectroscopy
  - Longer mid-IR wavelengths beyond 5 µm with orientation patterned GaAs and quantum cascade lasers