Status, Perspectives and Challenges using QCL for Plasma Diagnostics and Process Monitoring

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Wide Spread Applications of QCLAS

Plasma Industry / Exhaust Gas Treatment / Environmental Technology

Process Control in Deposition and Etching Reactors
  Semiconductor Industry
  Car Industry
  Medicine Technique
  Combustion
  Fusion Devices
  UF₆ enrichment …
Q-MACS-System

QCL-System „Q-MACS“
Plasma – and Trace Gas Analysis with Q-MACS

**Principle:** Absorption of the laser beam by gas / plasma molecules

**Result:** On-line concentration of molecules
Q-MACS Production

Q-MACS Head with Control Unit

www.q-macs.de

compact, exact, easy to use
Q-MACS with 5 Types of QCLs

NS mount  ST mount  TO 8  C mount

University of Sheffield  Alpes Laser  nanoplus  IAF Freiburg

Alpes Laser  Laser Components

QCLs from 5 different providers with 4 different packagings
Q-MACS – Intra Pulse Mode

Example of a fast measurement

→ single pulse is sweeping the laser frequency

→ fast QCLAS-measurements

fit with software

NH₃ Spectra

100 ns

t

t

A

Current

ν

Frequency

\[ t_{\text{on}} \approx (50 \ldots 255) \text{ ns} \]
Q-MACS - Inter Pulse Mode

Example of a slow Measurement

CH$_4$ and C$_2$H$_2$ Absorption Lines at 1347 cm$^{-1}$ with Fit

Measured with Current Ramp (Inter Pulse Mode)
Q-MACS-System

Q-MACS Head

Q-MACS Trace

Control Unit

1 channel system with 56 m long path cell

Sensitivity: ppb
(e.g. NH₃, CH₄)
Spin off - neoplas control GmbH

In co-operation with:

- VIGO – detectors
- A.R.T. Photonics – IR fibres

On the Market with Q-MACS - since 01/2006
New generation of compact QCLAS Equipment

See: www.neoplas-control.de
Measurements at Industrial PlasmaReactors

*Surface Treatment Industry*
Plasma Reactors of Eltro GmbH, Baesweiler

Open DC-Reaktor of Average Size

Working in Pulse Mode
Q-MACS Process

Simulation of the Beam Path Ways
Q-MACS Process

Q-MACS Process at Eltro GmbH, Baesweiler 02/2006
Monitoring of the BCl$_3$-Concentration in the Plasma Reactor
Measurements at Industrial Plasma Reactors

Semiconductor Industry
Q-MACS EtchD

- Q-MACS head
- Reference cell
- TE detector
- IR fibre
- MERIE plasma reactor
Q-MACS EtchD: on-line in-situ plasma etch species monitoring

- **NF₃** precursor
- **SiF₄** etch product

**SiF₄** detection:
- overlapping of spectra
- leak of QCLs for other IR active vibrational modes
- at 1028 cm⁻¹ the sensitivity is about 90 times higher for SiF₄
**Q-MACS EtchD:** on-line in-situ plasma etch species monitoring

**SiF₄:** Ar mixing ratio in gas phase

Based on:
- the measured absorption cross section
- TDL Wintel software using complex fit routines

A very good agreement of concentration obtained from:
- absorption measurement
- flowmeter measured values

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**[SiF₄] monitored during a plasma etch process**

SiF₄ / Ar: 1, 2, 3, 4, 5, 10, 15, 20% at p=0.333 mbar

- a) complete plasma etching
- b) injection of 2% SiF₄
- c) changes due to magnetic filed

Changes of magnetic field → changes of concentration
Measurements at 16.5 µm
Detecting Radicals - Methyl Radical (CH₃)

- microwave discharge (30/20/20 sccm CH₄/H₂/Ar, 1.5 kW, 1.5 mbar)
- methyl radical detected ($\nu_2$ band - TL 7)
Measurements with high time resolution
Time Resolved Experiments

Destruction of NO with a pulsed DC discharge

- 1 % NO in Ar
- p = 2 Torr
- t_{on} = 1 ms
- f = 1 Hz
- discharge current as trigger

Q-MAC System

- intra pulse
- laser pulse width = 80 ns
- delayed trigger
Time Resolved Results

- NO concentration changes within the pulse
- QCLAS: time resolution of 1 µs (≈ 100 ns possible)
Summary

- application of QCLAS in the MIR:
  - CH₄, C₂H₂, CH₃, HCN, CO, CO₂, N₂O, NO, NH₃, H₂O, HBr, SiF₄, NF₃, BCl₃,
- on-line in-situ monitoring of molecular species applied in industrial plasmas
- fast detectors necessary otherwise: underestimation of number densities
- sub-µs time resolution can be achieved
- effects due to rapid laser sweeping to be investigated
- QCL-System „Q-MACS“ – recent development for application in research and industry
- spin-off: neoplas-control GmbH
What we need – for the market!

- reliable QCLs
- in a robust packaging (NO open wires!)
- with stable parameters
- for a reasonable prize
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