Mid Infrared Absorption Spectroscopy System for Plasma Monitoring

Q-MACS Team

in cooperation with INP Greifswald

2009

www.neoplas-control.de

Content

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Quantum-Cascade-Measurement and Control System – Q-MACS®

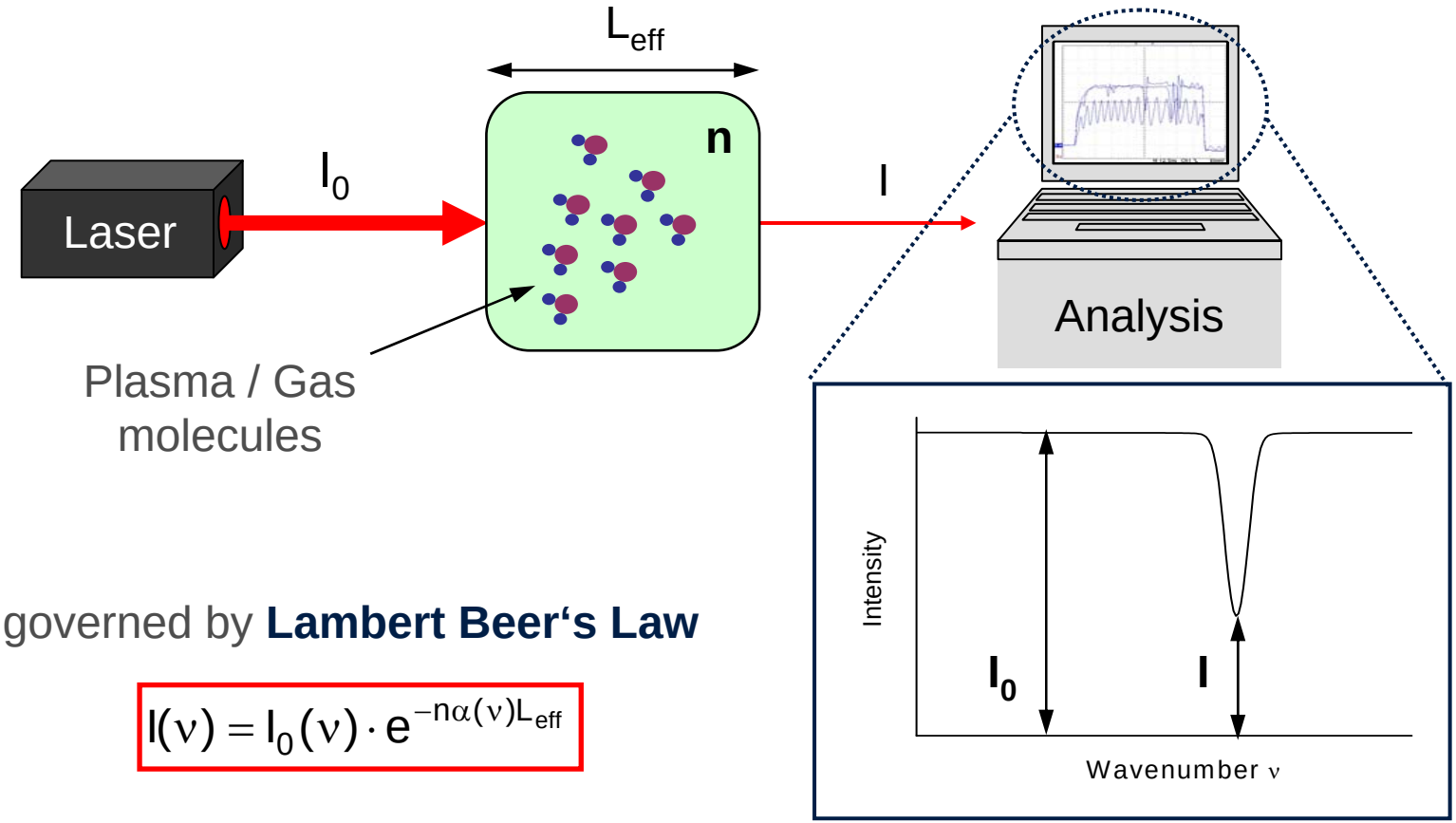
problem: real-time and in-situ control of plasma processes and trace gas analysis with a detection limit up to ppt

idea: application of a new class of infrared lasers: quantum-cascade-laser (QCL)

result: development of compact and easy to use systems for industrial and scientific applications

Q-MACS: Quantum Cascade Laser Measuring and Control System

Measuring Principle



governed by **Lambert Beer's Law**

$$I(\nu) = I_0(\nu) \cdot e^{-n\alpha(\nu)L_{eff}}$$

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

Result: On-line concentration of molecules

Why in the Mid IR?

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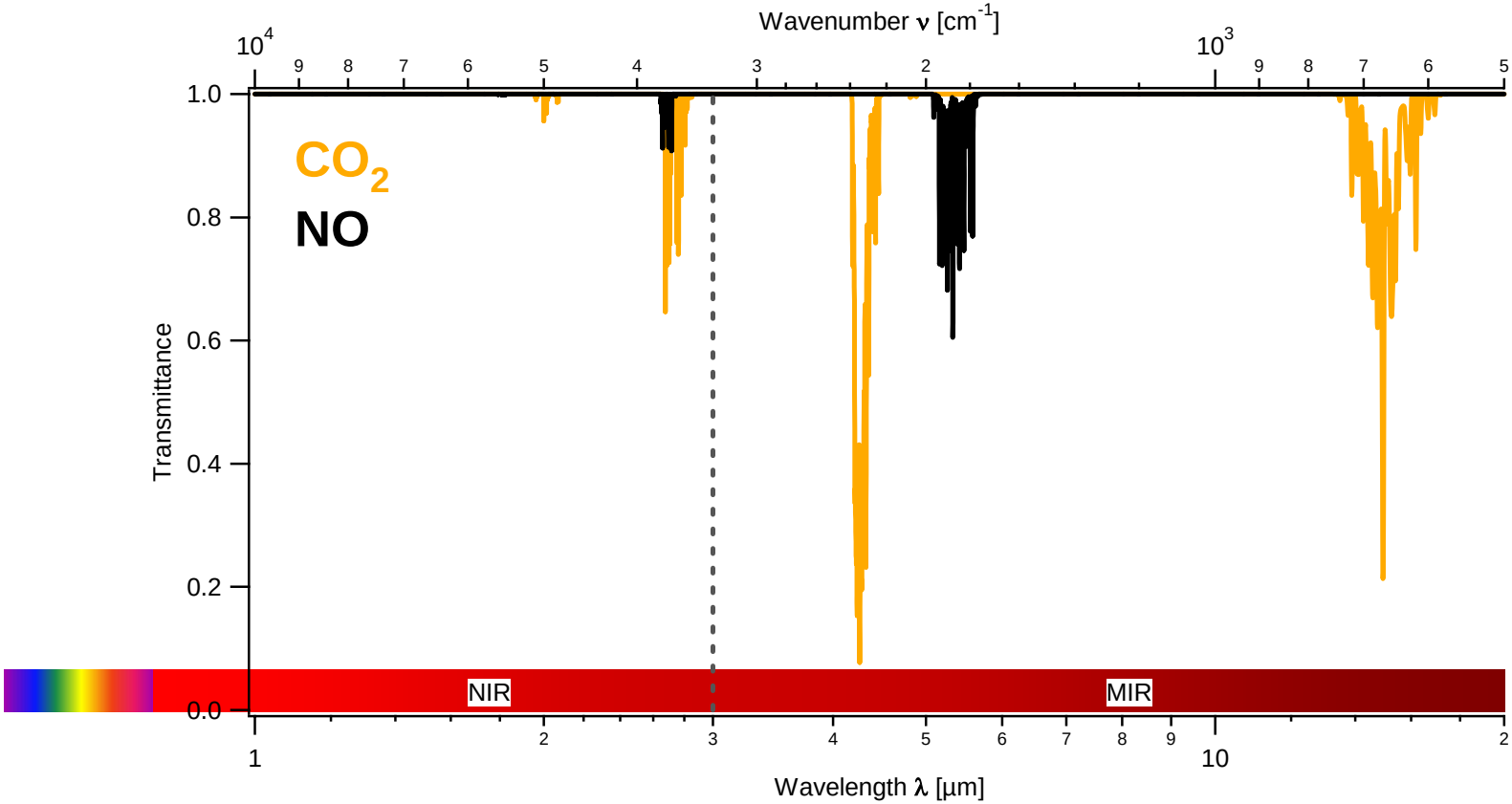
➔ many molecules ...

- only detectable in the (3 ... 20) µm spectral range (MIR)
- with higher absorption cross sections (compared to VIS, NIR, ...)



Comparison of Methods

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	IR - TDLAS	IR - QCLAS	CRDS	FT - IR
sensitivity $(I_0-I)/I_0$	☺ (10^{-3}...10^{-5})	☺ (10^{-3}...10^{-5})	☺ (10^{-3}...10^{-5})	☹ (10^{-2}...10^{-3})
selectivity $\Delta\nu$	☺ (10^{-4}...10^{-3}) cm^{-1}	☺ (10^{-3}...10^{-2}) cm^{-1}	☺ (10^{-4}...10^{-3}) cm^{-1}	☹ 0.1 cm^{-1}
tunability	😐 (10...100) cm^{-1}	☹ (1...10) cm^{-1}	☹ (1...10) cm^{-1}	☺ whole MIR
time resolution Δt	😐 ms (... µs)	☺ ms...ns	😐 s…ms	☹ min...s
operation/ detection	☹ (20 - 130) K ☹ LN_2 detectors	☺ near room T ☺ TE detectors	☹ needs highly reflective mirrors ☹ mirrors selected for single wavelength	☺ room T ☹ LN_2 detectors

Q-MACS Technology – wide spread applications

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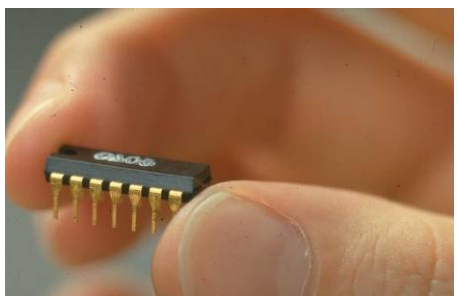
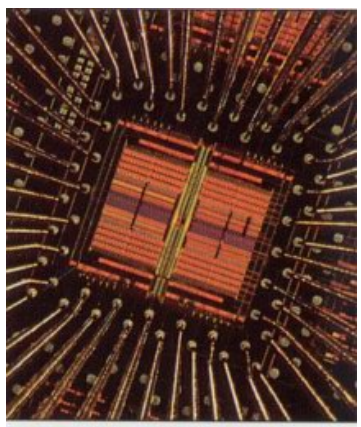
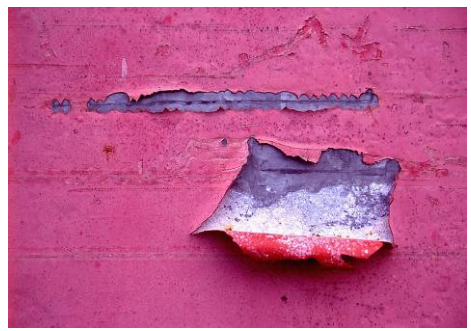
Plasma Industry /
Exhaust Gas Treatment /
Environmental Technology

Process Control in Deposition and Etching Reactors

- Semiconductor Industry
- Car Industry
- Medicine Technique
- Combustion
- Fusion Devices
- UF_6 enrichment …







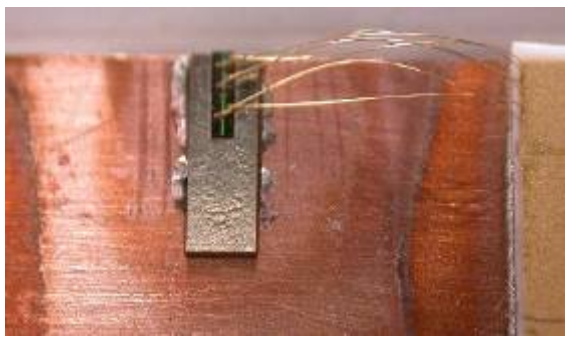
Q-MACS Technology

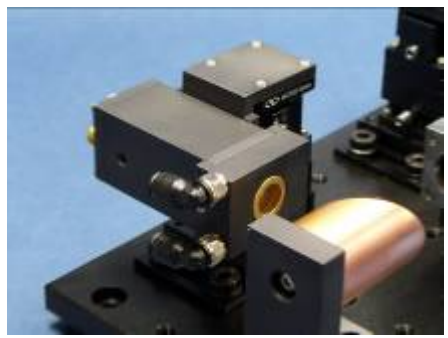
Technology

- quantum cascade laser – absorption – spectrometer
- identifies gases and plasma species and quantifies their concentrations
- very low detection limits (up to ppt)

- enables in-situ measurements
- very high temporal resolution (real-time, ns – ms - s)
- works at room temperature

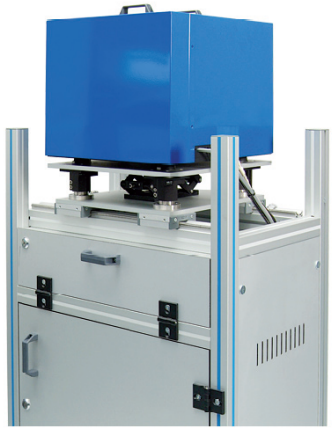
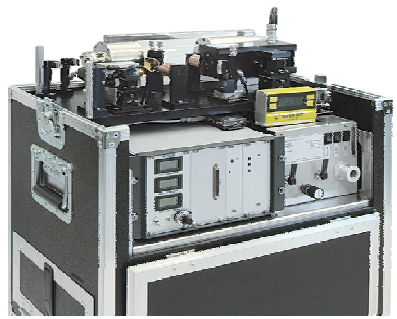
1 cm





Product Portfolio

Product variants for customized high performance diagnostics

Q-MACS Basic	Q-MACS Process	Q-MACS Trace compact	Q-MACS Process Fibre
key component, laser head with control- and supply unit	high sensitive real-time gas and plasma sensing	trace gas detection and environmental monitoring	measurement and control system for plasma etch systems
			

Q-MACS Basic

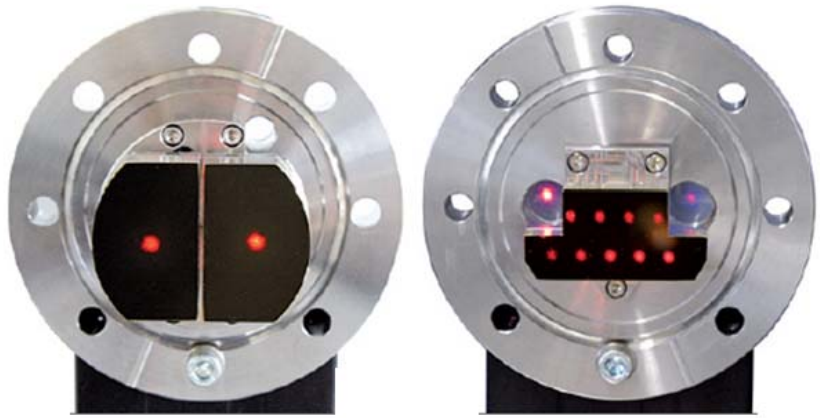
- key component for all Q-MAC Systems
- for operation with pulsed and cw QCLs
- laser head with control and supply unit for applications in spectroscopy

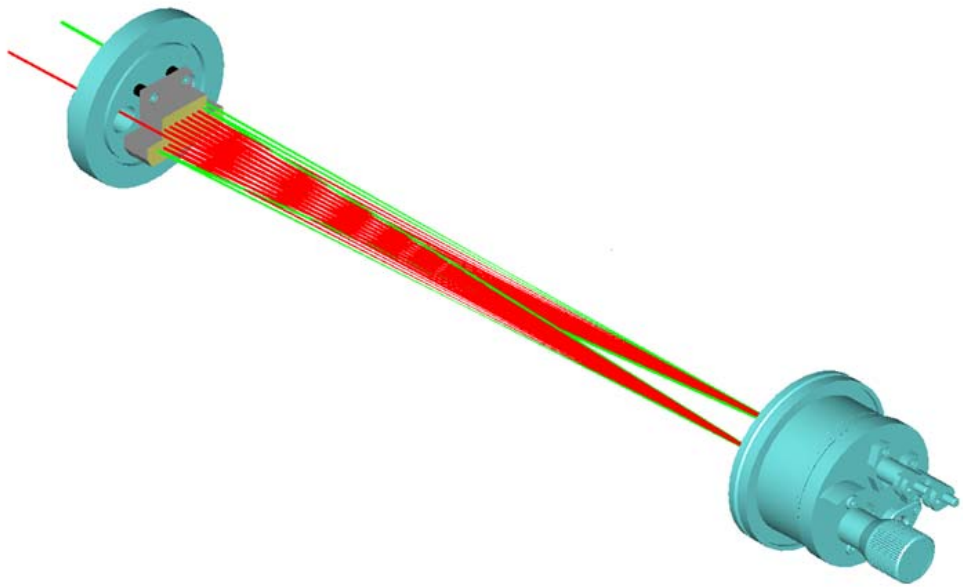
TO-3 Packaging of QCL in Q-MACS Applications

For robust handling in industrial environment

Q-MACS Multipass optics

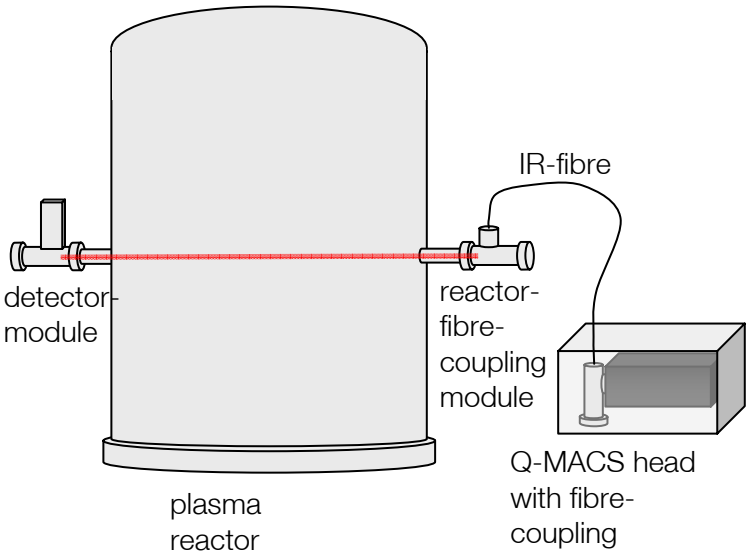
- efficient solution to increase the effective absorption length
- include a robust and compact set of gold coated mirrors
- flange mounted for in-situ installation at plasma chambers
- allow a wide range of possible absorption lengths





Applications of Q-MACS

Q-MACS Process with IR-fibre coupled to the industrial plasma reactor for surface treatment



Scheme

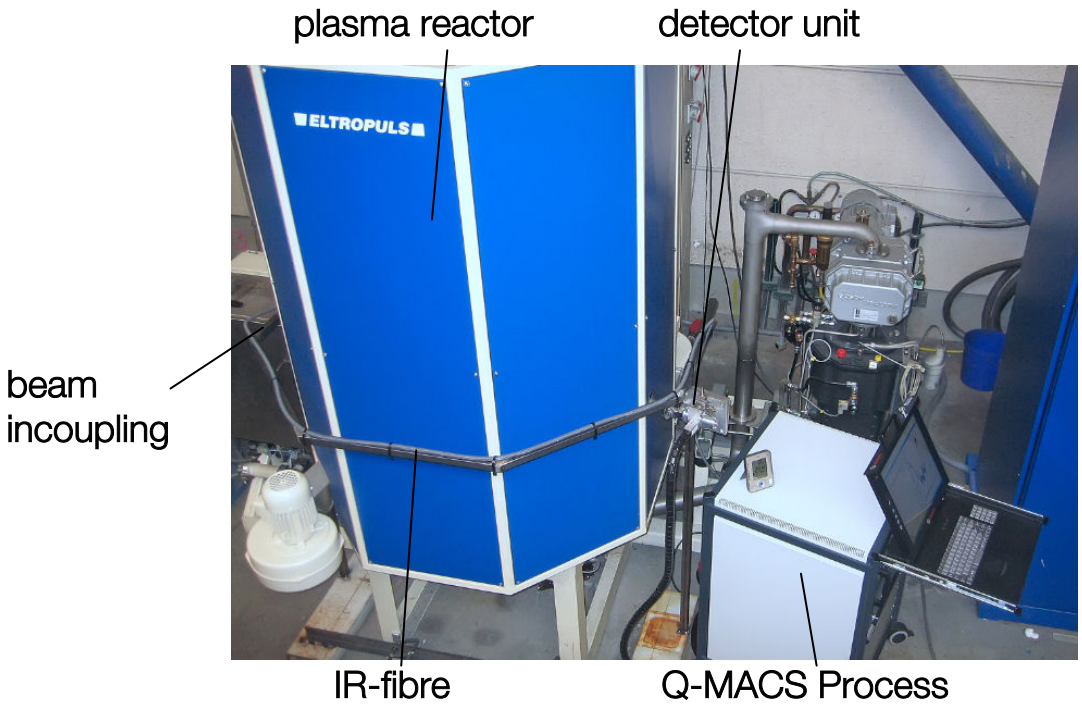
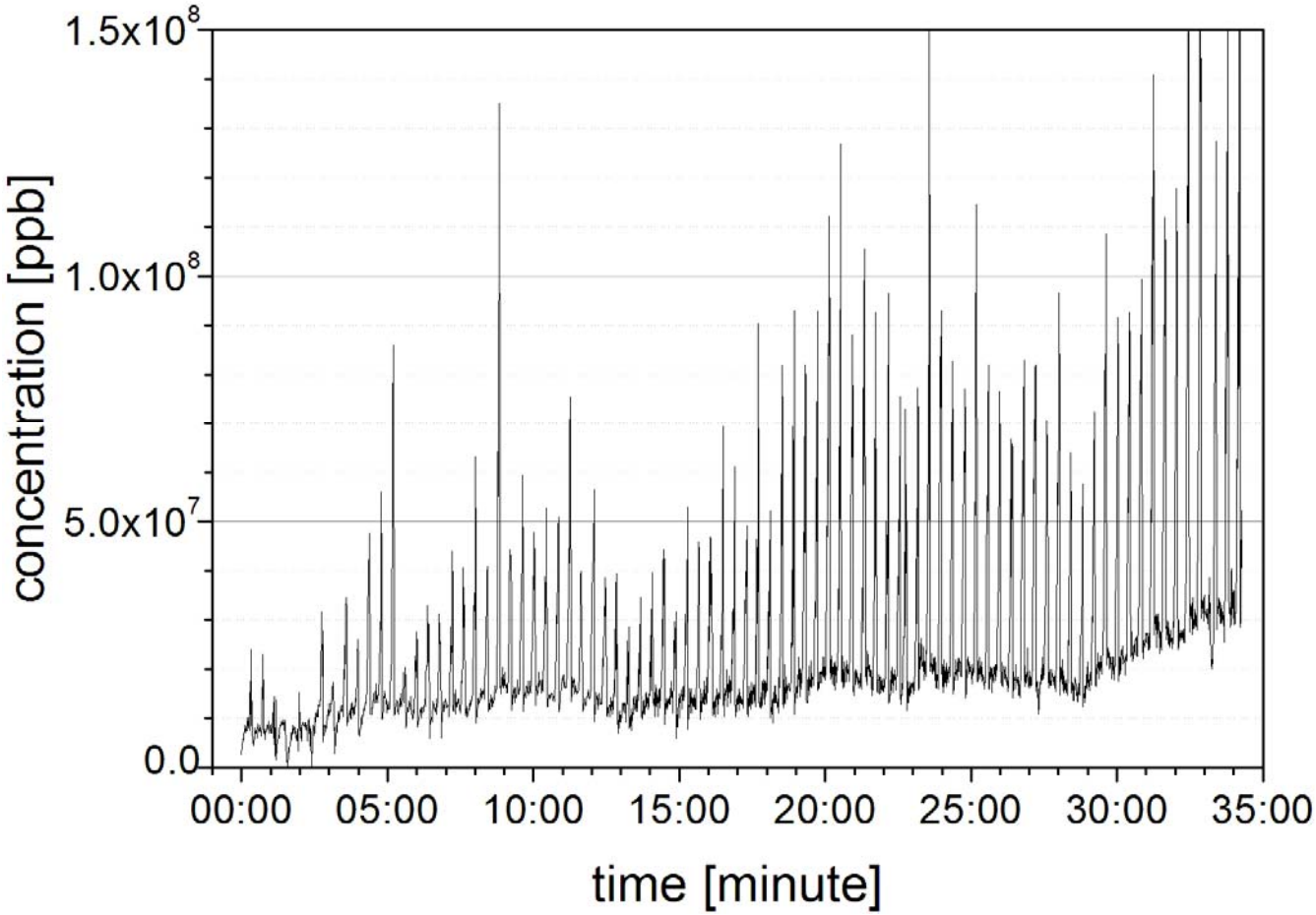


Photo at EltroPuls GmbH, Baesweiler, Germany

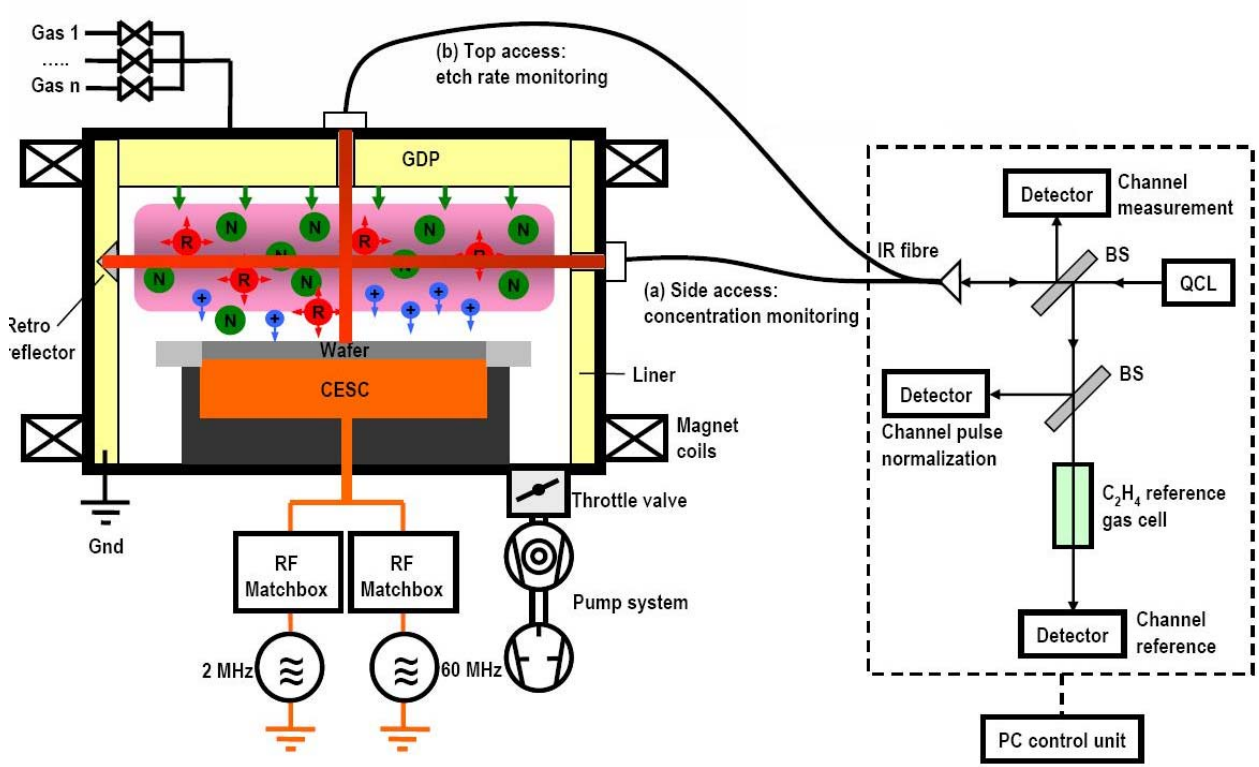
Change of the BCl_3 signal in an industrial plasma process



Applications of Q-MACS

Q-MACS Process Fibre - concept

- optical coupling of the radiation at the process chamber via IR fiber
- reflective elements in-situ (mirror, wafer) for detecting via single view port
- optic board with multi channels for referencing the laser emission



Q-MACS Process Fibre

Development objectives

- monitoring of species concentration relevant for silicon plasma etch processes via Quantum Cascade Laser Measuring and Control System (Q-MACS)
- adaptation of Q-MACS for in-situ application at process tools with single access (one window)
- process control via IR laser absorption spectroscopy
- monitoring of the etch progress via online depth control measurements

Q-MACS Process Fibre

- realization of a tool for in-situ monitoring of silicon plasma etching
- development and design of a compact and integrable product
- process control with Q-MAC System possible
- enables strong improvements in process stability and reproducibility

at a HART III plasma etch system

Applications of Q-MACS

Q-MACS Process fibre - 2008 edition (overall view)
control unit - optical unit - process coupling unit with IR fibre

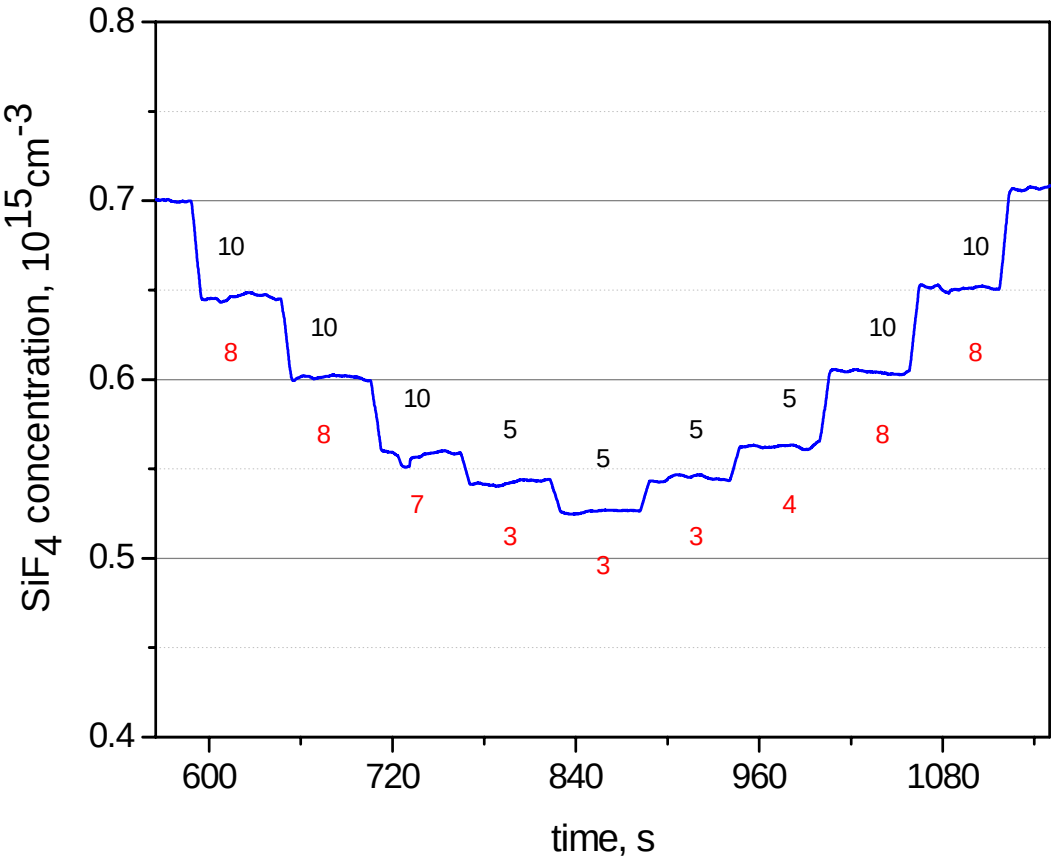
Applications of Q-MACS

Q-MACS Process fibre - 2008 edition

process coupling unit with IR fibre

Q-MACS Process Fibre - Dilution of SiF_4 with Ar

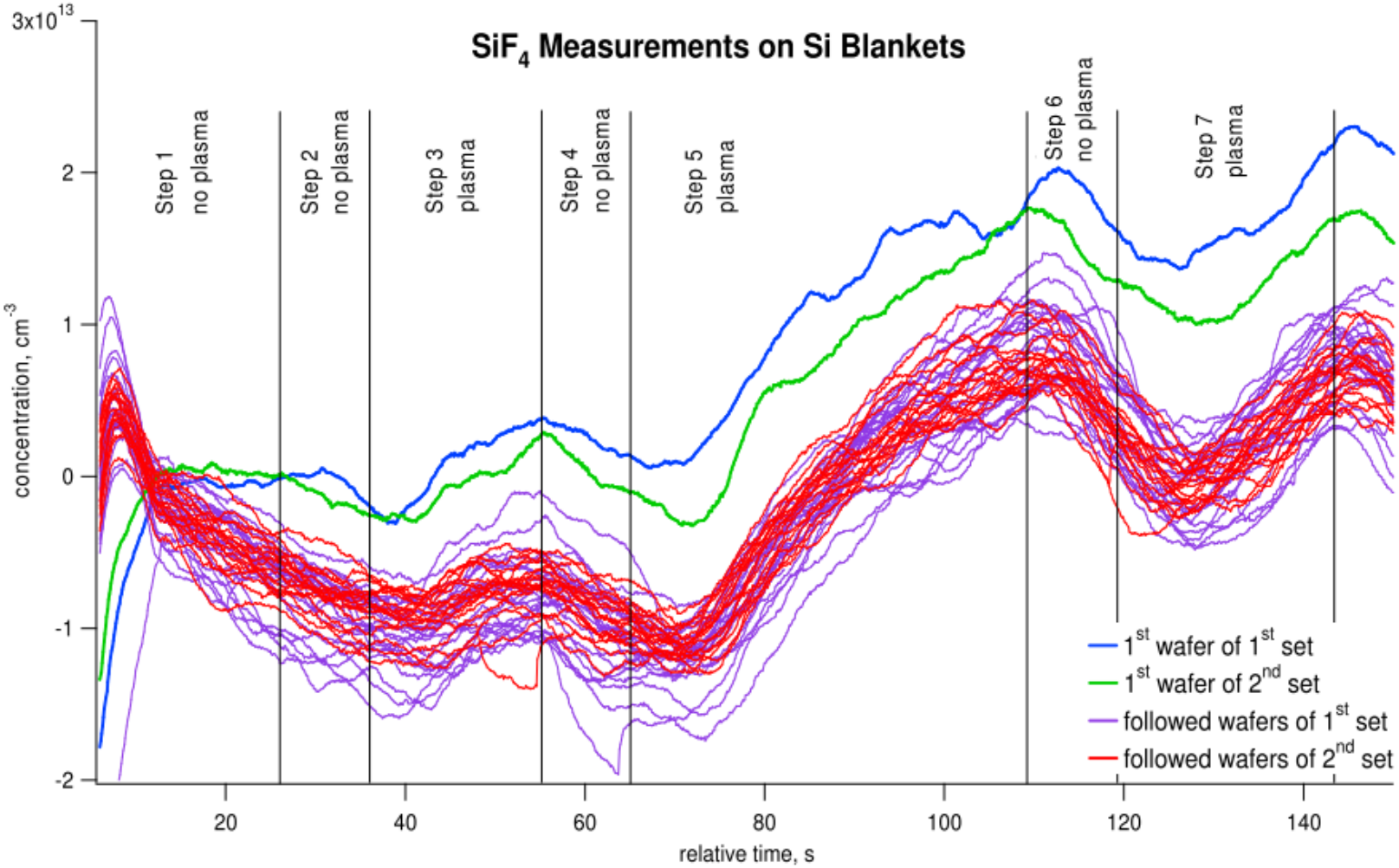
p= 50 mTorr, SiF_4 flow = 200 sccm



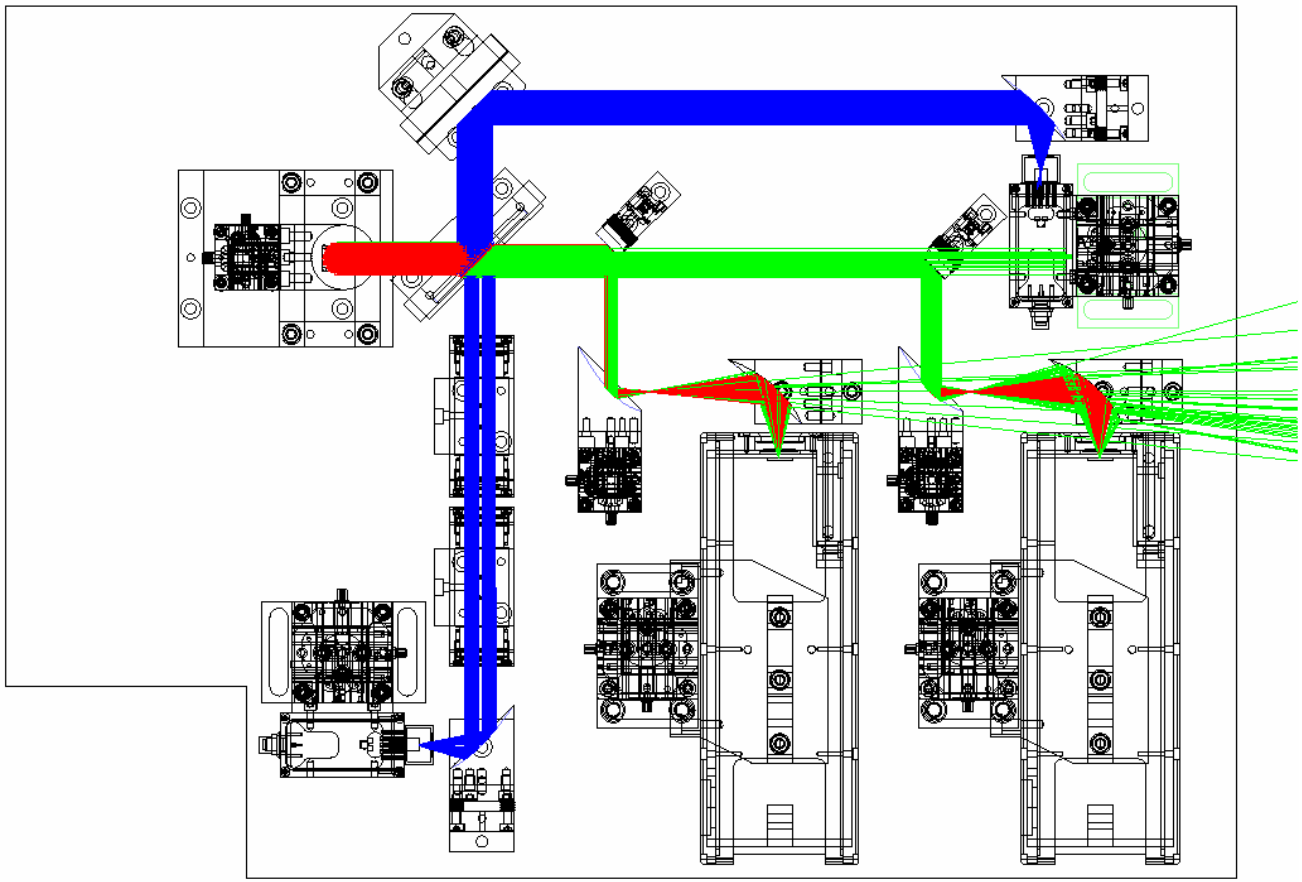
black numbers:
% step size of Ar-MFC-FSR
FSR: 400 sccm

red numbers:
% change of Ar concentration

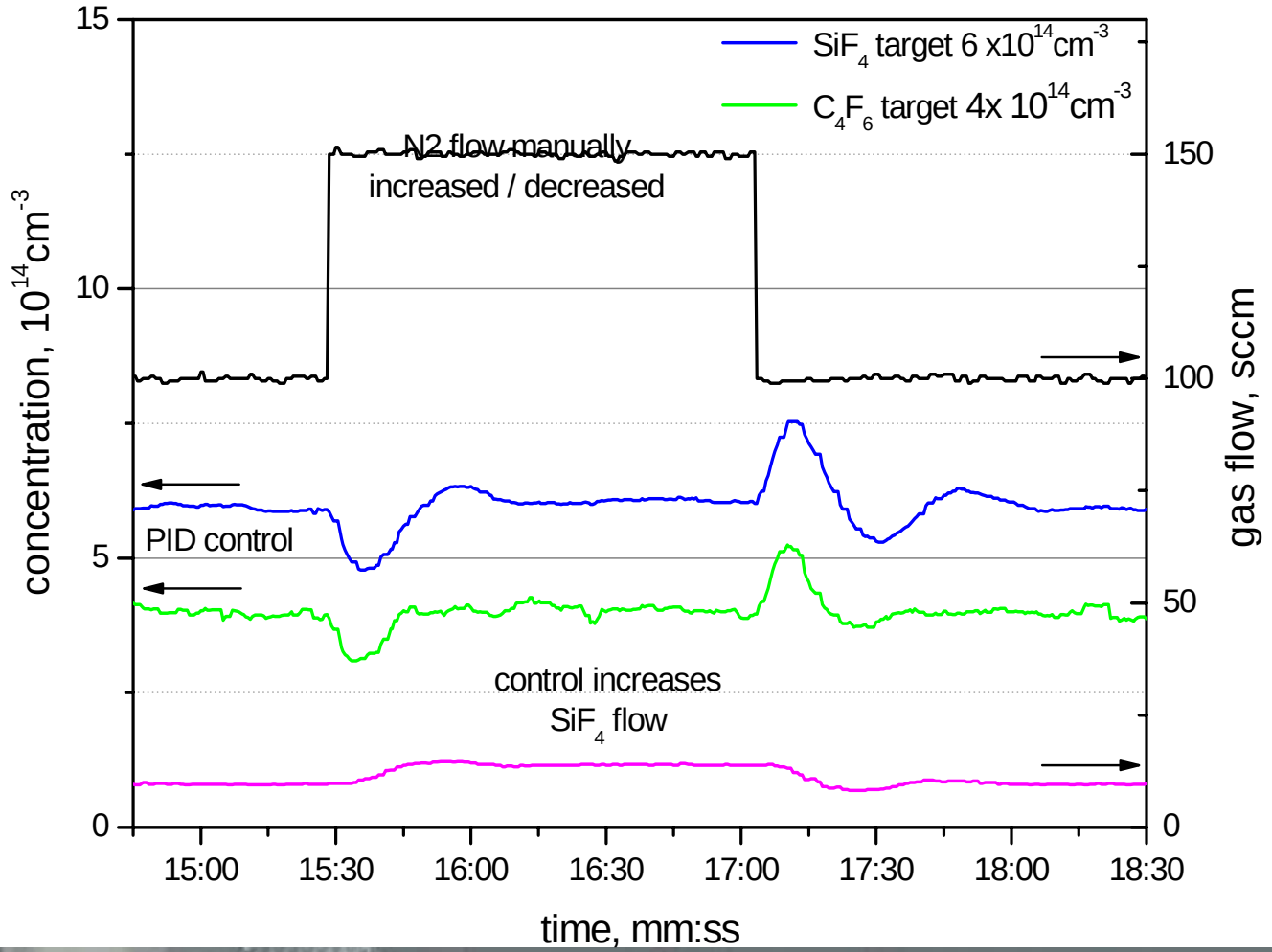
Q-MACS Process Fibre – etch monitoring



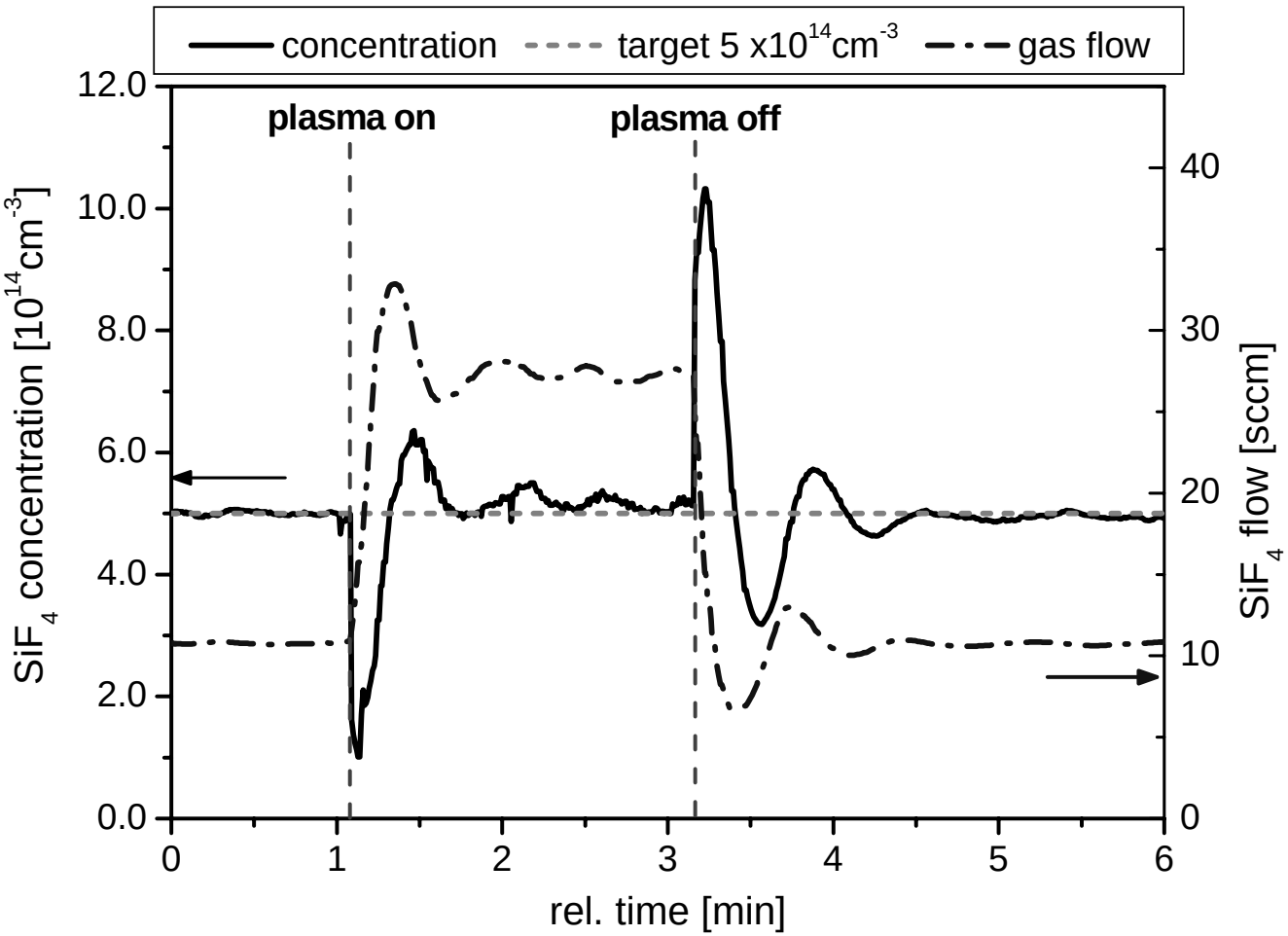
Q-MACS Process Fibre with 2 QCL Heads



Active Controlling of Gas Mixture of N_2, SiF_4 und C_4F_6, p= 0.3mbar

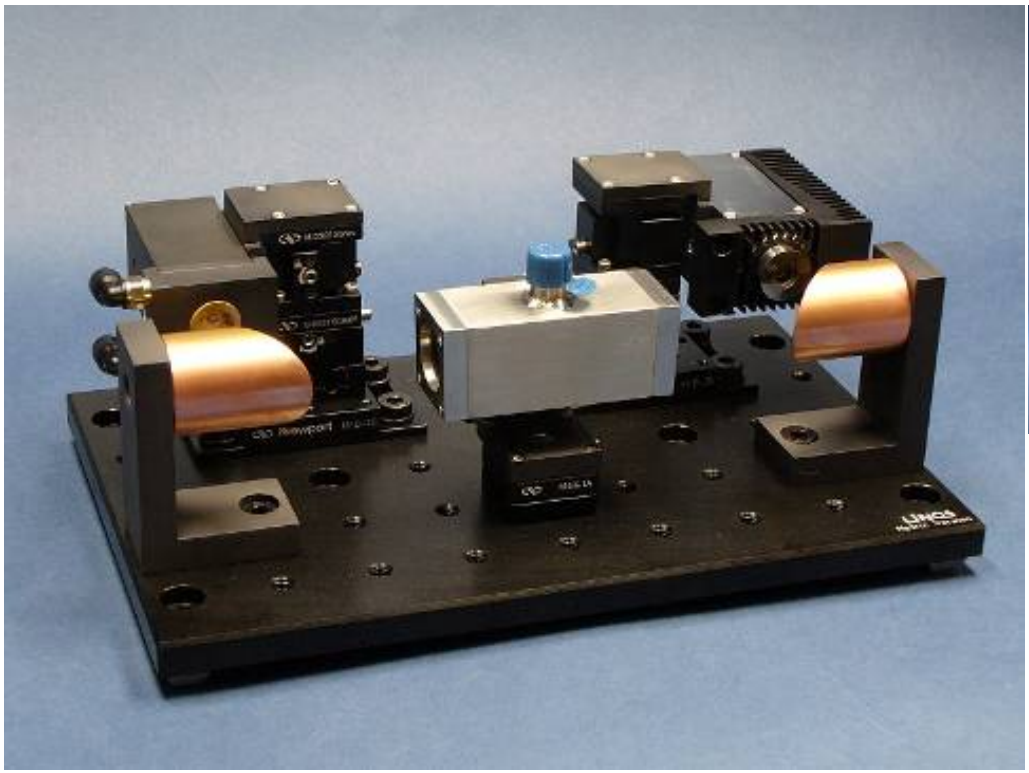


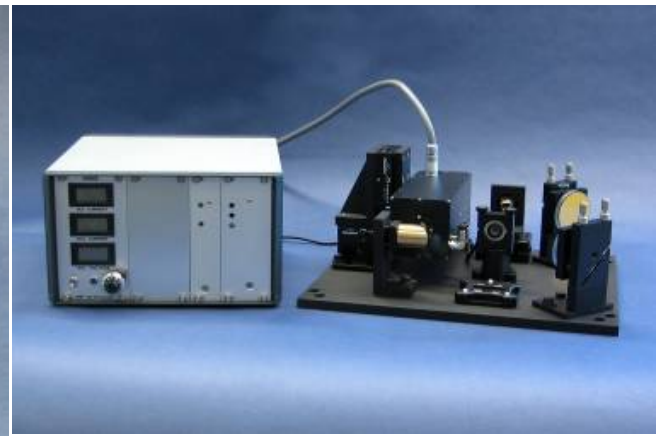
Active Controlling of SiF_4 Concentration in Plasma Reactor, p= 0.3 mbar



Future Developments of Q-MACS Technology

Examples of optimized and compact Q-MAC Systems





miniature detectors

Summary

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Principle of QCLAS

Q-MACS Technology

Applications of the Q-MAC System

- Surface Treatment Industry – *time resolved in-situ species monitoring*
- Semiconductor Industry – *process monitoring*
- Q-MACS Multi Component – *multiple species monitoring, MFC calibration*
- *CxHy, CO, CO_2, NO, NO_2, N_2O, NH_3, NF_3, BCl_3, B_2H_6, SiF_4, C_4F_6, $COCl_2$, PH_3, H_2O, O_3, SO_2, OH, HF, HCl, OCS, HCN, COF_2, H_2O_2, SF_6, SO_3, HNO_3, CH_3CL, H_2CO, CH_3OH and many others*