Zeiss <u>Process Gas Analyzer (PGA)</u> based on Ion Trap technology: Zeiss-PGA shows outstanding performances as *in-line, real time* gas analyzer





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- 1. Motivation and emergence of a novel method of mass analysis (ZEISS Process Gas mass Analyzer)
- 2. Technological requirements and performances for the semiconductor market
- 3. A new Concept and measurement-principle
- 4. Proof of Concept and results of applications
- 5. PGA Pre-series-Tool
- 6. Conclusion and Outlook

1. Motivation and emergence of a novel method of mass analysis (ZEISS Process Gas Mass Analyzer) relevant for *"7nm technology node"*



Process gas control in MOCVD systems



Process control in Etch/PECVD/CVD/PVD/ALD, Epi systems



Contamination control in high purity gas supply



Contamination control in EUV optical systems



Process control in FIB dual beam systems



Gas mixtures of advanced processes for "7 nm node" have basically partial pressures of gas-components with a very high dynamic-range up to 12 orders of magnitude!





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2. Technological requirements and performances for the semiconductor market







Parameter	Quadrupole Traps (World 1)	FT-MS (World 2) (ICR, Orbitrap)	
mass range	5 1000 m/z	100 5000 m/z	
mass accuracy	0.2 m/z	1 ppm	
dynamic range	~ 1000	~ 2000	
resolving power	~ 1000	> 10 ⁵	
Operating pressure in the analyzer	< 10 ⁻⁵ mbar	< 10 ⁻⁹ mbar	

Source: LABOonline http://www.labo.de



Quadrupole-Traps

ion accumulation/ storage possible for a long period of time robust / compact design in-situ MS/MS (ion cooling, CID, etc.)

FT-MS (ICR, Orbitrap) very high mass resolution possible resolution/sensitivity scalable by measurement time T

Get ALL benefits with the aid of a non-destructive ion detection (Image Current Detection with metal electrodes)!



actually some do (or have done so):

- H. G. Dehmelt, Adv. Atom. Mol. Phys. 3, 53 (1968)
 narrowband
- M. Soni, V. Frankevich, M. Nappi, R.E. Santini, J.W. Amy, R.G. Cooks, *Anal. Chem.* 68, 3314 (1996)
 broadband, small detection electrode
- M. Aliman, A. Glasmachers, *J. Am. Soc. Mass Spectrom.* 10, 1000 (1999)
- W. Xu, J.B. Maas, F.J. Boudreau, W.J. Chappell, Z. Ouyang, Anal. Chem. 83, 685 (2011)
 high pressure lin. trap, resonant excitation, narrowband

Crosstalk Compensation is Crucial!



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ZEISS







Parameter	FT-MS (World 2) (ICR, Orbitrap)	FT-MS (new) (Zeiss-PGA)	
mass range	100 5000 m/z	5 >2000 m/z	
mass accuracy	1 ppm	10 ppm	
dynamic range	~ 2000	> 10 ⁸	
resolving power	> 10 ⁵	> 10 ⁴	
Operating pressure in the analyzer	< 10 ⁻⁹ mbar	< 10 ⁻⁵ mbar	

Putting it all together





• optionally: Plasma or Laser

3. A new Concept and measurement-principle





very versatile - all in 1 instrument:

- ion accumulation
- ion separation
- ion manipulation
- Ion detection or mass scanning

Zeiss-PGA (CZ-SMT: Semiconductor Manufacturing Technology)







Zeiss-PGA Concept and Measurement principle: Technological requirements need new approaches!





PGA measurement principle is based on a FT-QIT which enables a very compact and robust MS-device





4. Proof of Concept and results of applications Selected performances of the PGA according to requirements 1, 2 & 4 from the PGA achieved after a short measuring time: Here in linear scale within a ppb-Range-Detection and in a "Single-Shot" using a 65 milliseconds-FFT-window



Selected performances of the PGA according to requirement 5 from the PGA achieved after a short measuring time: Here in logarithmic scale within a ppb-Range-Detection and in a Single-Shot" using a 65 milliseconds-EET-window!

"Single-Shot" using a 65 milliseconds-FFT-window!



Scaling Mass resolution using variable observation times T_{FFT} or monitoring ion inter-reactions by shifting the FFT- window





By removing dominating species we reach *ppb detection* limits within *milliseconds*





Selected performance of the PGA according to requirement "highest Dynamic Range(Dynamic > 10e10!)":



Here 100 pptV Toluene in Nitrogen was measured within 1 second!







Achieving multiple excitation of the same ion species





Keep in mind: even if ions suffer lots of collisions, they will still be trapped!





Performing arbitrary broadband excitation with better than 0.050 amu resolution in selectivity!





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5. PGA Pre-series-Tool: Ultra-compact analyzer hardware and modular infrastructure concept







Three configurations available

UHV Configuration

- For p < 1E-5 mbar</p>
- To be integrated in HV process chamber (e.g. UHV processes or as add-on detector in analytics tools / E-Microscope)

Standalone Configuration

- For pressures up to 1000 mbar
- To be coupled to your process chamber(e.g. CVD and etch processes, EUVL)

Mobile device

- For R&D and process engineers
- Maximum flexibility
- Based on a cart (under development)



ZEISS Gas Analyzer allows customers to conduct real time, in line advanced process gas control quantitatively



ZEISS Analyzer Technology		Parameter	Demonstrated Performance	Customer Benefit
		Lower Detection Limit	below 1E-15 mbar	Down to <i>a few thousand molecules</i> measurable
UHV Configuration	Standalone Configuration	Dynamic Signal Range	> 1E8	Resolve <i>minute amount of</i> analyte (< 10 ppb) in carrier matrix
		Mass Resolution m/∆m	m/∆m >> 2000	High accuracy molecule detection down to isotope level
~ 150 mm		Customer Input Pressure	from UHV to atmospheric pressure possible	In-line measurements for industrial processes
		Measuring Speed for one whole spectrum	200 ms possbile	<i>Real time</i> measurement for fast processes possible
	 300 mm 	Mass Range	Up to 2000 amu possible	Detect analytes from atoms to complex molecules
 For p < 1E-5 mbar To be integrated in HV process chamber (e.g. UHV processes or as add-on detector in analytics tools / E- Microscope 	 For pressures up to 1000 mbar To be coupled to your process chamber (e.g. CVD and etch processes, EUVL) 	Robustness & Sensor durability	Robust against H2	High up-time
		Dimensions	< 30x30x30 cm	<i>In-line</i> capability, <i>flexible</i> adaptation, modular
		Tool modularity	Adaptable to sp	ecific customer applications

6. Conclusion and Outlook Take-Home Message



QIT combines positive characteristics of ion traps with advantages of FT instruments

- instrument robustness
 electrodes as detectors
- high sensitivity
 - detection limit in the pptV range demonstrated
- dynamics enhanced by SWIFT
 - individual excitation or kick-out of selected ion species
- ✓ adjustable resolution
 - ion trapping enables long observation times
 - multiple excitation possible

The new ZEISS Gas Analyzer reduces CoO of S/C processing systems



Improve Run to Run yield

- Sensitive, fast and robust detection provides real time information about process drift or endpoint
- · Contamination variations can be detected in real time
- The etch or deposition process can be tuned from run to run



Recent oral Contributions of the Team



- M. Schmidt, A. Brockhaus, S. Butzmann, T. Benter, A. Laue, M. Aliman; *"Highly sensitive Fourier Transform mass spectrometer with non-destructive ion detection"*, DGMS, University of Wuppertal, march 2015
- M. Aliman, "*Development of a method of analysis for applications in the Semiconductor Technology*", ChemCologne 2015, University of Wuppertal, May 2015
- A. Brockhaus, M. Schmidt, S. Butzmann, T. Benter, A. Laue, M. Aliman; "*Combining the Best of Two "Worlds": FT Trap with Non-Destructive Ion Detection*", 63th ASMS Conference on Mass Spectrometry, May-June 2015
- M. Aliman, H. Y. A. Chung, M. Antoni, G. Fedosenko, A. Laue, R. Reuter, V. Derpmann, L. Gorkhover, A. Gorus, A. Pecher ; "Zeiss Process Gas Analyzer based on Ion Trap Technology, Outstanding Performances as In-line, Real Time Gas Analyzer", NCC AVS PAG-TFUG, Sept. 2015



We make it visible.