High-Sensitivity Mass Analysis with a Fourier-Transform Quadrupole Ion Trap Operating with Non-Destructive Ion Detection

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Introduction

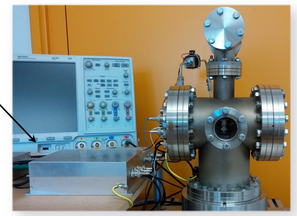
Overview:

Fourier transform mass spectrometers are well-known devices in applications demanding high mass resolution. By adapting similar techniques to quadrupole ion traps several benefits can be attained. The key advantage of the presented electrically driven ion trap is stable ion trapping. If combined with non-destructive ion detection the instrument allows for:

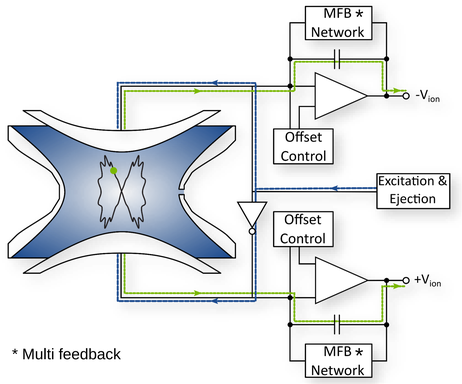
- High sensitivity broadband measurements
- Selective ion manipulation
  → Greatly enhanced dynamic range [1]
  → MS/MS without additional stages
- Multiple ion measurement of the same ion population
  → Increasing SNR and resolution

Setup

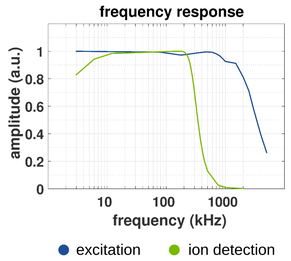
- We use a custom-made 3D ion trap with custom-built electronics → very compact setup (cf. single eurocard sized electronics)
- Ion image currents are measured via low-noise charge amplifier in a non-destructive manner (FTMS)
- The amplifier handles ion measurement and excitation
- Offset voltages are regulated at the endcap electrodes
  → Offset influences ion stability



electronics and vacuum chamber with ion trap



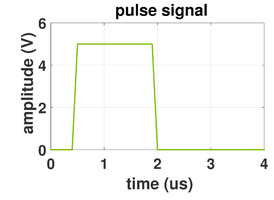
* Multi feedback

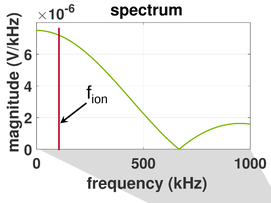


- The system provides high linearity for **ion measurement and excitation**
  →Distortion free ion manipulation possible

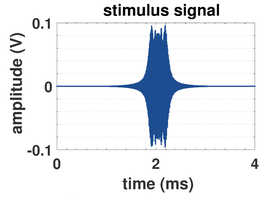
Excitation & Ejection

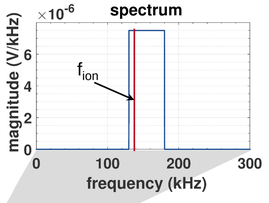
Pulse excitation

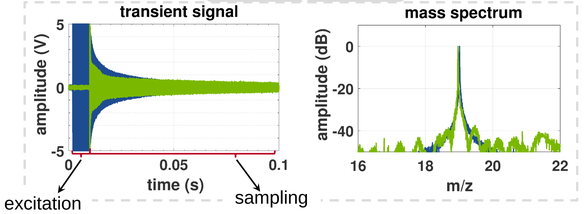




Long-term excitation







Ions are generated in-situ in the center of the ion trap. Before image current measurement ions need to be excited.

Pulse excitation

- Standard approach: pulse in the µs range
  →Sufficient for broadband excitation
  →For selective ion ejection or excitation advanced schemes are needed

Long-term excitation

- A common technique for selective ion excitation is SWIFT, i.e. the storage waveform inverse Fourier transform [4]. By adjusting the phase of the desired stimulus waveform amplitude and duration can be optimized to application requirements. (typ. mV & ms scale)

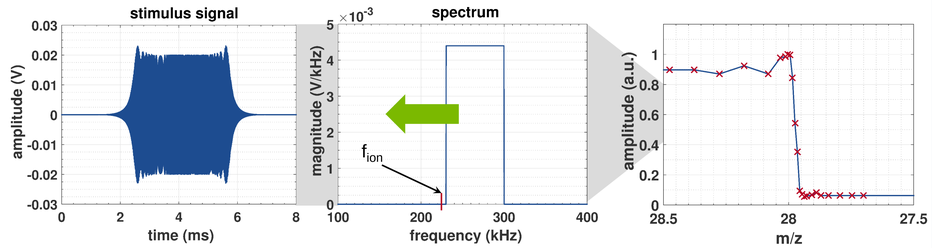
Challenge

- In our setup we use the endcap electrodes for both image current measurement and ion excitation & ejection
- Care has to be taken not to perturb the low noise charge amplifier (noise coupling, offset insertion etc.)

Results

Excitation Selectivity

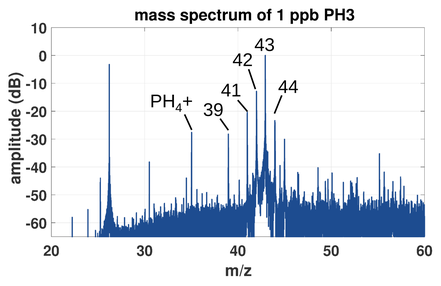
Excitation Selectivity has been studied with pre-calculated excitation waveforms. The corresponding excitation window was swept over the ion resonant frequency and the abundance of N_2 was registered.



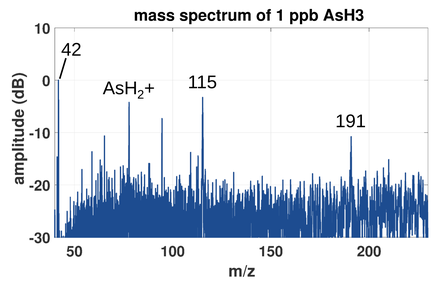
- Selectivity of **0.05 m/z** was achieved using a 8 ms excitation signal and amplitudes < 30 mV

Sensitivity

The following two spectra were gathered during a semiconductor process in H_2 background. Arsine and phosphine were used in known concentrations.



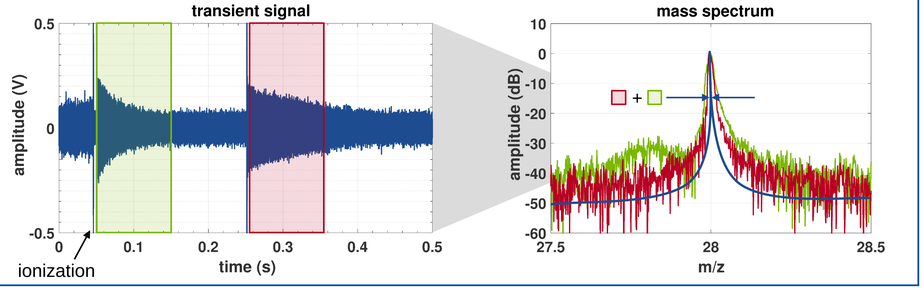
- Broadband ion detection with high sensitivity (1 ppb, 10^{-8} mbar, pulsed gas inlet)
- Single-shot measurements (e.g. one excitation)



- **10 – 20 ms** acquisition time only (fft-window)
- Example for process monitoring in an industrial environment
- ppt level achieved under lab conditions

Storage

- Averaging of mass spectra can be used to increase SNR
- With stable ion storage multiple ion measurements of <u>one</u> ion population are possible
  - This also improves mass resolution as for FTMS: **$R = f(\Delta T_{FFT})$**



Conclusions

Ion trap FTMS:

- Broadband spectra ~ 200 m/z with high sensitivities were achieved with single-shot measurements
- Selective ion manipulation is possible
- A low-noise amplifier has been developed to enable image current measurement and distortion-free excitation in one device
- Like other FTMS high resolution and SNR can be obtained with multiple ion measurements
- Resolution and acquisition time can be tuned to application requirements

The Fourier-transform quadrupole ion trap combines the advantages of the 3D ion trap technology with the advantages of known FT-based mass analyzers

Outlook:

- Improving mass range → higher trapping voltages

References

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