

Piezoelectric Driven Microplasma – a Non-Thermal Atmospheric Pressure Ionization Source



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Introduction

Overview:

The ionization source is a key component for every MS instrument. Different discharge types are used:

- corona
- low-pressure glow
- atmospheric pressure glow
- dielectric barrier discharge
- arc

The primary plasma ions may be used either directly or converted to other species, i.e. to achieve a "softer" ionization of the analyte.

Approach:

novel surface discharge plasma source for contamination-free ionization and UV generation at atmospheric pressure

Methods

ionization source self-made piezo plasma sources (cylindrical and planar design), self-made dielectric barrier discharge for comparison

Discharge gases Helium, Neon, Argon, Nitrogen, Air

MS PPM422 plasma process monitor equipped with cylindrical mirror energy analyzer (CMA) and 2-stage pumping system (Balzers, Liechtenstein)

Spectroscopy UV/VIS: EP200 scanning monochromator (Verity Instruments Inc., USA)

VUV: VM 502 spectrometer (ARC)

Piezo-Plasma: Principle of Operation and Different Geometrical Realizations

Ionization source is a non-thermal surface discharge operated at atmospheric pressure. High voltages are generated with a **piezoelectric ceramics transformer**

Principle:

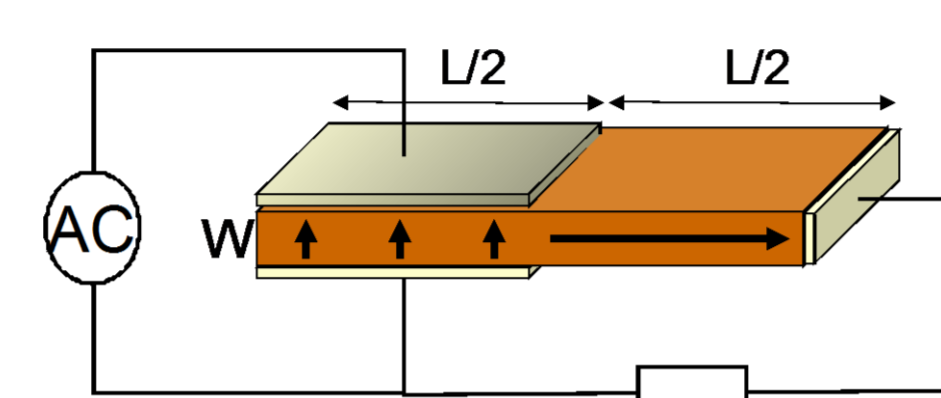
input V_i

- low ac input voltage (some V)
- inverse piezo effect at primary part

output V_o

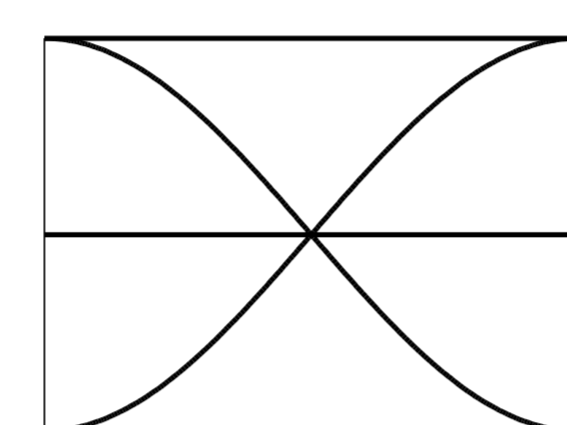
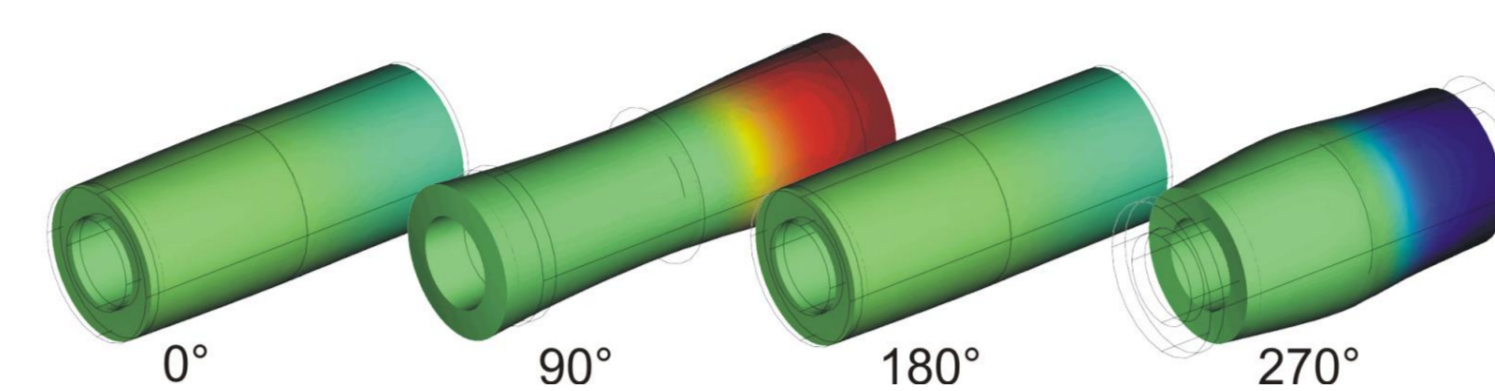
- high ac output voltage (kV)
- direct piezo effect at secondary part
- sufficient for gas breakdown

Piezo-electric transformer (Rosen type)

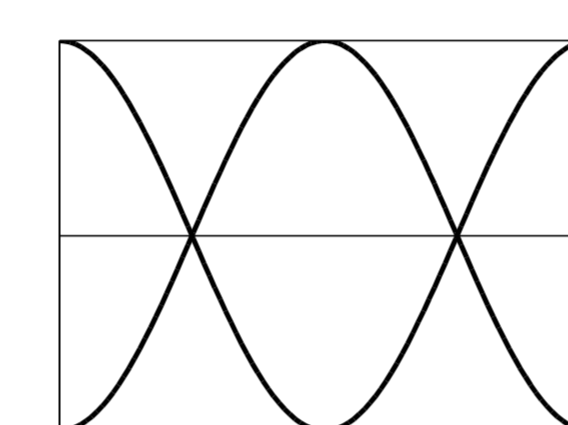


voltage scaling properties determined by geometry:

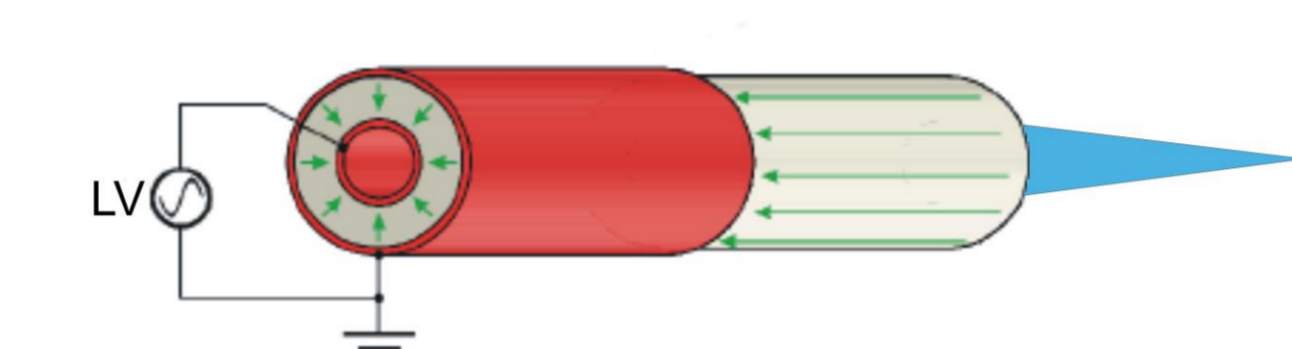
$$V_o/V_i \propto L/W$$



mode $\lambda/2$
frequency f_0



mode λ
frequency $2f_0$



cylindrical design

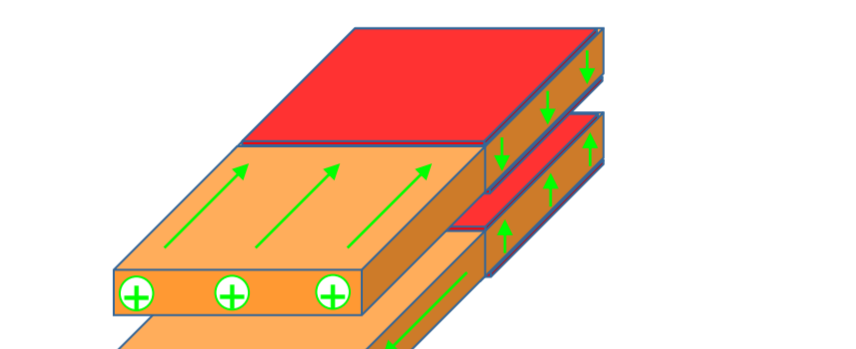
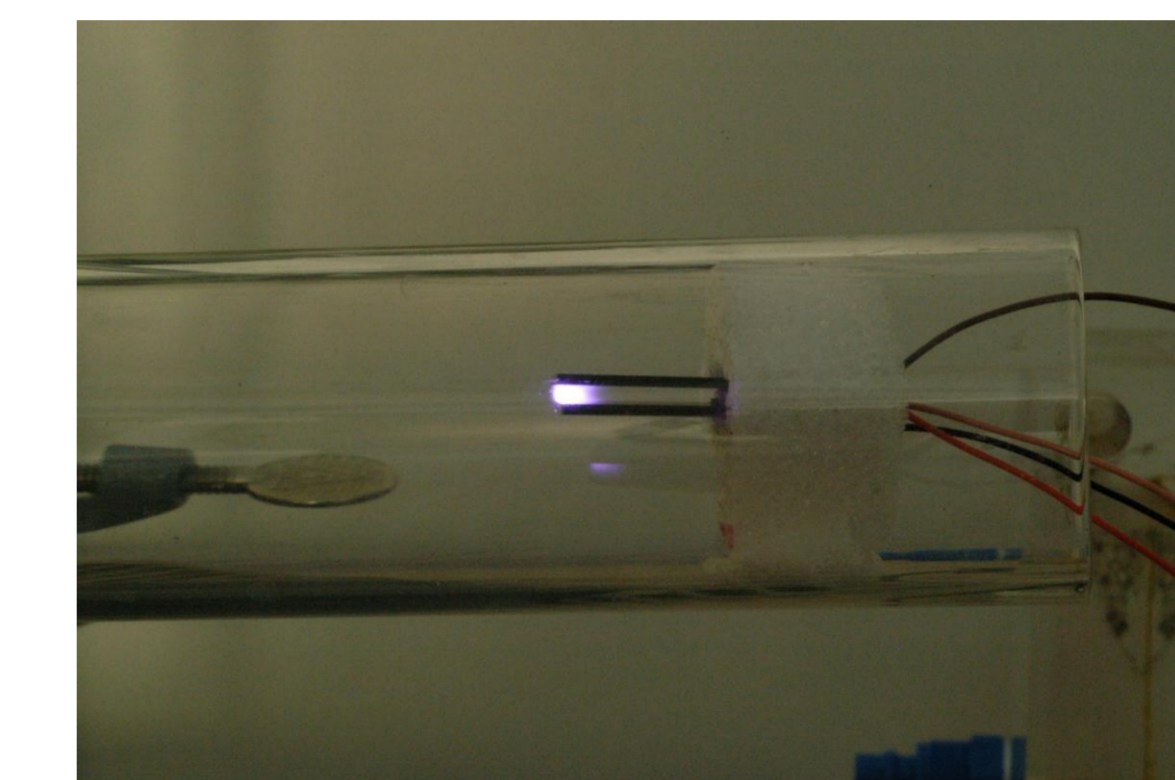
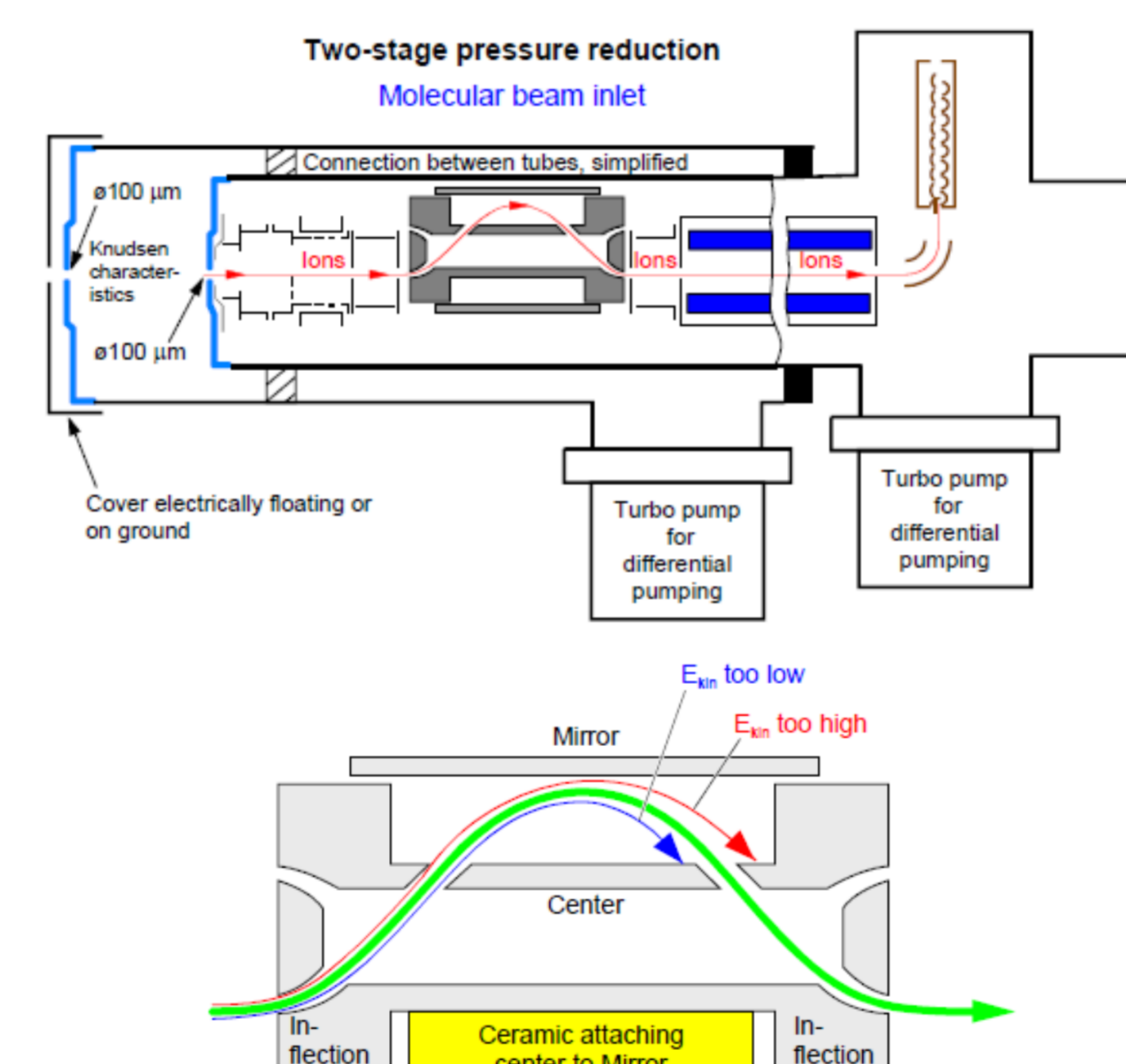


plate stack design

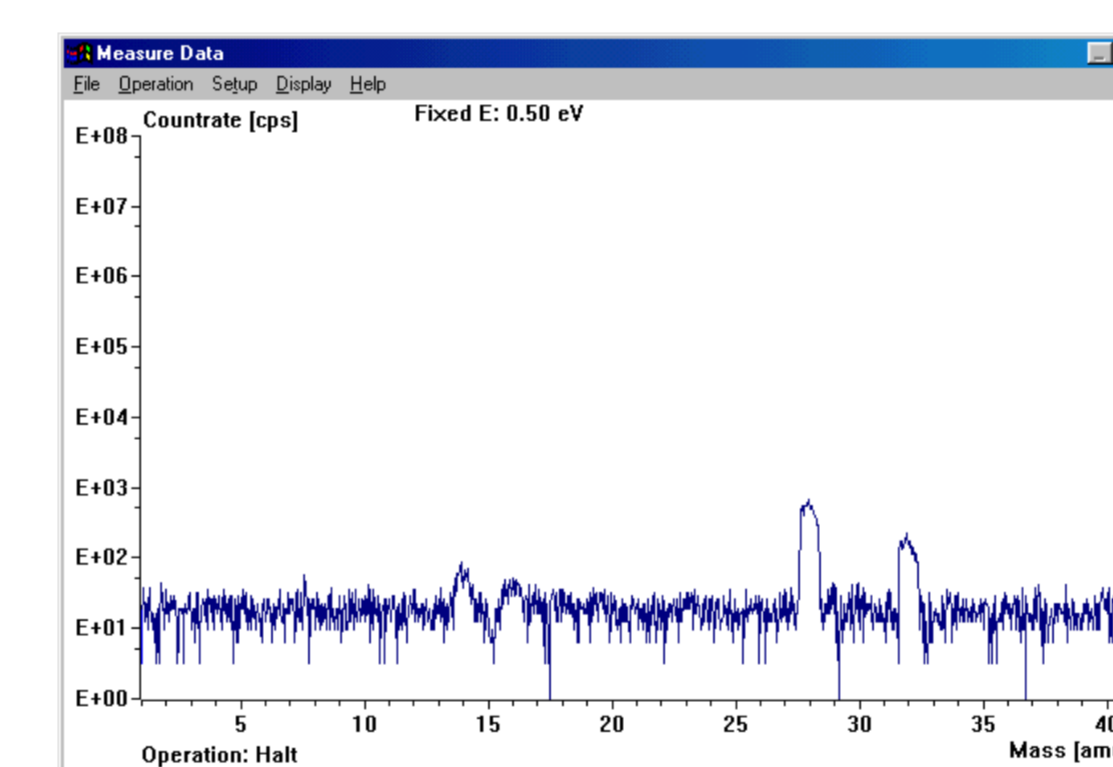
MS Characterization



MS experimental set-up. Piezo plasma source (not visible) is located in the small vacuum chamber to the right.

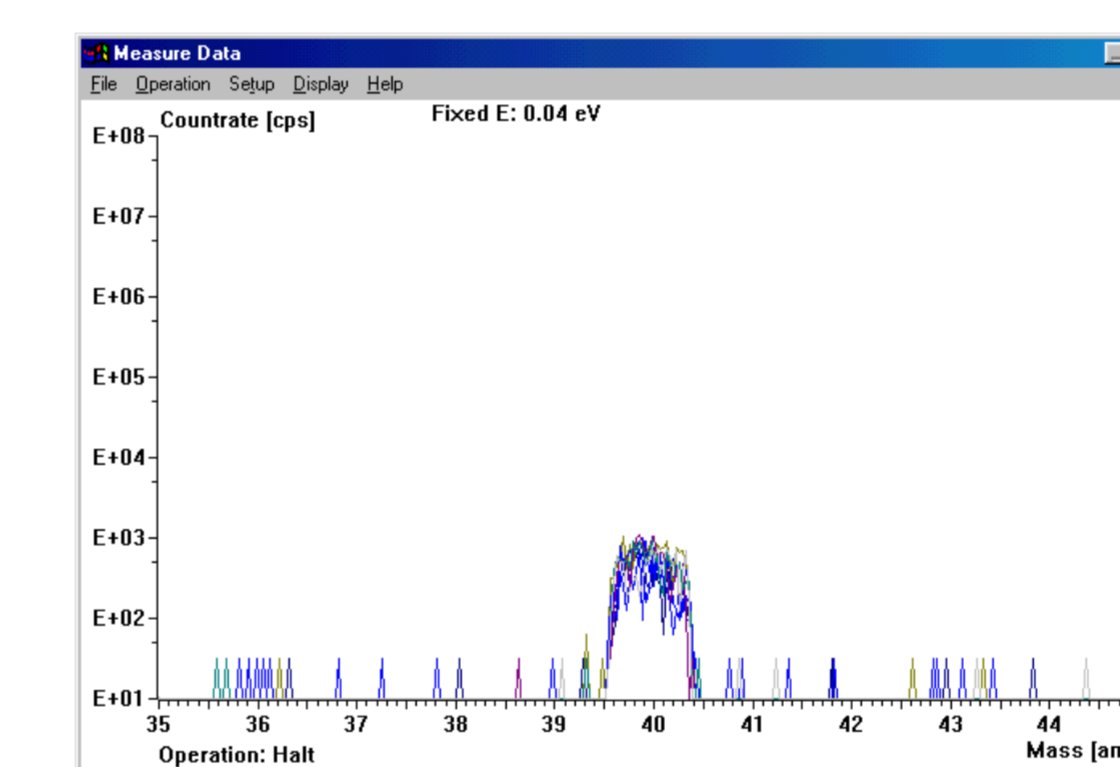


MS (top) with CMA (bottom)

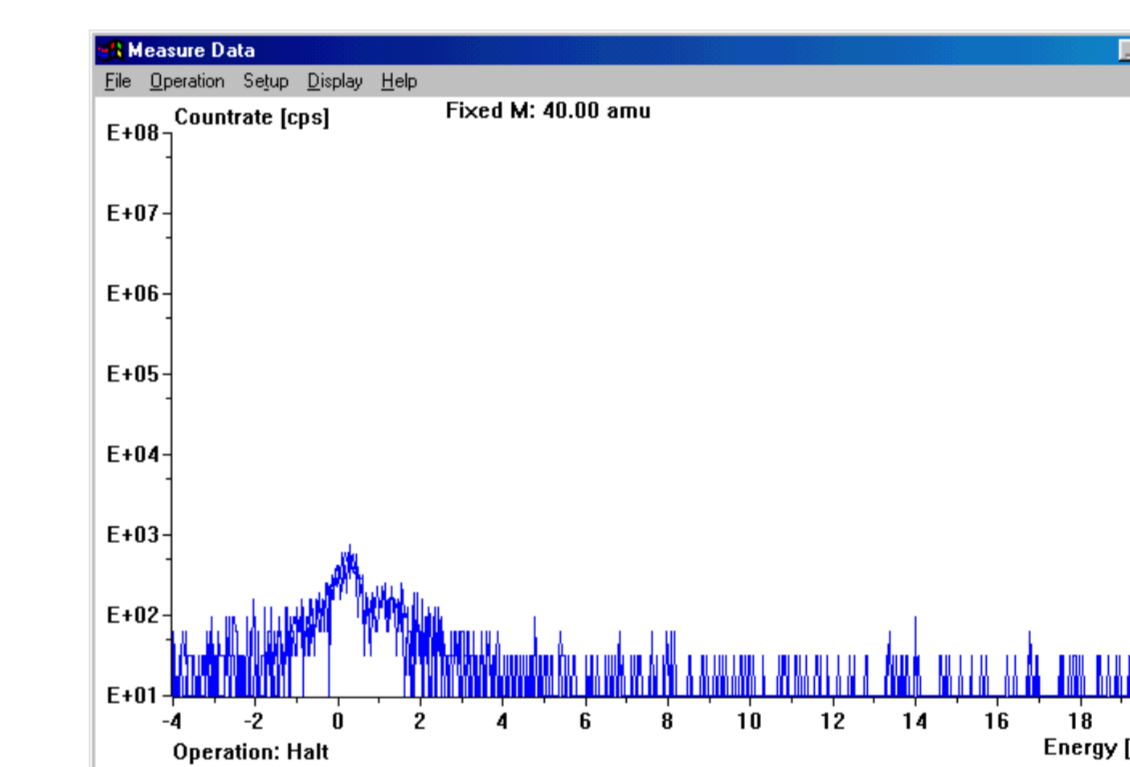


mass spectrum from operation in air.

Piezo plasma source input voltage for all measurements approx. 20V_{pp}



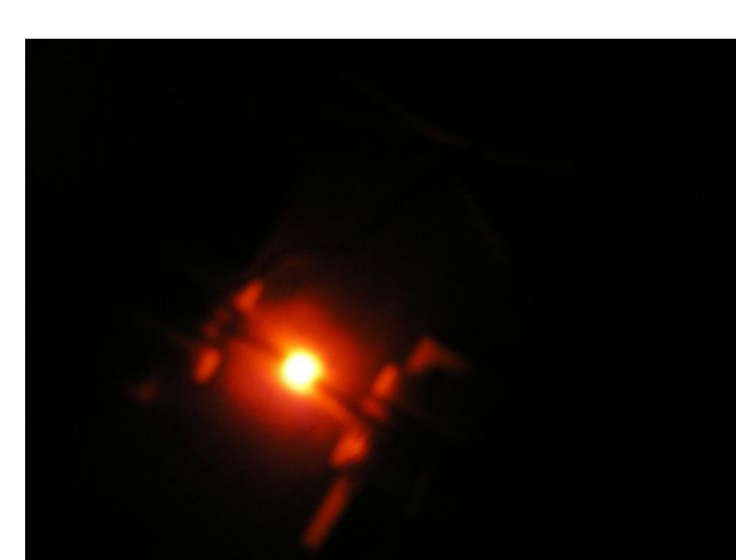
mass spectrum from operation in pure Argon. Piezo plasma is „weak“ but can be operated from atmospheric pressure down to 10⁻² mbar.



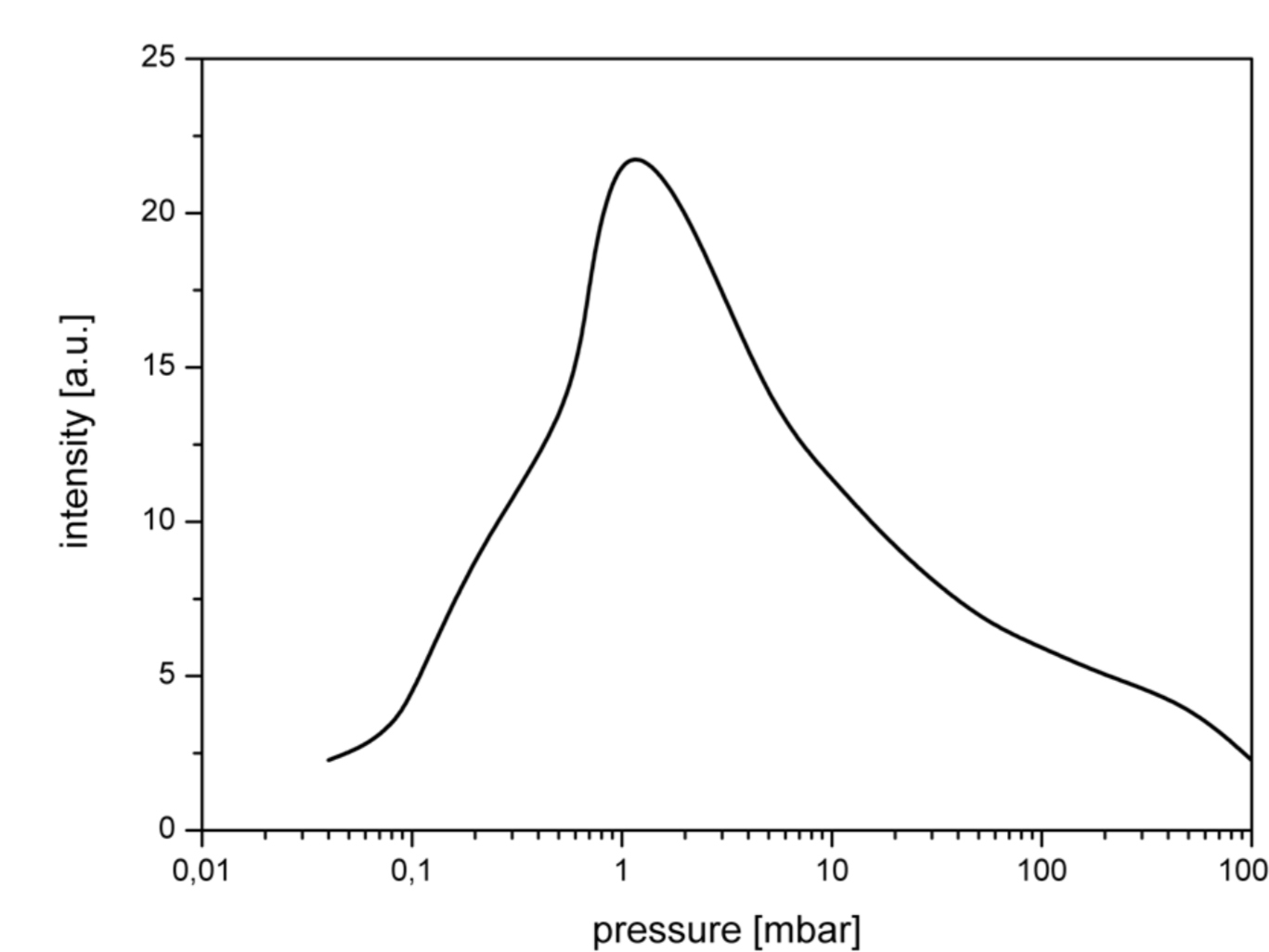
Argon ion energy spectrum determined by CMA

Energy resolution 0.5 eV.

OES Characterization

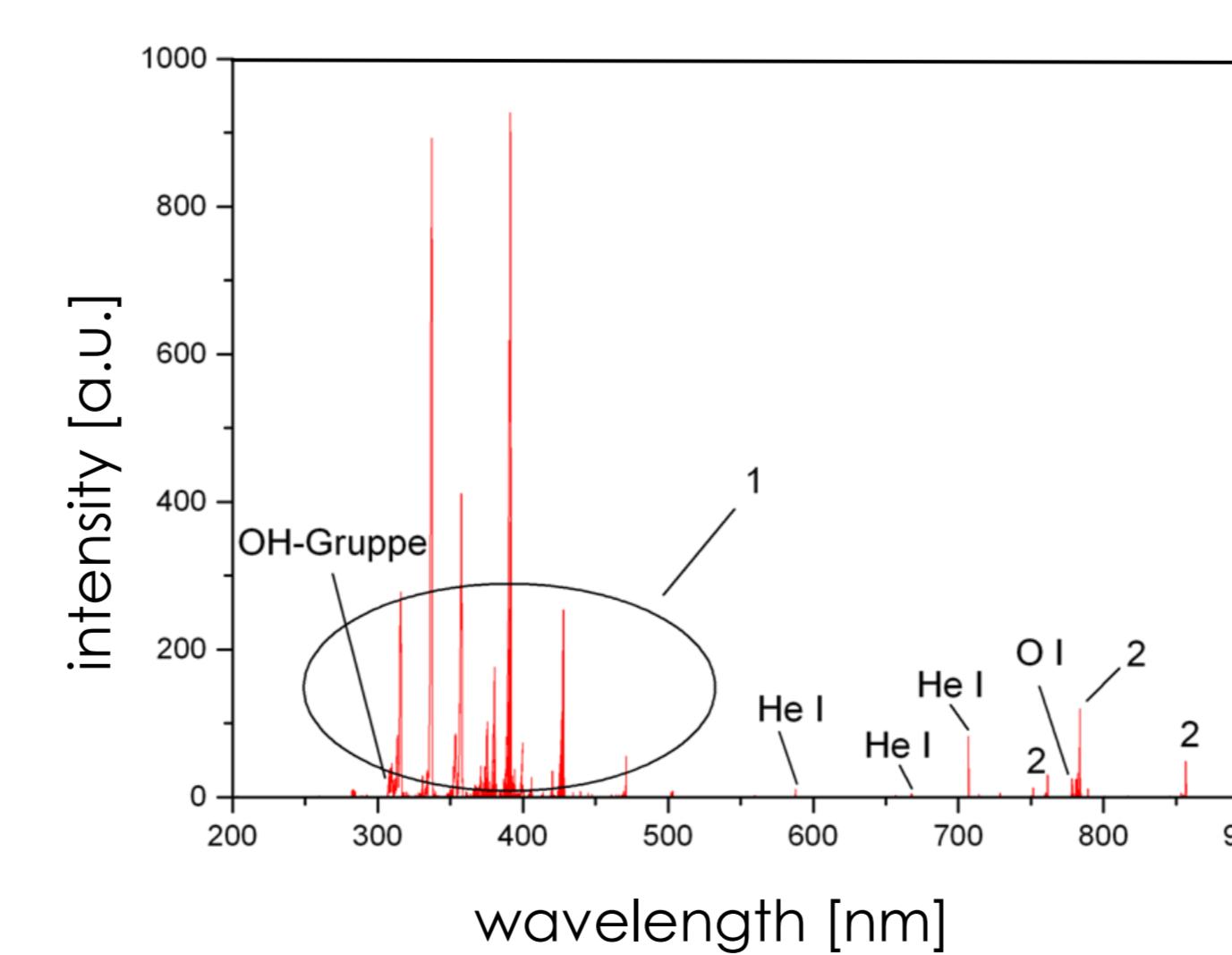


double plate piezo plasma in Neon at 10 mbar (top) and 0.2 mbar (bottom)

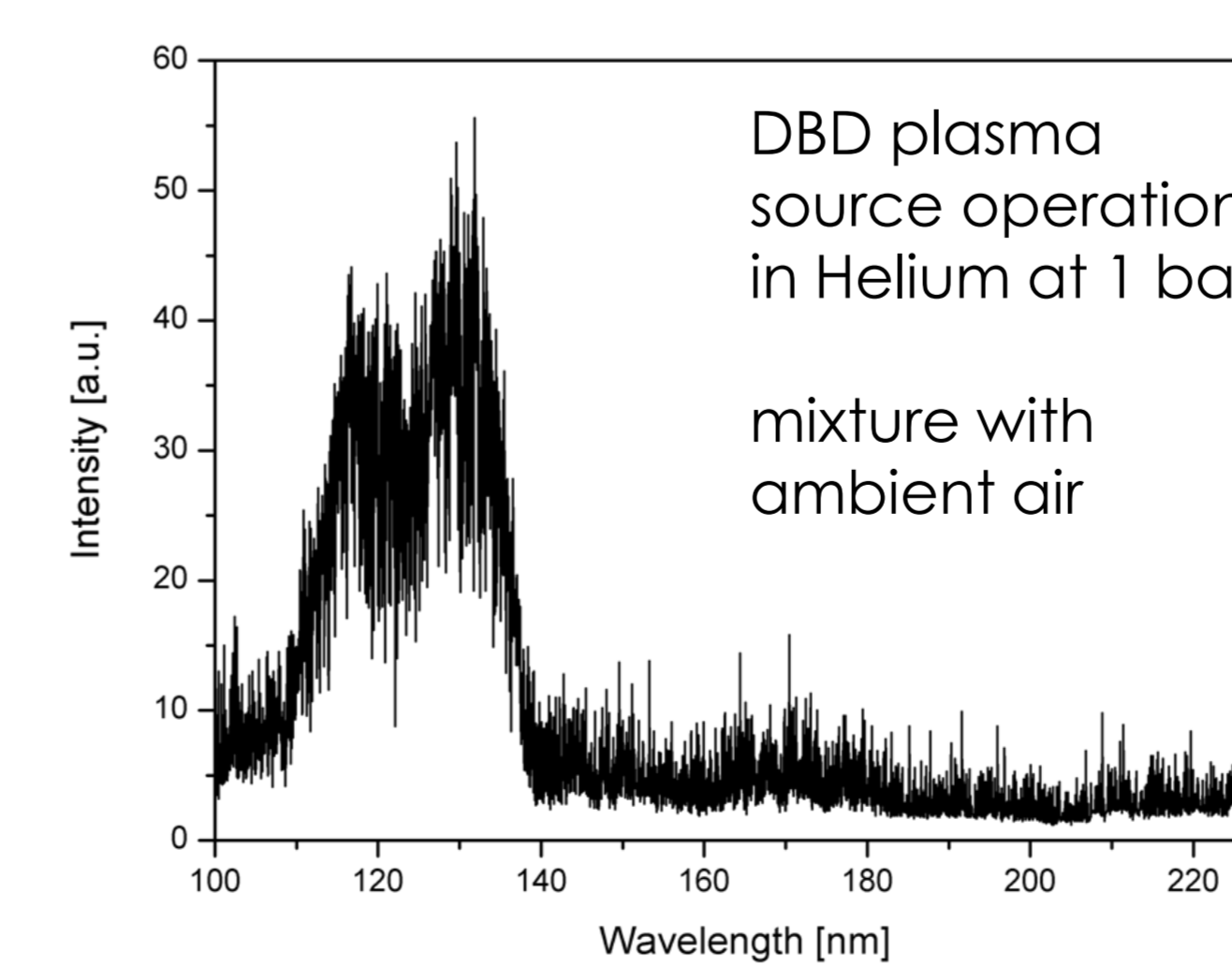


overall optical emission intensity versus pressure

other gases similar dependency but different intensities

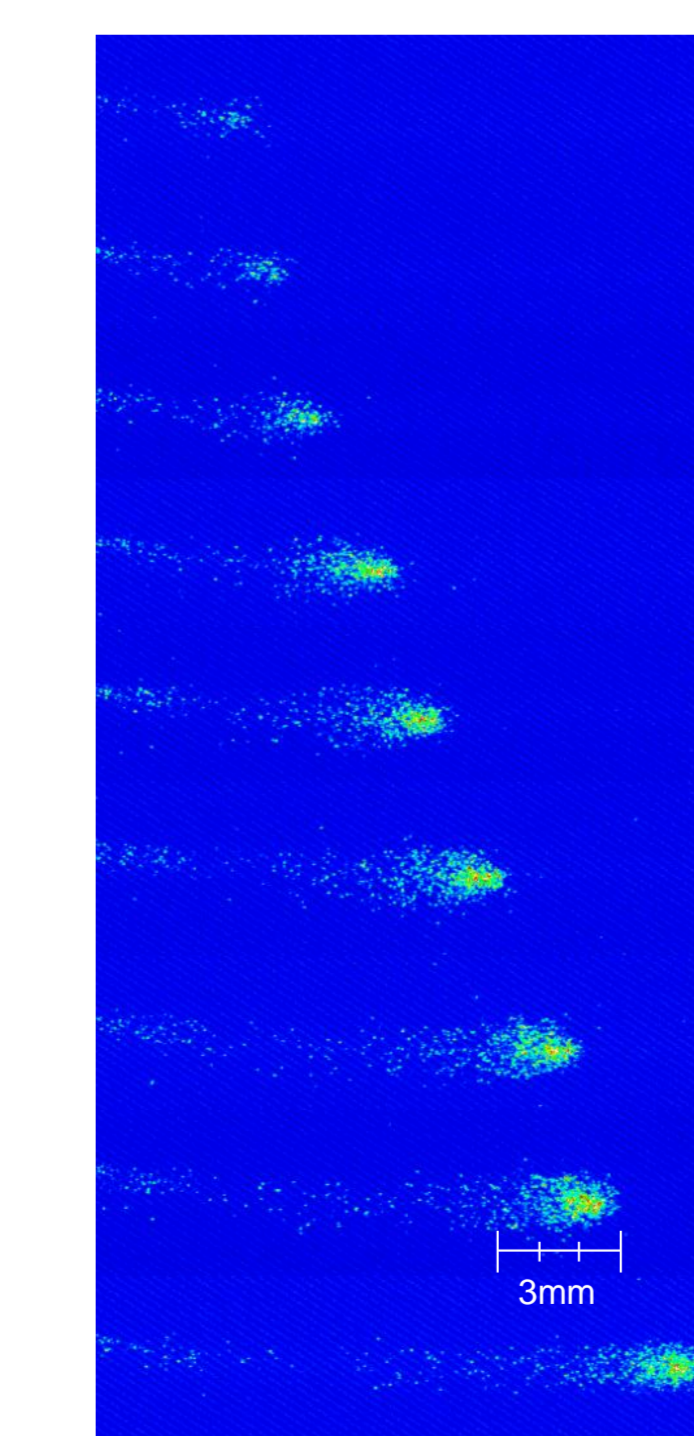


optical emission spectrum from a piezo plasma jet in He, expanding into air



DBD plasma source operation in Helium at 1 bar mixture with ambient air

Plasma Bullet Model



CCD photos: 100 ns delay

- luminous head is a positive space charge cloud
- generates photo-ionization at some distance in front of head
- accelerated electron avalanche causes backward towards head
- positive head is neutralized but electrons leave a new positive head region to the right

Conclusions

- piezo plasma source is a non-thermal surface discharge that may be operated in a wide pressure range
- can be realized in various geometrical designs (tubes, plates, stacks), either with or without metallic electrodes
- only some volts of primary voltage needed because of very efficient voltage amplification → "electrically safe"
- at atmospheric pressure conditions the produced ions are cold (approx. room temperature)
- in Helium not only He I lines are observed but also Nitrogen and Oxygen atomic lines and the OH band at 308 nm
- the optical spectrum of the piezo plasma source in the visible spectral range is very similar to the spectrum of a classical cylindrical dielectric barrier discharge (DBD)
- the VUV spectrum of the DBD shows H I and O I lines (air, water)
- at reduced pressures (down to 0.1 mbar) the plasma still ignites easily
- at lower pressure plasma is diffuse and expands to a larger volume
- plasma radiation is most intensive at approx. 1 mbar
- plasma consists of isolated "bullets" propagating with high velocities

References

- [1] B. Gellert, U. Kogelschatz, *Appl. Phys. B* **52**, 14 (1991)
- [2] International Patent WO2007006298
- [3] A. Brockhaus, R. Sauerbier, and J. Engemann, *Eur. Phys. J.: Appl. Phys.* **47**, 22809 (2009)
- [4] P. Kurucz, J. Lopez, H. Shah, K. Becker, *Int. J. Mass Spec.* **205**, 277 (2001)
- [5] B. L. Sands, B. N. Ganguly, K. Tachibana, *IEEE Trans. Plasma Sci.* **36**, 956 (2008)