INP
FROM IDEA TO PROTOTYPE

SIEMENS
Ingenuity for life

Properties of Vacuum Arcs Generated by Switching RMF Contacts at Different Ignition Positions

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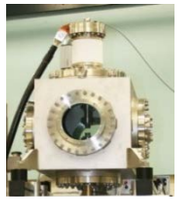
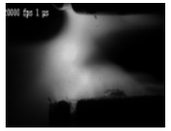
FROM IDEA TO PROTOTYPE

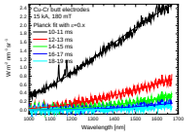
Outline

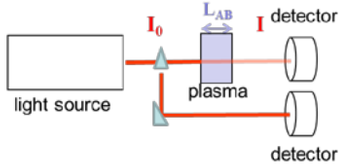
- Introduction
- Motivation



- Experimental setup
- Results and discussion
  - Arc dynamics
  - Surface temperature measurements
  - Vapour density measurements







- Summary

Introduction

Vacuum interrupters

- outstanding insulation properties
- simple design, small number of components
- environmentally friendly operation – zero emission (no harmful gases, no light emission, no waste products)
- maintenance-free

High-current operation

- strong electrode melting and evaporation
- measures of for reduction of thermal load necessary
- use of magnetic filed for arc control

Two basic operation principles

- radial magnetic field (RMF) contacts: arc rotation over the electrode surface (constricted arc)
- axial magnetic field contacts (AMF): expansion of the arc column over most of the electrode surface (diffuse arc motion, and thereby the performance of the contacts.

Introduction: vacuum interrupter design

Terminal disc

Insulator (ceramics)

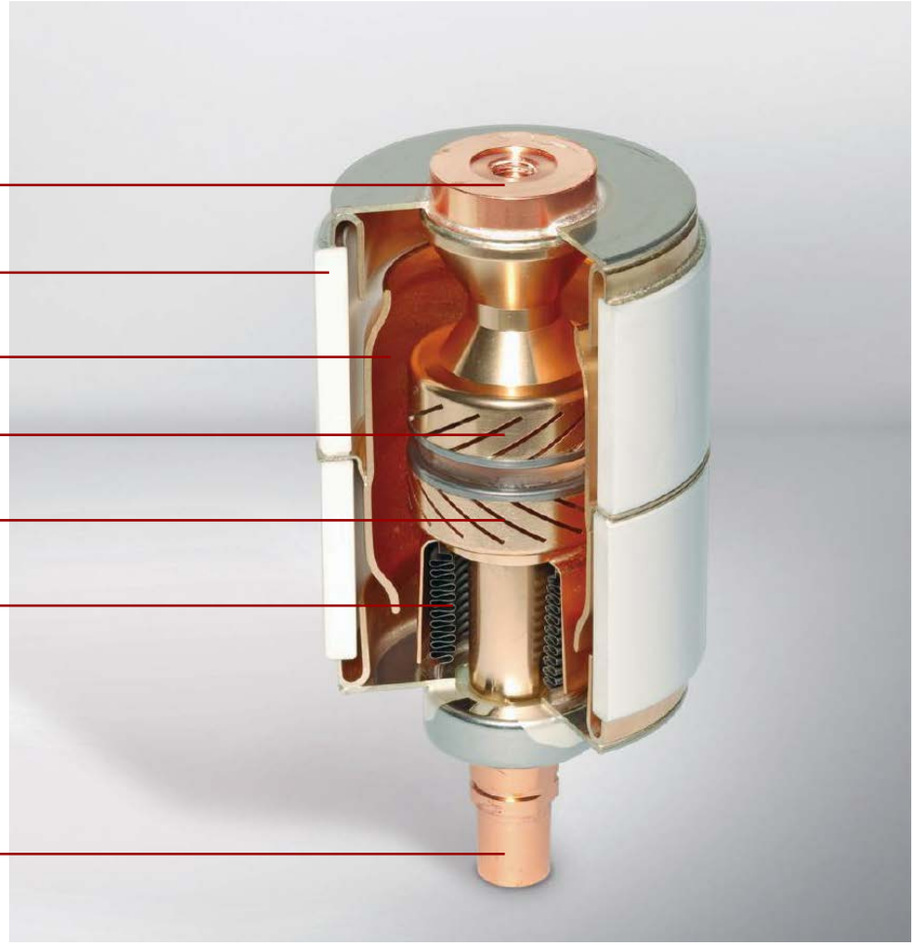
Arcing chamber made of copper

Fixed contact

Movable contact

Metal bellows

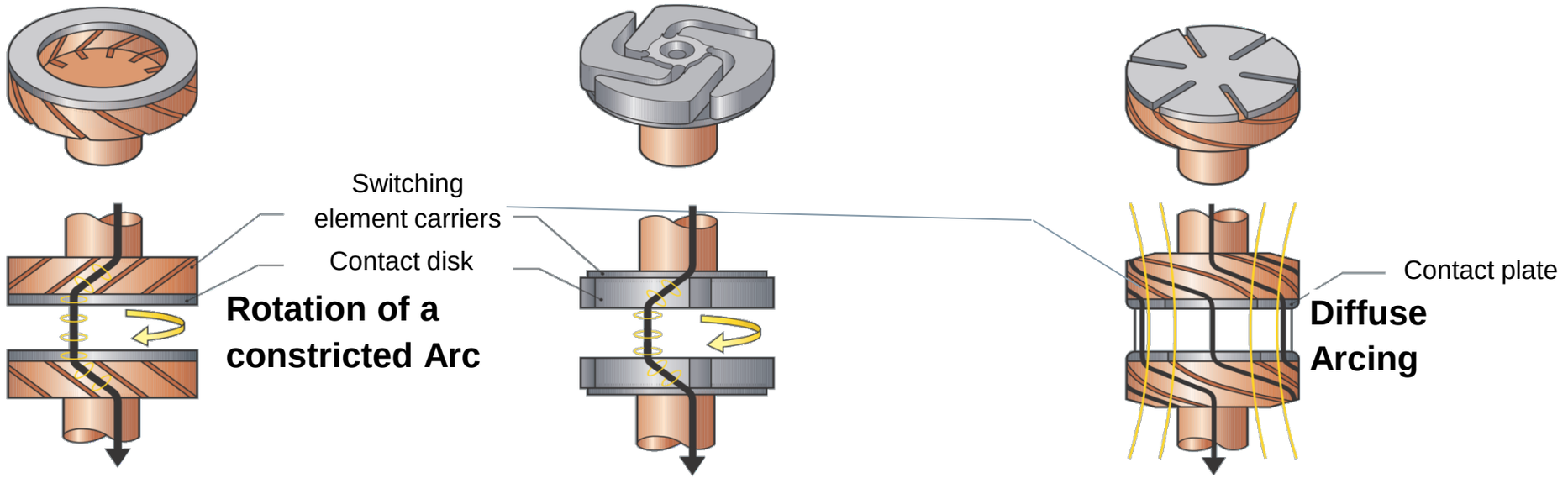
Operating and connecting bolt



Introduction: vacuum arc controlled by magnetic fields

Radial magnetic field contact (RMF)

Axial magnetic field contact (AMF)



The contact geometry & magnetic field creation have a decisive influence on the switching capacity of a vacuum interrupter. Various contact geometries are used depending on the current & voltage ratings.

Motivation

Open questions

- Influence of initiation behavior of the drawn arc on
  - arc motion
  - arc characteristics during the active phase
  - post-arc parameters

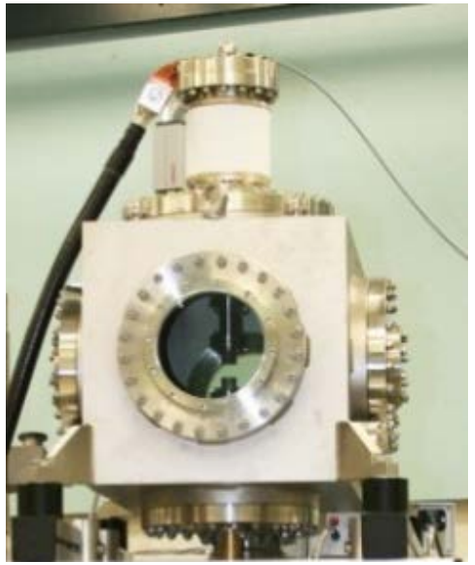
Focus on

- arc dynamics
- anode surface temperature after current interruption
- neutral vapor density after current zero crossing

Experimental setup: model vacuum interrupter

commercial vacuum interrupter

- Typical volume 0.5 l
- Stroke 5 – 20 mm
- Operation velocity 0.5 - 2 m/s



model vacuum interrupter

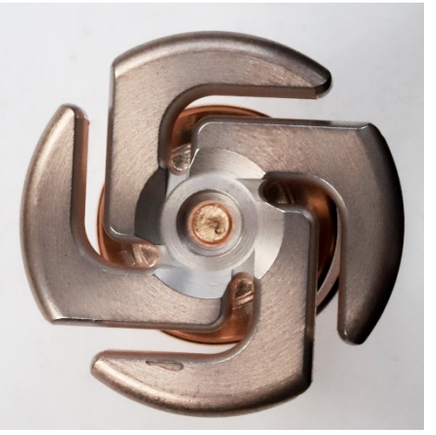
- Volume 52 l
- Mountings for various electrodes
- Stroke 5 - 25 mm
- Operation velocity 0.5 - 4 m/s

Experimental setup: electrodes

type A

type B

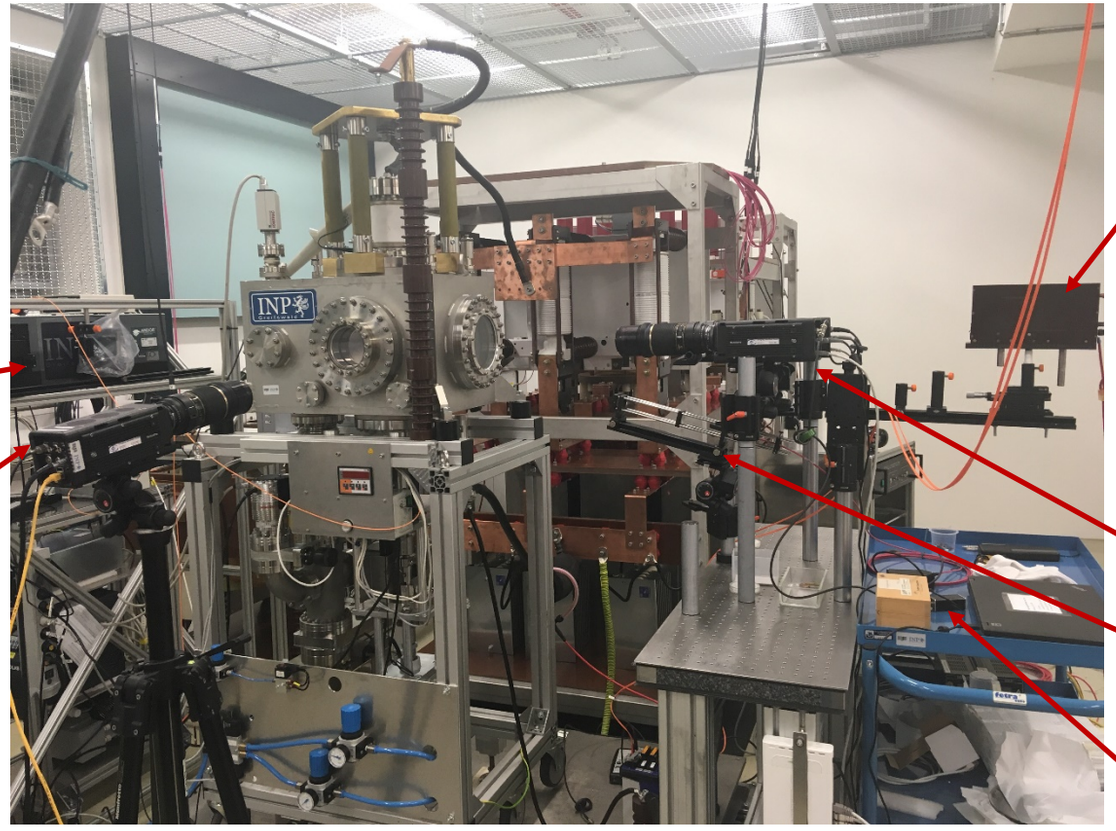
cathode



anode

- CuCr 60/40, ∅ 34 mm
- Defined ignition positions on movable electrode (cathode)
- Two distinguished positions – close outer boundary and close to the center

Experimental setup: diagnostics



0.75 m Spektrograph

High-speed camera, arc dynamics

Xe flash lamp

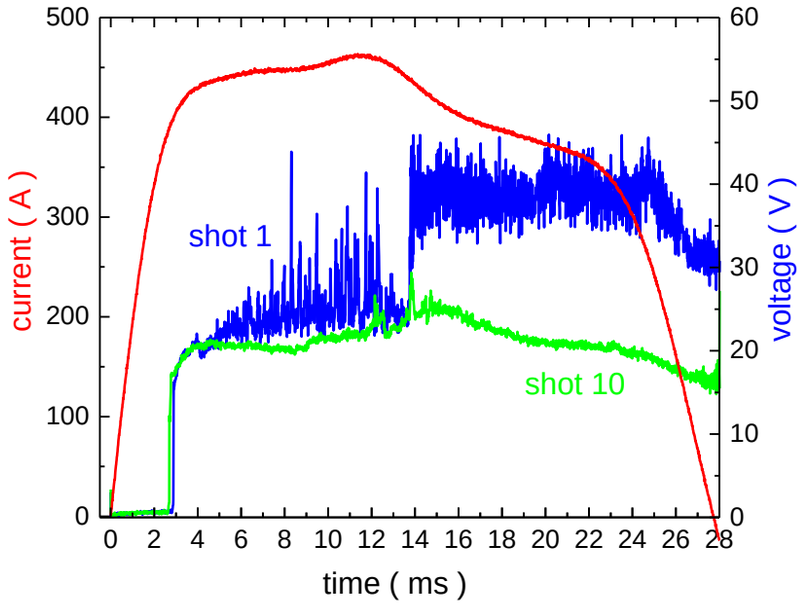
2x high-speed cameras with filter

NIR optics

NIR spectrometer

- Broad use of optical diagnostics: non-invasive methods, quantitative characterization of arc plasma and electrode surface

Results: electrodes conditioning

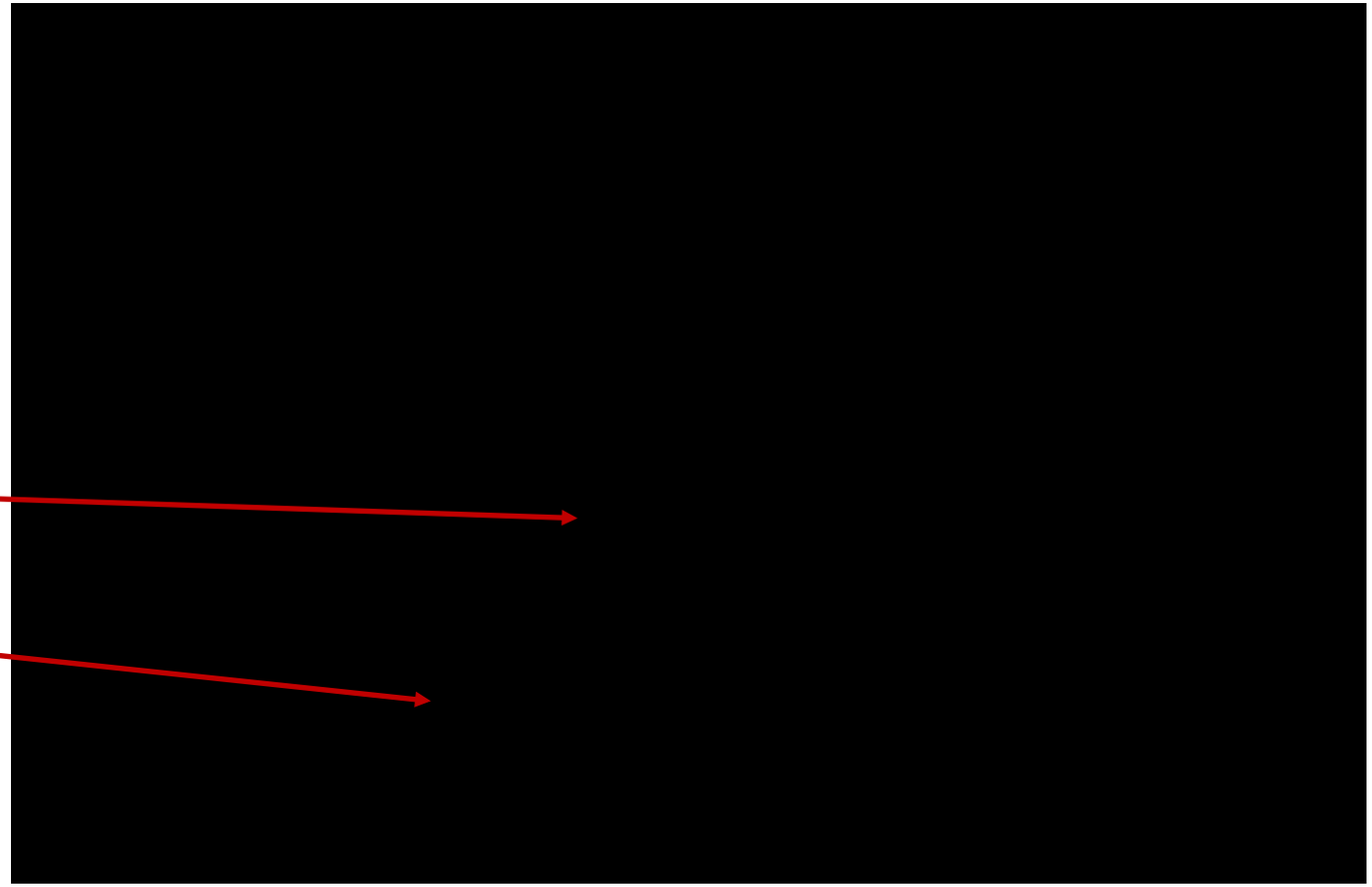


electrical signals

video

- Diffuse arc at pulsed DC operation, 20 ms, 430 A, 10 shots
- Control over the shape of voltage curve and pressure increase inside the chamber after the shot – ca 2×10^{-5} mbar after 1st shot, ca 2×10^{-6} mbar after 10th shot (measured at the instant of 20 seconds after shot)

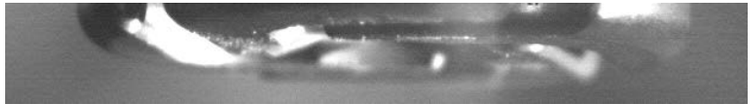
Results: arc dynamics

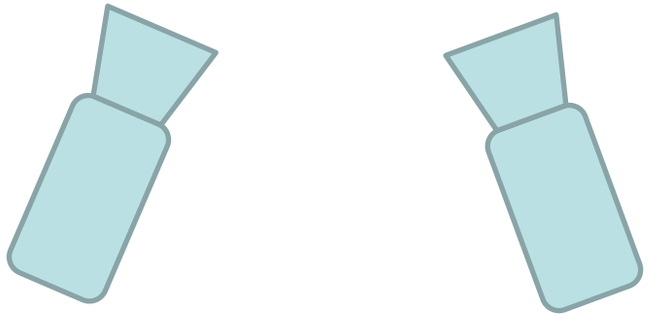


- Ignition at desired position (outer boundary, type A)
- Arc movement starts after appearance of an anode spot and arc constriction
- 2 rotations per ms at present experimental conditions
- Longer residence time in central part of electrode in case of ignition position B

Results: arc dynamics

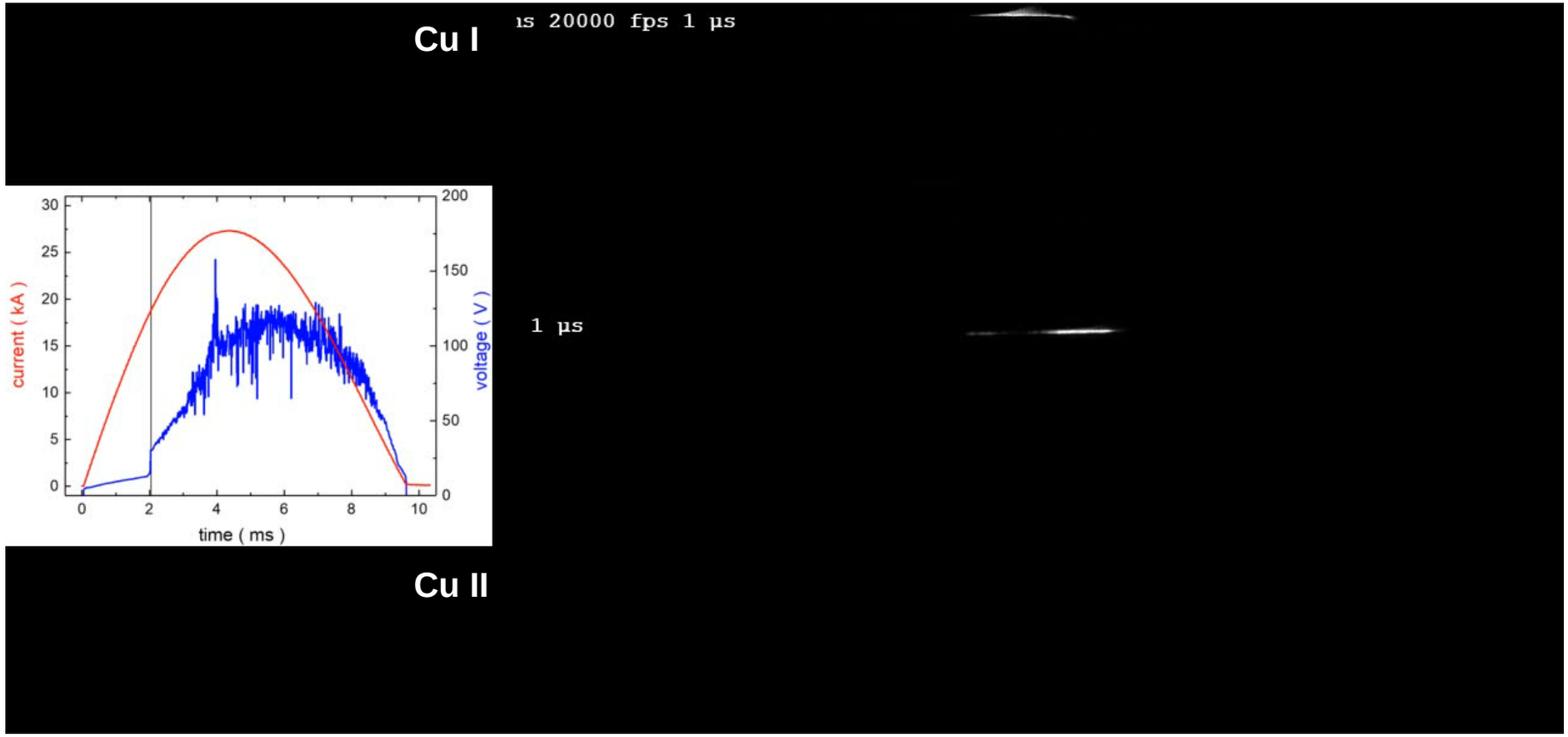
Acquisition with narrow-band filter (MIF, 1 nm FWHM) 521 nm (Cu I) and 494 nm (Cu II)





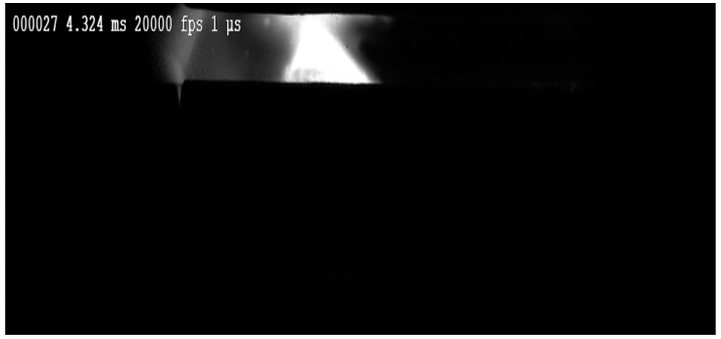
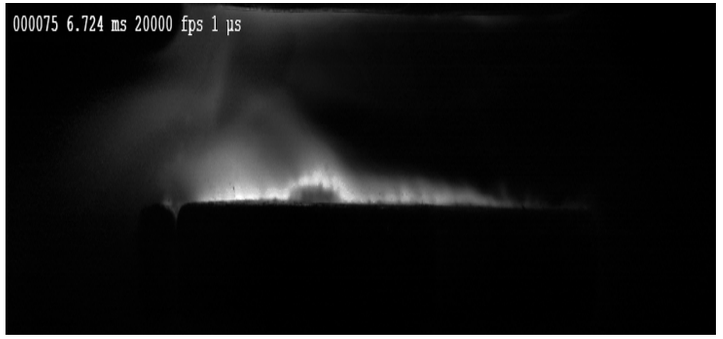
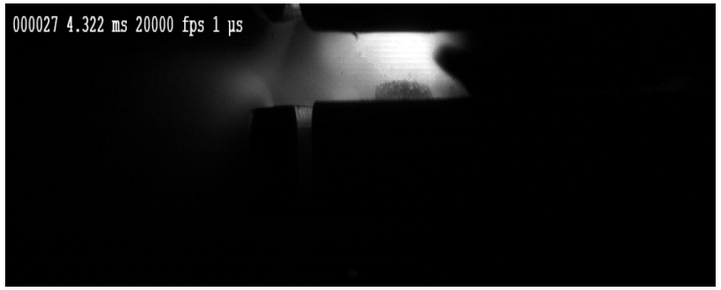
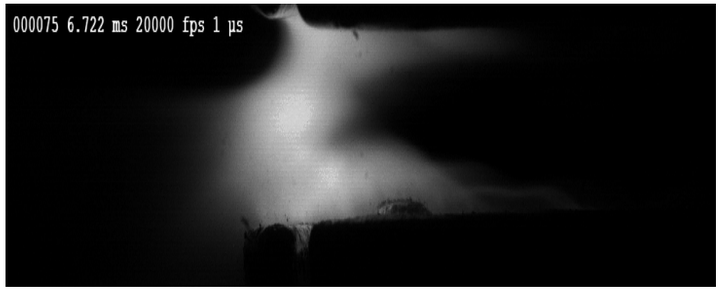
- Focus on distinguishing between ion and atom dynamics

Results: arc dynamics



- Pronounced differences in spatial distribution of atoms and ions

Results: arc dynamics

	4.3 ms	6.7 ms
Cu I		
Cu II		

- Higher atomic line radiation intensity at the beginning
- Increasing intensity of ionic lines with progressing time
- Localization of atomic line radiation in the broader regions close to the electrode surface
- However, no differences between studied ignition positions found

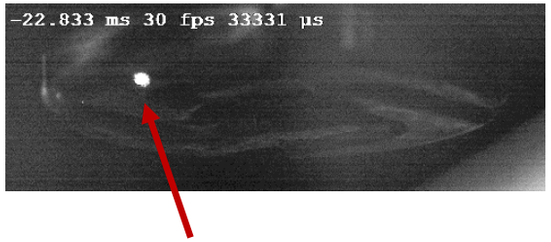
Results: anode surface temperature

NIR 900-1600 nm

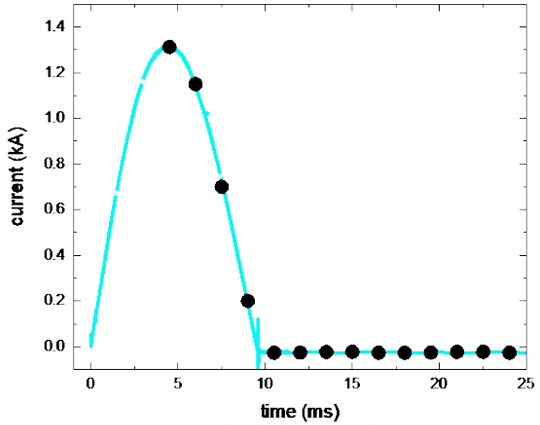
+

NIR optics

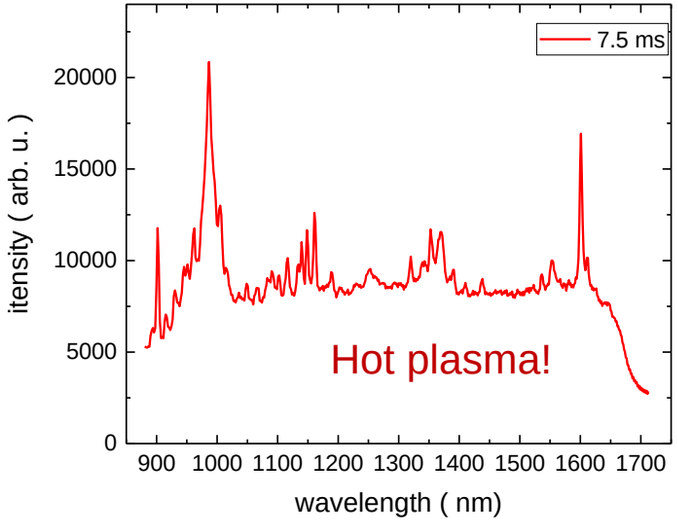
=

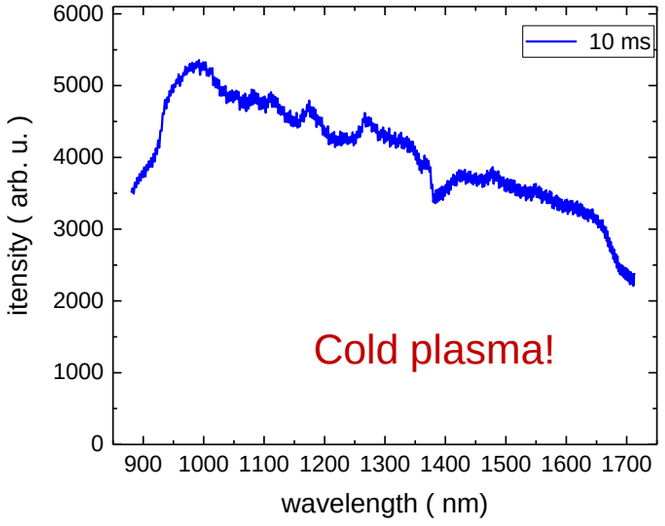


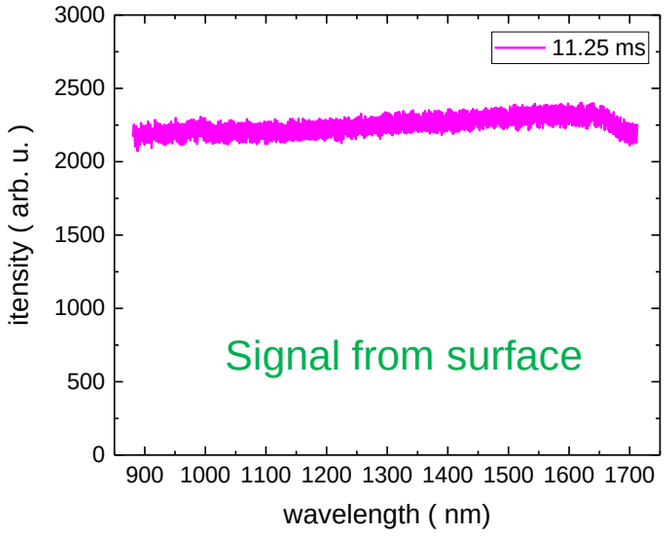
measuring point



acquisition times



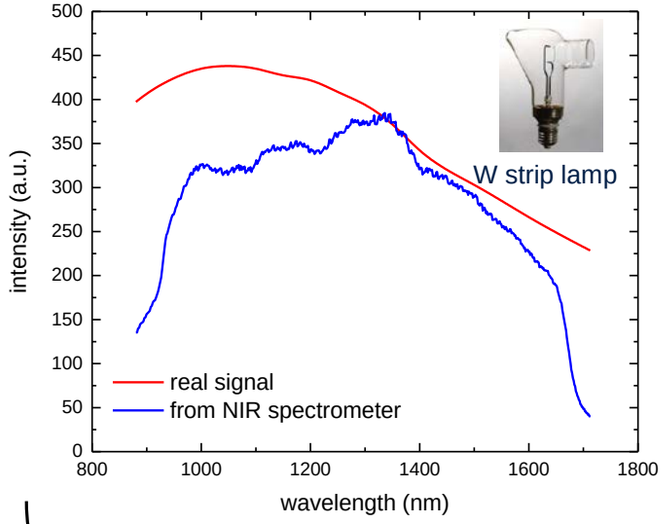




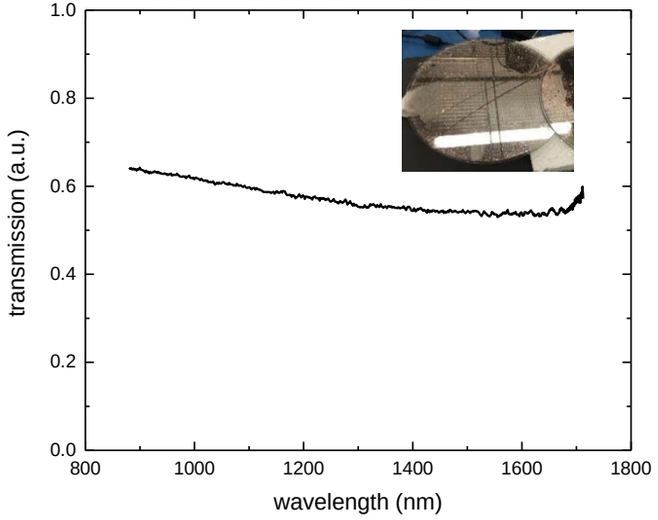
- Evaluation of NIR spectra emitted by hot electrode surface

Results: anode surface temperature

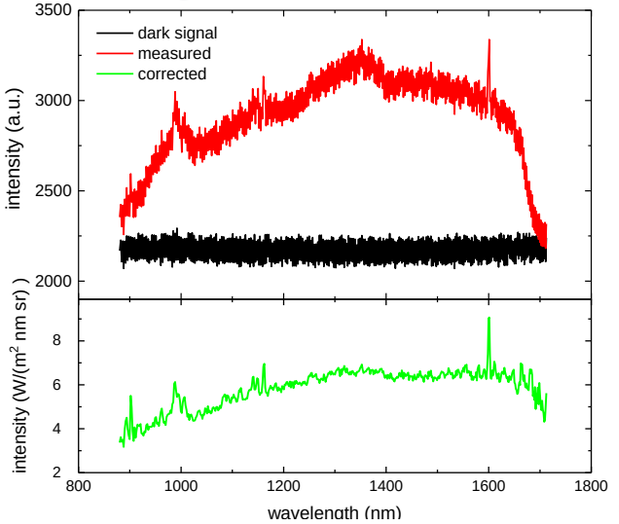
calibration



window transmission

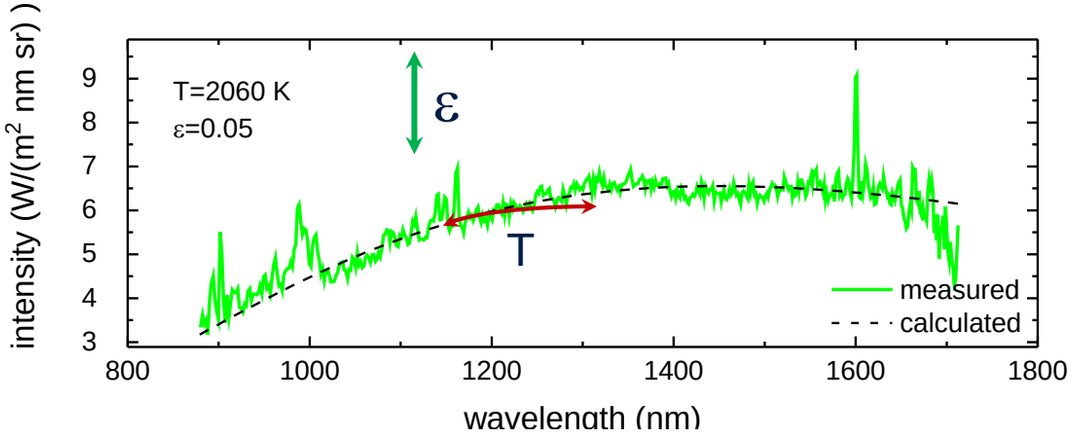


background correction

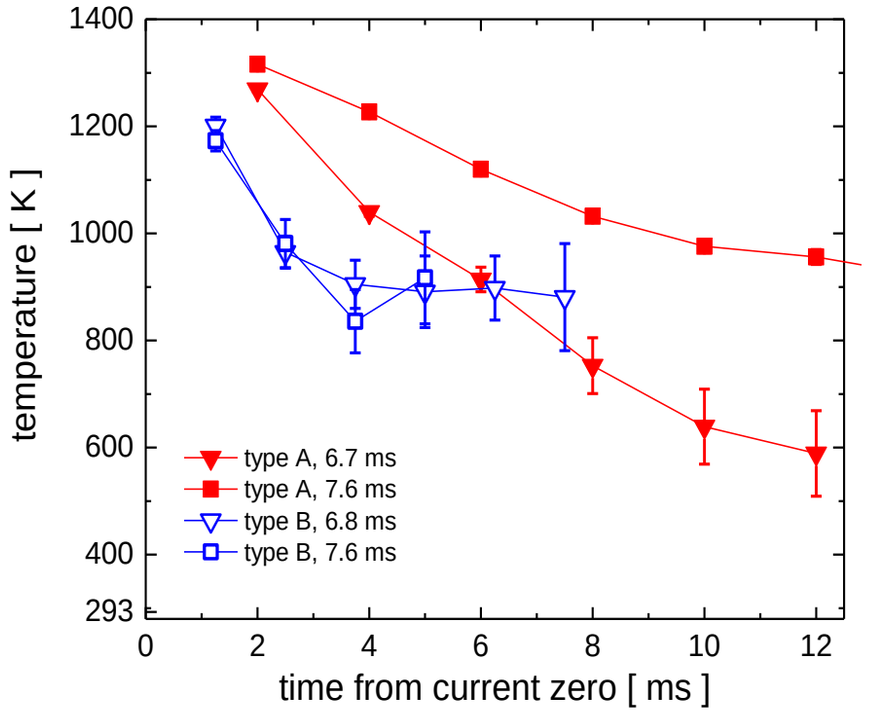


determination of T and ε from Planck fit

$$B_\lambda(T) = \varepsilon(\lambda, T)\,\frac{2hc^2}{\lambda^5}\cdot\frac{1}{e^{\frac{hc}{\lambda\cdot kT}}-1}$$



Results: anode surface temperature

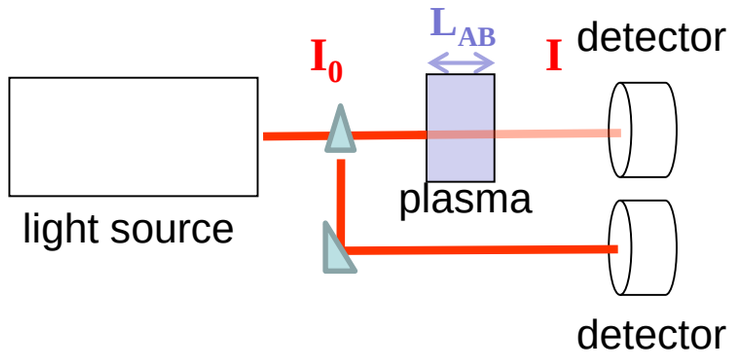


- Initial temperature in the range between 1200 K and 1400 K
- Higher temperature at longer arc duration
- Higher temperature in case of position A probably due to higher total residence time of the arc at this position

Results: vapour density

Principle of absorption spectroscopy

- Light source and detector



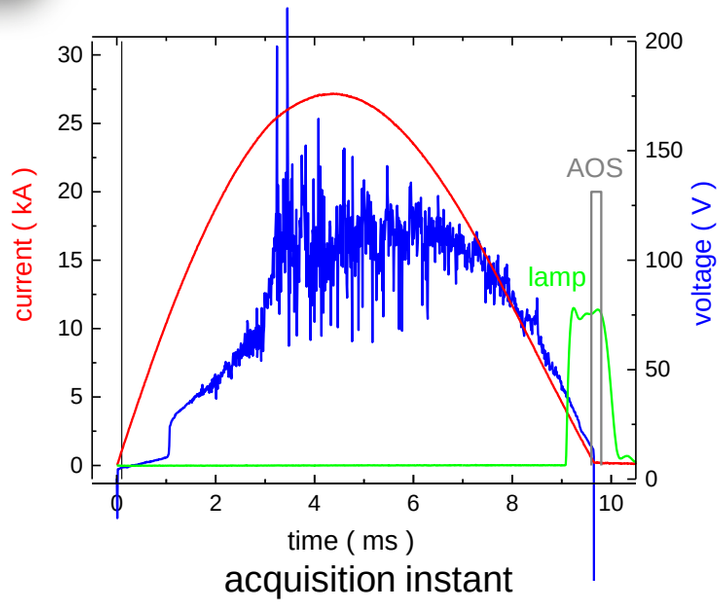
- Optical thickness

$$\tau(\lambda_L) = -\ln\left(\frac{I(L_{Ab},\lambda_L)}{I_0(\lambda_L)}\right)$$

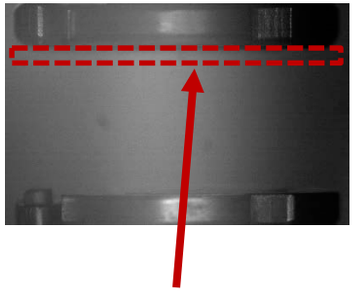
- Density of absorbing species

$$\frac{1}{L_{AB}}\int_0^\infty \tau(\lambda_L)d\lambda = \frac{\pi e^2\lambda_0^2}{\varepsilon_0 m_e c^2} N_l f_{lu}$$

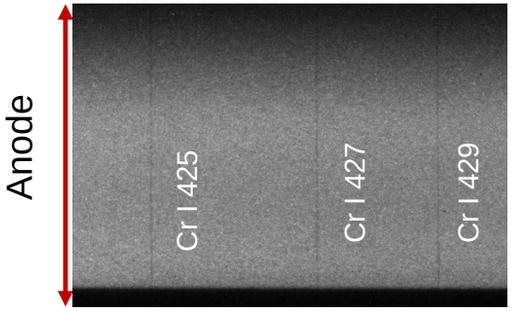
Results: vapour density

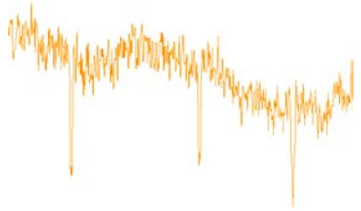


acquisition instant

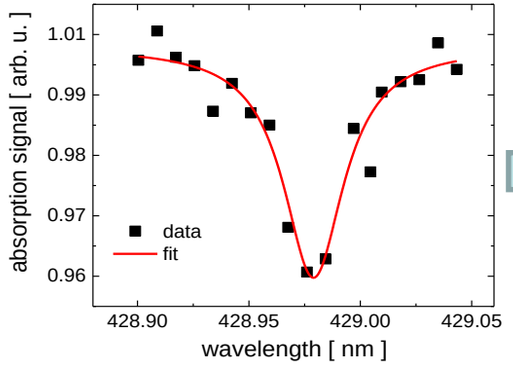


slit orientation





absorption spectrum

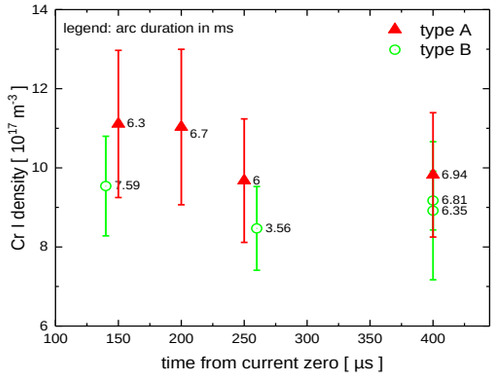


line fit

central wavelength λ	oscillator strength f_{lu}
425.435	0.11
427.481	8.42×10^{-2}
428.973	6.23×10^{-2}

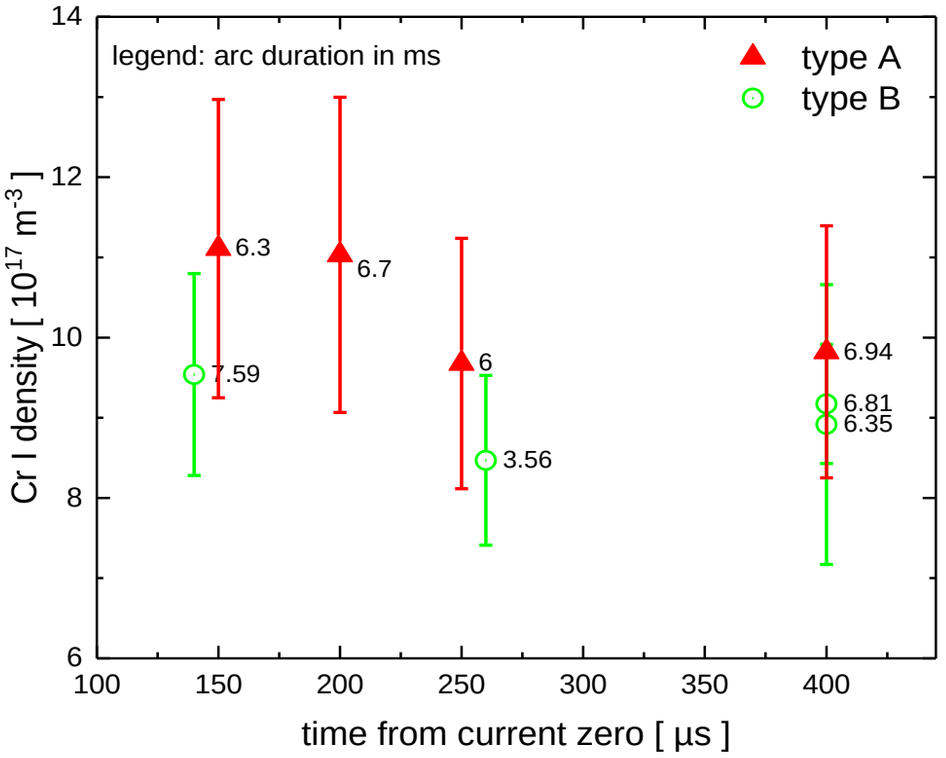
$$\frac{1}{L_{AB}} \int_0^{\infty} \tau(\lambda_L) d\lambda = \frac{\pi e^2 \lambda_0^2}{\varepsilon_0 m_e c^2} N_l f_{lu}$$

data processing



density

Results: vapour density



- Slow density decay within first 400 µs after current interruption
- Higher chromium density in case of longer arc duration
- Higher chromium density in case of position A due to higher anode surface temperature

Summary

- Clear influence of initiation behavior of the drawn arc on arc parameters was found
- Higher electrode temperature in case of the electrodes with position A (ignition point near the outer boundary of the electrode)
- Consequently higher density of chromium vapor, even though the arc duration was longer.

Thank you very much for your attention!

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Optical diagnostics: advantages and disadvantages

- Clear advantages of optical methods
  - non-invasive
  - qualitative and quantitative measurements possible
  - high spatial resolution – local properties
  - high temporal resolution – dynamics
  - applicable in a wide parameter range due to variability of methods
- Some disadvantages of optical measurements
  - optical access to the object necessary
  - radiation intensity must be sufficient
  - distortions in the optical pathway through hot fluxes and plasma itself
  - costs of the devices, complex apparatus and evaluation methods