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FROM IDEA TO PROTOTYPE

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Surface Temperature Dynamics of Switching RMF and AMF Contacts

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FROM IDEA TO PROTOTYPE

Outline

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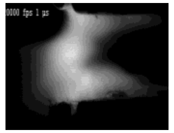
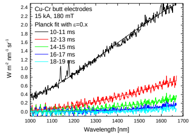
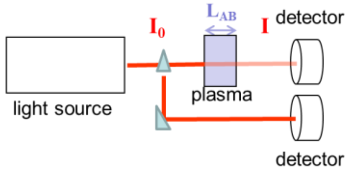
- Motivation

- 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

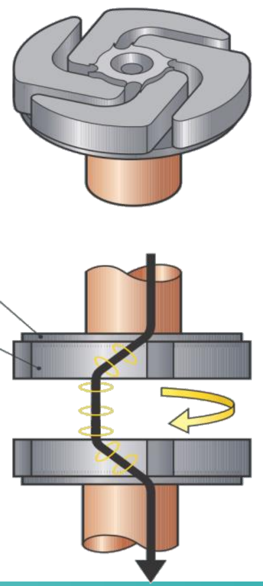
- strong electrode melting and evaporation
- measures for reduction of thermal load necessary
- use of magnetic field for arc control

Two basic operation principles

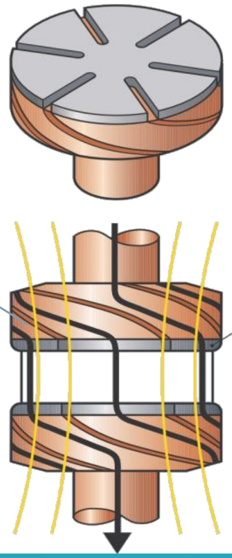
- radial magnetic field (RMF) contacts: arc rotation over the electrode surface (constricted arc motion)
- axial magnetic field contacts (AMF): expansion of the arc column over the total electrode surface (diffuse arc expansion)

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

- Role of electrode evaporation
  - source of the switching medium – metallic vapour arc
  - shorter lifetime due to local thermal load/electrode surface overheating
  - reduce of the switching capacity in case of too high vapor density after current termination
- High neutral metal vapor density caused by anode activity
- Control over the arc behavior and over anode thermal load is necessary
- Focus on
  - arc dynamics
  - anode surface temperature around current zero crossing
  - neutral vapor density after current interruption

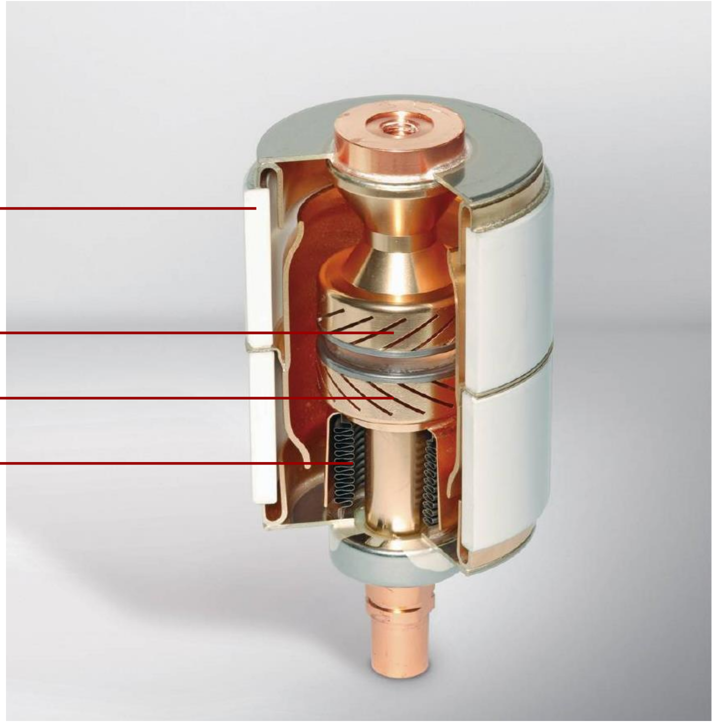
Experimental setup: model vacuum interrupter

Insulator (ceramics)

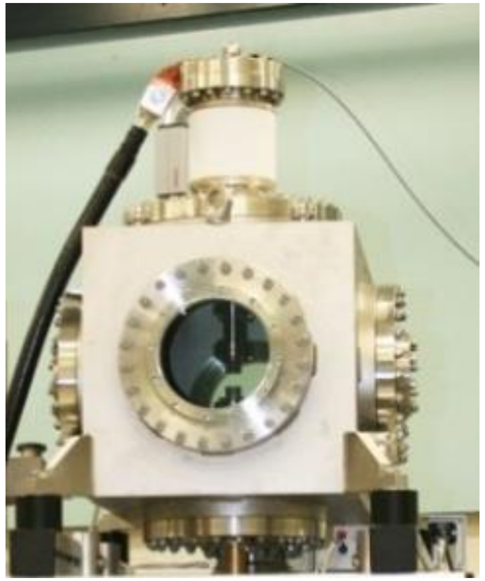
Fixed contact

Movable contact

Metal bellows



commercial vacuum interrupter



model vacuum interrupter

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

Experimental setup: electrodes

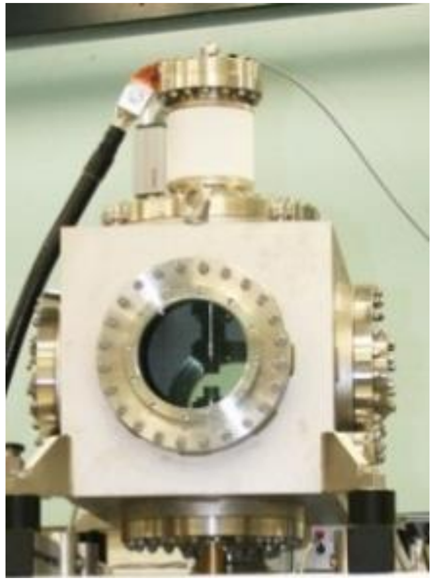
RMF

- CuCr
- ∅ 34 mm
- Max. current 28 kA (peak)

AMF

- CuCr
- ∅ 40 mm
- Max. current 23 kA (peak)

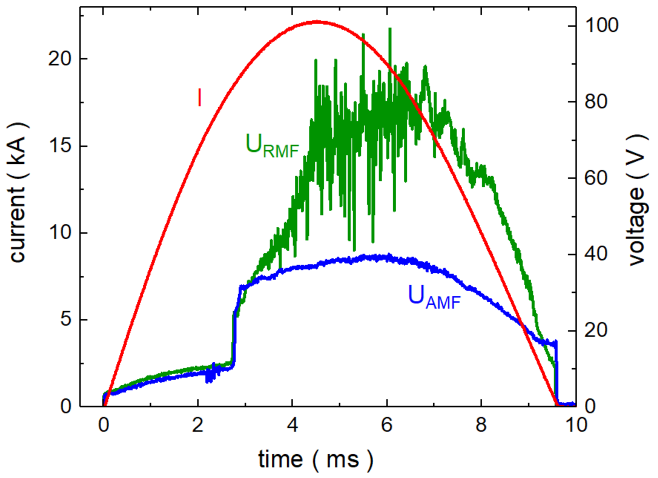
Experimental setup: diagnostics



vacuum chamber with moveable electrodes

- High-current generator, ~50 Hz, current range 400 A ÷ 28 kA
- Broad use of optical diagnostics: non-invasive methods, quantitative characterization of arc plasma and electrode surface

Results: arc dynamics



RMF contacts

AMF contacts

- Higher arc voltage in case of RMF system
- RMF contact system:
  - localisation of the arc center at the periphery
  - ca. two rotations per ms at present experimental conditions
- AMF contact system:
  - localisation of the arc center in central part of electrode, independent on initial ignition position
  - expansion of the arc core with increasing arcing time

Methods: I. NIR spectroscopy

NIR 900-1600 nm

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NIR optics

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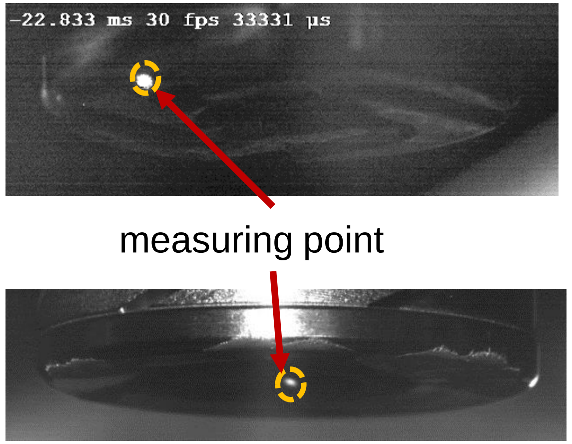
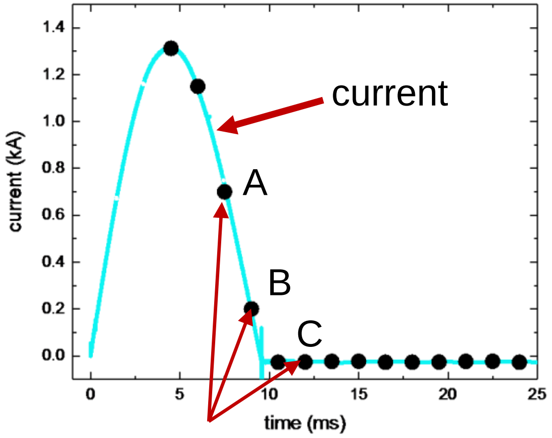
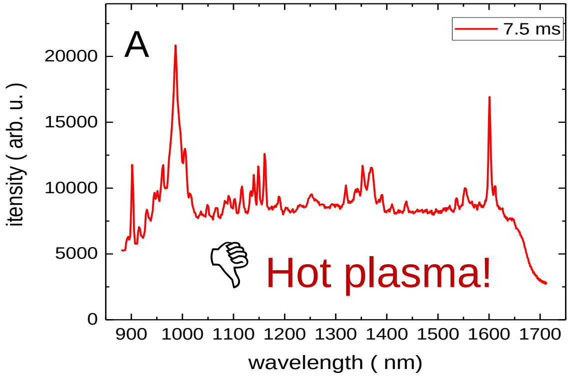
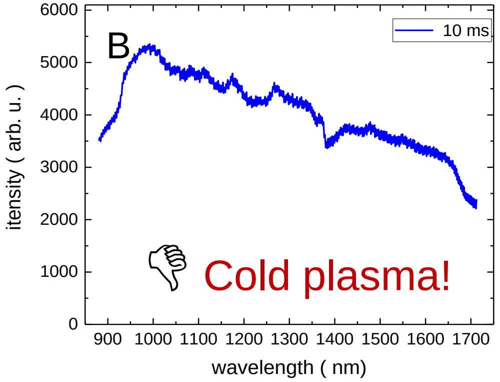
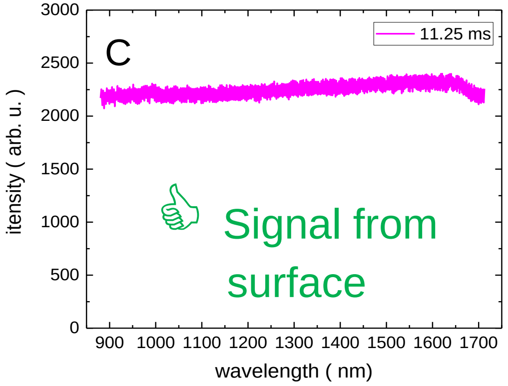
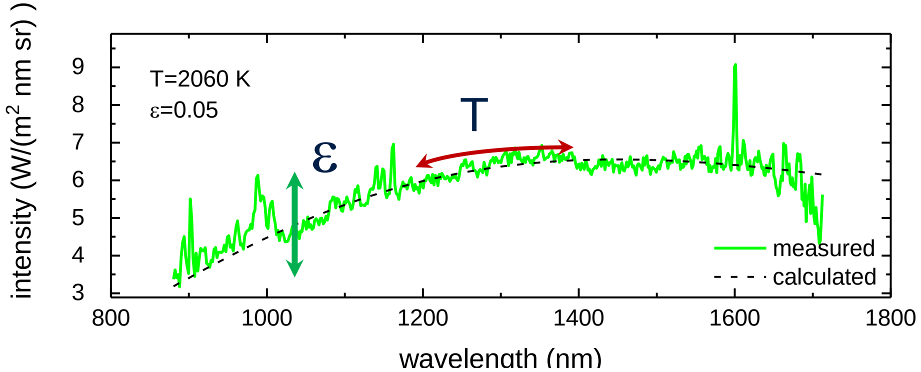








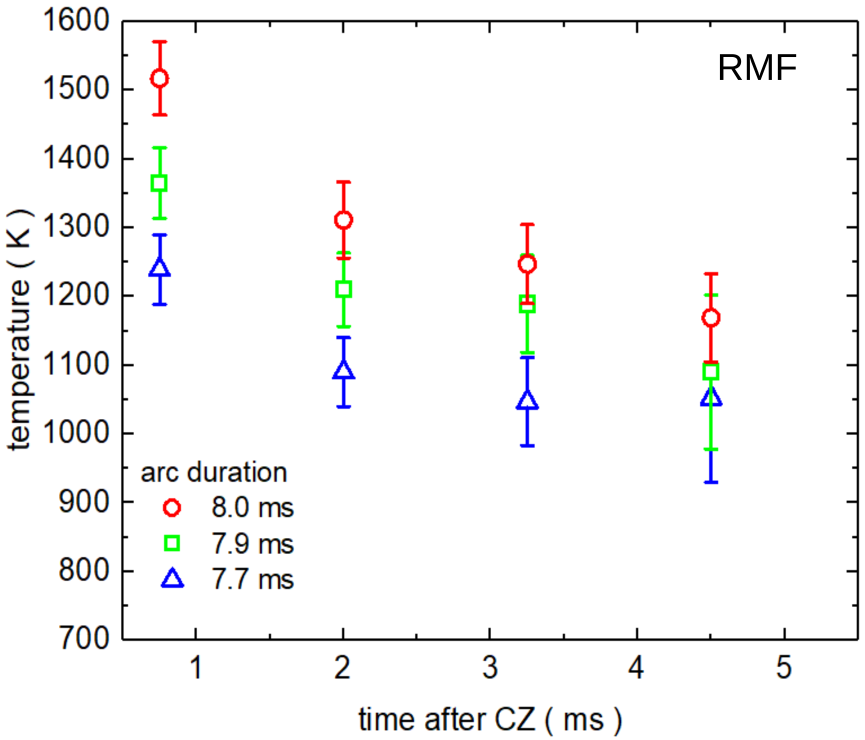


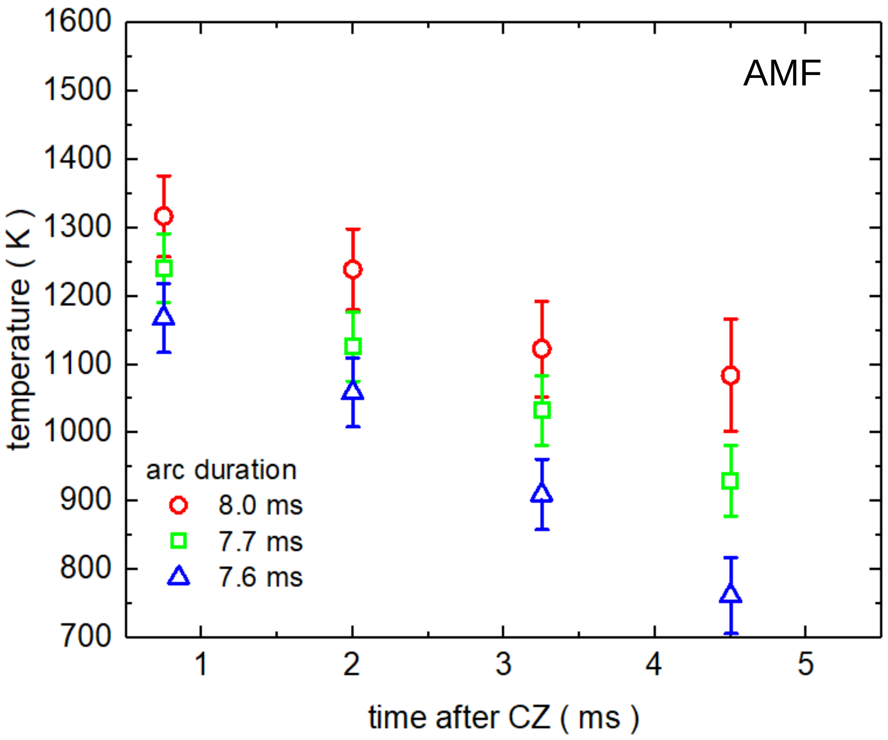


$$B_\lambda(T) = \varepsilon(\lambda, T)\frac{2hc^2}{\lambda^5}\cdot\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$$

- Evaluation of NIR spectra emitted by hot electrode surface
- Temporal resolution 1.25 ms

Results: anode surface temperature (I) - NIR spectroscopy





- Initial temperature in the range between 1150 K and 1520 K
- Higher temperature at longer arc duration
- Higher temperature in case of constricted arc (RMF contacts)
- Tendency to a faster temperature decay in case of AMF contact system

Methods: II. High-Speed Camera (HSC) with filter

High-speed camera
IDT Motion Pro Y4
5000-20000 fps

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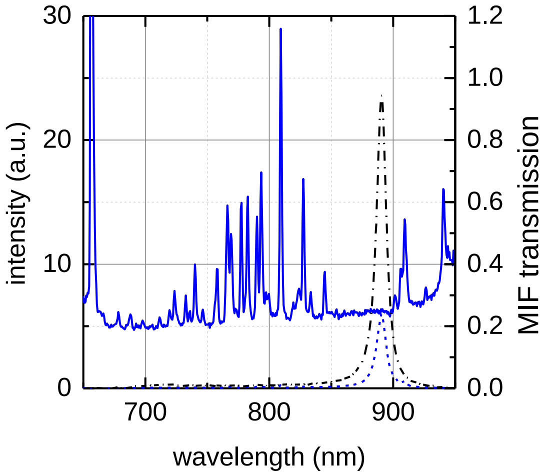

filter, which “blocks” plasma radiation

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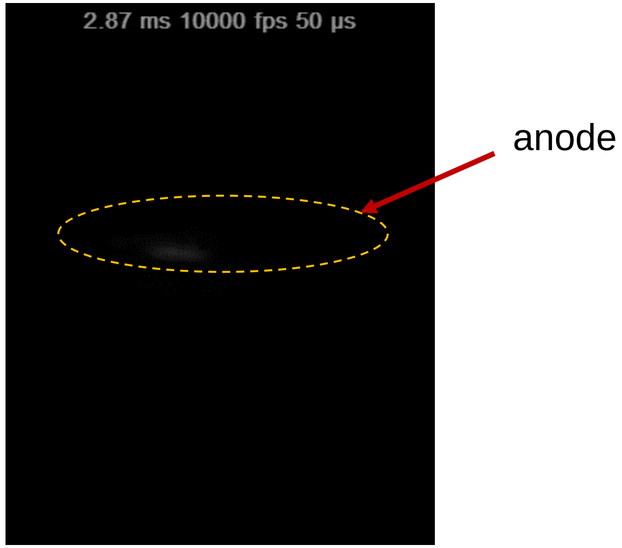
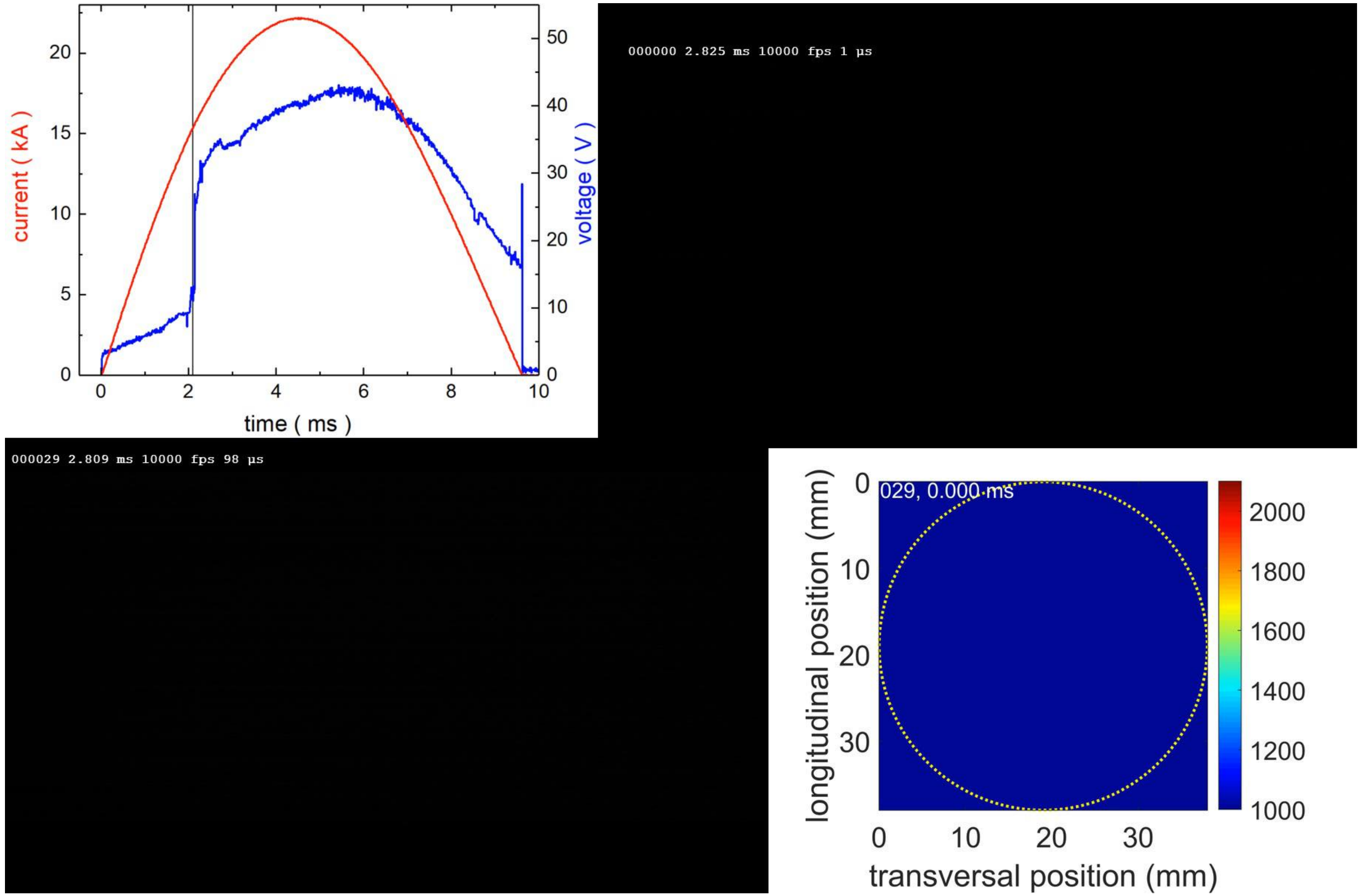


radiation image dominated by surface contribution

- The method gives **qualitative** 2D temperature distribution with high temporal resolution
- **Quantitative** temperature can be obtained after comparison with results of NIR measurements at certain spatial position and time instant
- Challenge: continuum radiation of plasma must be taken into account (“removed”)
- Subtraction of plasma radiation works well for diffuse arc only (AMF contacts) !

Results: anode surface temperature (II) – HSC with filter



- Evaluation possible after current maximum only
- Melting point reached in a wide region

Methods: III. Optical Absorption Spectroscopy (OAS)

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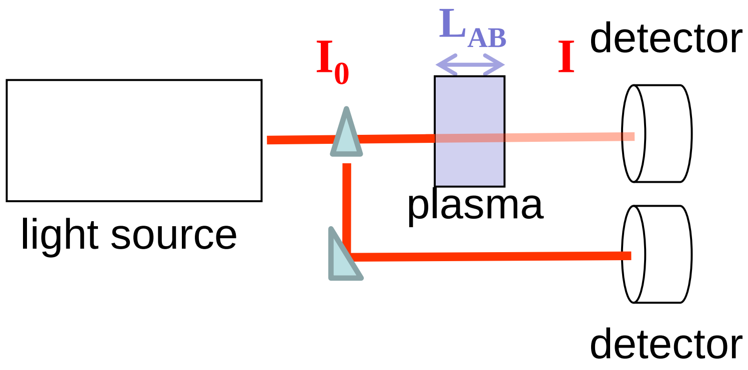
Principle of absorption spectroscopy

- Light source and detector



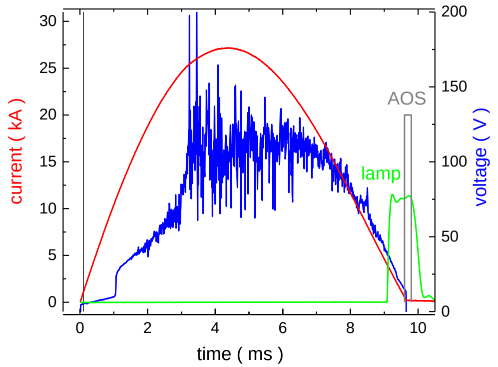
- Optical thickness

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

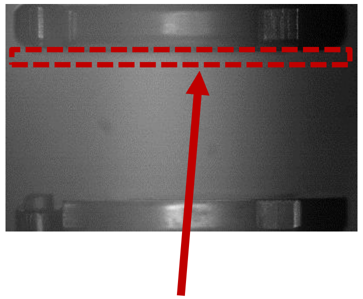
- Density of absorbing species

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

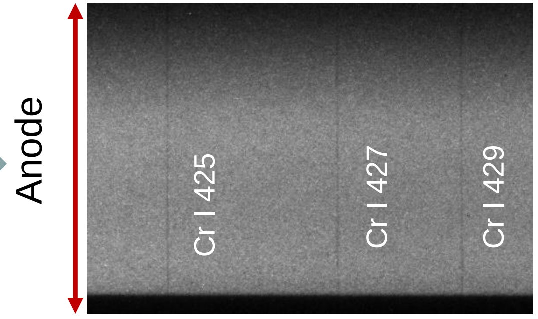
Methods: III Optical Absorption Spectroscopy (OAS)



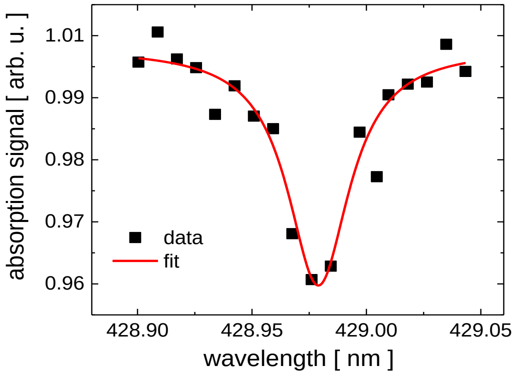
acquisition instant 80 µs after CZ



slit orientation



2D spectrum (iCCD image)

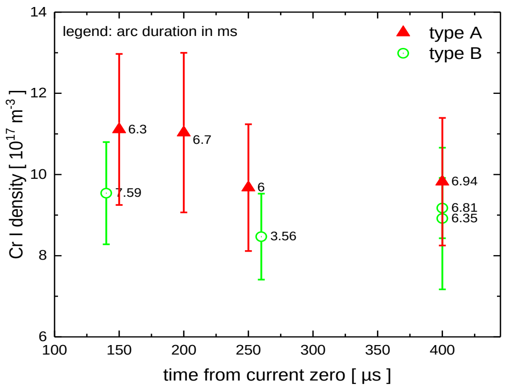


line fit

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

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

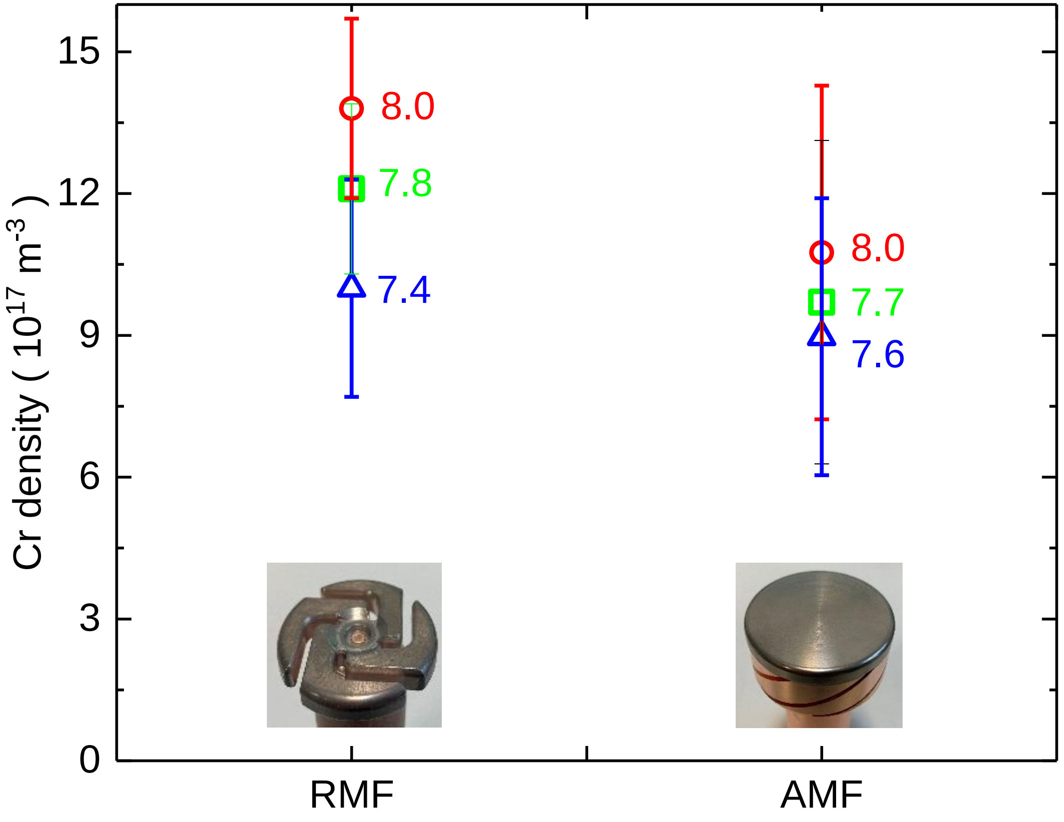
data processing



density

- The method gives **quantitative** distribution of ground state atoms
- Challenge: assumption on spatial distribution of vapour density (standard = homogeneous)

Results: Cr I density by OAS



- Higher chromium density in case of longer arc duration
- Deviations up to 30% both due to different operation conditions and electrode type

Summary

- Two optical methods for determination of surface temperature have been tested for switching vacuum contact systems, RMF and AMF.
- NIR spectroscopy works well for both type of contacts after current interruption (no plasma radiation).
- The method based on the high–speed camera techniques has restricted applicability. It works well for diffuse arcs and at certain electrode distance, which is typically reached after current maximum.
- RMF contact system tends to higher local anode surface temperature after current interruption due to more localized thermal load comparing to AMF system.
- Mean Cr density after current interruption is higher in case of RMF contacts.

Thank you very much for your attention!

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