Study of switching contacts by optical techniques

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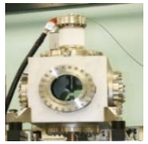
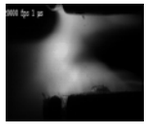
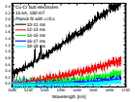
FROM IDEA TO PROTOTYPE

Outline



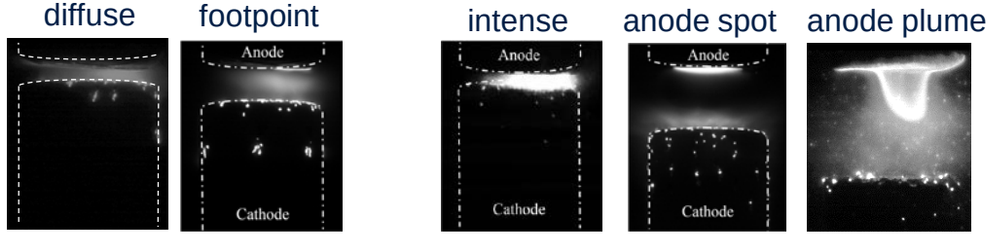
- Introduction/Motivation
- Experimental setup
- Results and discussion
  - Arc dynamics
  - Surface morphology
  - Surface temperature measurements
  - Dielectric withstand after current interruption
- Summary





Introduction

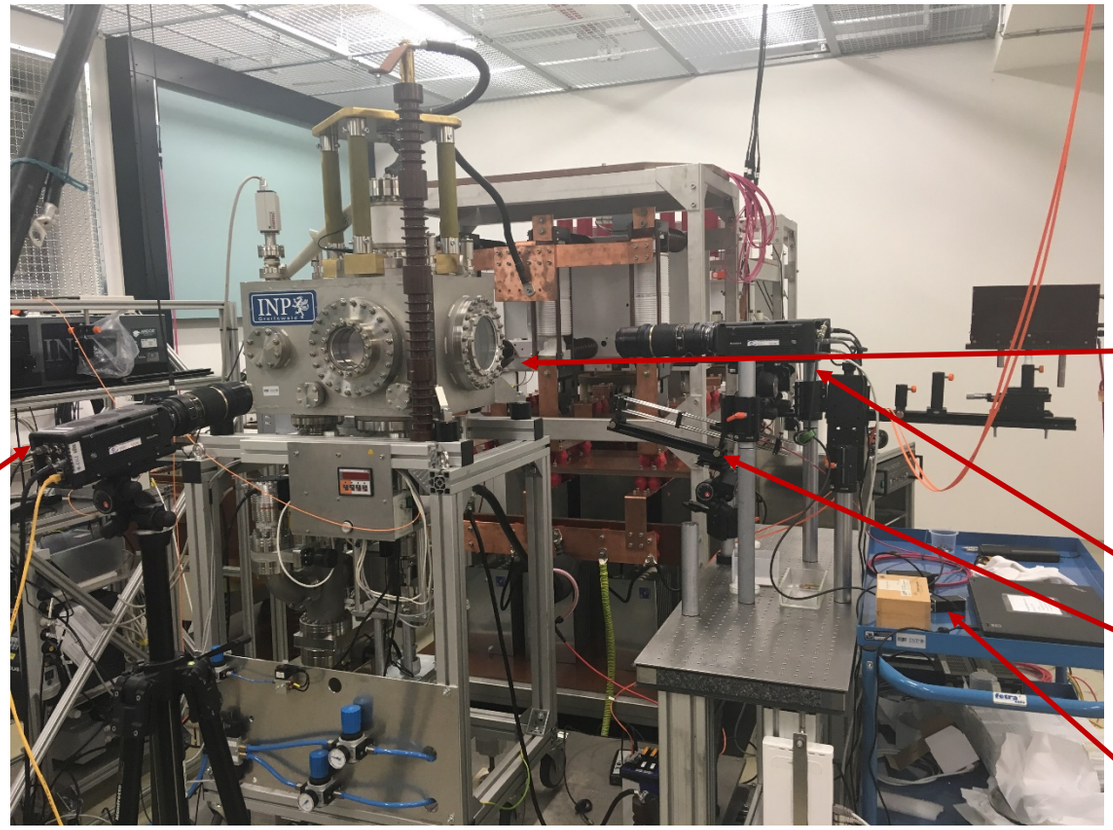
- Vacuum arcs widely used in switching devices
  - simple design, small number of components
  - environmentally friendly operation – zero emission (no harmful gases, no light emission, no waste products)
- Dual role of electrode evaporation
  - source of the switching medium – metallic vapor arc
  - 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
- Monitoring of thermal load and exploration of material limits for high-current operation required



Motivation

- Exploration of material limits for high-current operation
- Test of applicability of temperature determination method for various materials
- Focus on
  - arc dynamics
  - analysis of surface morphology
  - measurements of anode surface temperature
  - dielectric performance after current interruption

Experimental setup: diagnostics

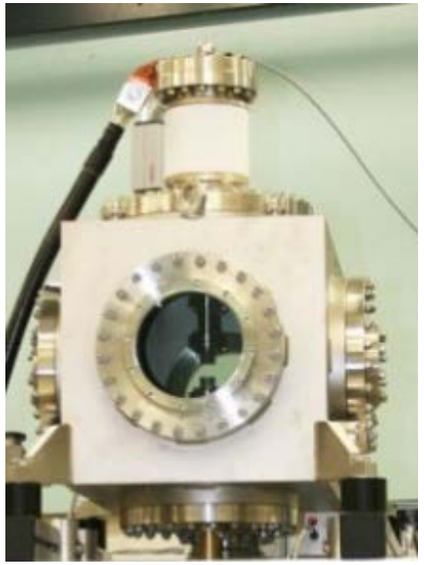


high-speed camera, arc dynamics

high-speed camera, surface temperature

NIR optics

NIR spectrometer



vacuum chamber with moveable electrodes

- Synthetic test circuit- combination of high-current generator 400 A ÷ 7 kA @ 50 Hz and transient recovery voltage (TRV) generator 42 kV@1000 Hz
- Broad use of optical diagnostics: non-invasive methods, quantitative characterization of arc plasma and electrode surface

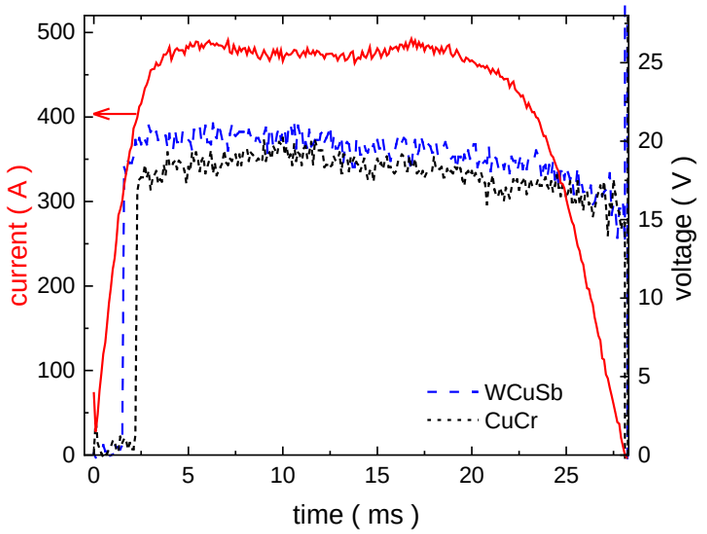
Experimental setup: electrodes

CuCr

WCuSb

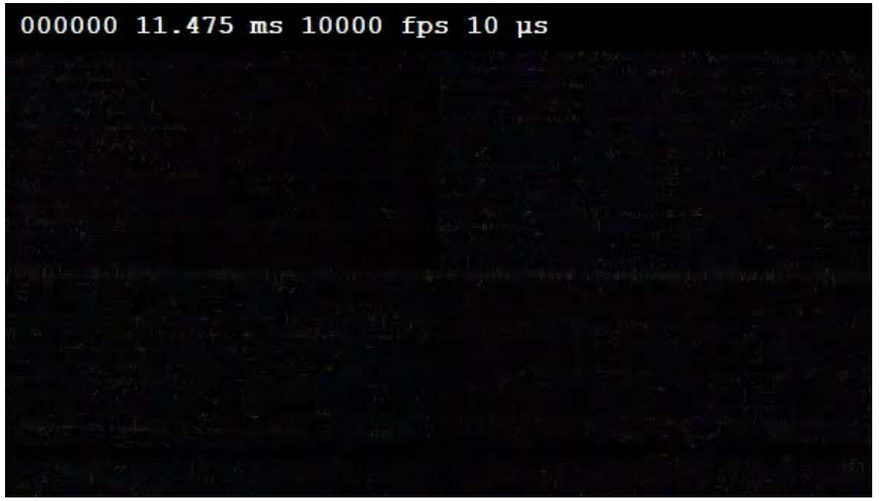
- ∅ 24 mm
- Max. current 0.5 kA (20 ms pulsed DC), 7 kA (peak, AC 50 Hz)
- Arcing time 3.3 – 9 ms
- Max TRV 21 kV

Results: arc dynamics – DC current



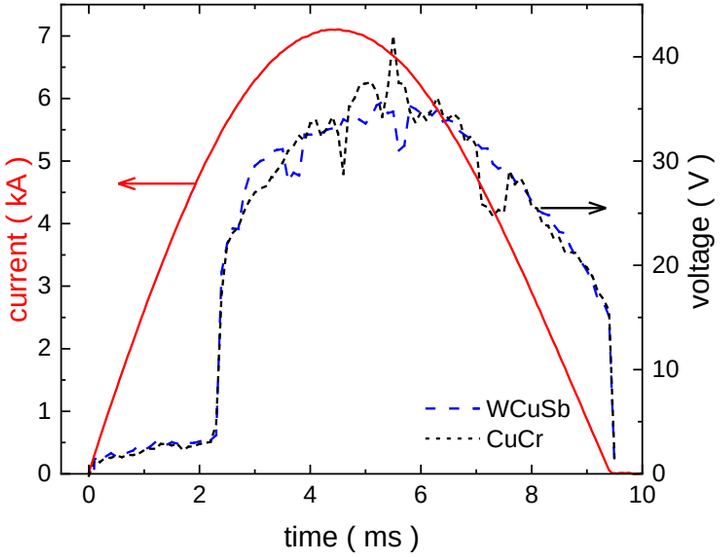
CuCr

WCuSb

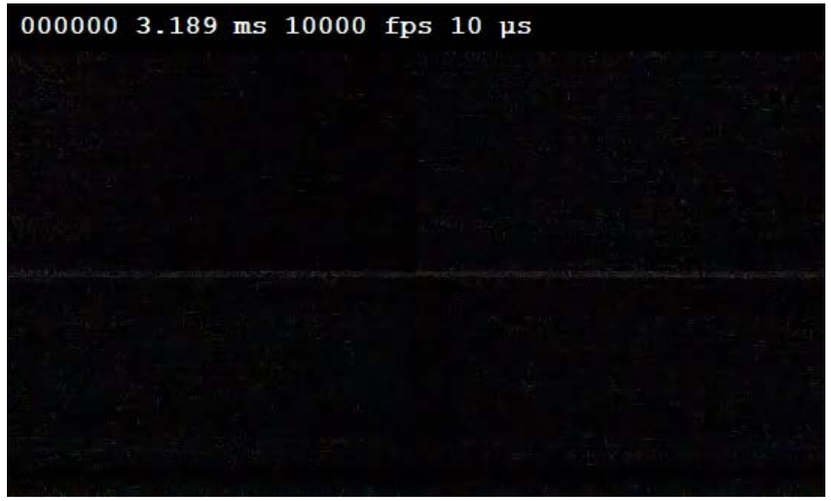


- Higher arc voltage in case of WCuSb electrodes (ca + 2 V)
- Higher cathode spot dynamics in case of CuCr
- Stronger localisation of cathode spots in case of WCuSb

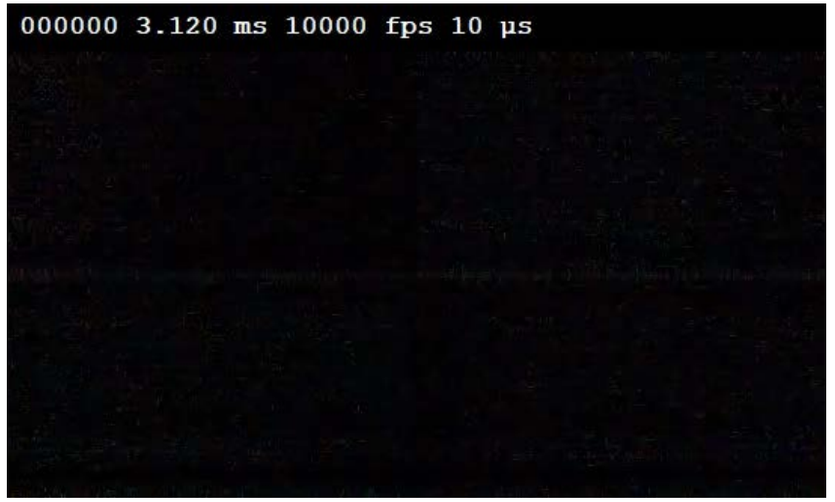
Results: arc dynamics – short circuit AC current



CuCr



WCuSb



- Distinct anode spot formation for CuCr only
- Less influence of material on the arc voltage

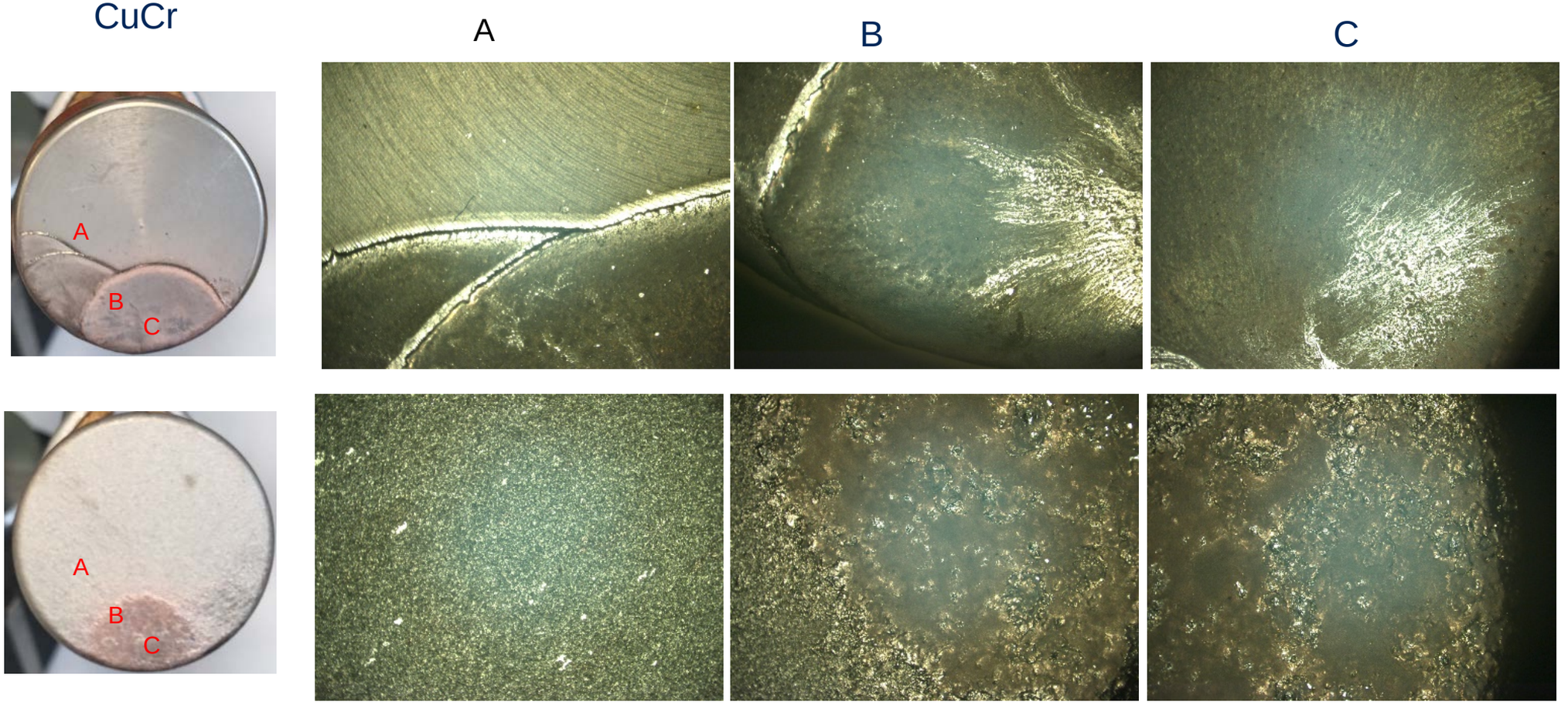
Results: Surface morphology

	new	anode	cathode
CuCr			
WCuSb			

- Arc root on the anode side is moving from shot to shot
- Cathode uniformly loaded by arc, localised arc attachment zones on anode

Results: Surface morphology

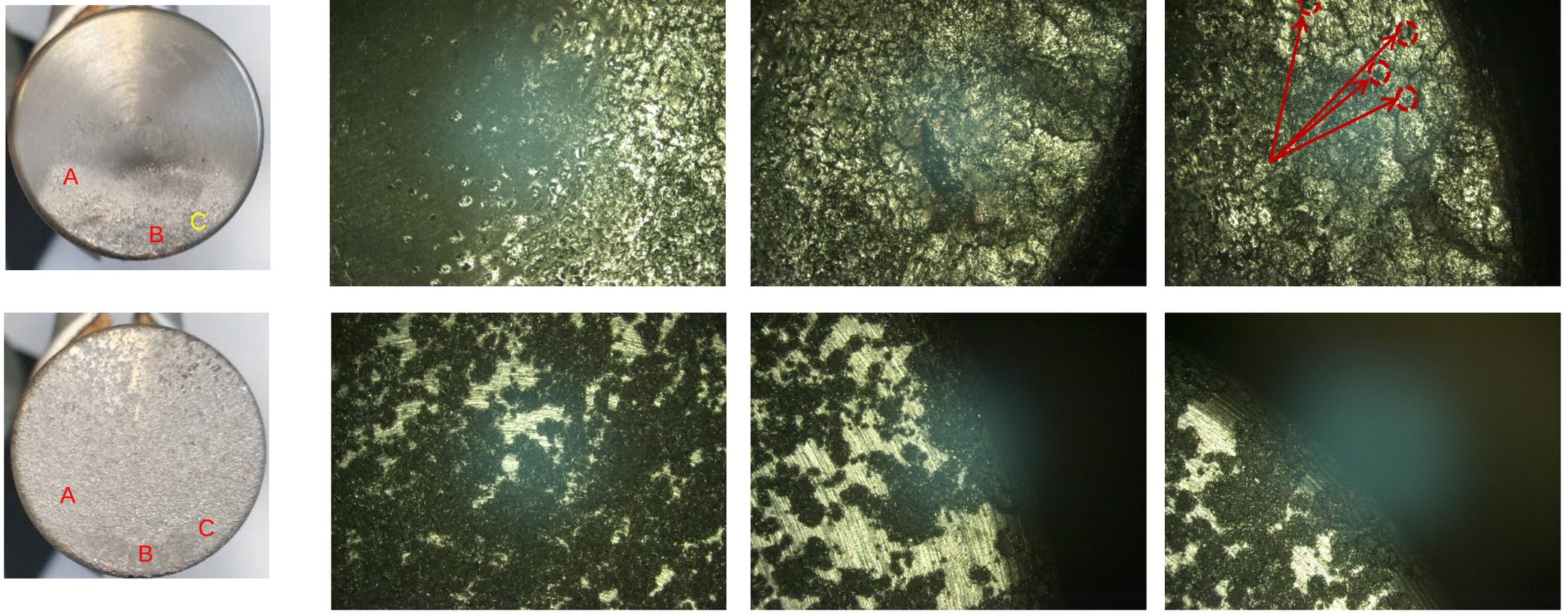
CuCr



- Cathode uniformly loaded by arc, localised arc attachment zones on anode
- Smooth surface on both electrodes (absence of big droplets and big craters)

Results: Surface morphology

WCuSb



- Cathode uniformly loaded by arc, localised arc attachment zones on anode
- Strong changes in anode morphology
- Crater on cathode and spikes on anode

Methods: I. NIR spectroscopy

NIR 900-1600 nm

+

NIR optics

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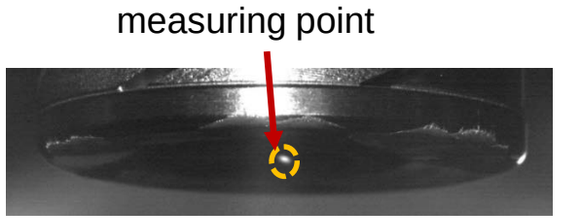
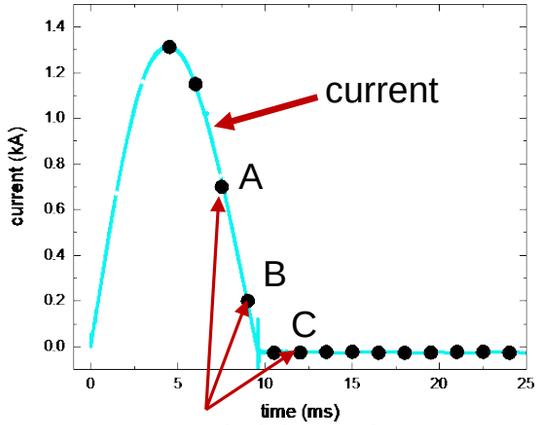
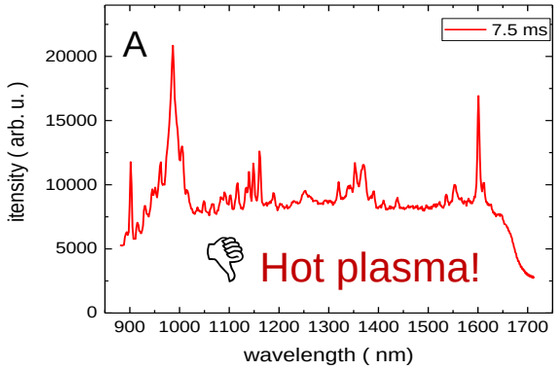
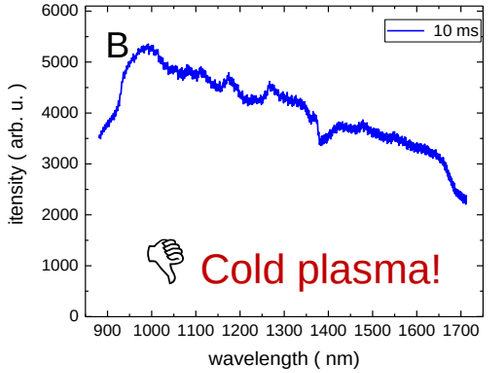
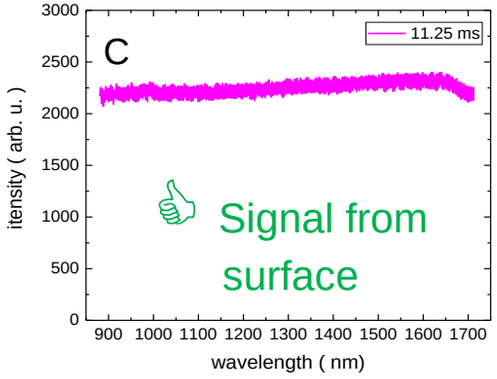


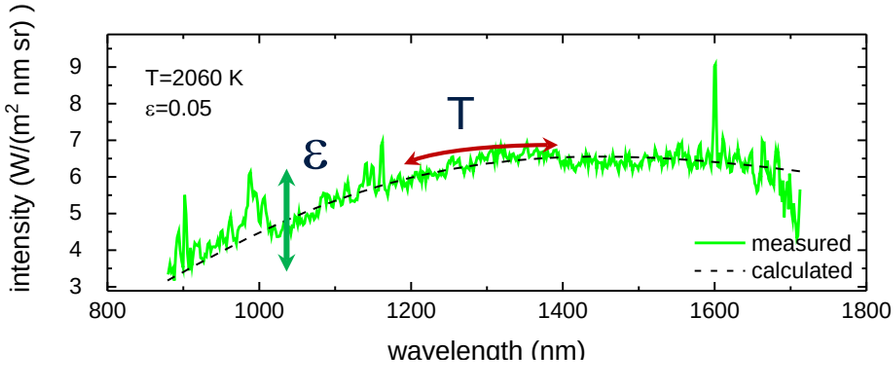


acquisition times





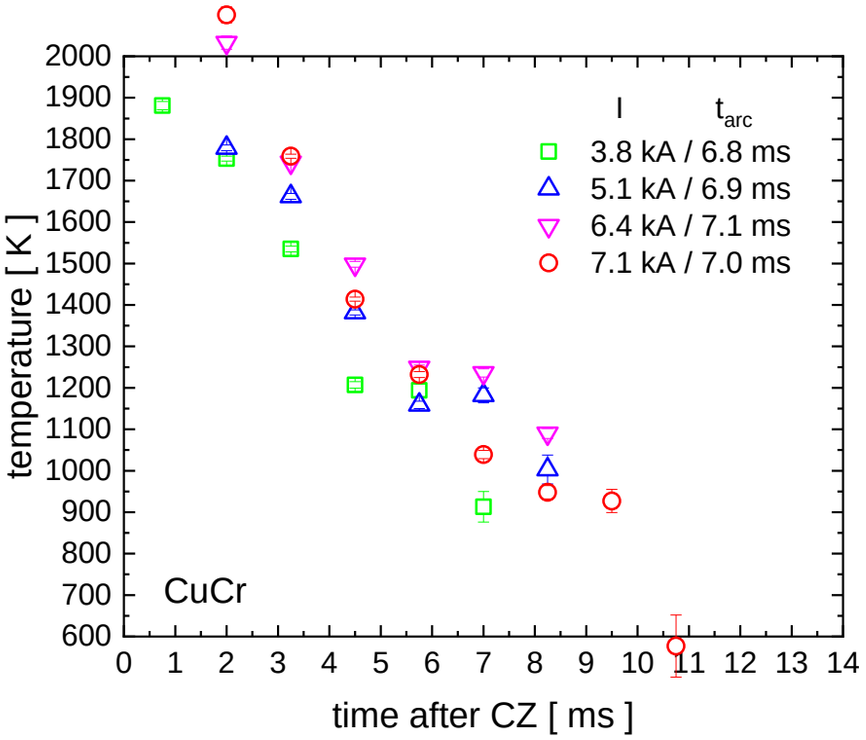


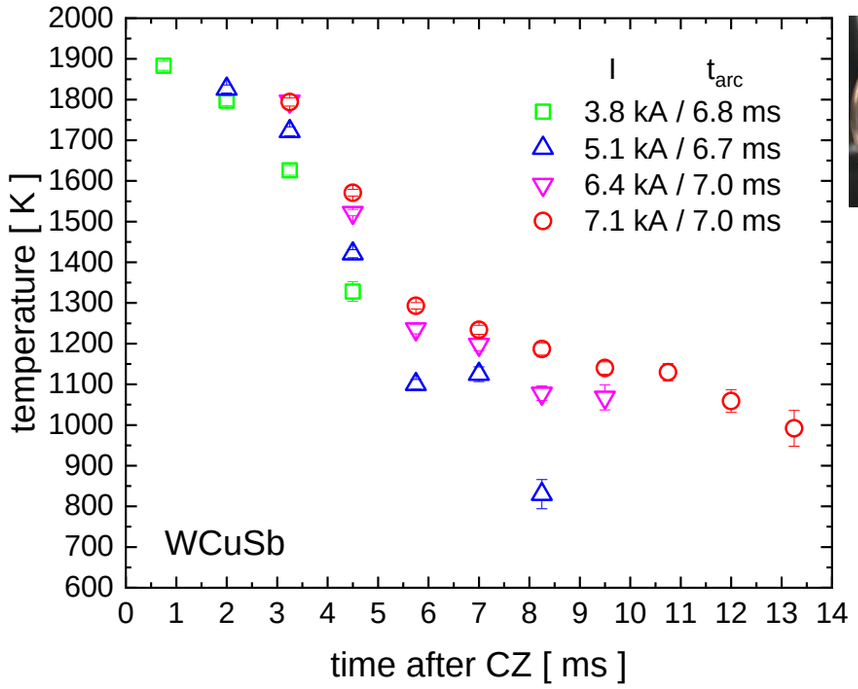


$$B_\lambda(T) = \varepsilon(\lambda, T)\frac{2hc^2}{\lambda^5}\cdot\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$$

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

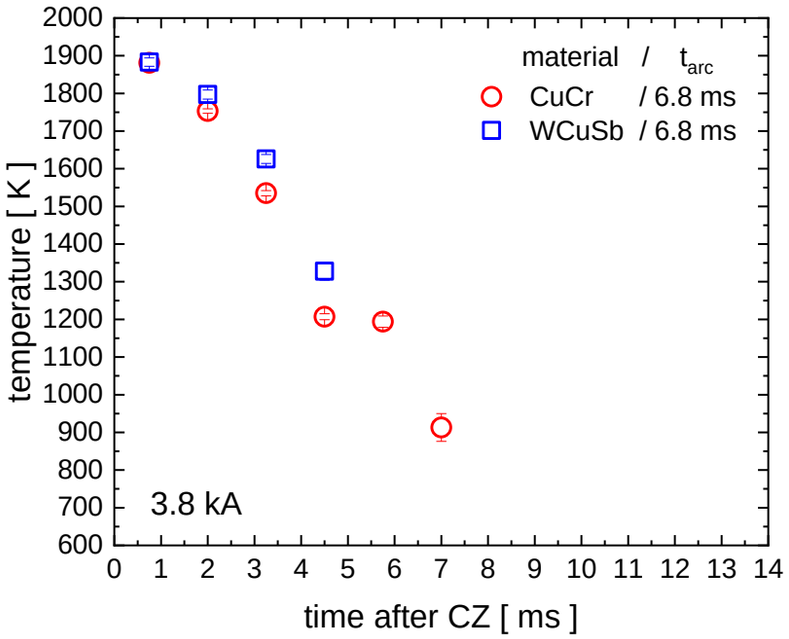
Results: anode surface temperature (I) - NIR spectroscopy

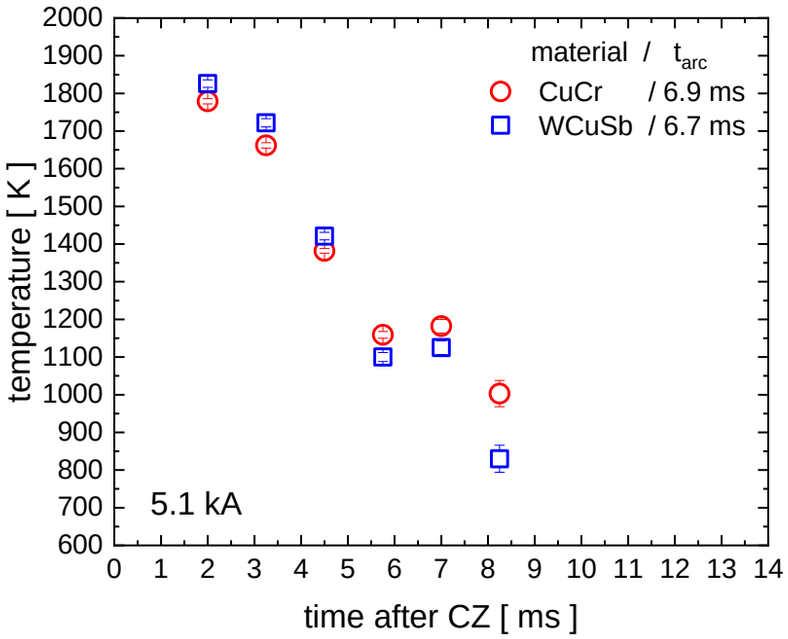


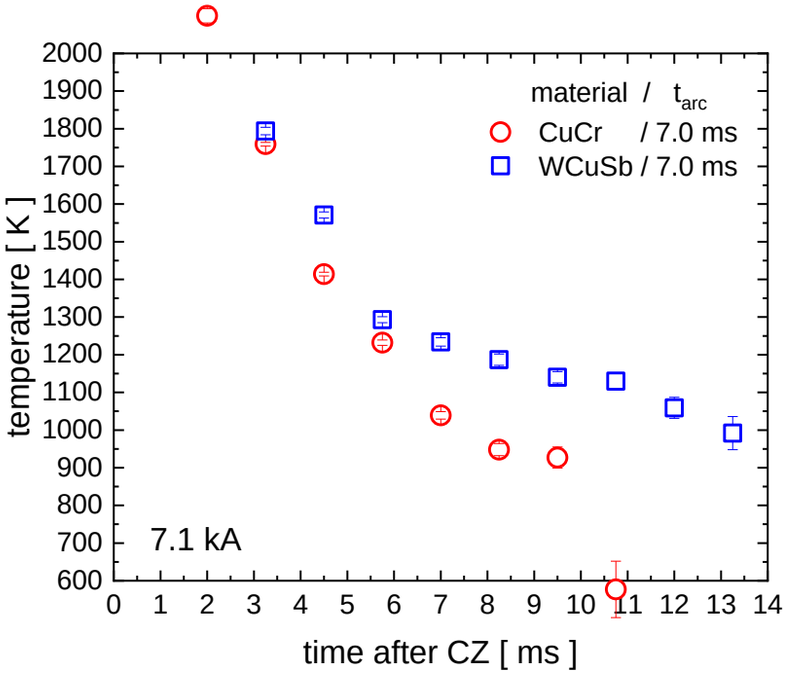


- Comparable initial temperature for both materials
- Higher temperature at higher current
- Faster temperature decay in case of CuCr for highest current

Results: anode surface temperature (I) - NIR spectroscopy







- Comparable initial temperature for both materials
- Longer decay for higher current
- Enhanced temperature in case of WCuSb
- Faster temperature decay in case of CuCr for highest current

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

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

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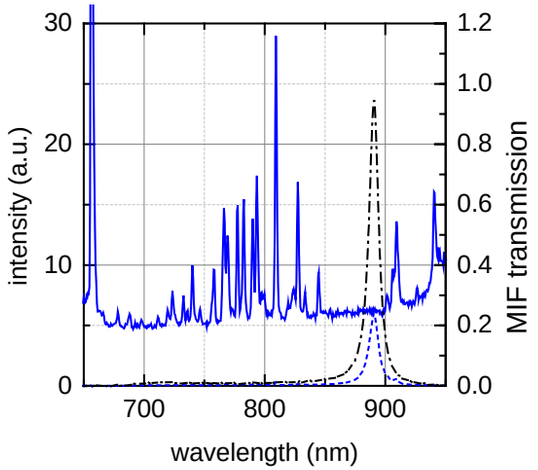

filter, which “blocks”
plasma radiation

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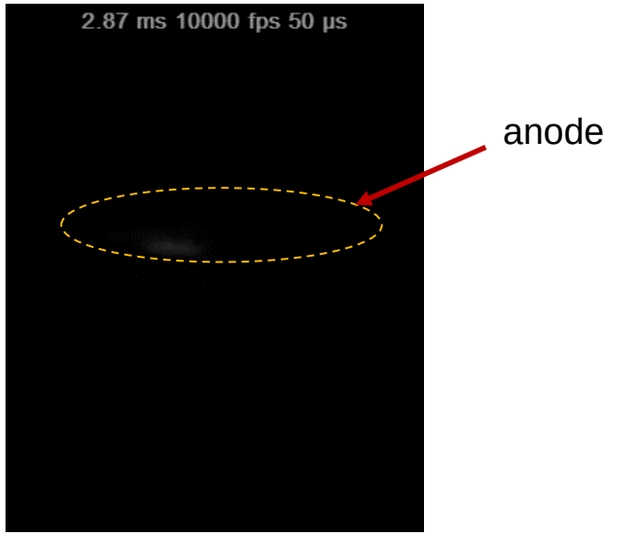
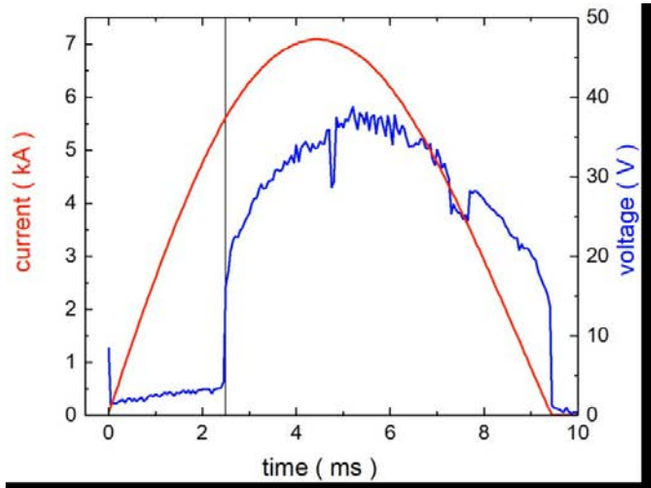


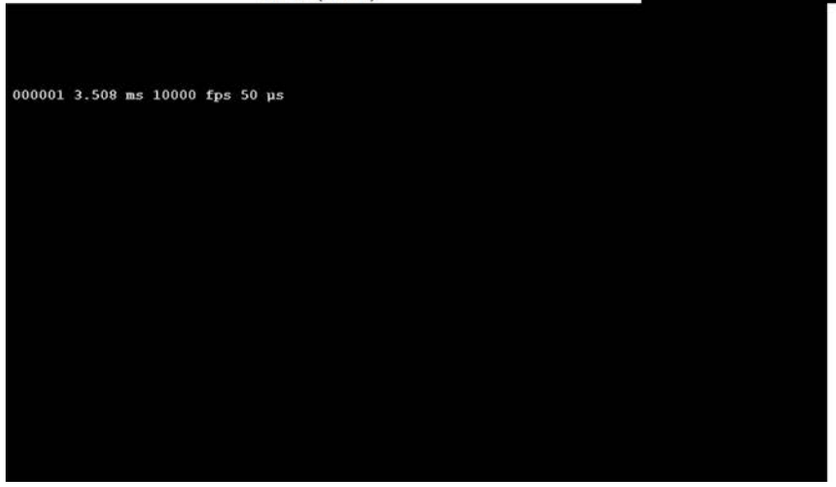
radiation image dominated
by surface contribution

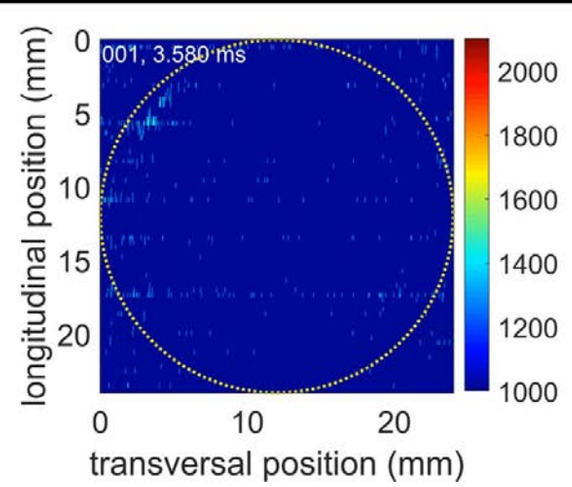
- The method gives **qualitative** 2D temperature distribution with high temporal resolution
- **Quantitative** temperature can be obtained after comparison with results of NIR measurements at certain spatial position and time instant
- Challenge: continuum radiation of plasma must be taken into account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

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

CuCr



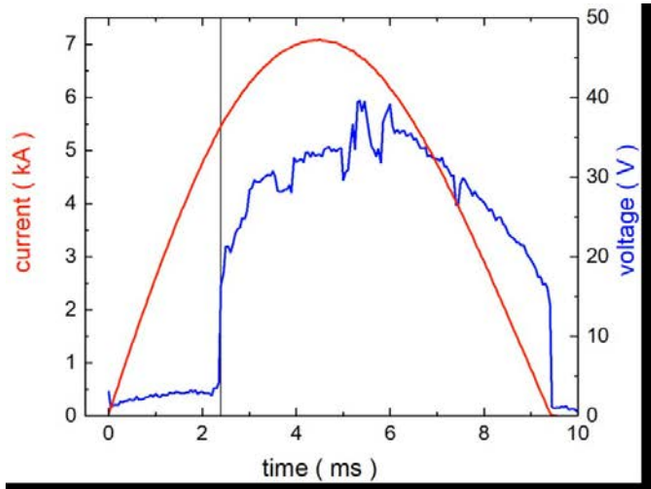


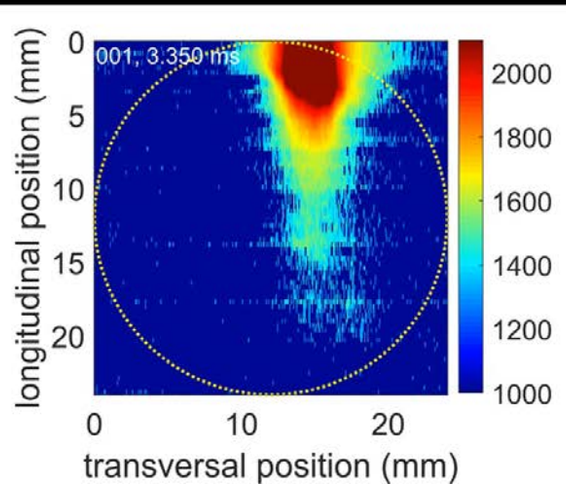


- Evaluation possible after current maximum only
- Pronounced anode spot with wide melted region

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

WCuSb



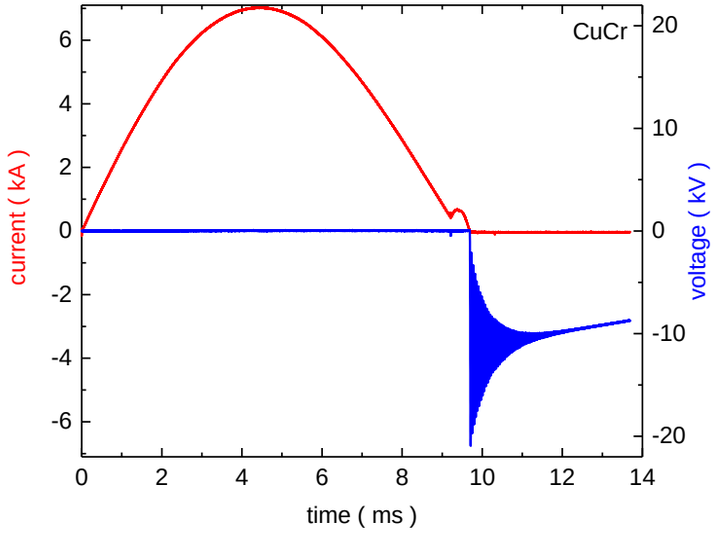


- Evaluation possible after current maximum only
- No pronounced anode spot, but many “hot spots” on the anode

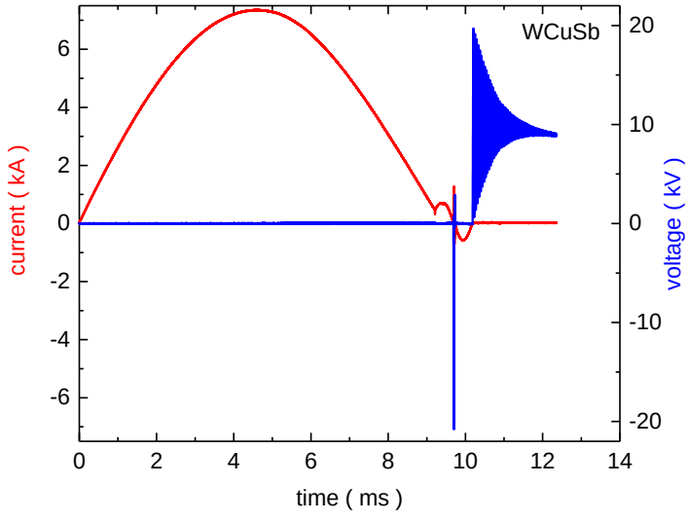
Results: Dielectric withstand after current interruption

Conditions

- Current from 1.1 kA to 7.1 kA (peak)
- Max TRV value 21 kV @ 1000 Hz
- Arc duration 3.3 – 7.4 ms



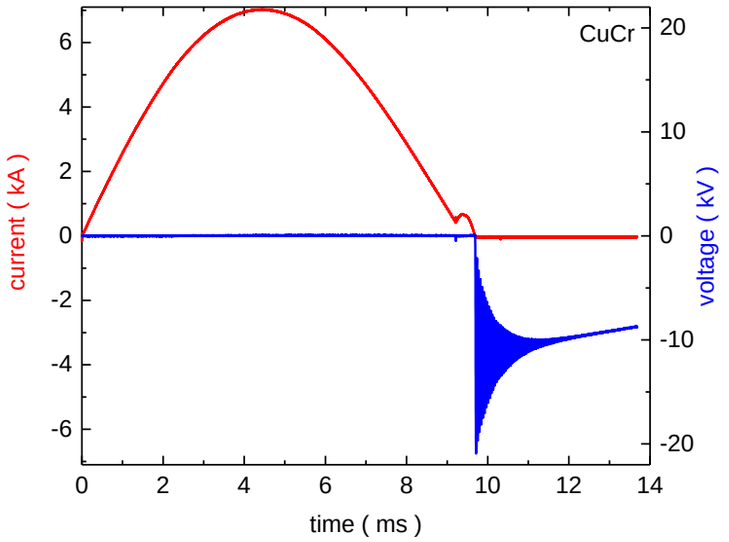
success

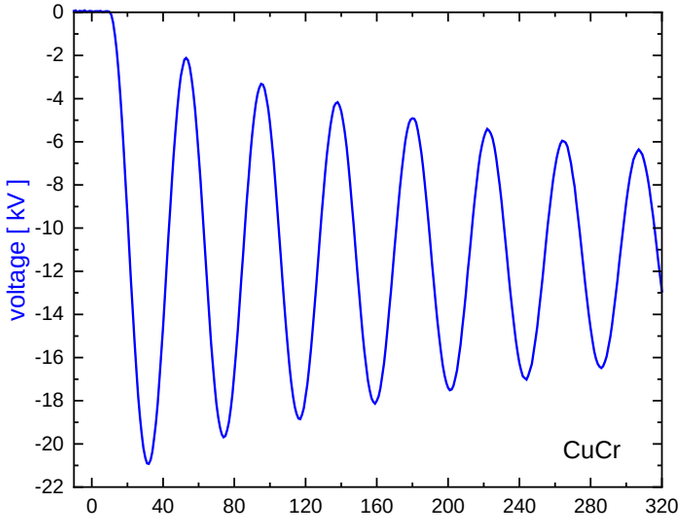


failure

Results: Dielectric withstand after current interruption

CuCr

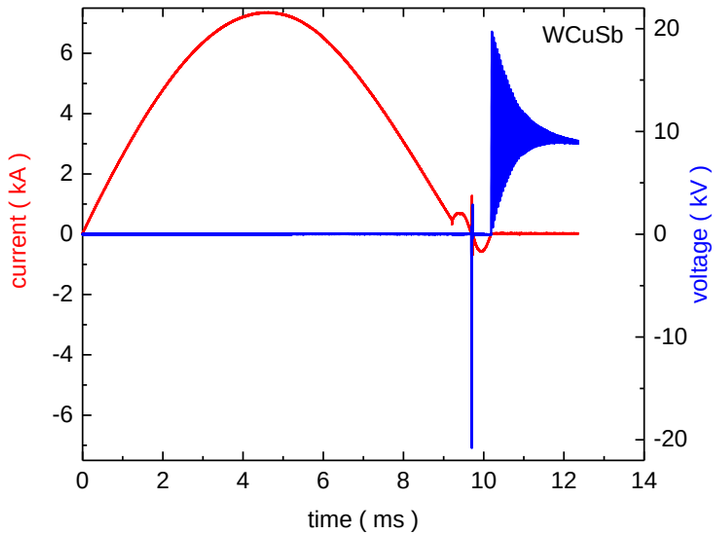


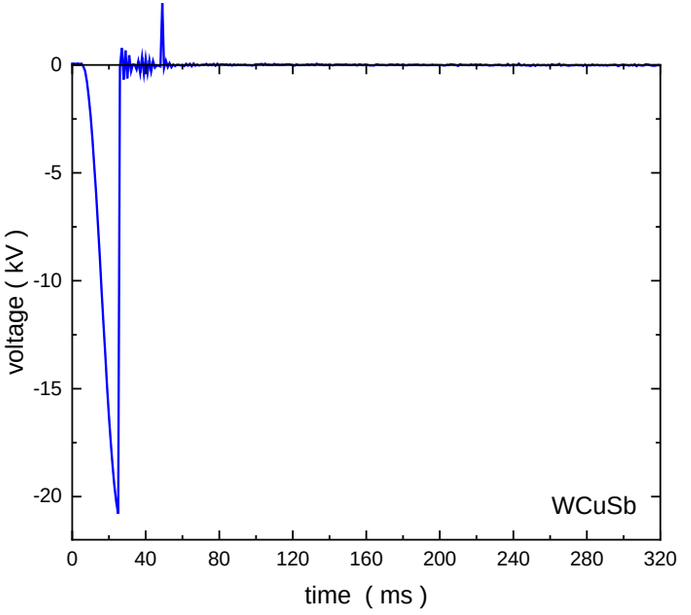


- Successful interruption for all conditions: anode spot, anode plume, lateral attachment, droplets on surface …

Results: Dielectric withstand after current interruption

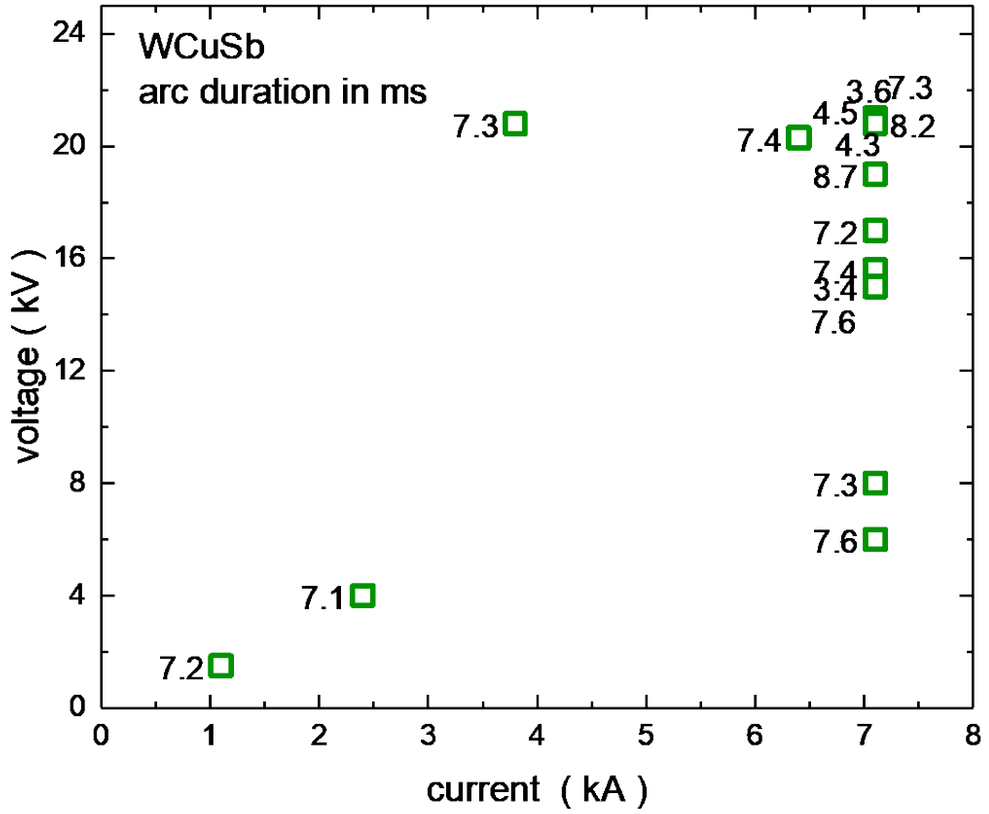
WCuSb





- Stable breakdown at all studied conditions

Results: Dielectric withstand after current interruption



- Stable breakdown at all studied conditions, sometimes after second voltage peak
- Possible reasons: hot spots on the anode surface, spikes at the anode surface, stronger droplets formation

Summary

- Various optical methods for determination of surface temperature have been successfully tested for different electrode materials
- Formation of micro structures on WCuSb electrodes – craters on cathode, spikes on anode – causes breakdown after TRV application
- Comparable anode surface temperatures for CuCr and WCuSb at the instant of current zero crossing
- Longer temperature decay for higher current and longer arc duration
- Longer temperature decay in case of WCuSb for highest current

Thank you very much for your attention!

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