SPECTROSCOPIC STUDY OF VACUUM ARC PLASMA EXPANSION

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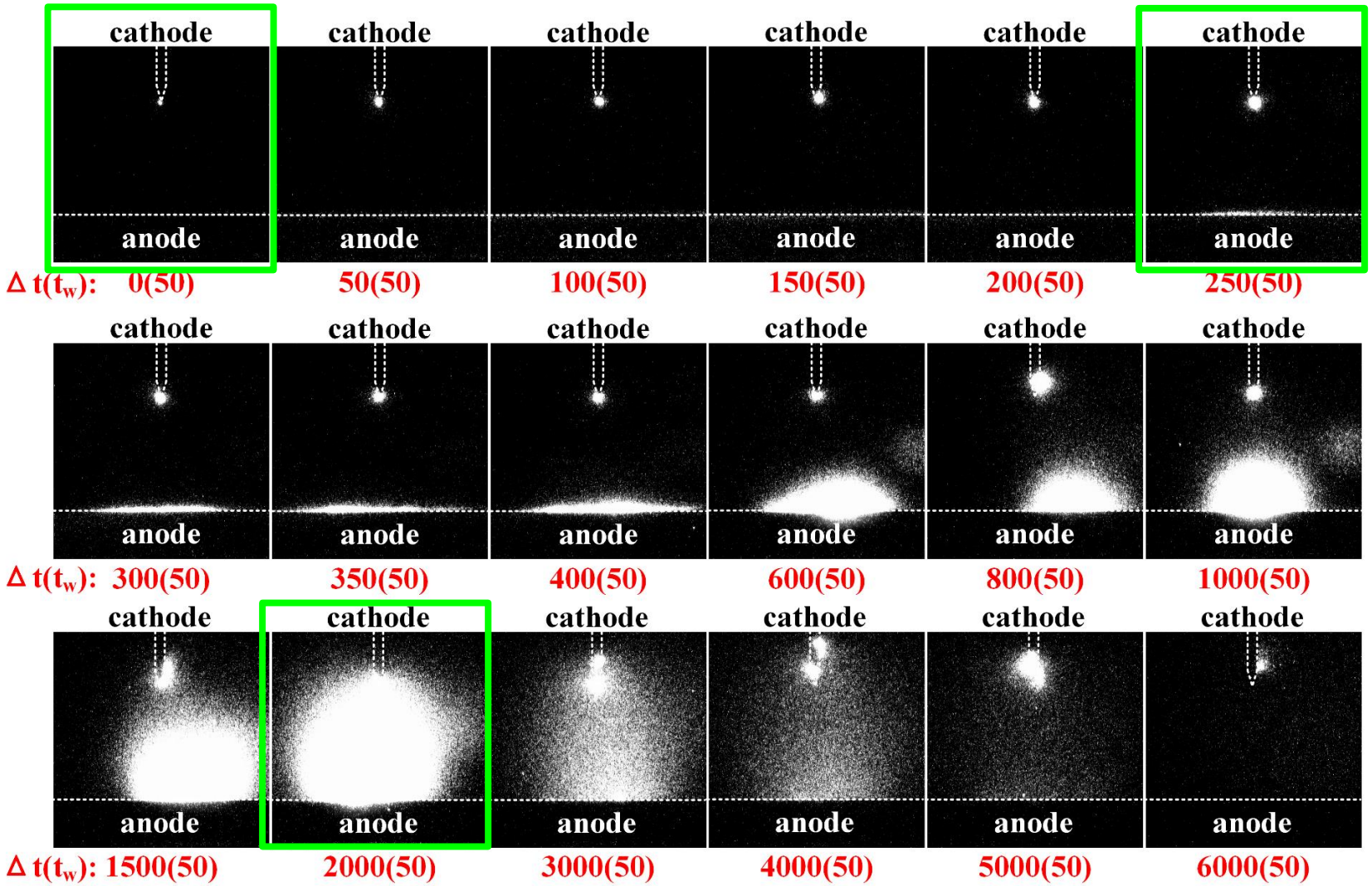
MOTIVATION

Vacuum breakdown process



Cathode Glows

- Cathode glows immediately after a breakdown occurs.
- Anode region keeps dark.

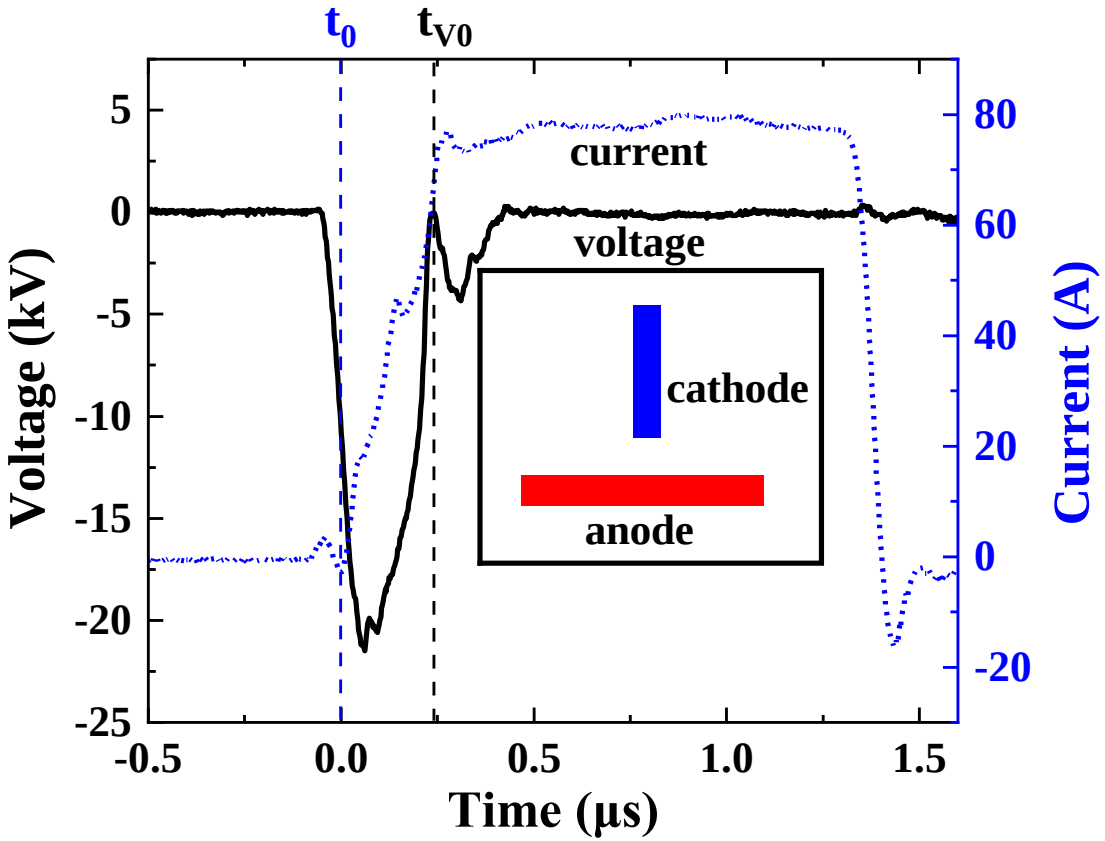
Anode Glows

- Anode light region expands towards the cathode.

Gap Bridged

- Light emission near anode and in the gap decays gradually. (Current ends after 5000 ns)
- Cathode light remains until the end of the current supply.

Vacuum breakdown process



- t_0 – breakdown initiation
- t_{V0} – voltage collapse, fully conductive channel formed

Gap length	Conductive channel	Gap bridged
5 mm	350	2050
3 mm	200	850
1 mm	110	300
0.5 mm	80	150

- Conductive channel was formed **well before** the gap is bridged by expanding anodic glow, when most of the gap is still dark.
- We can infer that the expansion of anodic glow does not contribute much to the formation of the conductive channel.
- The main power driving the formation of conductive channel should be the cathode activity, i.e. the expansion of the cathode plasma.

Objective and methods

How does a conductive channel forms in a vacuum breakdown process?

How does the cathode plasma expand?

Hard to know, because of the darkness.

Investigation on the anodic glow may give some clue on the cathode plasma expansion.

Anodic glow is a secondary phenomenon of cathode plasma expansion.

Spectroscopic analysis

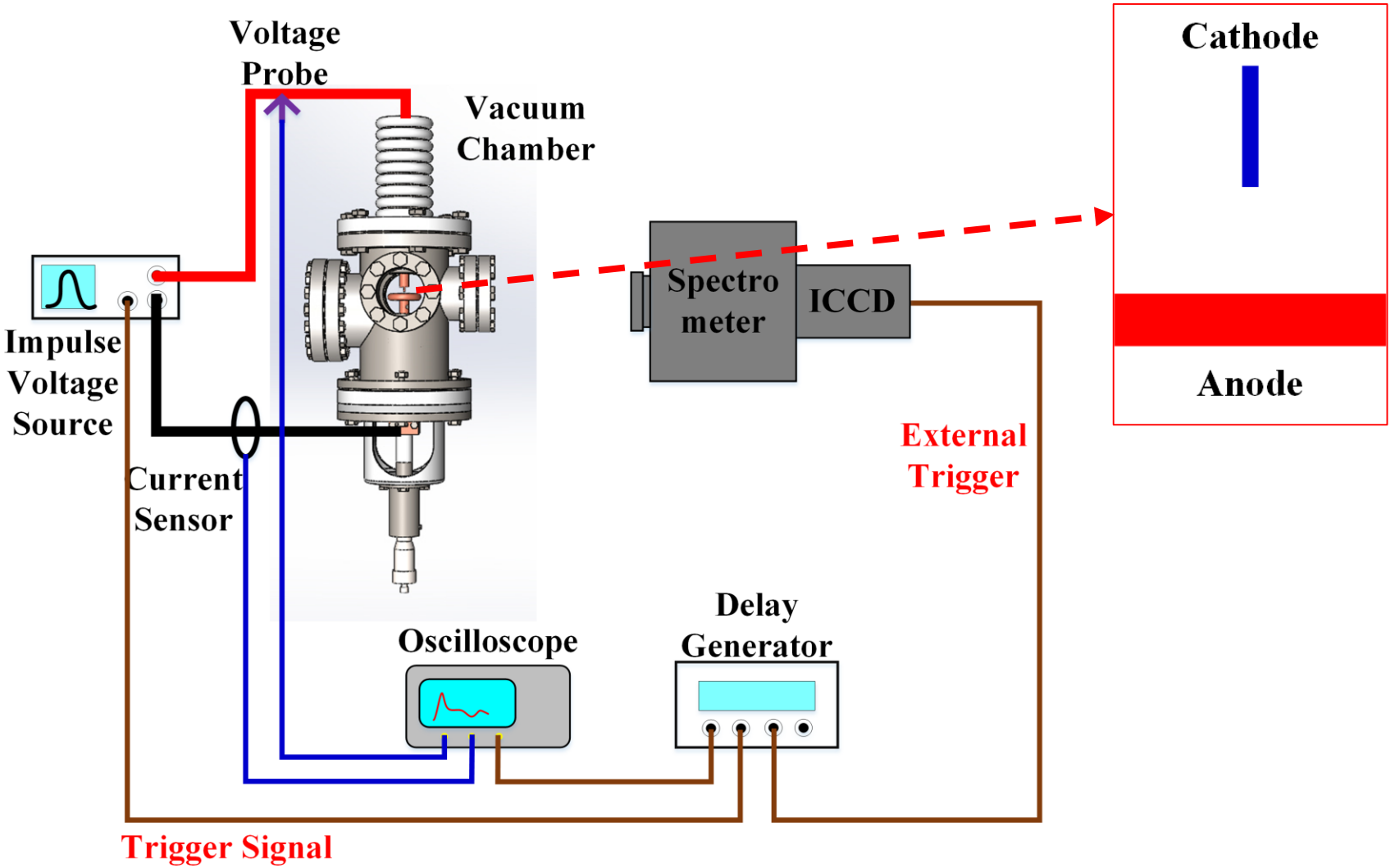
- Light emission during the breakdown process, especially near the anode.

SEM (Scanning Electron Microscopy) and EDS (Energy-Dispersive X-ray Spectroscopy)

- Electrode surfaces after breakdown experiments.

EXPERIMENTS AND RESULTS

Experimental setup



Pressure

- 2.5×10^{-4} Pa

Current

- 80 A, 5 μs

Spectroscopy

- Andor SHAMROCK SR-500
- Andor ICCD

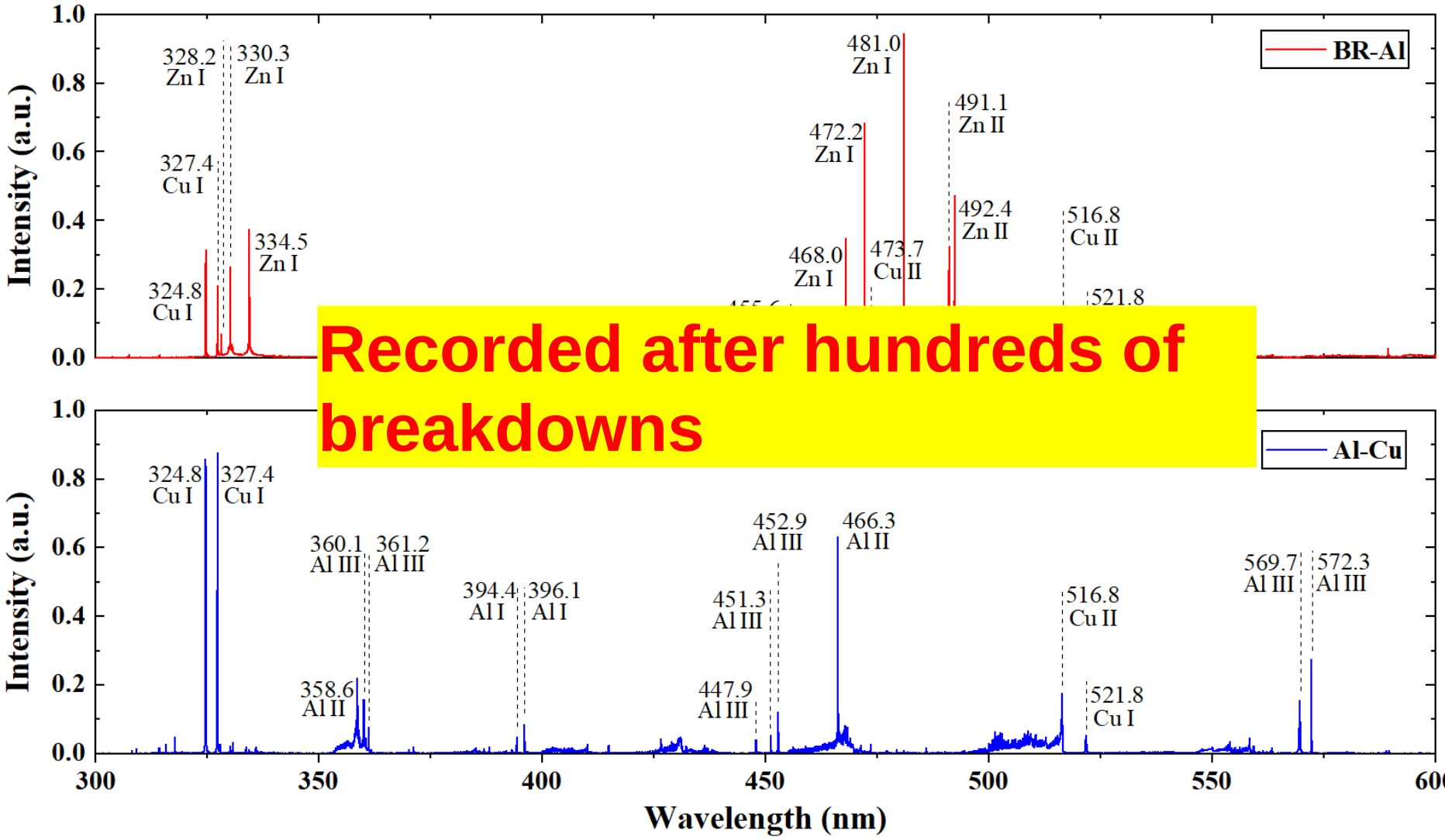
Trigger signals

- SRS DG645

Waveform recording

- Voltage probe
- Current sensor
- Oscilloscope

Spectrum distribution



Recorded after hundreds of breakdowns

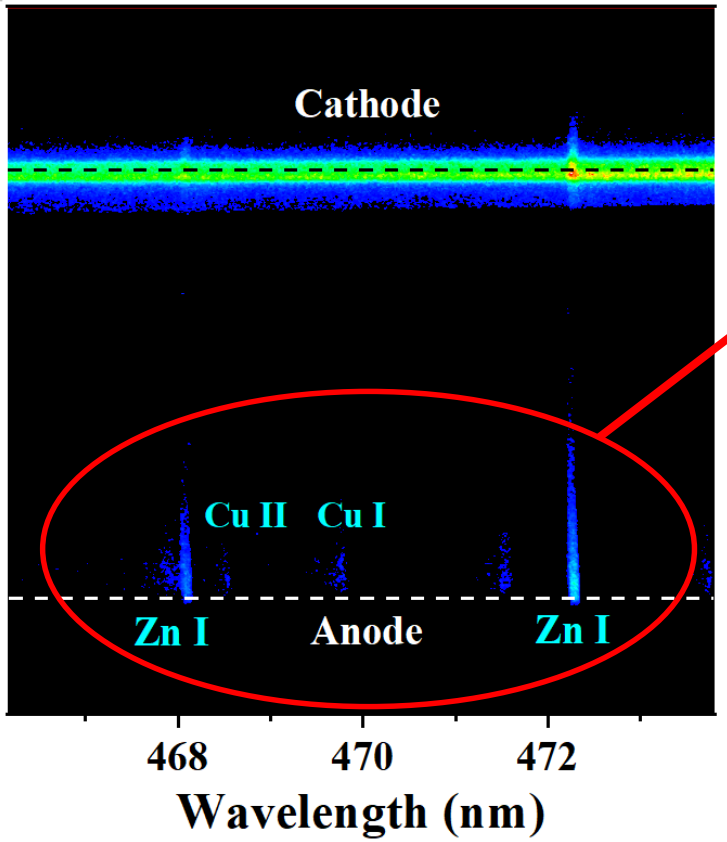
Cathode – brass (Cu, Zn)
Anode – aluminum (Al)

Only spectra of cathode materials?

Cathode – aluminum (Al)
Anode – copper (Cu)

Spectra of both cathode and anode materials

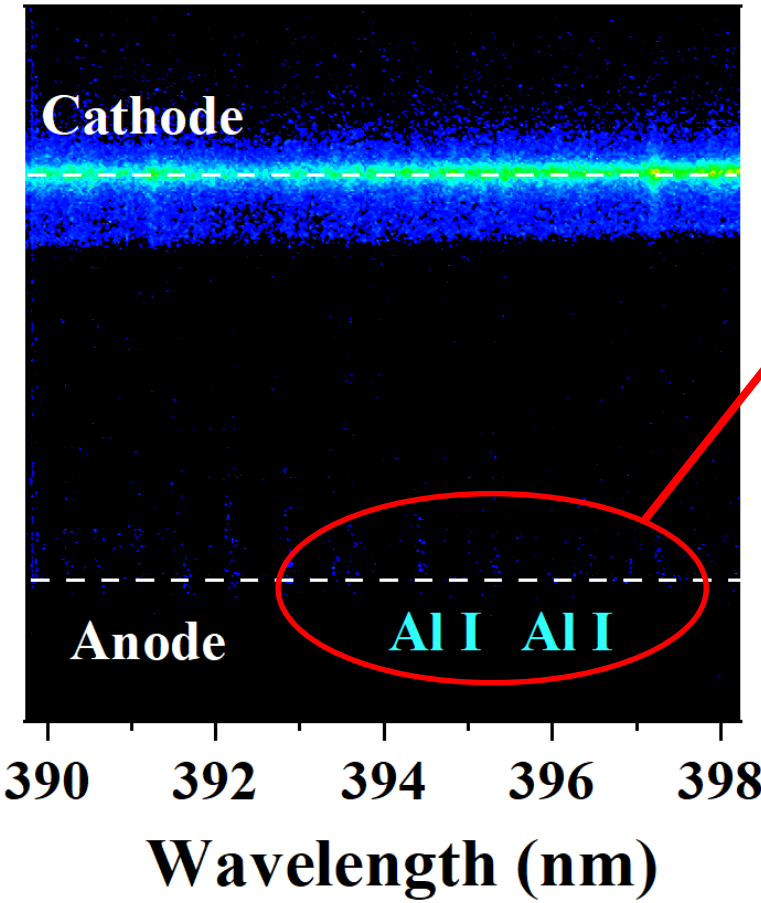
Spectrum distribution



Obvious cathode material signals in the anodic glow.

1

Typical spatial distribution of spectra in BR-Al case

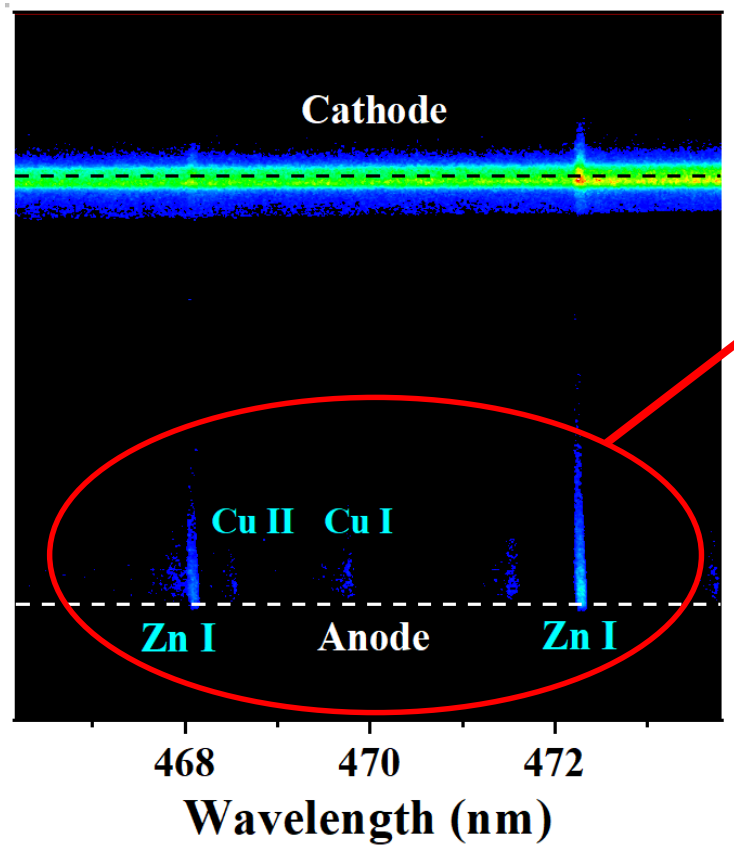


Absence of Al (anode) signals in BR-Al case.

2

Spectrogram at the range for Al signals, BR-Al

Cathode material in anodic glow



Typical spatial distribution of spectra in BR-Al case

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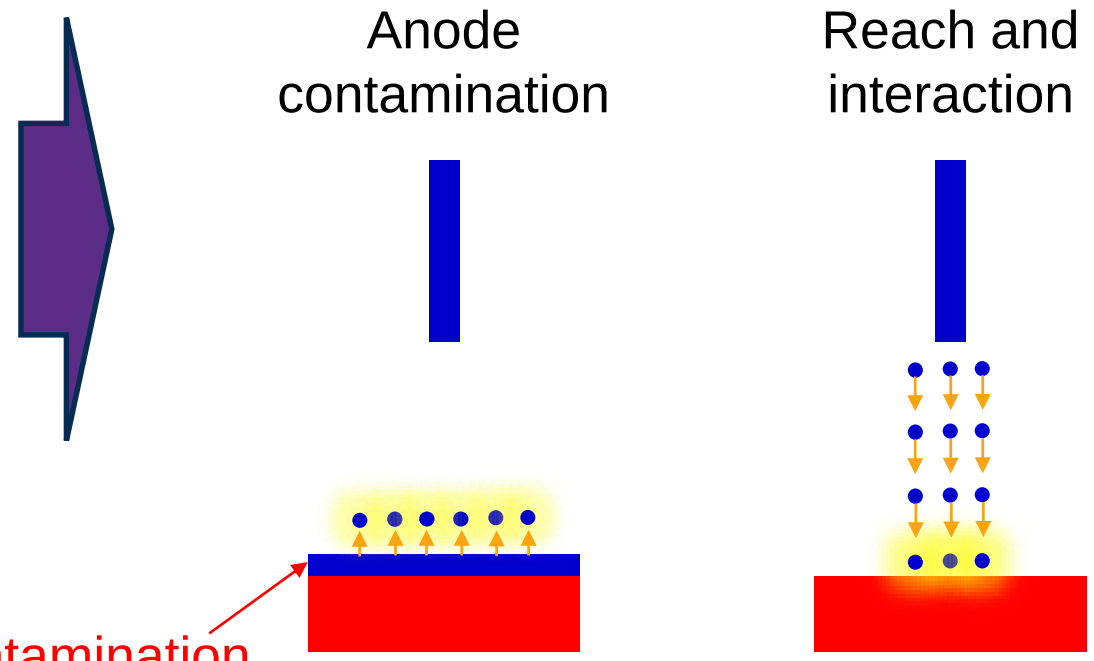
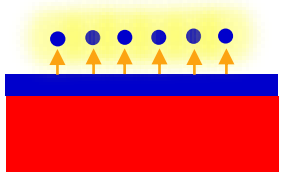
Two possible explanations



Cathode material in anodic glow

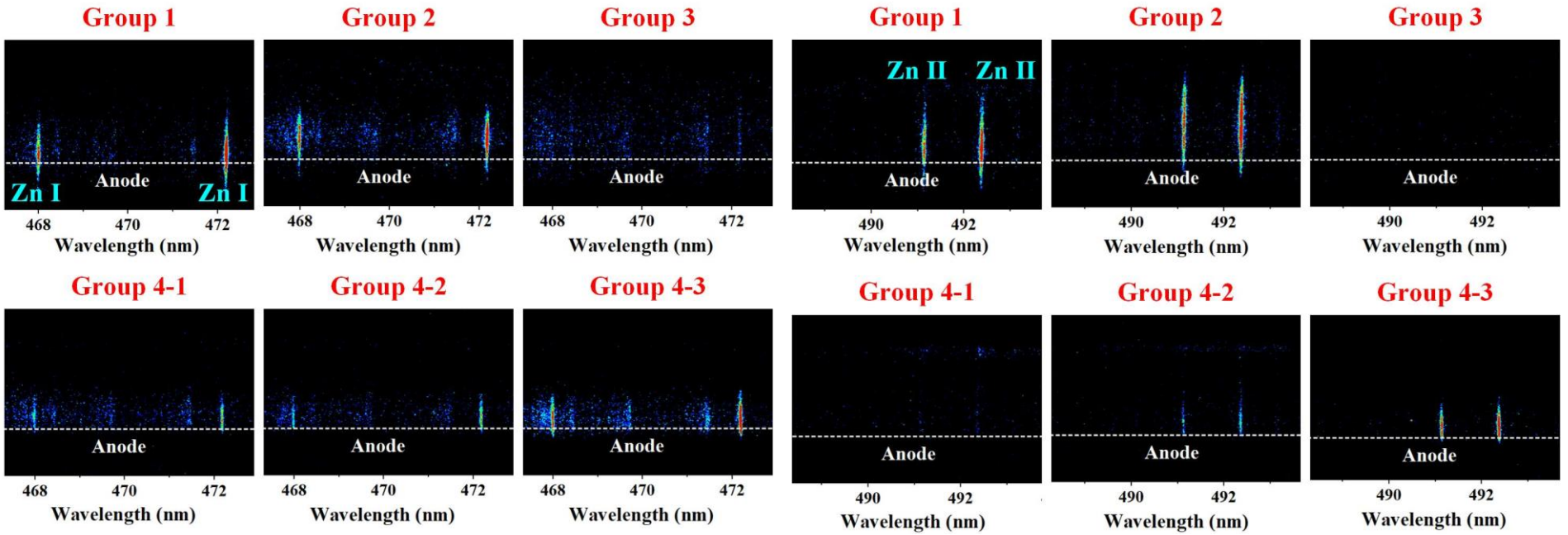
Investigations on the anode contamination

Anode contamination



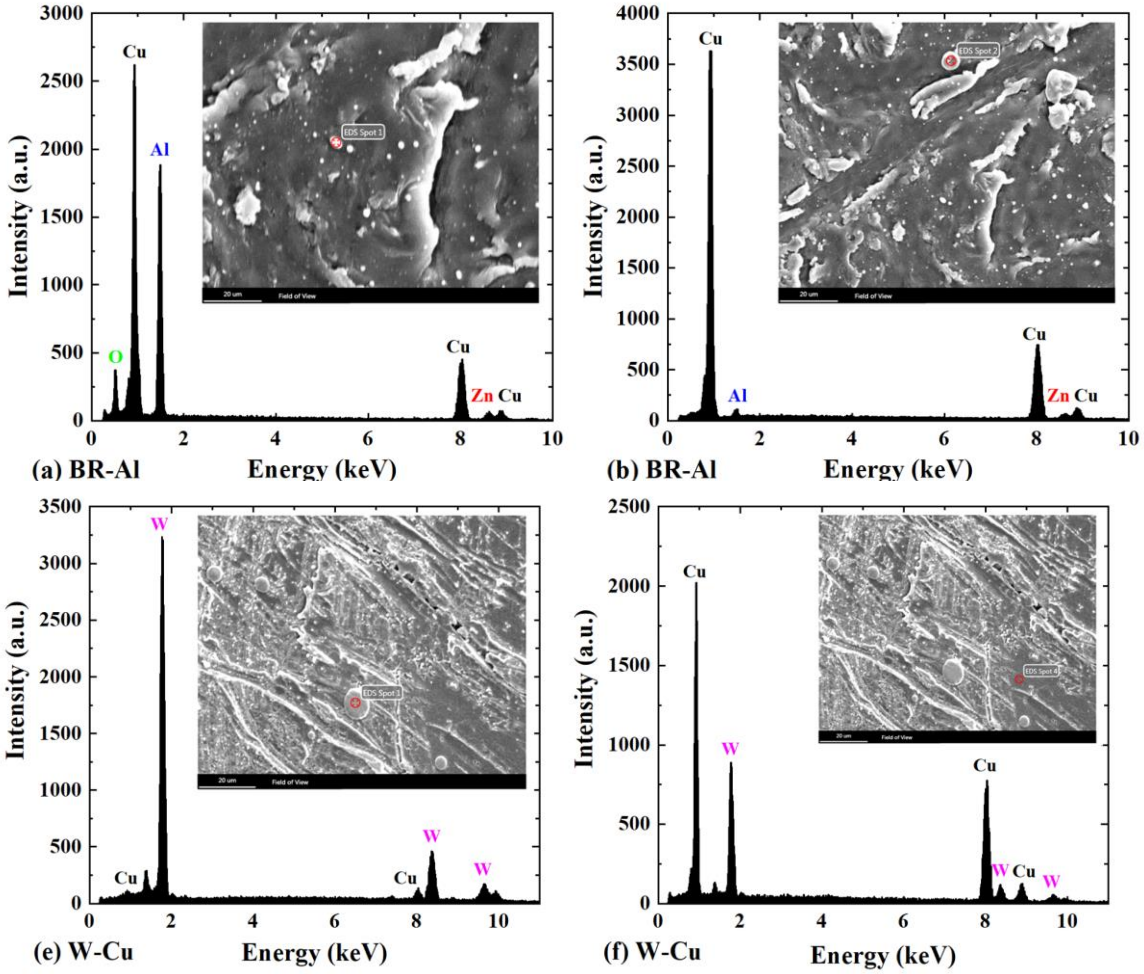
Blue: cathode material
Red: anode material

Group No.	Cathode material	Anode material	Anode state
1	Brass	Aluminum	After discharges with brass cathode
2	Tungsten	Aluminum	After used in Group 1
3	Tungsten	Aluminum	New
4	Brass	Aluminum	New



Cathode material in anodic glow

Investigations on the anode contamination

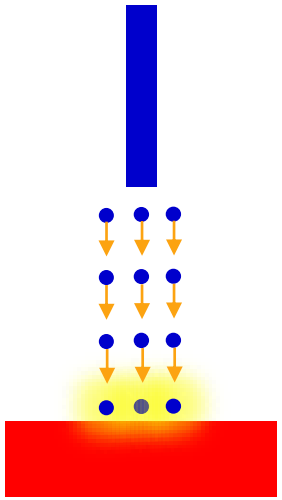


- The cathode material is deposited on the anode surface in both forms of micron-size particles and condensed vapor.
- **The contamination layer on the anode surface can supply atoms to the anodic glow during the following discharges.**

Cathode material in anodic glow

Investigations on clean electrode system

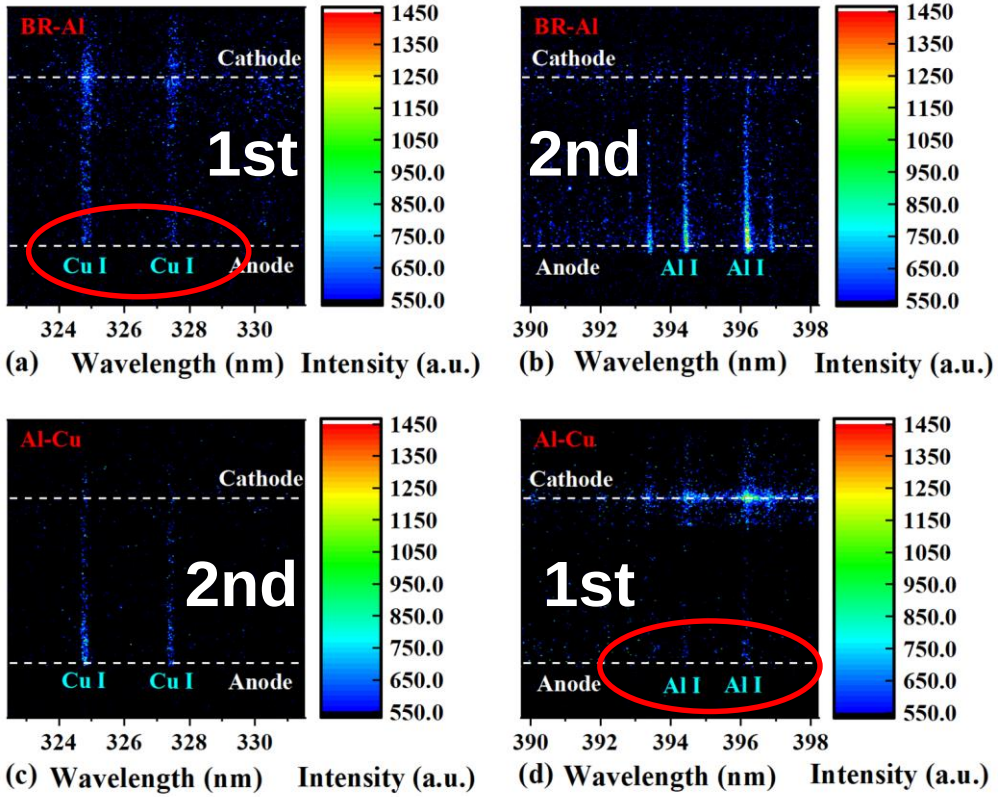
Reach and interaction



Blue: cathode material
Red: anode material

Measures to minimize the effect of the anode contamination during a breakdown

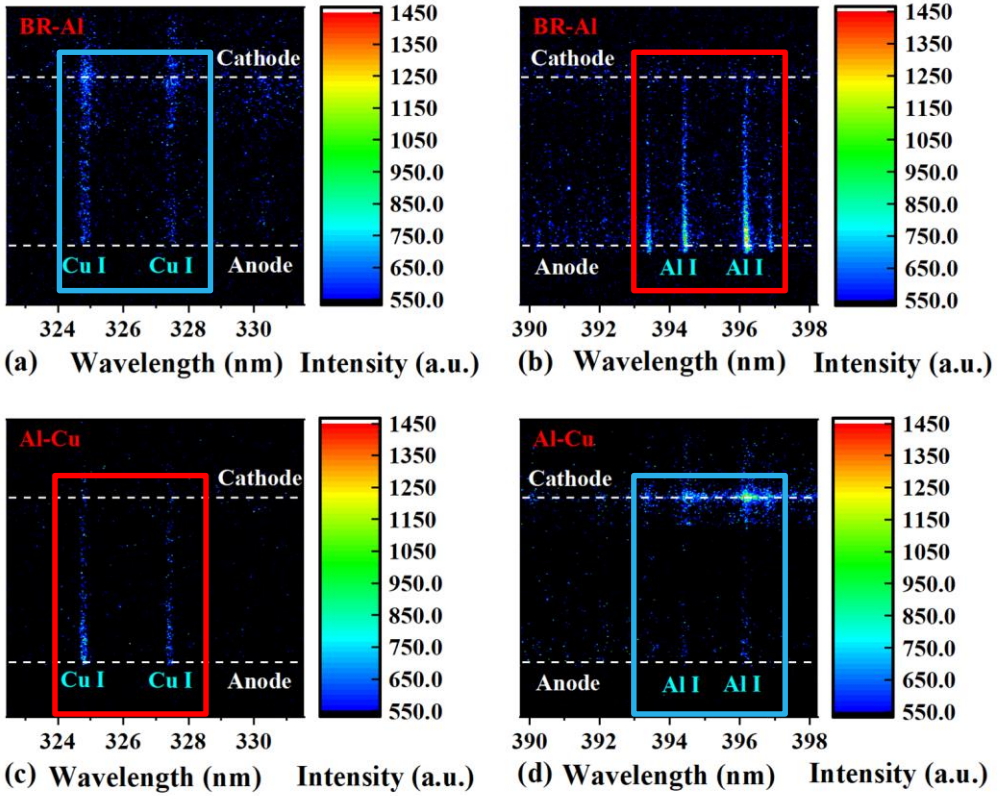
- Observing the spectra of the cathode and anode material in the first few breakdowns right after installation of clean electrodes.
- Recording the spectra at the initiation stage of the anodic glow.



- Clear cathode material signals near the anode surface.
- **Cathode flare does provide atoms to the anodic glow region.**

Cathode material in anodic glow

Investigations on clean electrode system

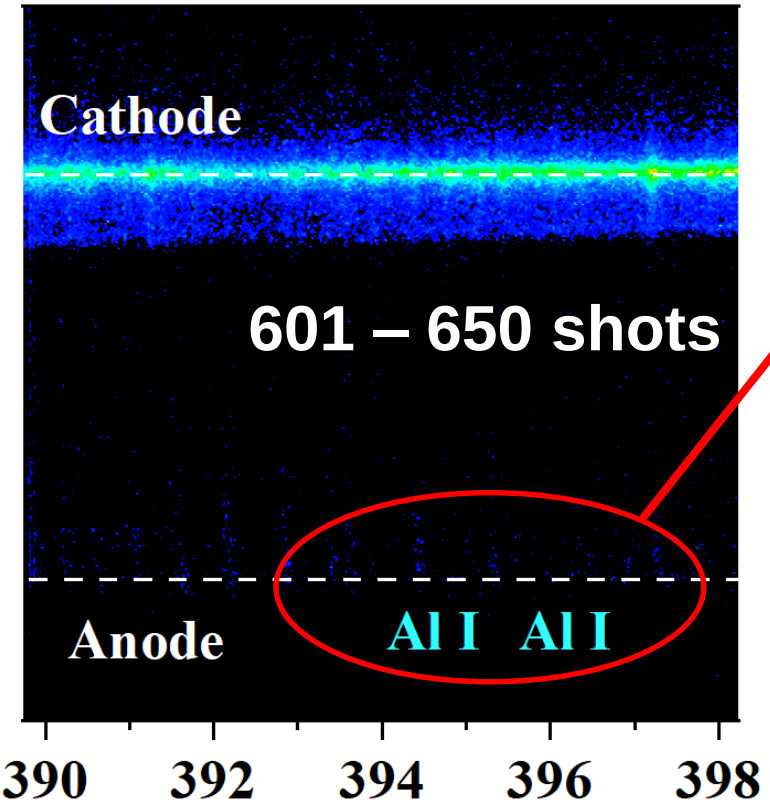


- Intensities of these cathode material spectra have higher values at the cathode and anode than at the middle of the gap.
- Cathode atoms can have higher probability of emitting light after interact with the anode surface.

- Existence of the anode material peaks near the anode surface.
- The anode material also contributes atoms to the anodic glow.

- ***WE SEE ALUMINUM SIGNAL IN BR-AL CASE!!!***

Absence of Aluminum signal in BR-Al case

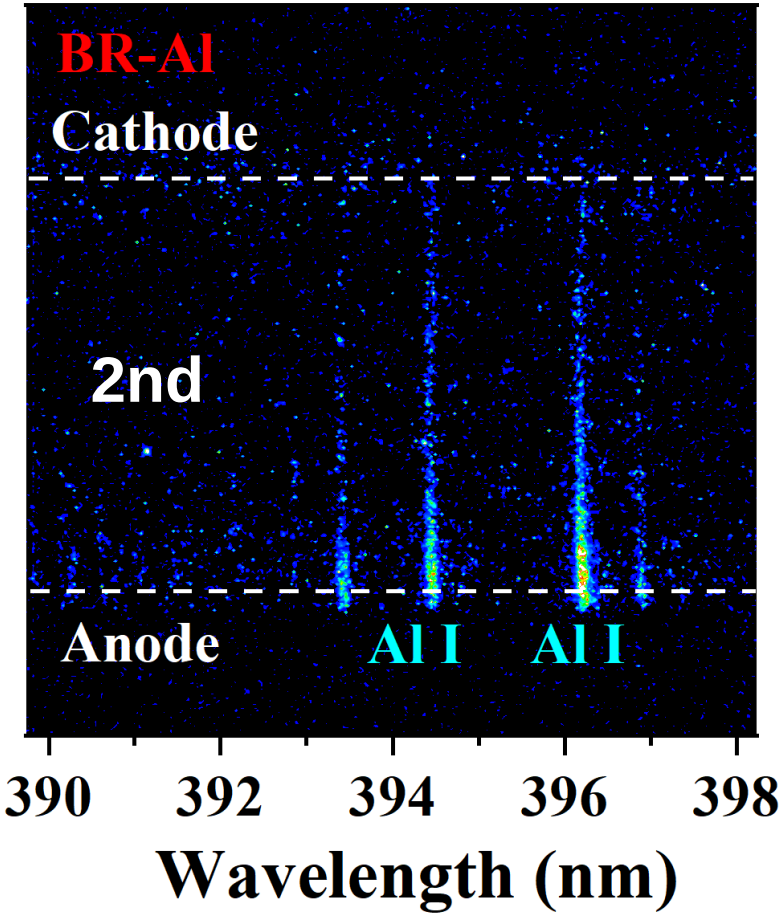


Spectrogram at the range for Al signals, BR-Al

Absence of Al (anode) signals in BR-Al case.

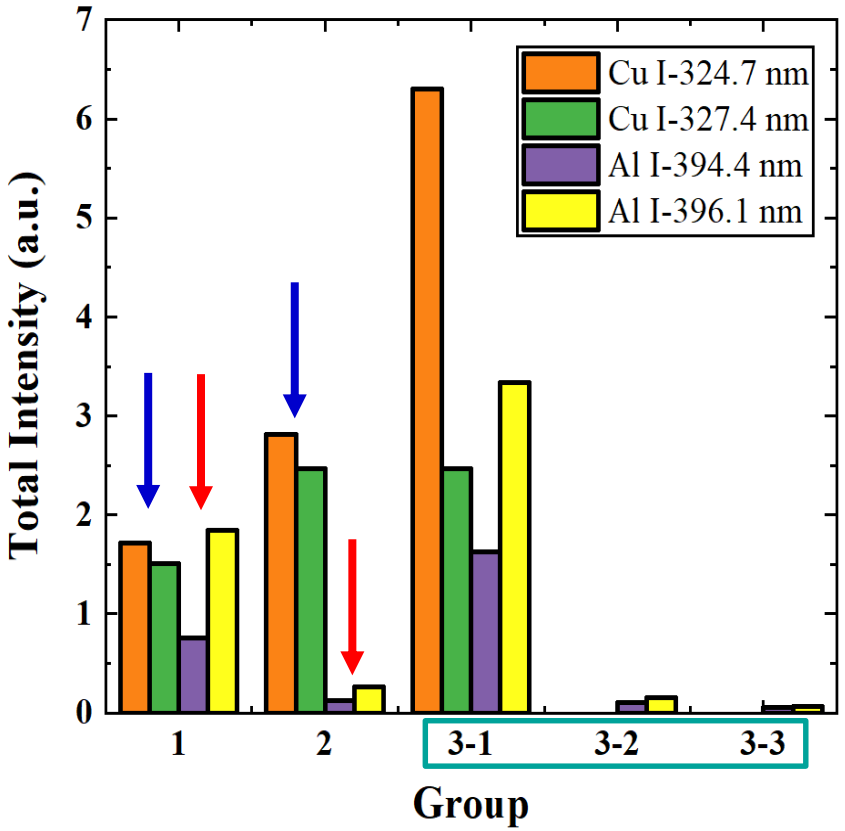
2

After 600 breakdowns



- The anode material signals disappear after hundreds of breakdowns.
- **This should be a consequence of the contamination of the anode surface by deposited cathode materials.**

Absence of Aluminum signal in BR-Al case



Total intensities of Cu I and Al I spectra.
3-1: 1-25 shots
3-2: 276-300 shots
3-3: 526-550 shots

Group No.	Cathode material	Anode material	Anode state
1	Tungsten	Copper	After discharges with aluminum cathode
2	Tungsten	Aluminum	After discharges with brass cathode
3	Brass	Copper	After discharges with aluminum cathode

- Cu signals are stronger on Al surface (contaminated by brass).
- Al signals are stronger on Cu surface (contaminated by Al).
- Al signals decrease gradually with increasing number of breakdowns.

The contamination layer on the anode surface contributes to the anodic glow more easily than the bulk anode material, and sometimes can eliminates the signal of anode bulk completely.

Summary

- We conducted spectroscopic and microscopic experiments on the vacuum breakdown processes. The main conclusions can be summarized as follows.
  - Both the cathode and the anode electrodes significantly contribute atoms to the anodic glow. The atoms from the cathode flare reach the anode surface already at the beginning of the anodic glow. The absence of light in the middle of the gap implies the existence of a concentration process for the cathode atoms to start emitting light only in vicinity of the anode. Further investigation of the nature of this process is required.
  - The cathode material contaminates the anode surface during the process of vacuum breakdown, resulting in a layer of cathode material on the anode surface. This contamination layer includes both smoothly condensing cathode vapor and micron-sized spherical particles.
  - Only a thin layer of the anode surface contributes to the anodic glow, as shown by the fact that the gradually increasing contamination layer on the anode surface causes the decay and possible elimination of the anode bulk signals in the anode glow spectra.

THANK YOU!