New (TH)GEM coating materials characterised using spectroscopy methods

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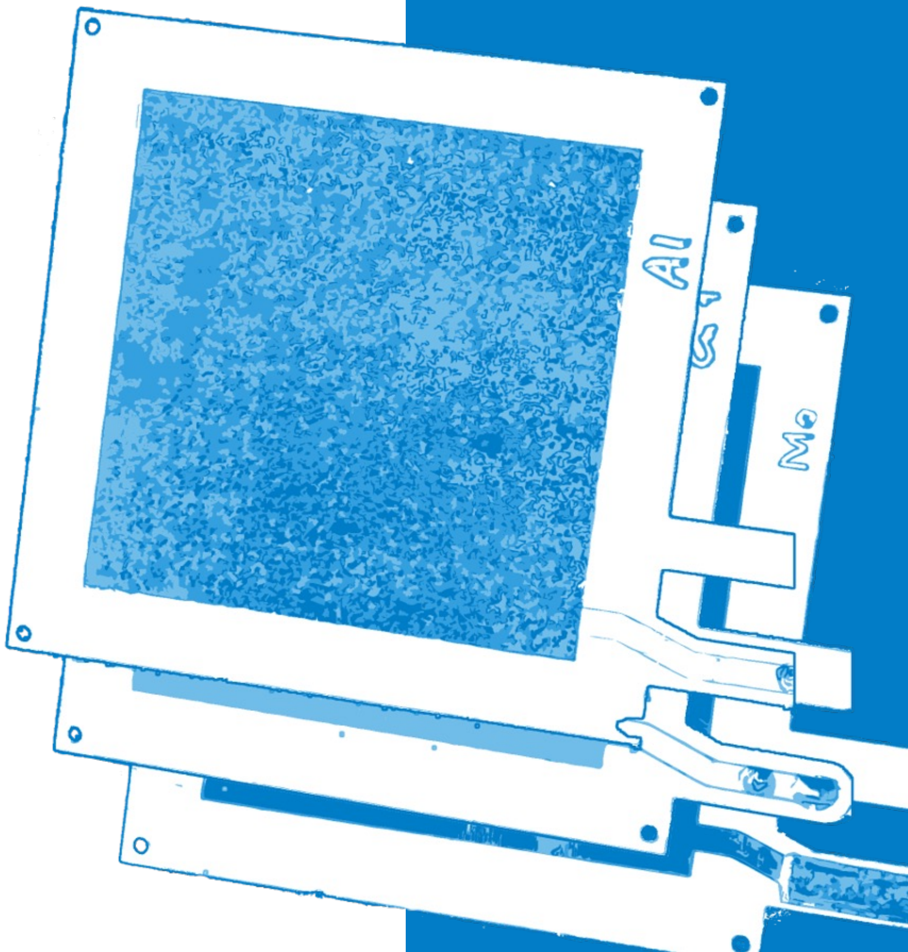
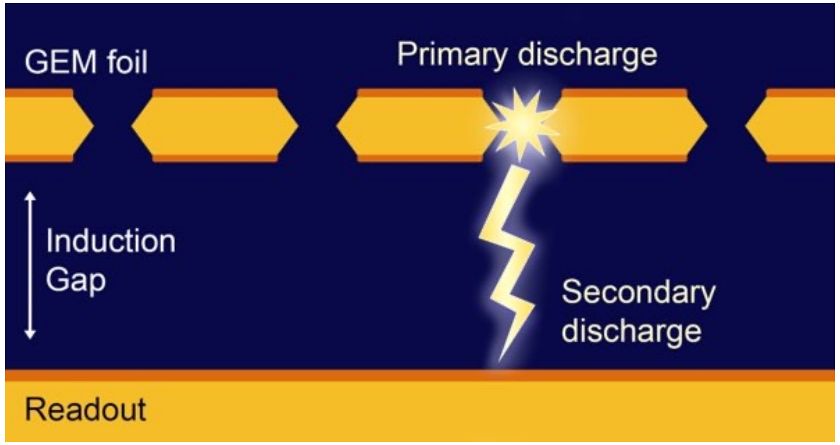
Micro Pattern Gaseous Detectors 2022
15th December 2022, Weizmann Institute of Science, Rehovot, Israel

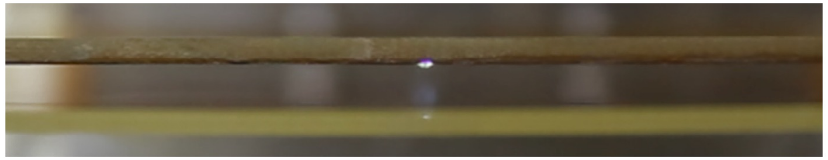


Discharges in (TH)GEMs

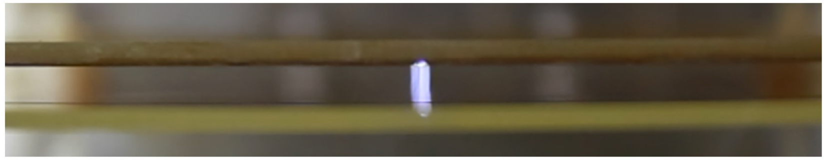
- GEM discharges (sparks) have been widely studied
- There are different types of GEM discharges
  - **Primary discharges** occur inside GEM hole and are most prominent
  - **Secondary discharges** occur in the gap between GEM and anode and are more dangerous
- Methods have been developed to mitigate them during operation
  - RC components, gas, foil properties, etc.
    - S. Bachmann et al. NIM A 479 (2002) 294-308
    - P. Gasik et al. NIM A 870 (2017) 116
    - A. Deisting et al. NIM A 937 (2019) 168-180
    - L. Lautner et al. JINST 14 (2019) P08024
    - …



Types of discharges in (TH)GEM detectors



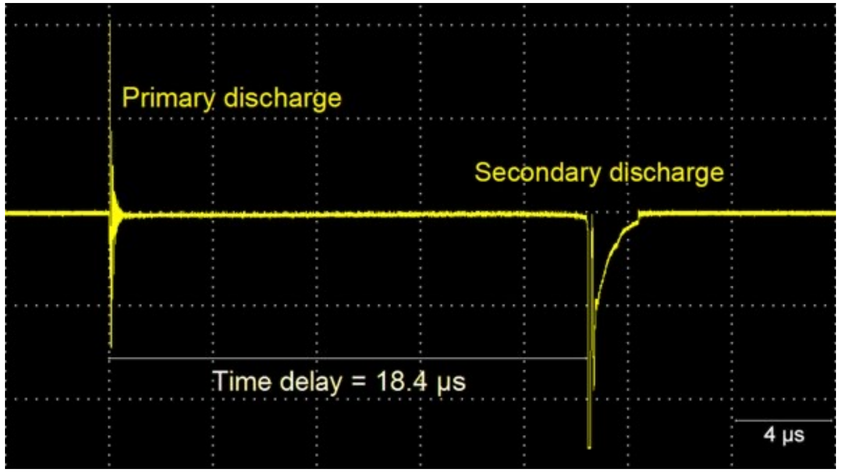
Primary discharge in a GEM hole



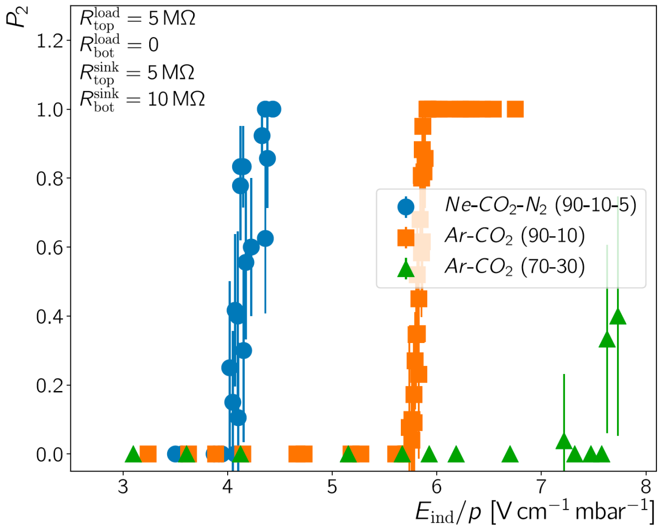
Secondary discharge between GEM and anode

Secondary discharges in (TH)GEMs

- Time delay in the order of µs between primary and secondary discharge
- Steep onset of secondary discharge probability vs E_{ind} below amplification values
- However, there are remaining questions especially concerning their formation mechanisms
  - Thermal processes considered as main mechanism of secondary electron emission
    - [A. Deisting et al. NIM A 937 (2019) 168-180]
    - [A. Utrobicic et al. NIM A 940 (2019) 262-273]



Signals induced by discharges on the readout electrode



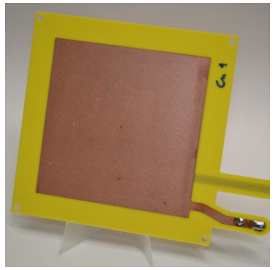
NIM A 937 (2019) 168

Secondary discharge probability of GEMs vs E_{ind}

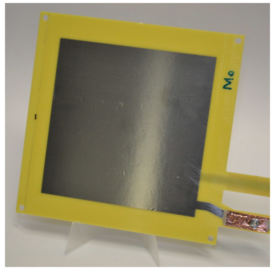
(TH)GEMs with different coating materials

- So far there are not many systematic studies investigating the effects of material choice in (TH)GEMs on various performance criteria
  - Conductive top and bottom electrode layers are typically made of copper
- GEMs, THGEMs and SH-THGEMs (single hole) with various cladding materials were produced and studied
  - Results from the SH-THGEMs summarized in [B. Ulukutlu et al. NIM A 1019 (2021) 165829]

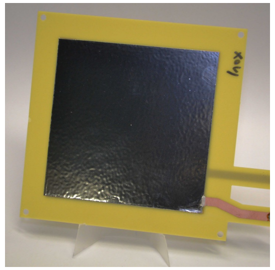
Cu GEM



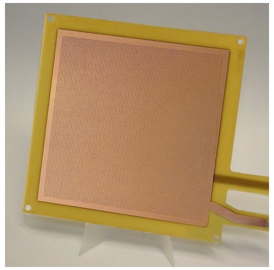
Cu SH-THGEM



Mo SH-THGEM

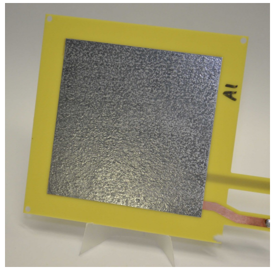


Inox SH-THGEM

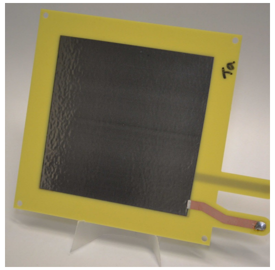


Cu THGEM

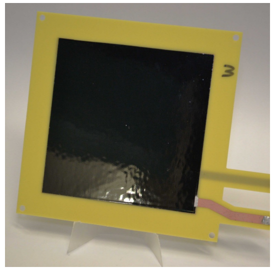
Al GEM



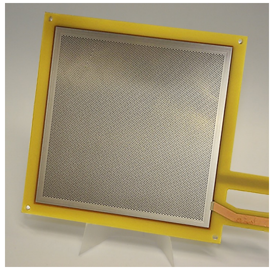
Al SH-THGEM



Ta SH-THGEM



W SH-THGEM



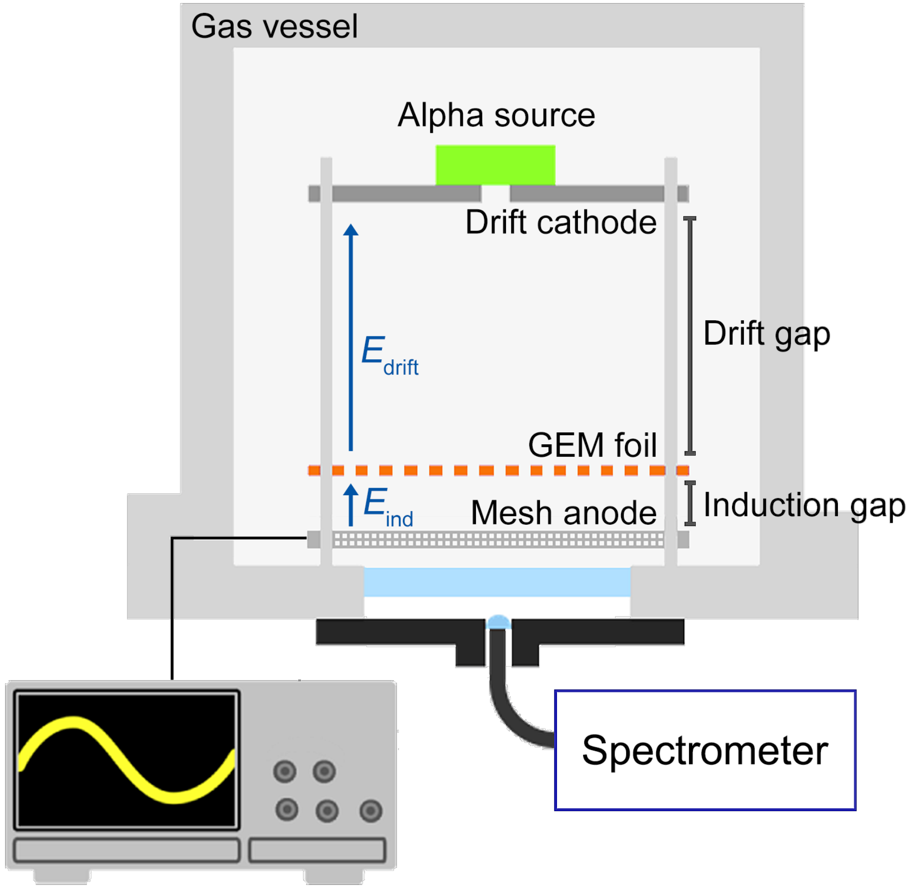
Mo THGEM

	Conductivity [10^6 S/m]	Work function [eV]	Melting point [°C]	Boiling point [°C]	Thermal conductivity [W/m*K]	Density [g/cm^3]
Al	36.9	4.08	660	2470	237	2.702
W	8.9	4.5	3422	5550	174	19.35
Cu	58.7	4.7	1083	2575	386	8.96
Inox	1.37	4.4	1510	2750*	16.3	7.85
Ta	7.6	4.22	3017	5365	57.5	16.65
Mo	18.7	4.5	2623	4651	138	10.22

*for Fe

Experimental setup

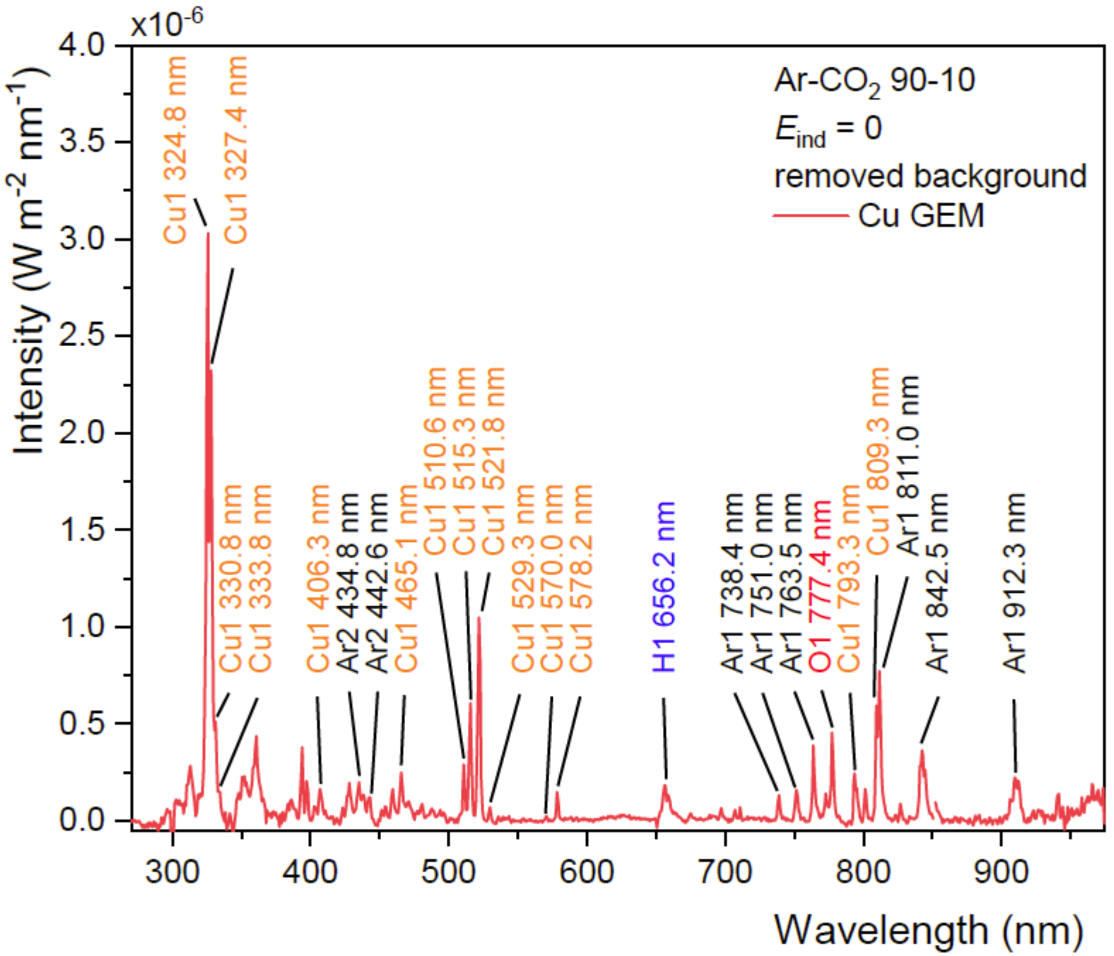
- GEM detector
  - Mixed alpha source (^{239}Pu+^{241}Am+^{244}Cm)
  - Gas mixture: Ar-CO_2 90-10
  - Drift gap = 27 mm, drift field = 400 V/cm
  - Induction gap = 2 mm
- Discharges are counted/identified with an oscilloscope via the electrical signal they induce on the readout electrode
- Light emitted from discharges is studied with spectroscopy methods
  - A transparent mesh anode and a window is used
  - Light is collected with a collimating lens
  - Emission spectrum is analysed with Ocean Optics QE65000 (UV-VIS-NIR) spectrometer



Schematic of the used detector setup

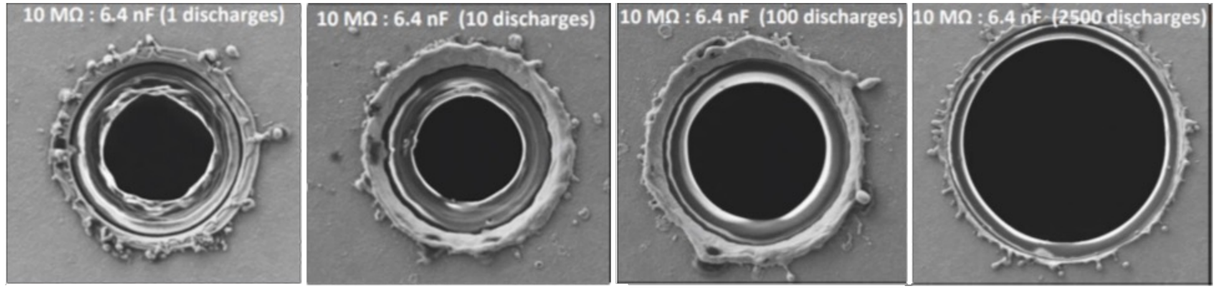
Spectra of primary GEM discharges

- Measuring emission spectra of the light emitted during primary discharges
- Calibrated spectrometer and removed background
- Identifying emission lines via peak fitting and comparing to spectroscopy database
- Longer wavelength regions dominated by the emission lines from the used gas mixture (e.g. Ar-CO_2)

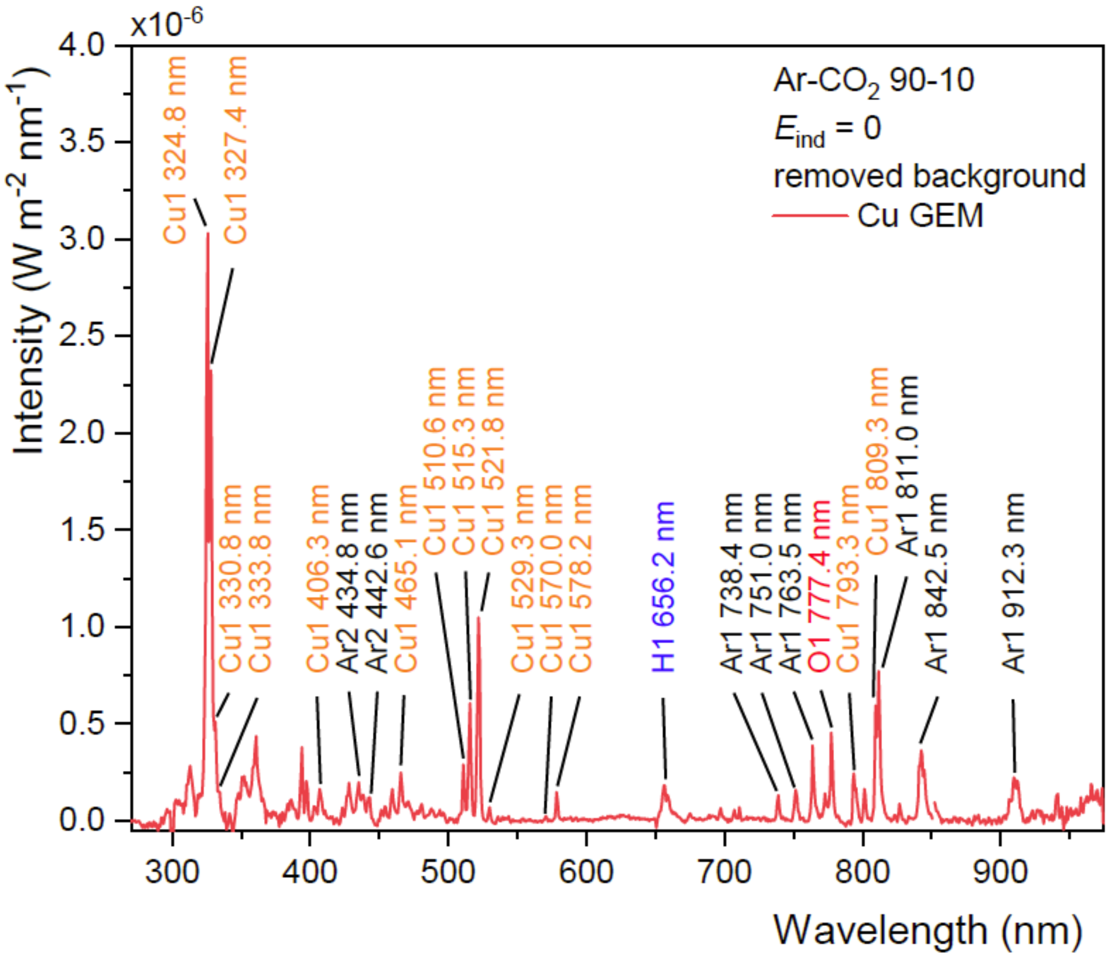


Spectra of primary GEM discharges

- Copper emission lines observed!
  - Presence of foil cladding material in the hot discharge plasma
  - Vaporization of the copper layer
  - Can be observed indirectly via the damage caused by discharges

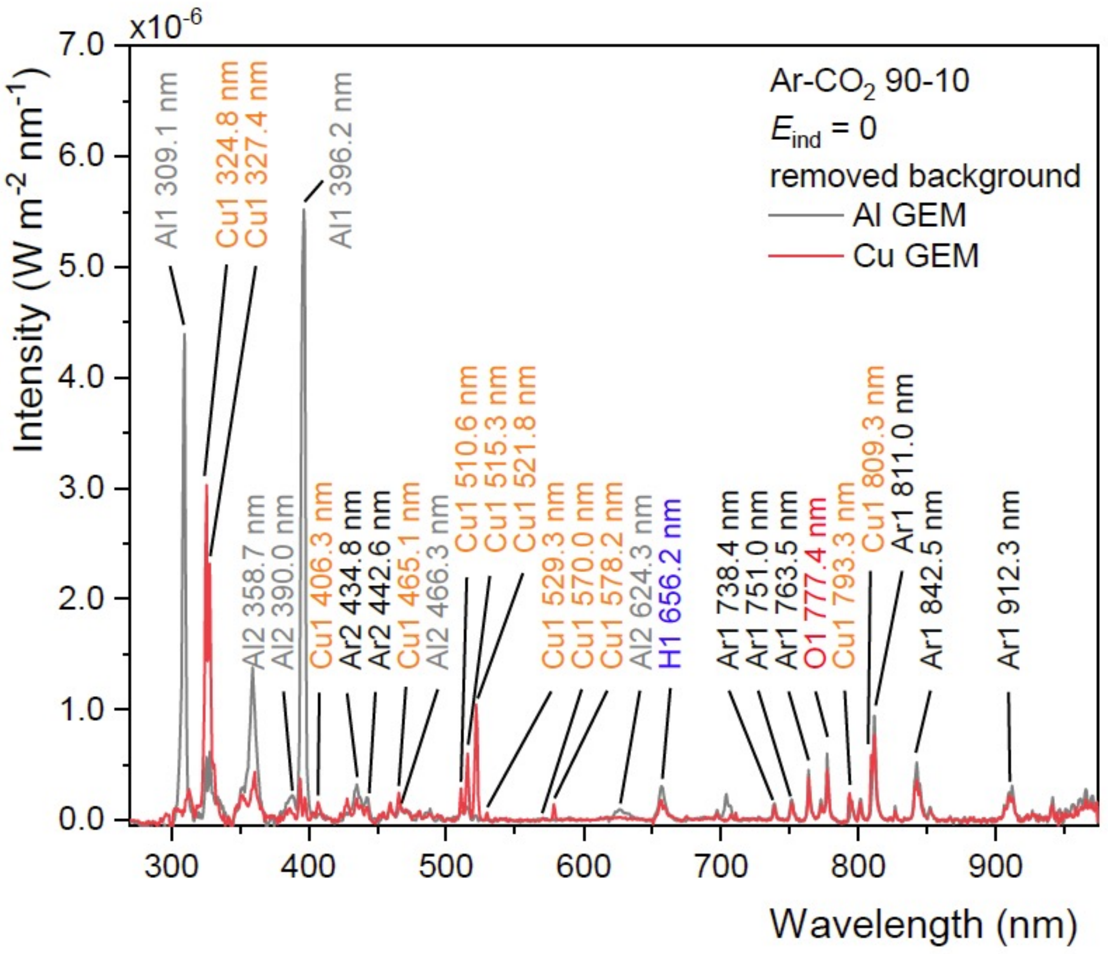


Effects of discharges on a GEM hole [J.A. Merlin, RD51 Collaboration Meeting 2018]



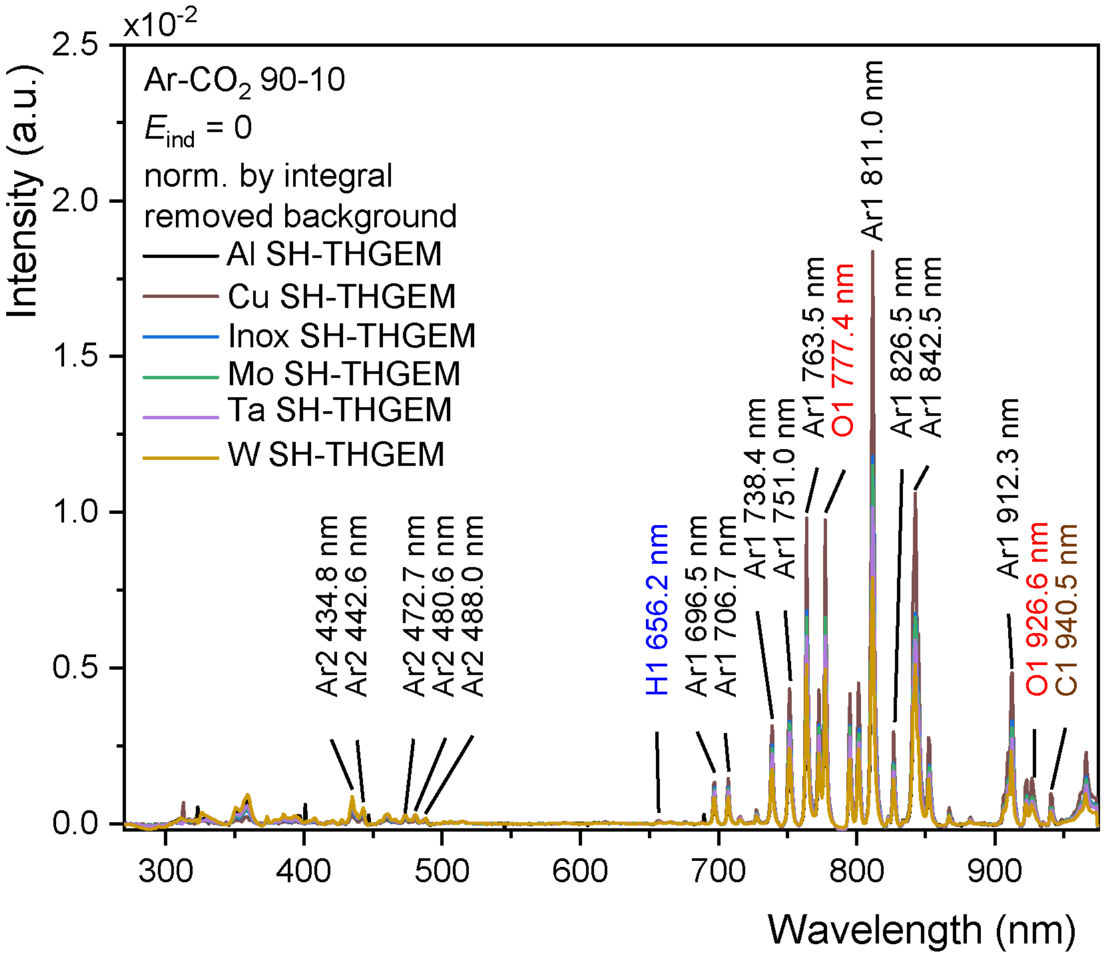
Comparing different GEM materials

- Comparison with aluminium GEM
  - Aluminium emission lines observed
  - Comparable intensity of peaks from the excitation of the used gas
- Further confirmation of the presence of foil material in discharge plasma
- Correct identification of the emission lines



Comparing different THGEM materials

- Using single-hole THGEMs for improved consistency in measured light from the constrained discharge location
- Very similar emission spectra in all SH-THGEMs
  - Spectra dominated by the gas emission lines
  - None of the used THGEMs lead to emission lines corresponding to foil cladding material
- Reduced material vaporization from discharges in THGEM hole geometry
  - Better heat dissipation due to thicker cladding material and larger area
- Secondary discharges still prevalent in THGEMs
  - No direct connection between material vaporization and secondary discharge formation



Stability against primary discharges

- Primary discharges occur at very similar applied fields regardless of material
- Streamer mechanism does not depend on the cathode material
- Charge density as the driving factor for primary discharge formation
  - Critical charge limit shown to be dictated by the used gas mixture and field geometry inside hole [NIM A 870 (2017) 116]

➢ No material dependence expected and none observed!

Onset of primary discharge formation	
THGEM cladding material	Applied voltage across foil [V]
Copper	1680
Aluminium	1690
Molybdenum	1700
Stainless steel	1685
Tantalum	1700
Tungsten	1683

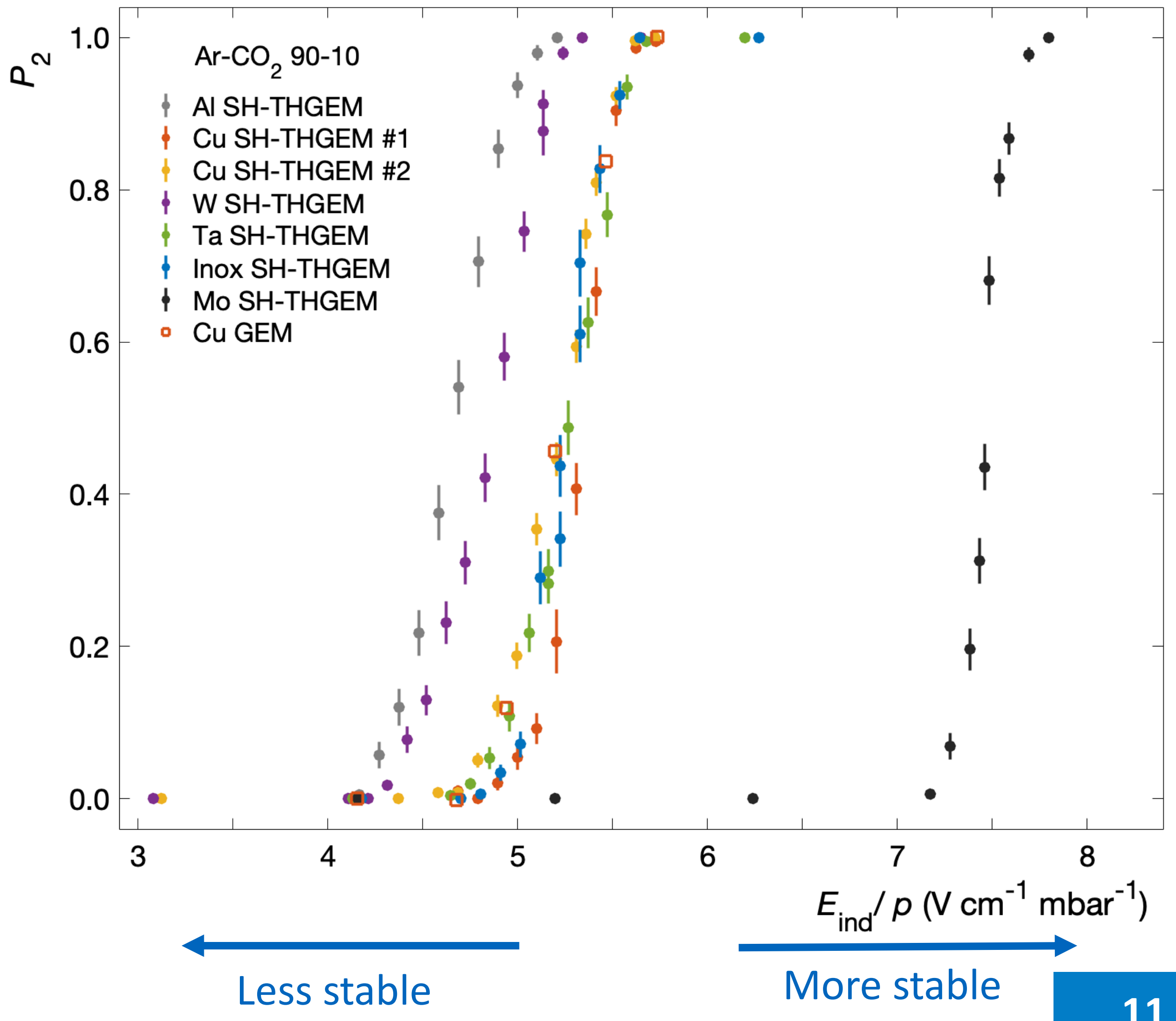
Secondary discharge stability

- Secondary discharge probability:

$$P_2 = \frac{N_{\text{Secondary Discharge}}}{N_{\text{Primary Discharge}}}$$

- Data for Cu GEM from [NIM A 937 (2019) 168]

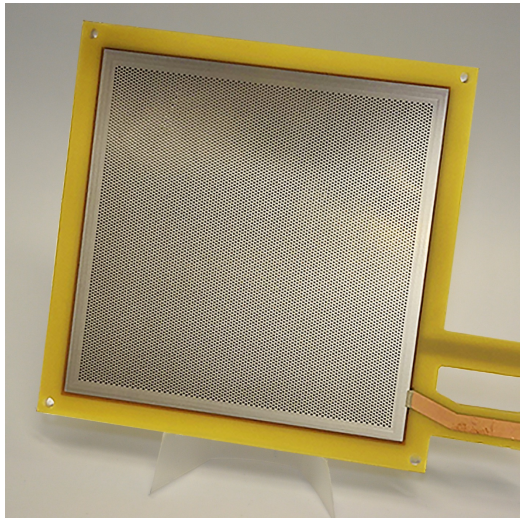
- **Molybdenum SH-THGEM** displays especially high stability
  - Is this due to the material properties?
  - The observed hierarchy cannot be explained by any of the material properties expected to be relevant for discharge formation
  - Surface quality?



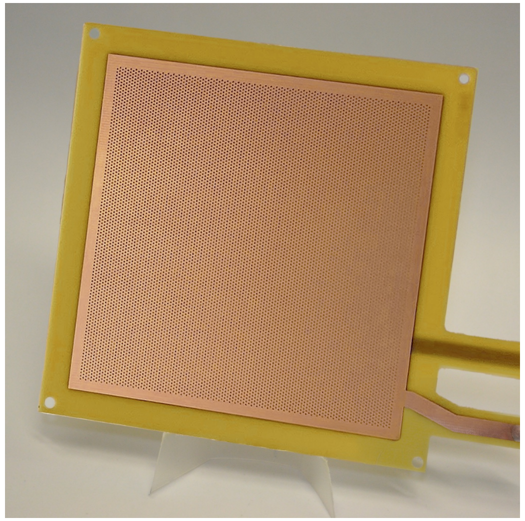
Multi-hole Mo-THGEM

- Further investigations on Mo stability
- First, full-scale Mo-THGEM produced at the CERN MPT lab
  - 25 µm thick molybdenum foil glued on the fiberglass PCB material

- Cu multi-hole THGEM for reference
- Same dimensions and tools used for production
- Special surface treatment to ensure smoothness
  - Polishing and cleaning



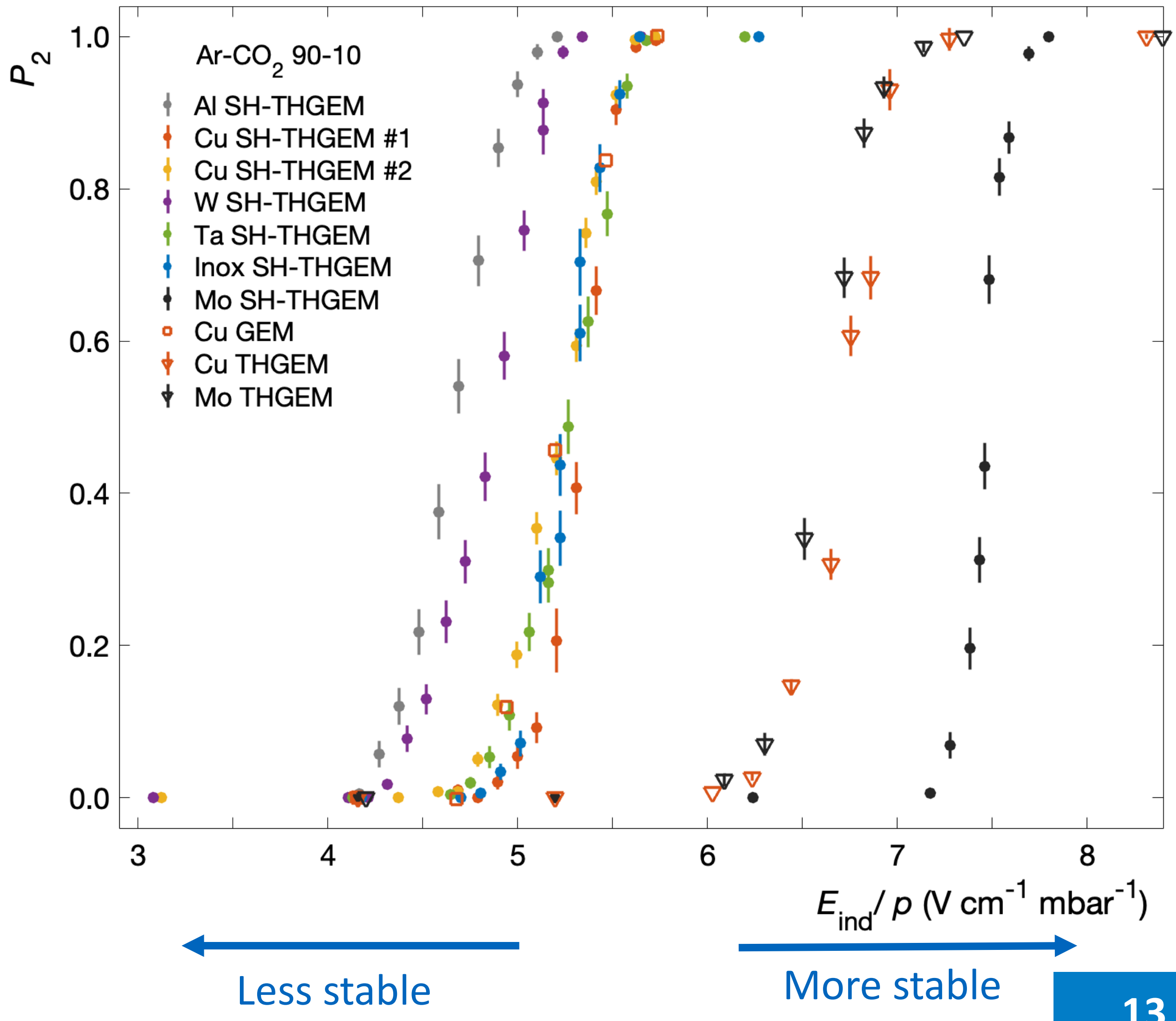
Mo THGEM



Cu THGEM

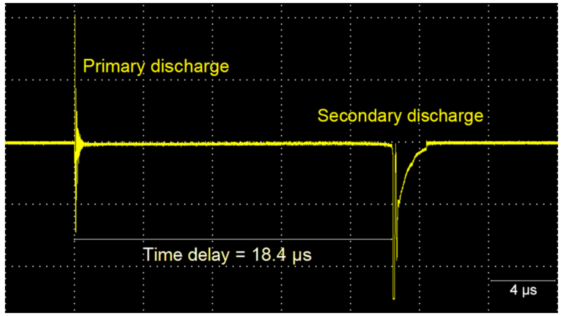
Secondary discharge stability

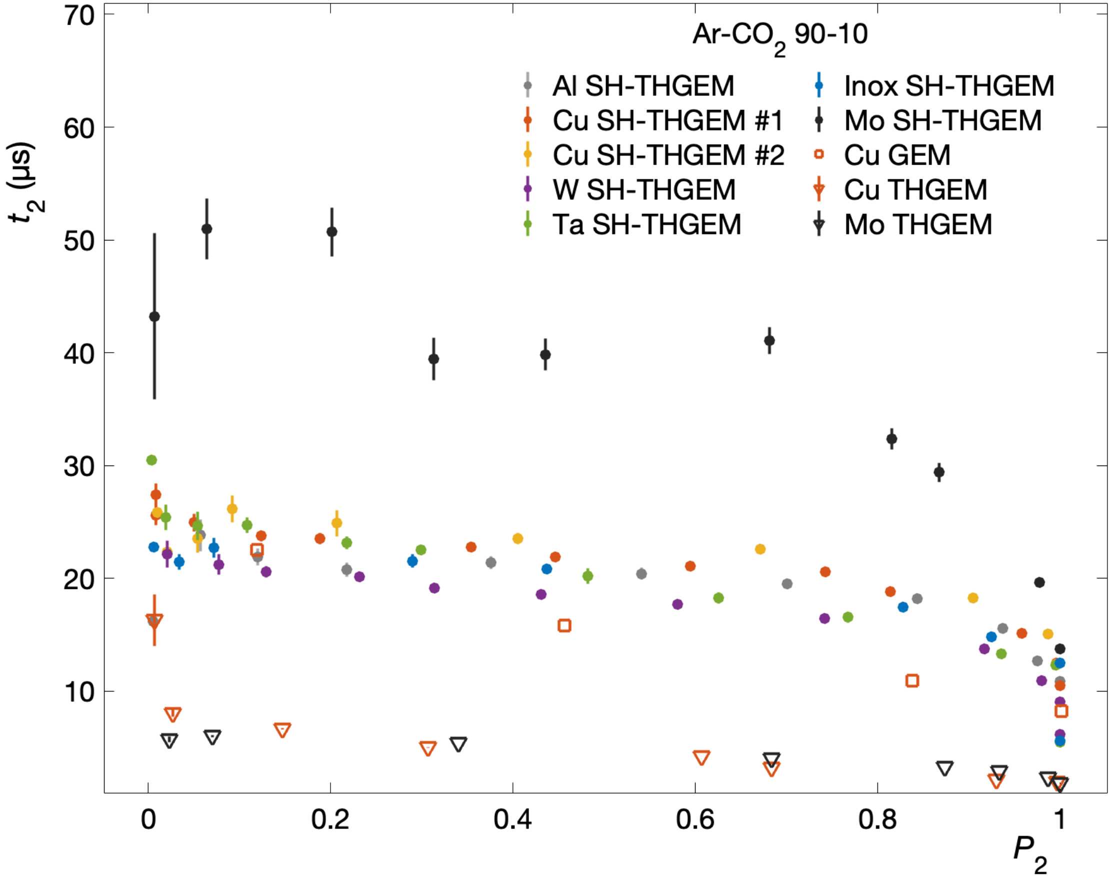
- Both multi-hole THGEM samples are stable against secondary discharges compared to previous results from:
  - [A. Deisting et al. NIM A 937 (2019) 168-180]
  - [A. Utrobicic et al. NIM A 940 (2019) 262-273]
- The enhanced stability of molybdenum not replicated with the multi-hole Mo THGEM
  - Polished Cu THGEM is equally stable
- Effect of surface properties more than material properties?
  - Flipping THGEMs (vs. drilling direction) observed to make no difference



Time delay

- Duration between the primary and secondary discharges
- Most of the SH-THGEMs are consistent with previous observations with GEMs
- Molybdenum SH-THGEM is again an outlier
- Both tested multi-hole THGEMs lead to quicker secondary discharges





Conclusion and outlook

1. Spectroscopy offers a new perspective on GEM discharge studies
   a. Vaporization of foil material observed for GEM foils
   b. Vaporization rate significantly reduced with THGEMs → better heat dissipation
2. Significant variance in secondary discharge stability observed between samples
   a. Not easily explained by material properties and could be related to oxide layers or quality of the hole edges
   b. Surface quality of the structure could be the key
3. Further visual studies with multi-hole THGEMs to rule out local hotspots
   a. Microscope imaging of the THGEM holes surfaces

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New (TH)GEM coating materials characterized using spectroscopy methods

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[d] European Organization for Nuclear Research (CERN), Geneva, Switzerland

Thank you for your attention!

Any questions?

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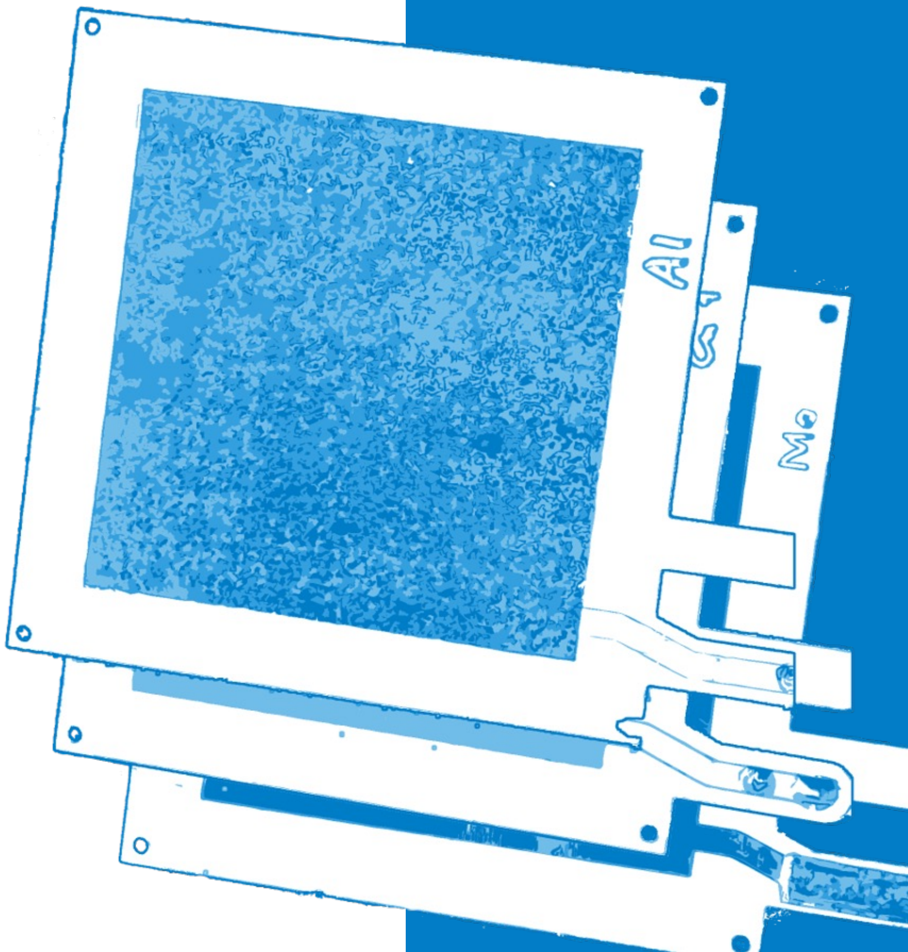
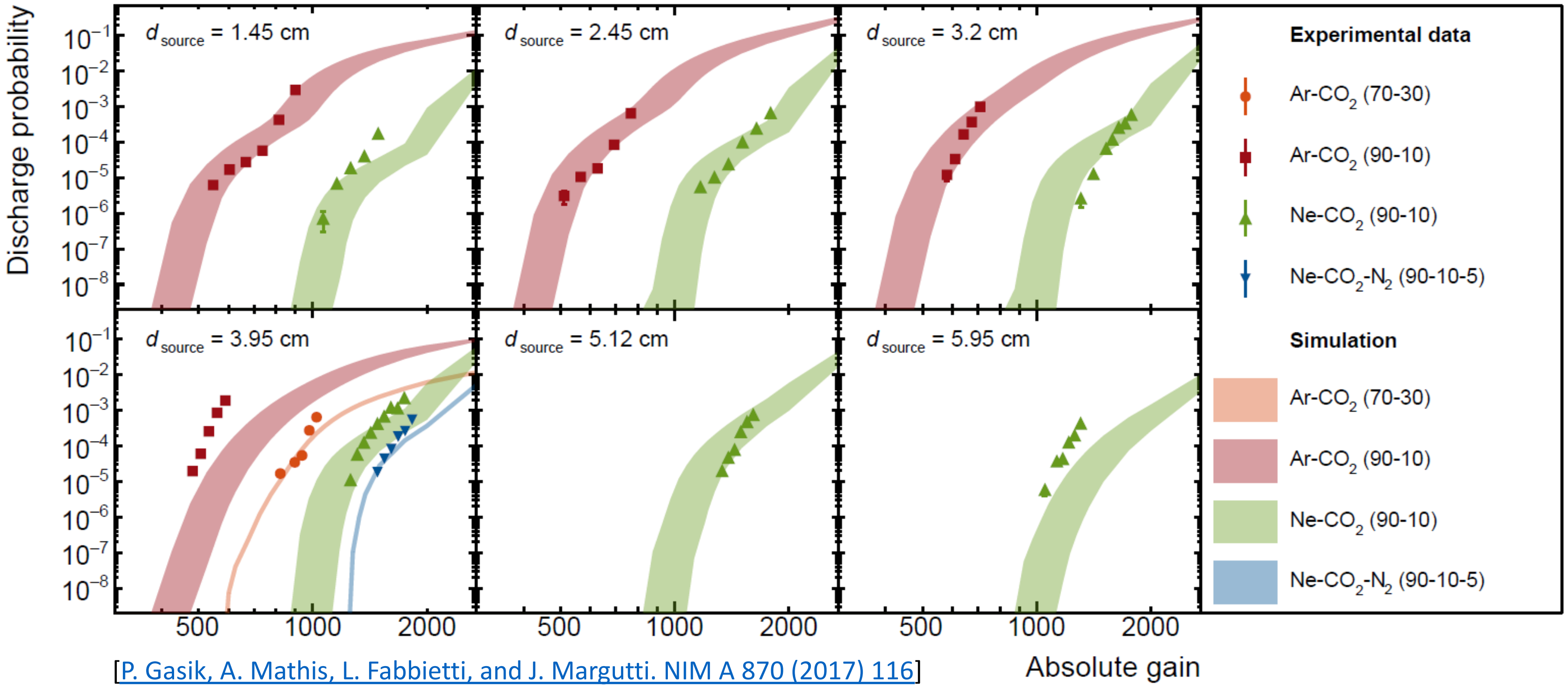
Sachbeihilfe: „Eine umfassende Untersuchung der Entladungserzeugungsmechanismen in Micro-Pattern Gas Detektoren“



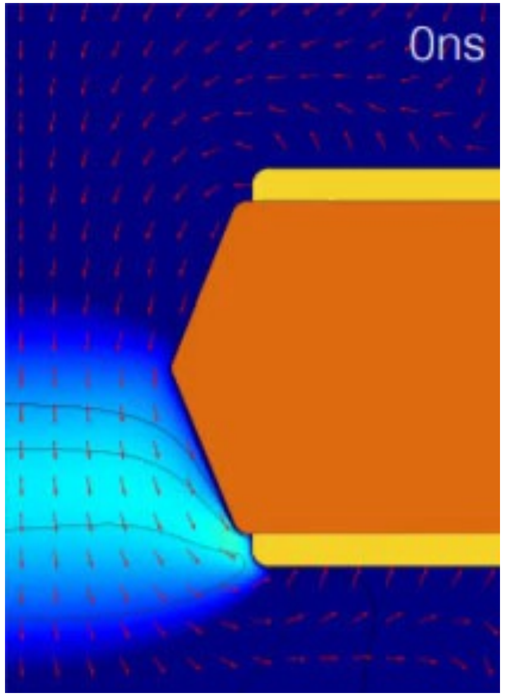
Formation of primary discharges

- Charge density as the driving factor for primary discharge formation
  - Primary discharge occurs when a critical number of charge carriers is exceeded within the hole



[P. Gasik, A. Mathis, L. Fabbietti, and J. Margutti. NIM A 870 (2017) 116]

Streamer development in GEM hole leading to primary discharges

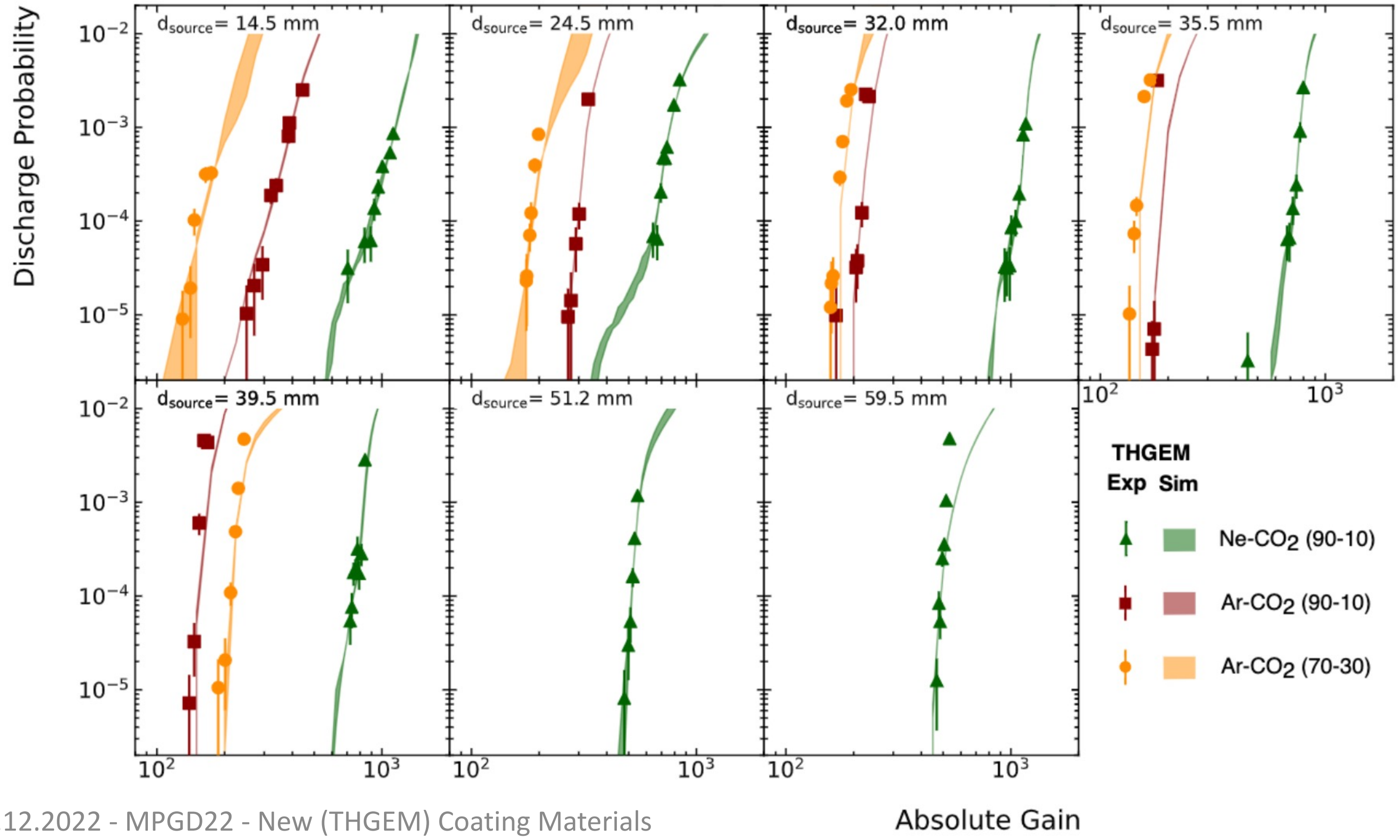


Standard GEM

Gas	Q_{crit}
Ar-CO_2 (90-10)	$(4.7 \pm 0.6) \times 10^6$
Ne-CO_2 (90-10)	$(7.3 \pm 0.9) \times 10^6$

Primary discharge limits for THGEMs

- This theory was also shown to explain the observed reduced primary discharge stability of THGEMs



11.2x 11.2 cm^2 THGEM

Gas	THGEM $\langle Q_{crit} \rangle$ [$\times 10^6$ e]	THGEM t_{int} [ns]	GEM Q_{crit} [$\times 10^6$ e]	GEM t_{int} [ns]
Ne-CO_2 (90-10)	7.1 ± 2.2	30–210	7.3 ± 0.9	20–90
Ar-CO_2 (90-10)	4.3 ± 1.5	20–110	4.7 ± 0.6	15–50
Ar-CO_2 (70-30)	2.5 ± 0.9	40–310	–	–

[P.Gasik, L.Lautner et al. NIM A 1047 (2022) 167730]

See also talk from P. Gasik tomorrow!

Delayed secondary discharges

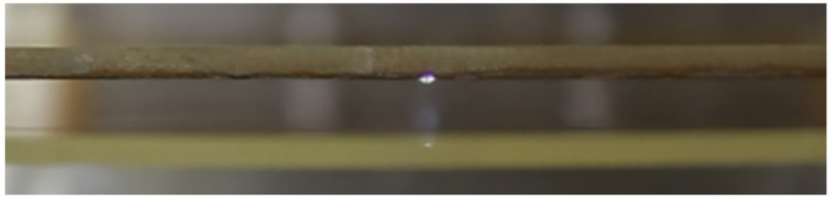
More dangerous discharge in the transfer/induction gap appearing μs after the primary spark

- Mitigation strategies established
  - ❑ L. Lautner, et al. JINST 14 (2019) no.08, P08024
  - ❑ A. Deisting, et al. NIM A 937 (2019) 168-180

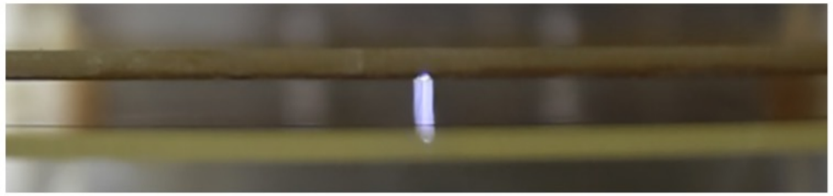
For discharges to occur a source of electrons is needed. This source is not fully understood for delayed secondary discharges.

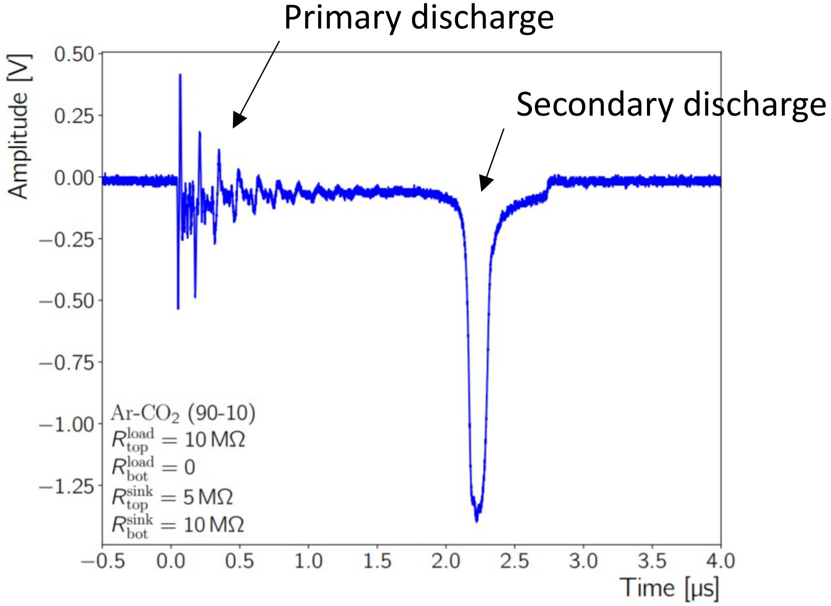
- Leading theory:
  Heating of the cathode after the primary discharge
  - ❑ A. Deisting, et al. NIM A 937 (2019) 168-180
  - ❑ A. Utrobicic, et al. NIM A 940 (2019) 262-273

a) Primary discharge



b) Secondary discharge

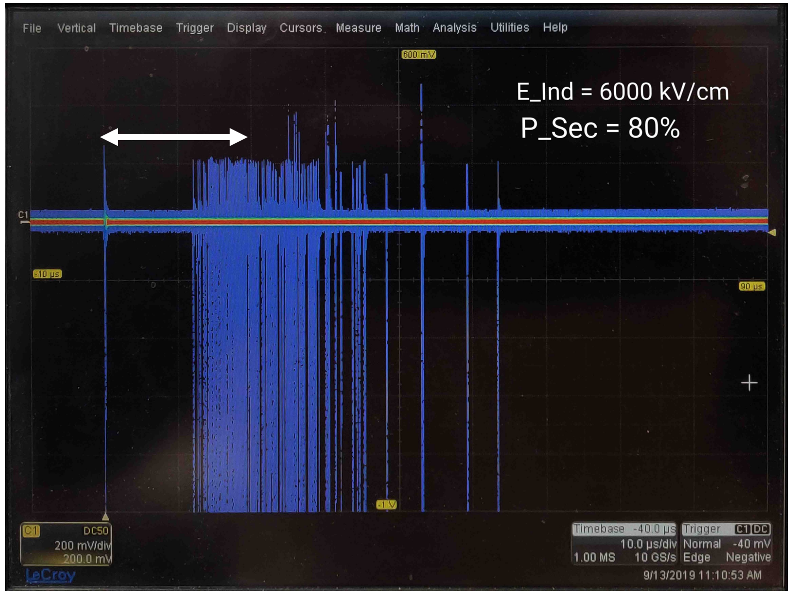


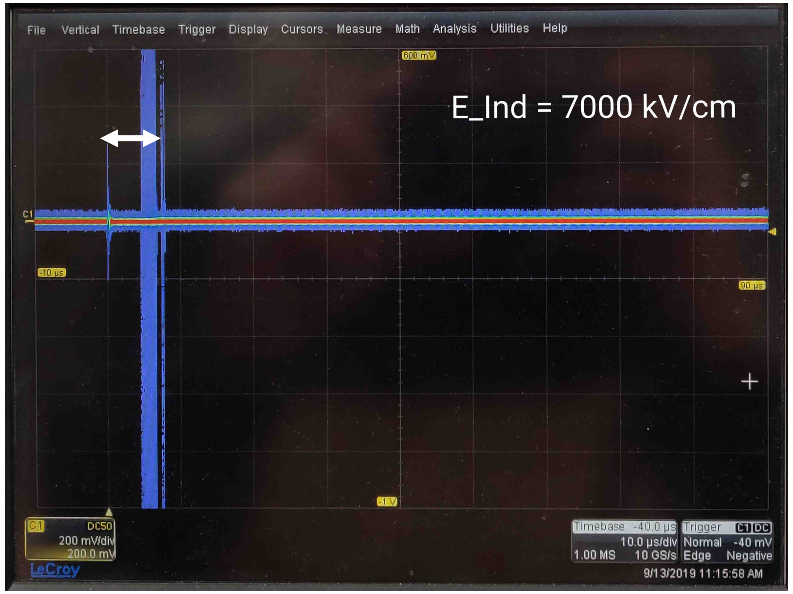


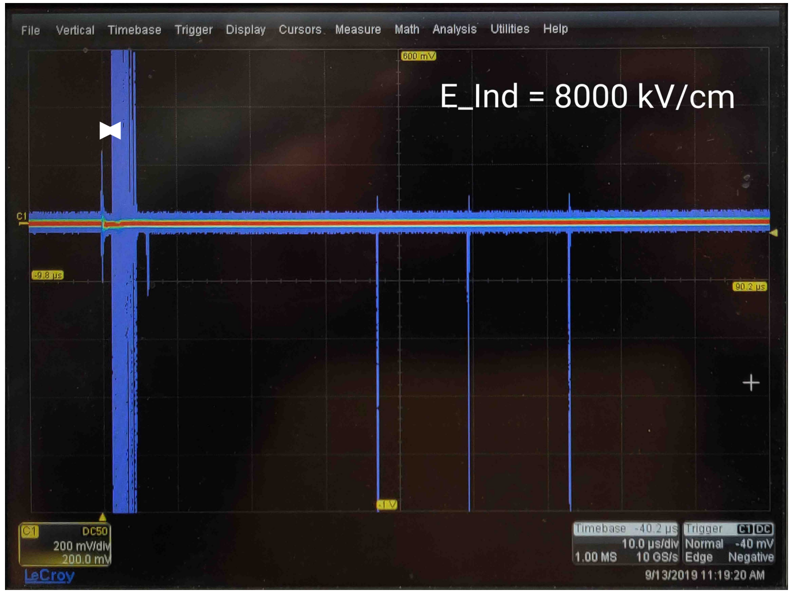
[A. Deisting, et al. NIM A 937 (2019) 168-180]

Time delay

- The time difference between the primary and secondary discharge events
  - Depends on the transport properties of the used gas
  - Up to 100 µs in Argon based gas mixtures
  - Shorter delay with increased induction field

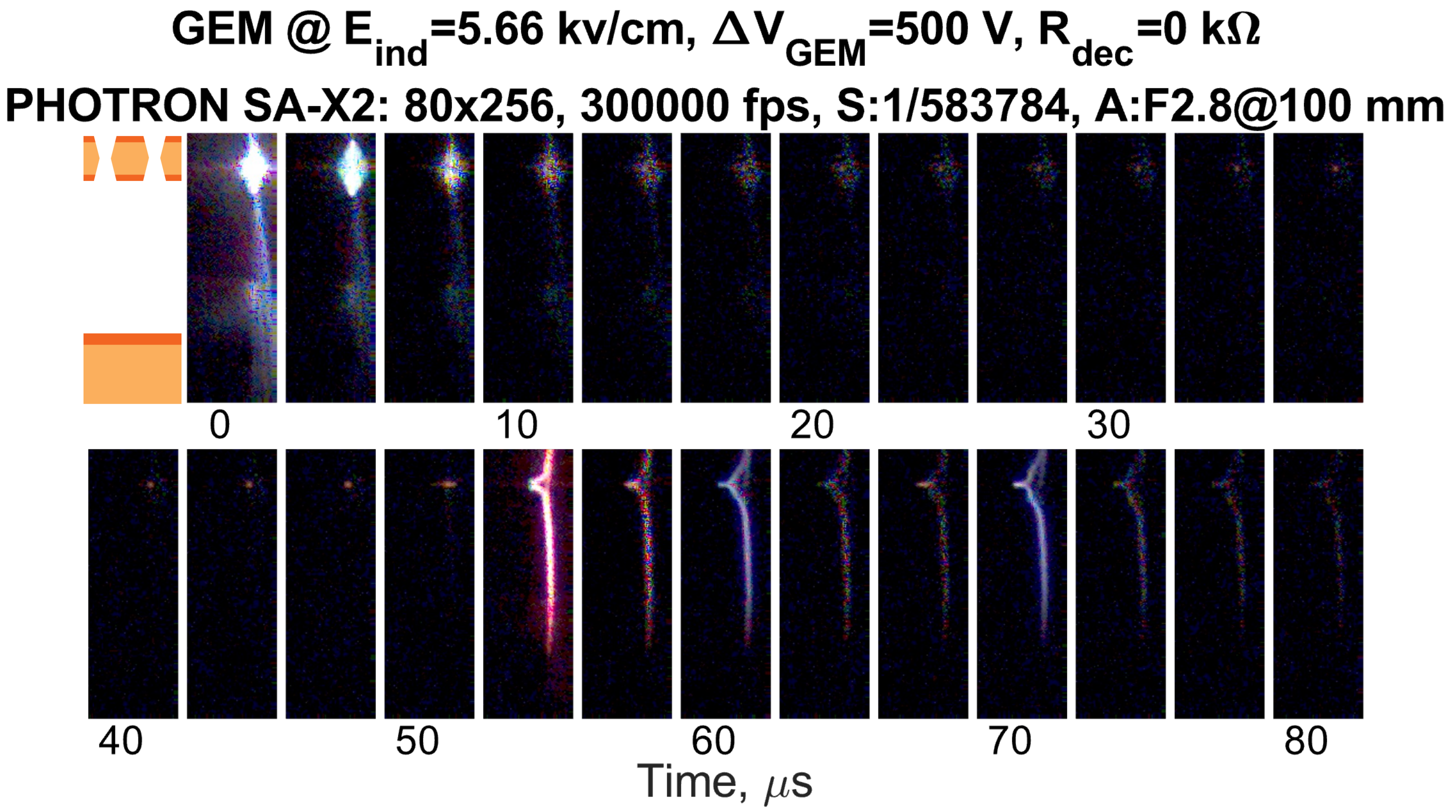




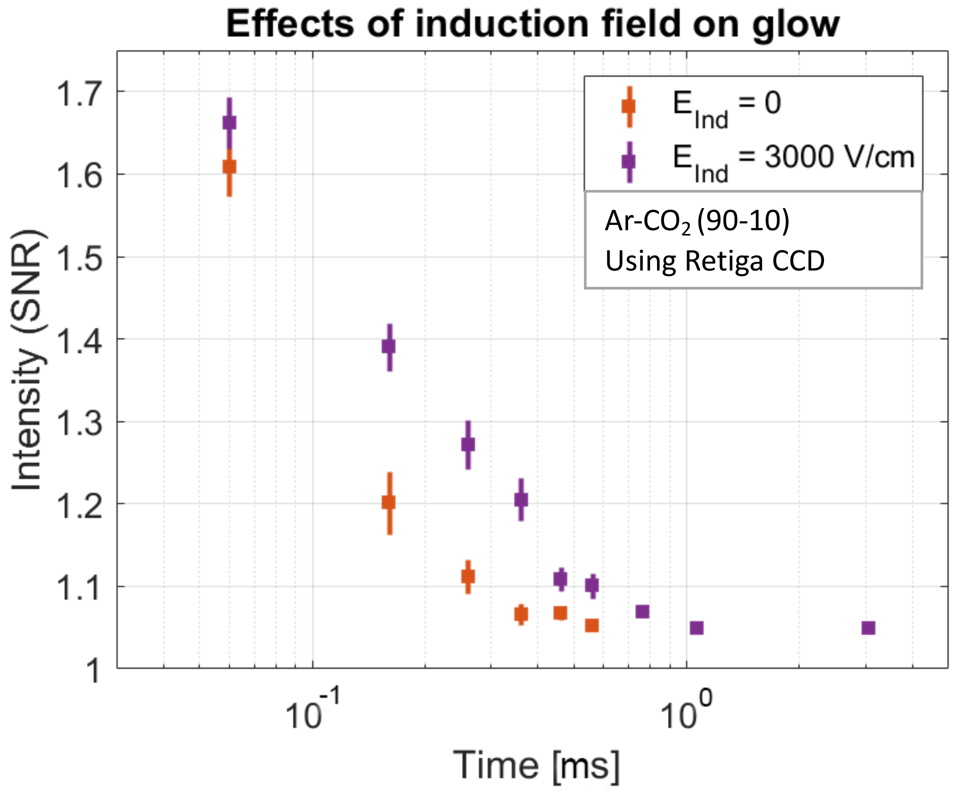


Thermionic emission of electrons

- Increased activity around the discharged hole observed to persist with applied induction field



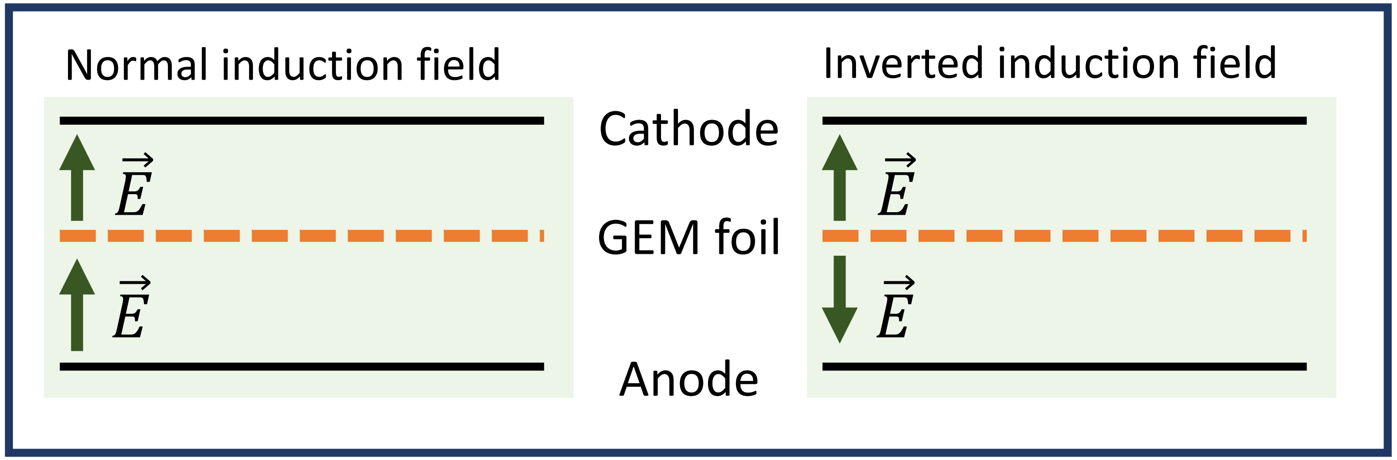
[A Utrobicic, et al. 2019 NIM A 940 262-273]

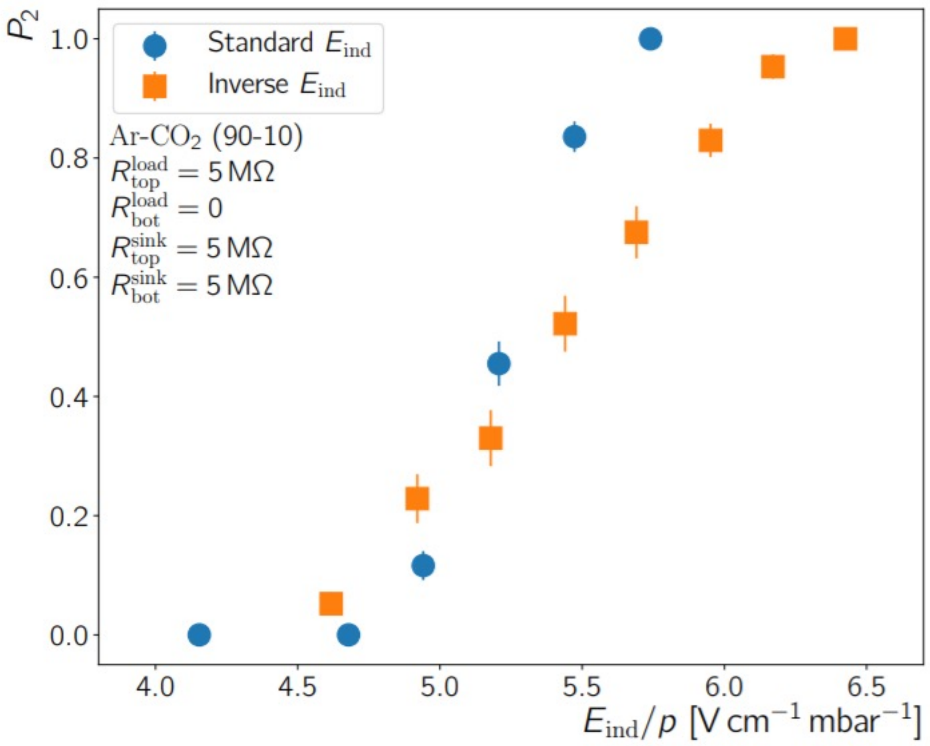


[B Ulukutlu and P Gasik 2020 J. Phys.: Conf. Ser. 1498 012035]

Secondary discharges in inverted field

- Secondary discharges also occur even if you apply the induction field in the opposite direction
  - At similar field strengths
  - With similar time delays



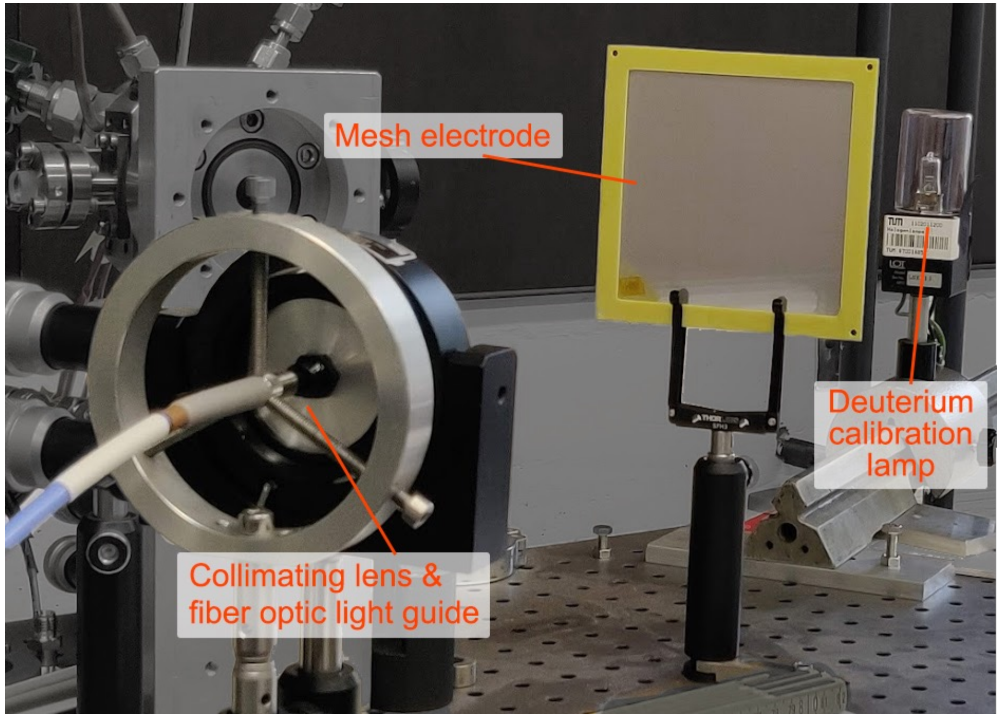


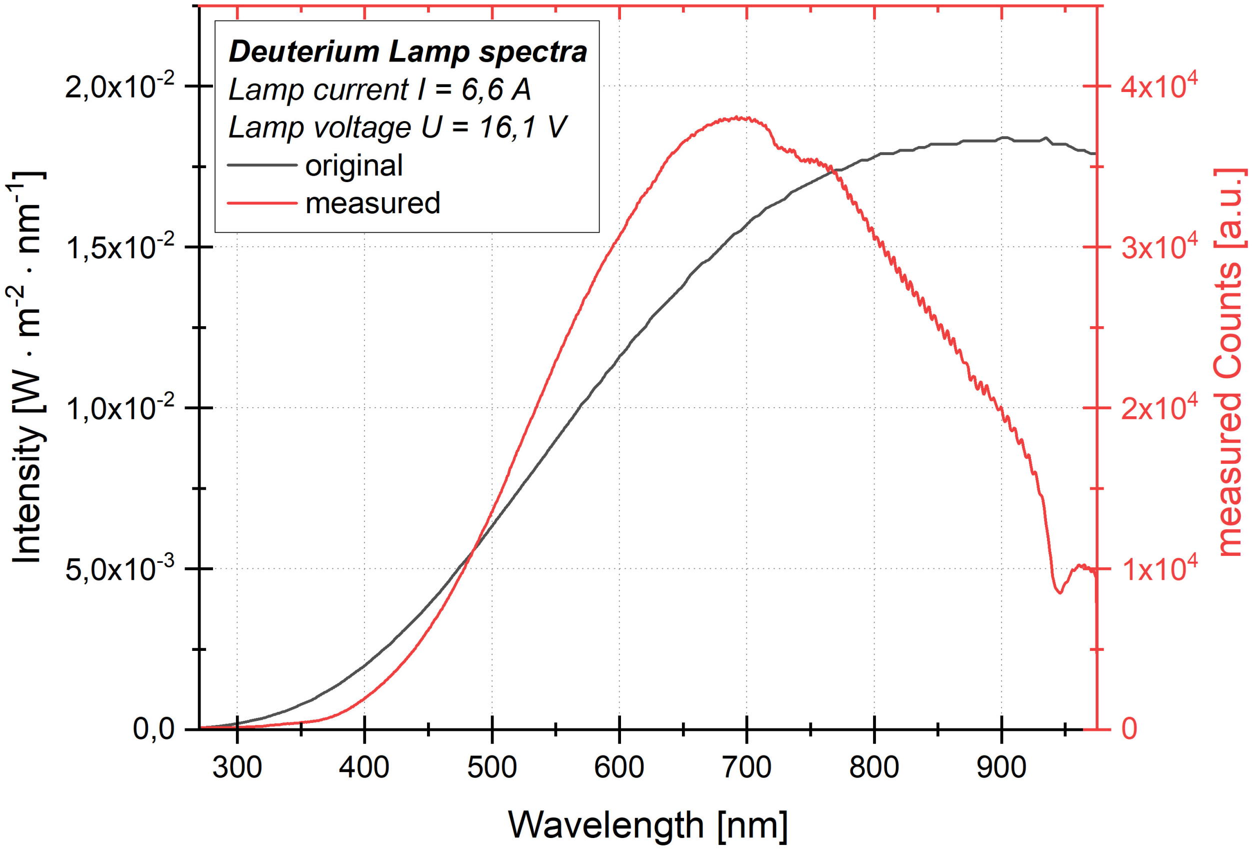
Secondary discharge probability as a function of the applied induction field strength

[A. Deisting, et al. NIM A 937 (2019) 168-180]

Calibration of the spectrometer

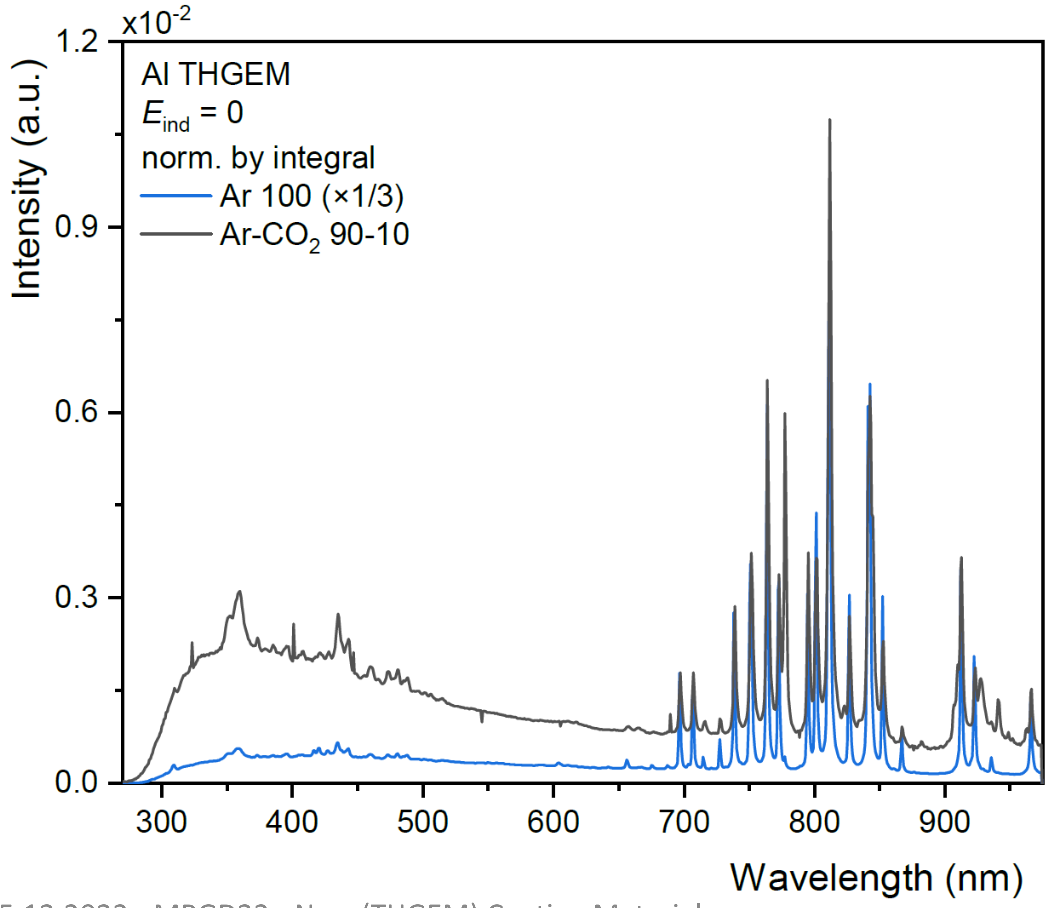
- Using a characterized deuterium lamp for the intensity calibration

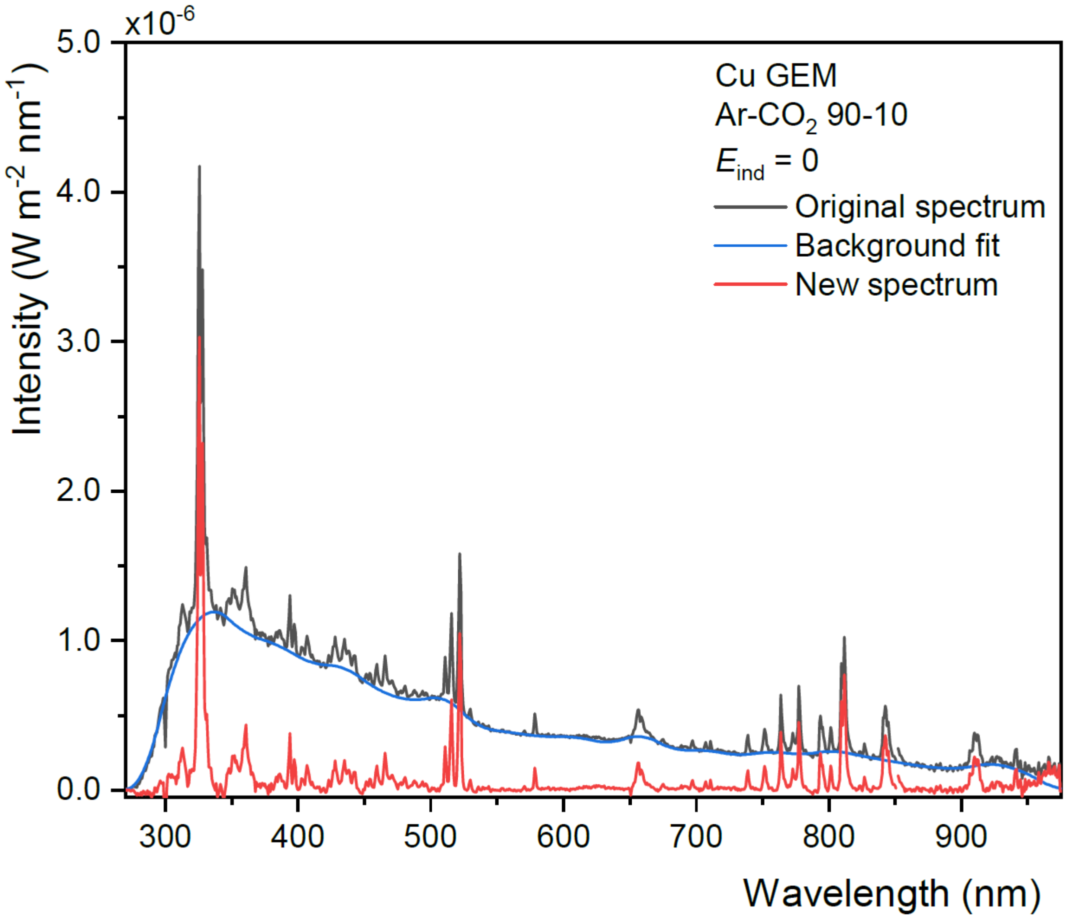




Background subtraction on spectra

- The continuous background distribution originates from the broad emission from molecules in the plasma



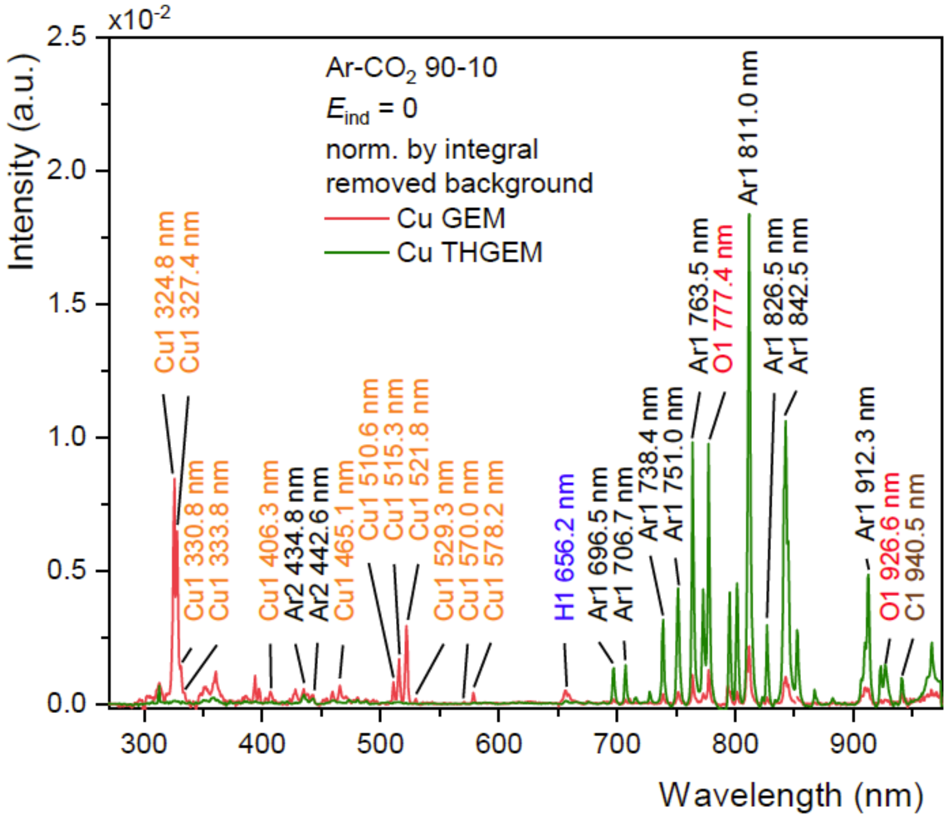


Spectra GEM vs SH-THGEM

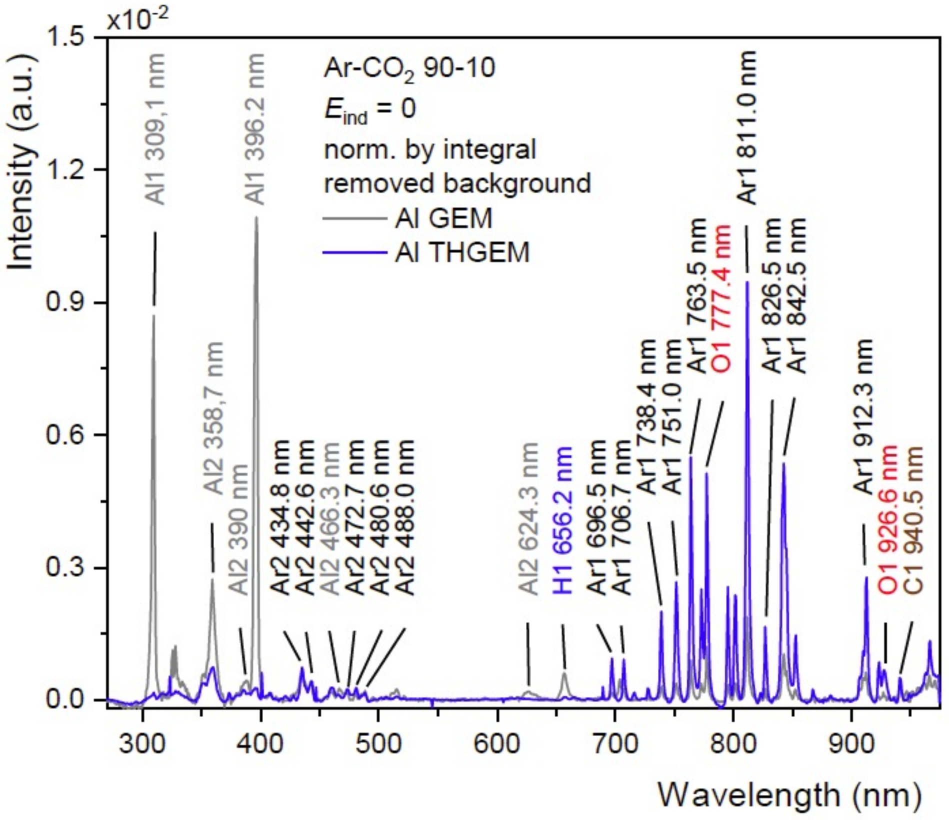
No cladding material emission lines observed with single hole THGEMs

→ None or much less vaporization of the foil material

Copper GEM vs SH-THGEM

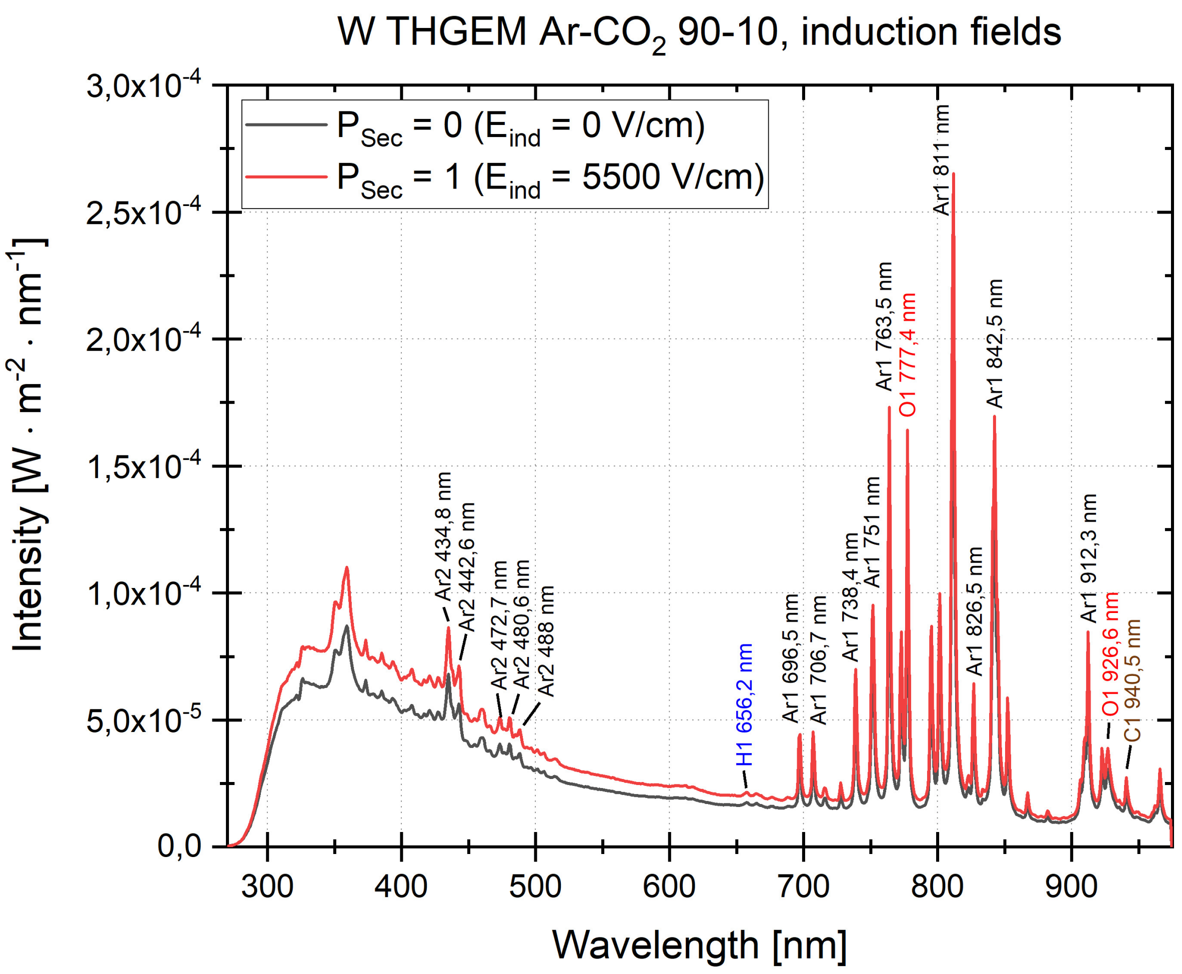


Aluminium GEM vs SH-THGEM



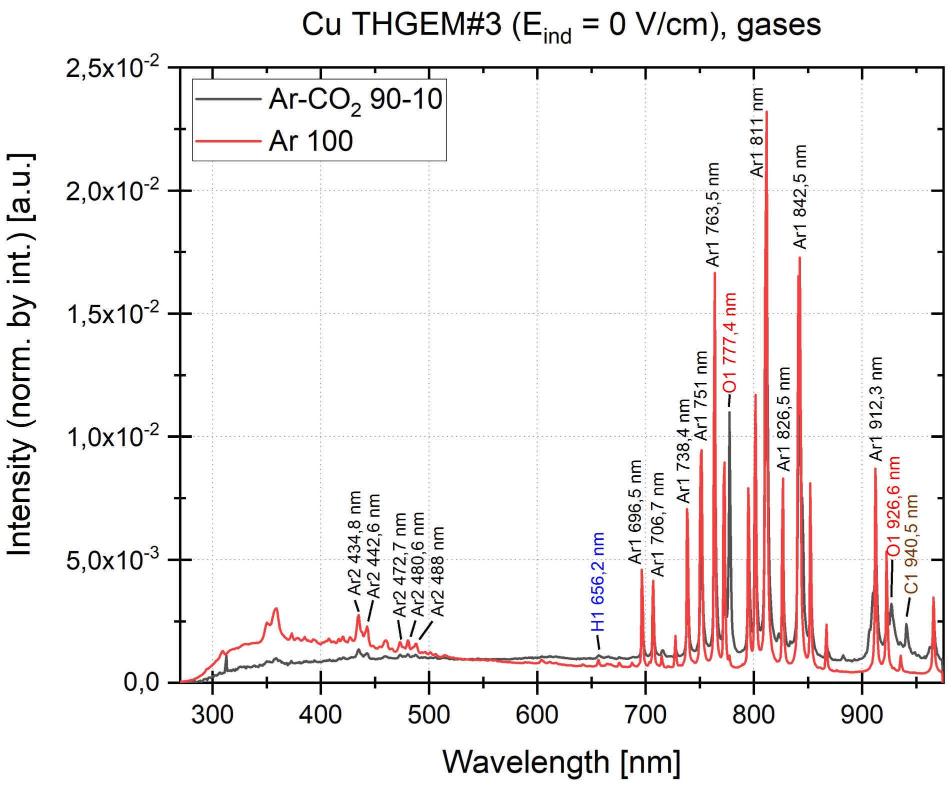
Spectra of secondary discharges

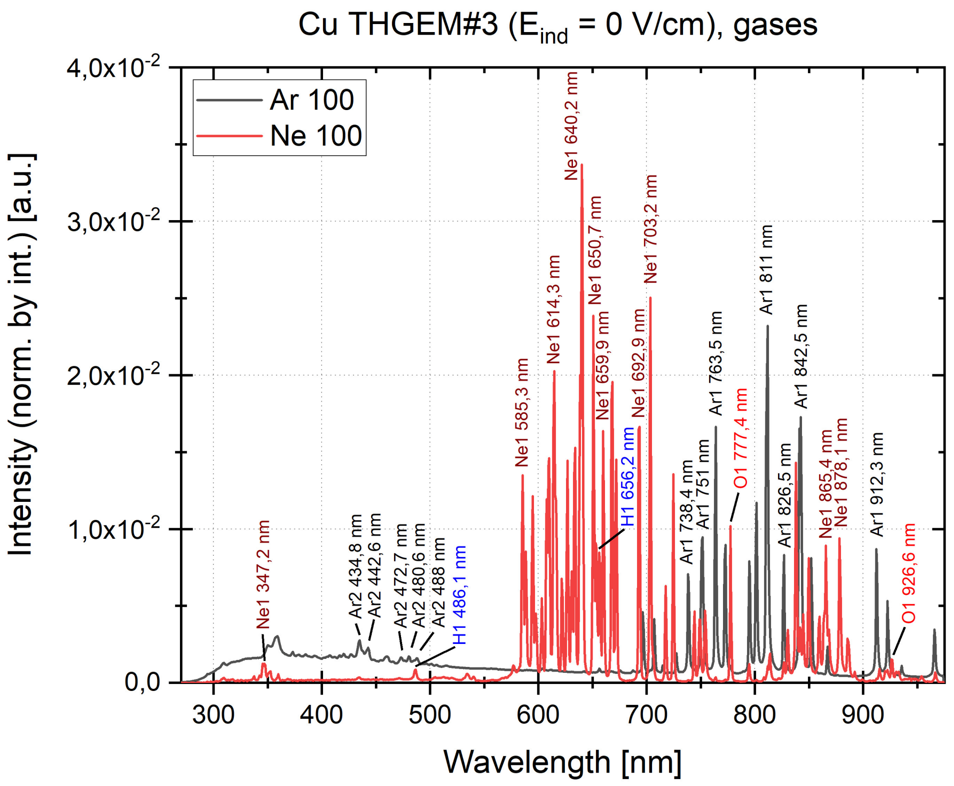
- No major differences observed in emission spectra from primary and secondary discharges
- Slightly increased overall intensity
  - Higher light emission with secondary discharges
- The underlying physical light emission processes same for both discharge types



Different gas mixtures

- THGEM spectra were also measured using Ar (100) and Neon (100) gas mixtures
- Corresponding gas lines can be identified



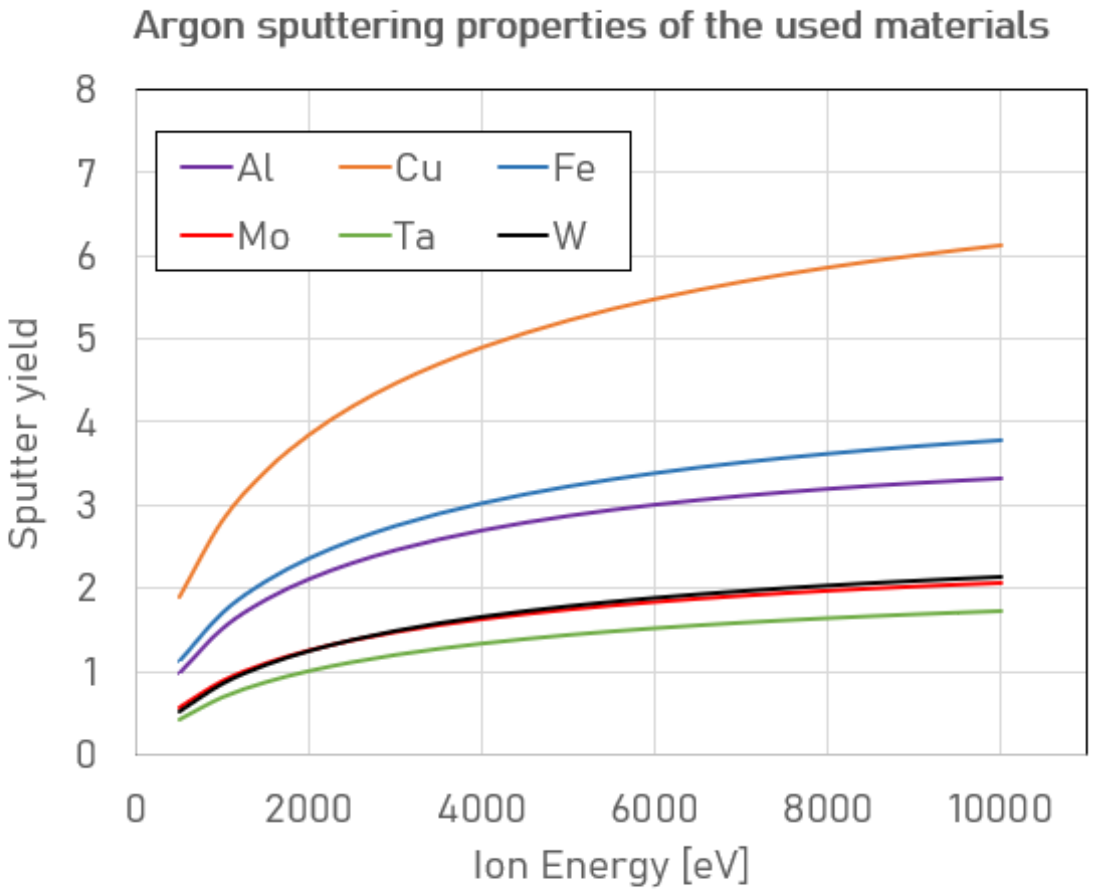


Sputtering vs vaporization

Could sputtering be the reason we observe foil material in discharge plasma or explain the secondary discharge hierarchy?

Probably not:

- Burn marks observed mainly on bottom side of foils
  - Ions would cause sputtering on the top side
- No material lines observed with THGEMs
  - THGEM foils having thicker metal layer shouldn't decrease sputtering yield
- Sputtering properties don't scale with the observed secondary discharge stability hierarchy of the used materials



[N. Matsunami, et al. in Energy Dependence of the Yields of Ion-Induced Sputtering of Monatomic Solids, IPPJ-AM-32 (Institute of Plasma Physics, Nagoya University, Japan, 1983)]