Study of wires for drift chambers coated with a magnetron

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Outline

- Motivation
- Magnetron sputtering method (setup at BINP)
- Factors that cause electron emission
- Variants of studied cathode wires
- Experimental setup for HV tests
- Measurement technique
- Study 1 - comparison of **Au**- or **Ag**-coated wires with uncoated wire in dimethyl ether (DME) gas
- Study 2 - comparison of **Ag**-coated wire with uncoated wire in various operating gases
- Conclusions

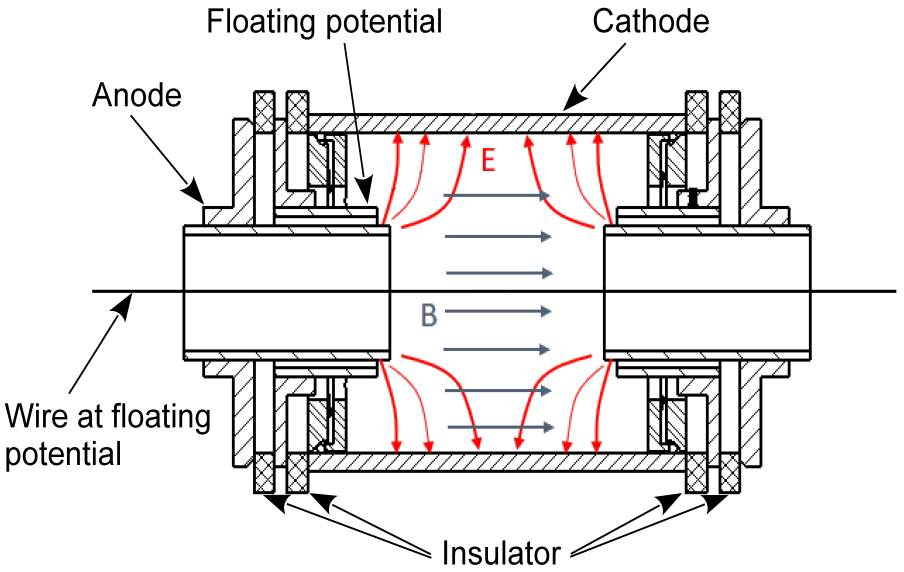
Motivation

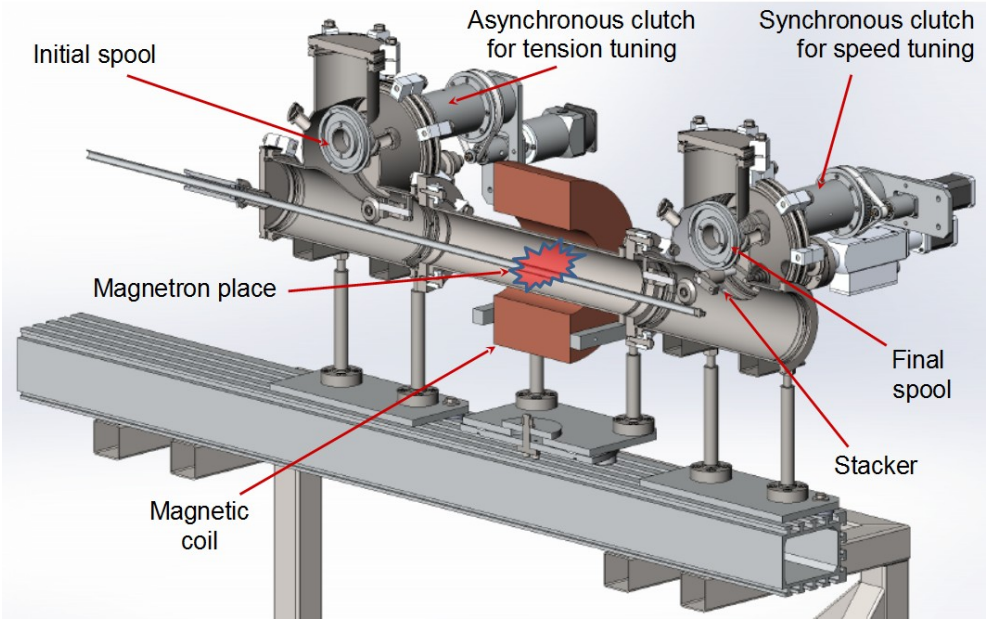
- In wire chambers, to reduce the contribution of passive material, uncoated aluminum wire is widely used.
- High strength aluminum-magnesium alloy Al5056 (Mg is about 5%) is preferred.
- Uncoated wire problems:
  - bad behavior under high loads;
  - complications when soldering wires.

Annealed material	Al	Al5056
Yield Strength, MPa	30	160
Tensile Strength, MPa	80	300

- Currently, there are difficulties in finding a manufacturer of coated wire. Therefore, an attempt has been made at BINP to develop a coating technology using the magnetron sputtering method.
- Advantages of the method:
- - conductivity, wettability and chemical resistance to reagents are not required;
- - possibility of metallization of non-metallic monofilaments;
- - the surface quality of the coated wire repeats the quality of the original wire, and finish wire-drawing is not required.

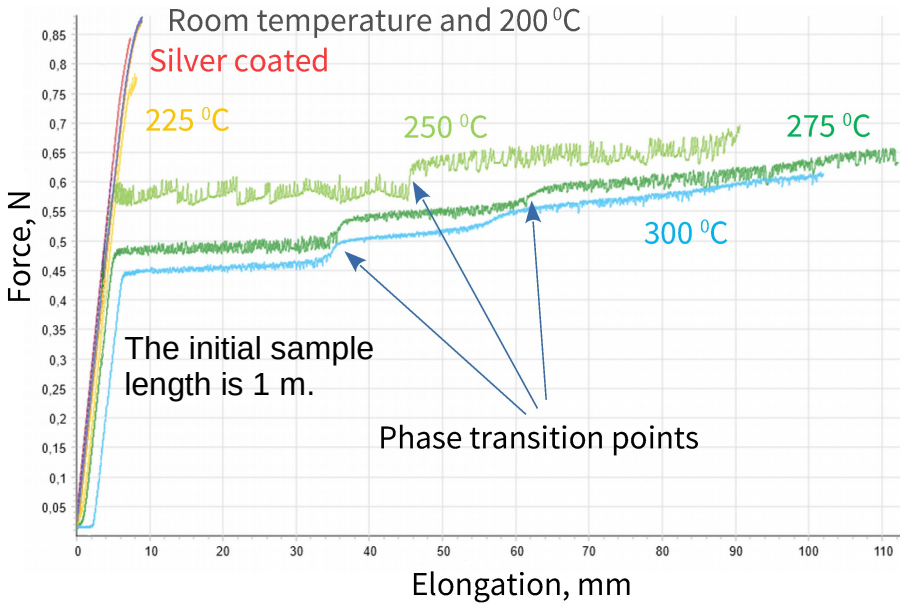
Magnetron





- Operating principle: cathode sputtering of a target in a magnetron discharge plasma in crossed **E** and **B** fields.
- Cylindrical design: axisymmetric anode and cathode.
- The wire is fed along the axis of the magnetron. Some of the atoms of the cathode substance are deposited on the wire, forming a dense film.
- Film thickness depends mainly on the wire feed speed and the power of the magnetron discharge.
- The design of the installation allows for increasing the length of the magnetron to increase sputtering productivity, as well as installing additional magnetrons to obtain multilayer coatings.

Magnetron: optimal operating mode

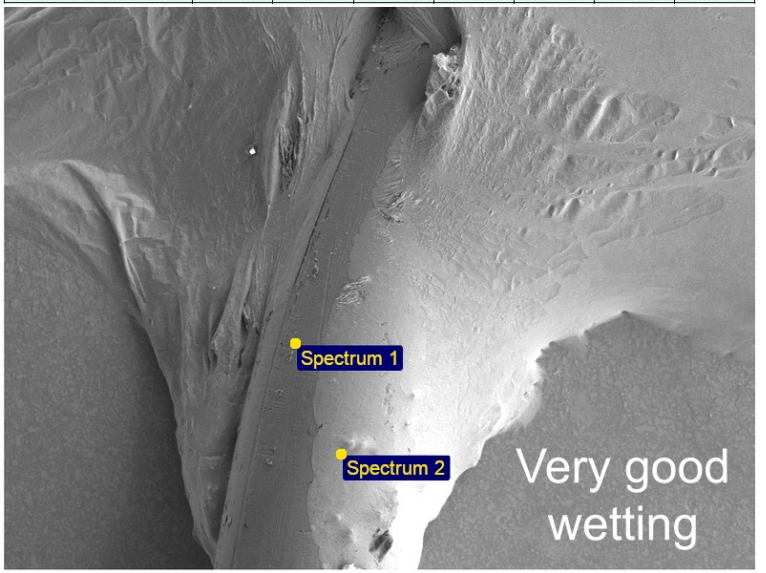


- During the sputtering process, thermal power is released on the wire (hot operating gas, heat of condensation of atoms of the cathode substance and their kinetic energy)
- The permissible limit for heating the wire, at which its mechanical properties do not change, is not higher than 200-225 ºC.

- For satisfactory soldering, a two-layer coating is sufficient:
nickel (Ni) sublayer 10 nm or more thick,
silver (Ag) layer 20 nm or more thick.
- Image of the soldering area: good surface wettability with solder.
- Coating productivity in optimal mode:
up to 4 meters per minute for Al wire with a diameter of 40 microns or more.

Ni ~ 20 нм
Ag ~ 60 нм

Spectra \ Element	C	Mg	Al	Ni	Ag	Sn	Pb
Spectrum 1	3.38	1.15	20.51	6.89	68.07		
Spectrum 2	5.88					89.12	5.00



Electron emission

- Field emission

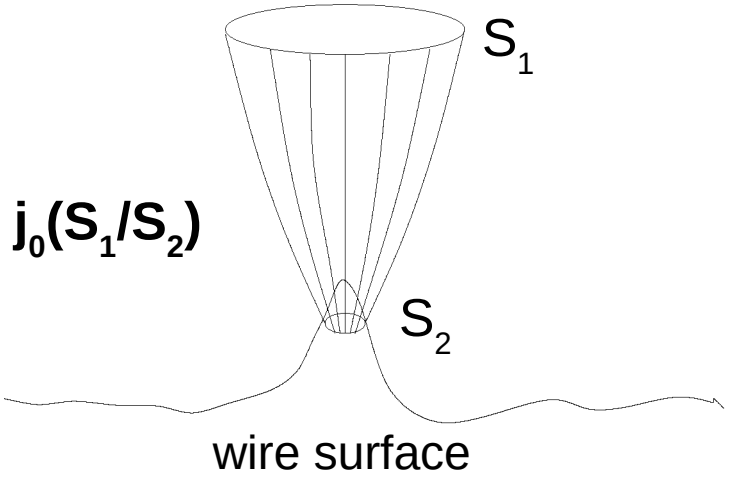
  tunneling of electrons through a potential barrier near a metal surface under action of an external electric field

- Thin film field emission (Malter effect [1])

  emission from a metal under the action of a strong electric field in a thin insulating film with a positive charge on the surface

- Photoelectric effect

Ion current density on the tip surface $\mathbf{j \sim j_0(S_1/S_2)}$



[1] *L.Malter*, Thin Film Field Emission. Phys. Rev. 50 (1936) 48.

Variants of wires

Aluminum alloy wire

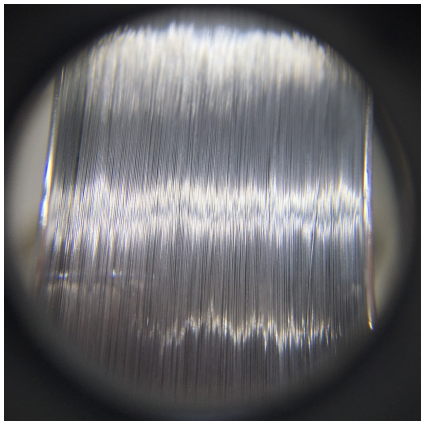
Reference wire

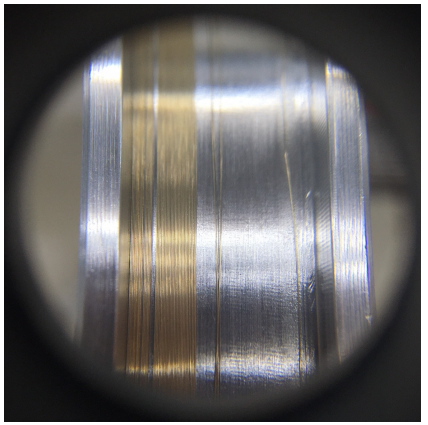
Al5056 uncoated

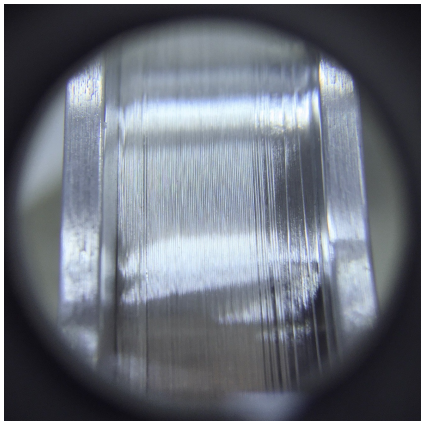
Al5056/Ni/Au

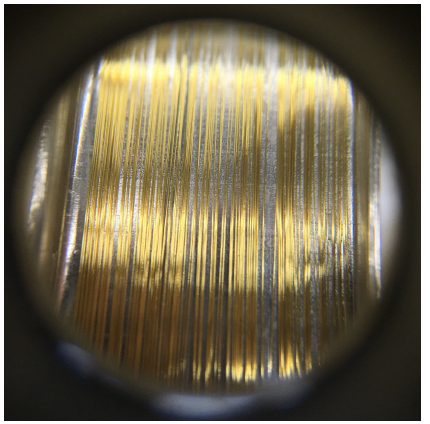
Al5056/Ni/Ag

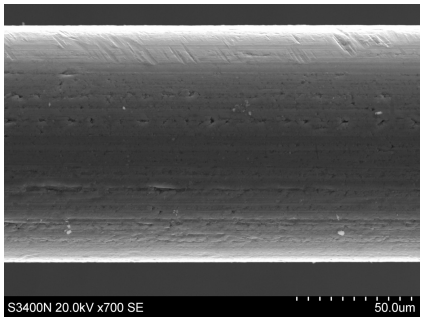
Mo/Au

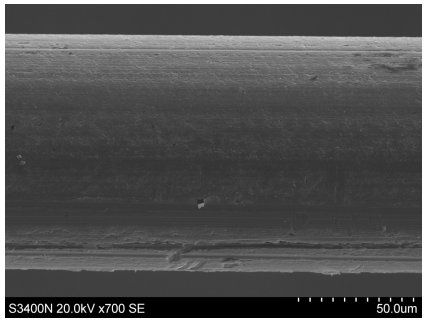


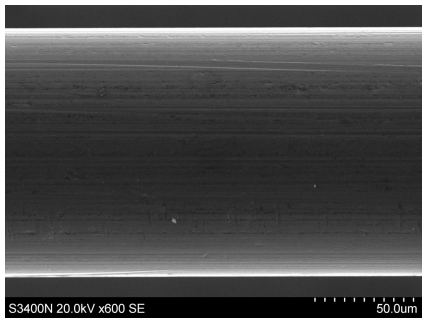


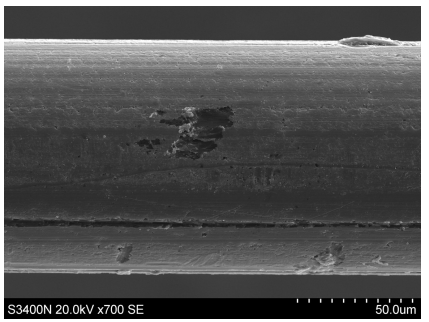












Source wires:

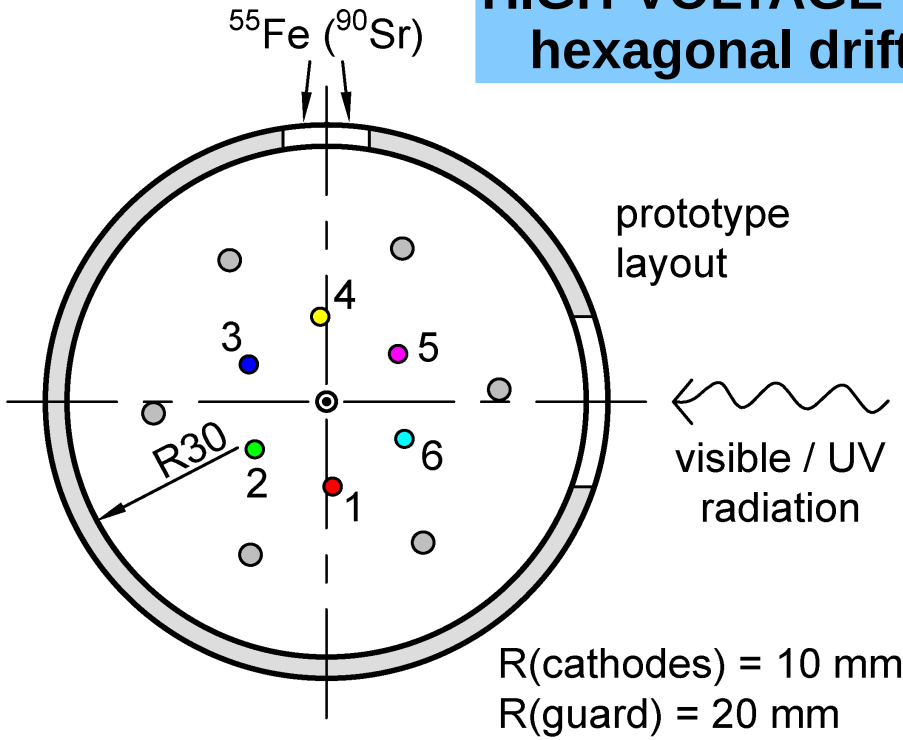
1. Al5056 uncoated 100 um in dia.

2. Molybdenum wire 100 um in dia. (reference) was coated by the hot gilding method.

Layer thicknesses:

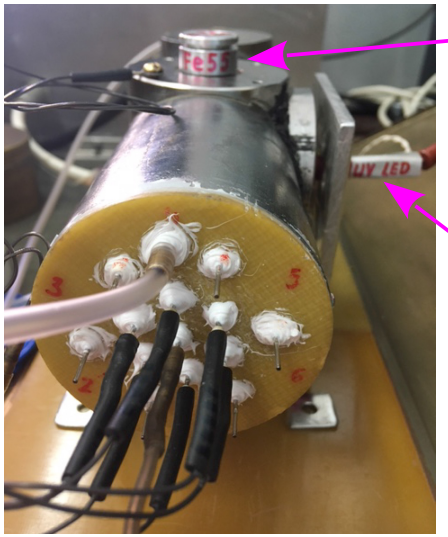
Ni (magnetron) ~ 25 nm
Au (magnetron)~ 30 nm
Ag (magnetron)~ 30 nm
Au (reference) ~ 1500 nm

HIGH-VOLTAGE WIRE TEST SETUP: hexagonal drift cell prototype [2]



		Study 1	Study 2
Cathodes	●	100 um Mo/Au	Mo/Au
	●	**100 um** **Al5056, Mo/Au, Al5056/Ni/Ag**	**Al5056**
	●	100 um Mo/Au	Mo/Au
	●	100 um Al5056/Ni/Au	Al5056/Ni/Ag
	●	100 um Al5056/Ni/Au	Al5056/Ni/Ag
	●	100 um Al5056/Ni/Au	Al5056/Ni/Ag
Anode	⊙	20 um WRe20/Au	
Guard	○	150 um Ti/Cu/Au	

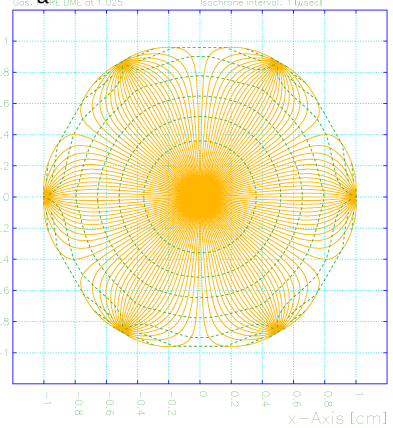
- Anode wire is strained in the center of the chamber.
- High voltages of positive polarity are applied to the anode and guard wires.
- The cathode wires are grounded.
- **In study 1** the aluminum unplated cathode ‘2’, marked in green, was replaced first with gold-plated molybdenum wire (Mo/Au), then with silver-plated aluminum wire (Al5056/Ni/Ag).
- **In study 2** the aluminum unplated cathode ‘2’ was used only.



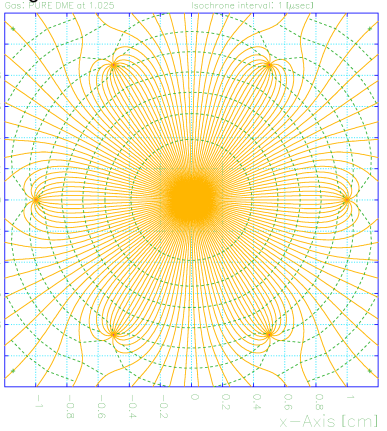
[2] *V.E. Blinov, V.G. Prisekin,* A study of cathode aging and the threshold of autoemission from cathode wires in drift chambers // Instruments and Experimental Techniques, vol. 55, p. 429–439 (2012).

Study 1
Gas gain, U-E relations, drift lines

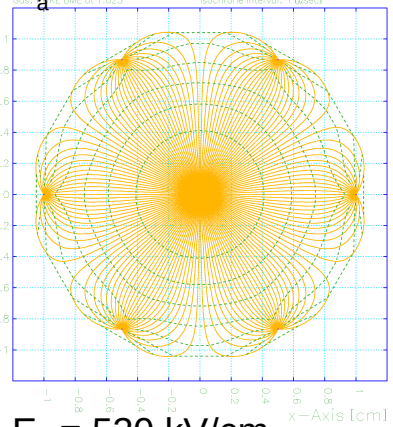
E_c = 20 kV/cm = const
E_a = 330 kV/cm



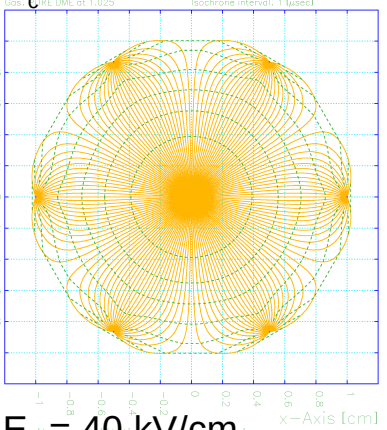
E_a = 385 kV/cm = const
E_c = 8 kV/cm



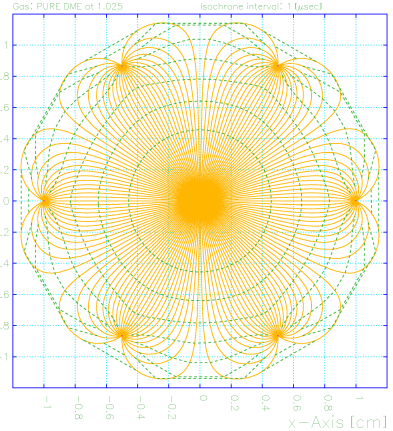
E_a = 430 kV/cm



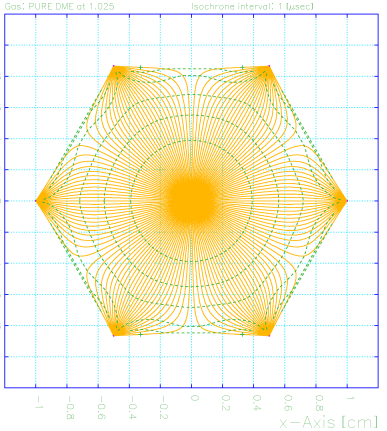
E_c = 20 kV/cm



E_a = 530 kV/cm



E_c = 40 kV/cm



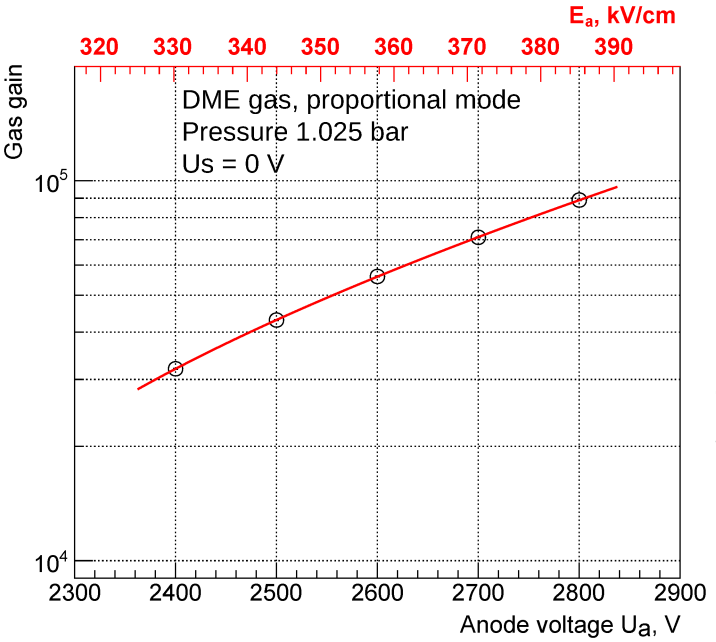
- Field matrix:

$$\begin{pmatrix} U_a \\ U_g \end{pmatrix} = \begin{pmatrix} 6.90 & -17.85 \\ -2.41 & -117.00 \end{pmatrix} \cdot \begin{pmatrix} E_a \\ E_c \end{pmatrix}$$

U_a, U_g — voltages on anode and guard wires, V;

E_a, E_c — surface electric field strength on anode and cathode wires, kV/cm.

- Operating gas: Dimethyl Ether (DME)



Drift cell parameters in MEG2 exp.:

E_a = 240 kV/cm
E_c = 25 kV/cm
20 um (W/Au)
50 um (Al unpltd)
He+iC_4H_{10}(90/10)

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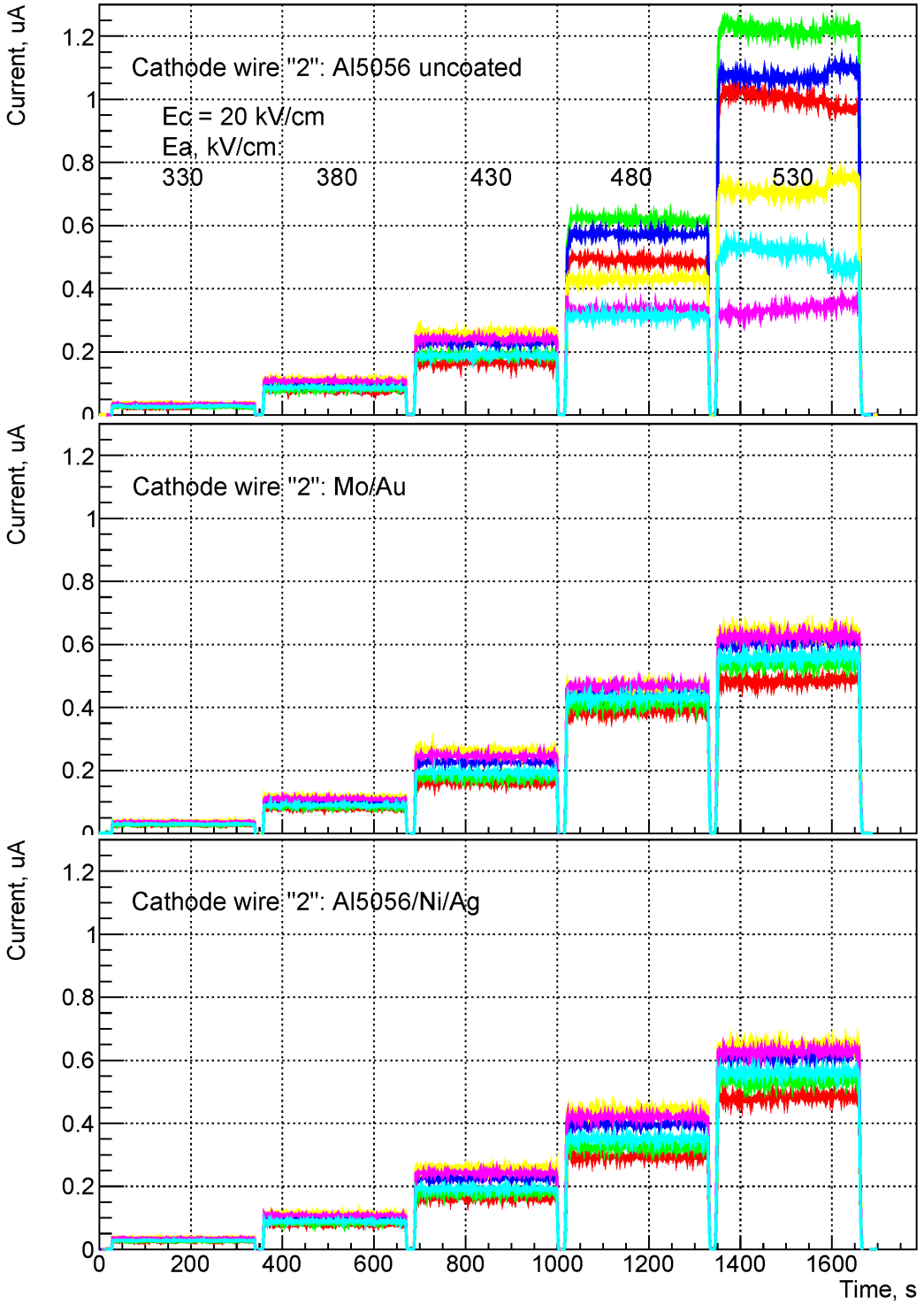
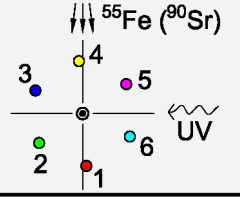


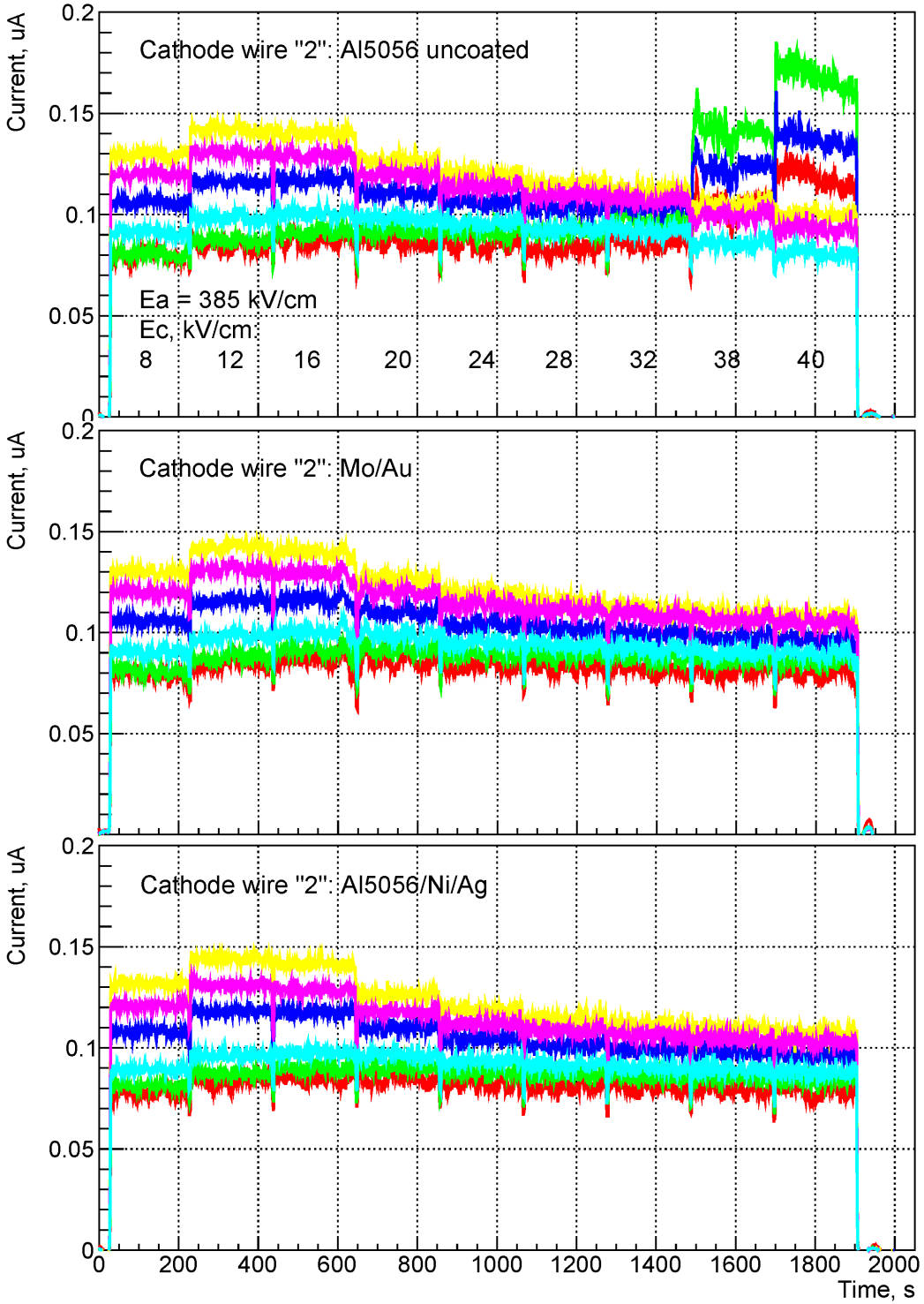
Hexcell cathode wires 100 um in diameter

- wire '1' Mo/Au
- wire '2' Al5056 -> Mo/Au -> Al5056/Ni/Ag
- wire '3' Mo/Au
- wire '4' Al5056/Ni/Au
- wire '5' Al5056/Ni/Au
- wire '6' Al5056/Ni/Au



- In the streamer mode of gas amplification, the current from the uncoated aluminum cathode (wire ‘2’) increases significantly. The difference between the currents from diametrically opposite cathodes reaches 4 times.
- In other cases, a small spread between cathode currents is associated with different values of the flux density of isotope irradiation in the collection regions corresponding to each cathode.

Study 1. Cell cathode currents under ^{55}Fe X-ray source irradiation (E_{anode} = const, $E_{cathode}$ = var)



Hexcell cathode wires 100 um in diameter

- wire '1' Mo/Au
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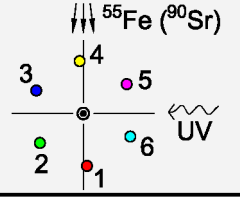
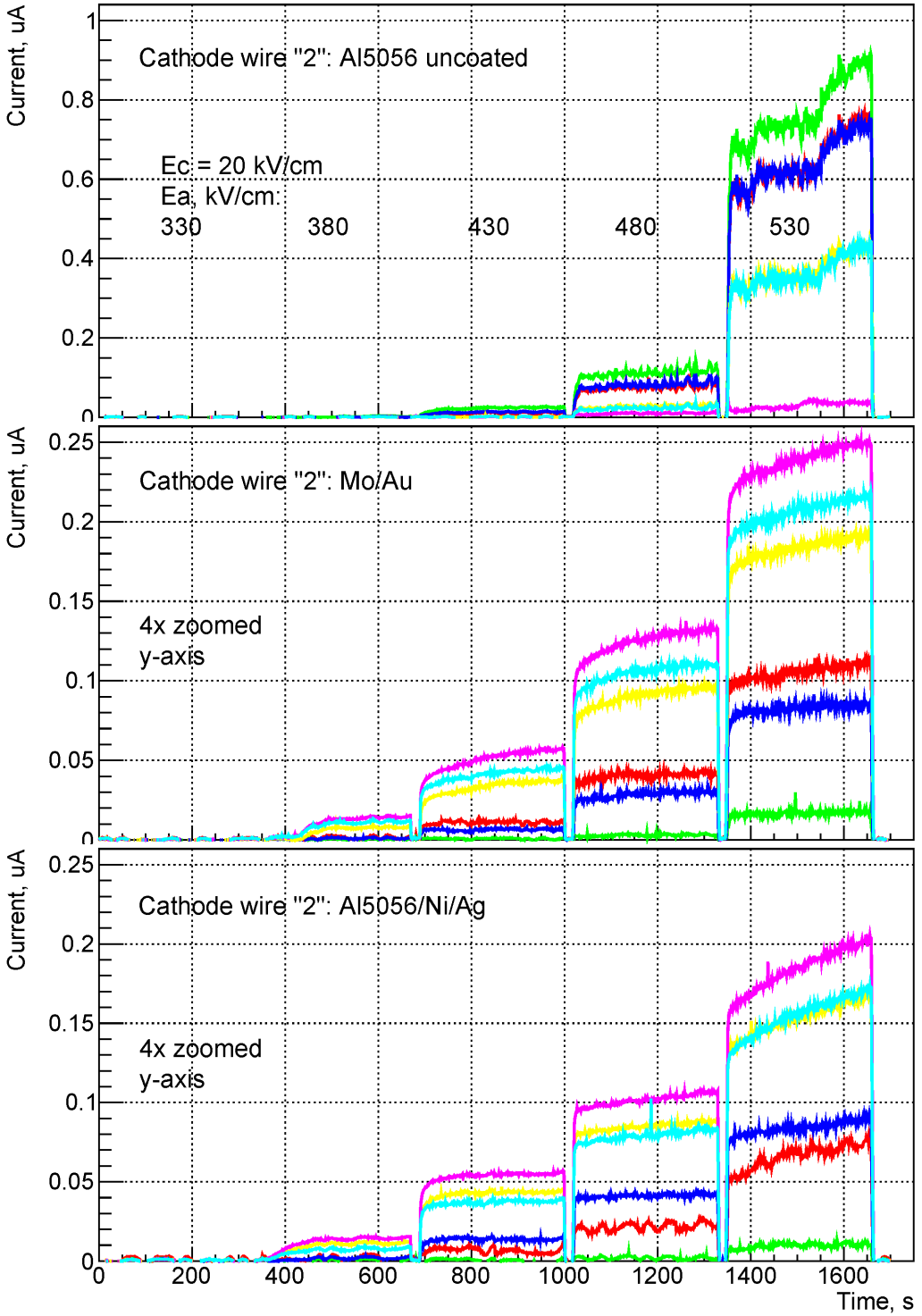
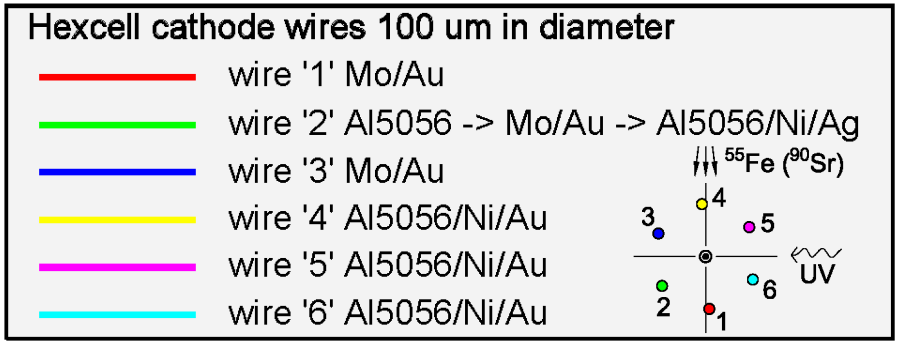
- wire '5' Al5056/Ni/Au
- wire '6' Al5056/Ni/Au



- At a field strength of more than 32 kV/cm on the uncoated aluminum cathode (wire ‘2’) the probability of field emission increases and the current becomes 1.5-2 times larger.
- In other cases, a decrease in the spread between the cathode currents is observed as the field strength at the cathodes increases. This can be explained by a reduction in the collection region of ionization from the isotope in the drift cell.

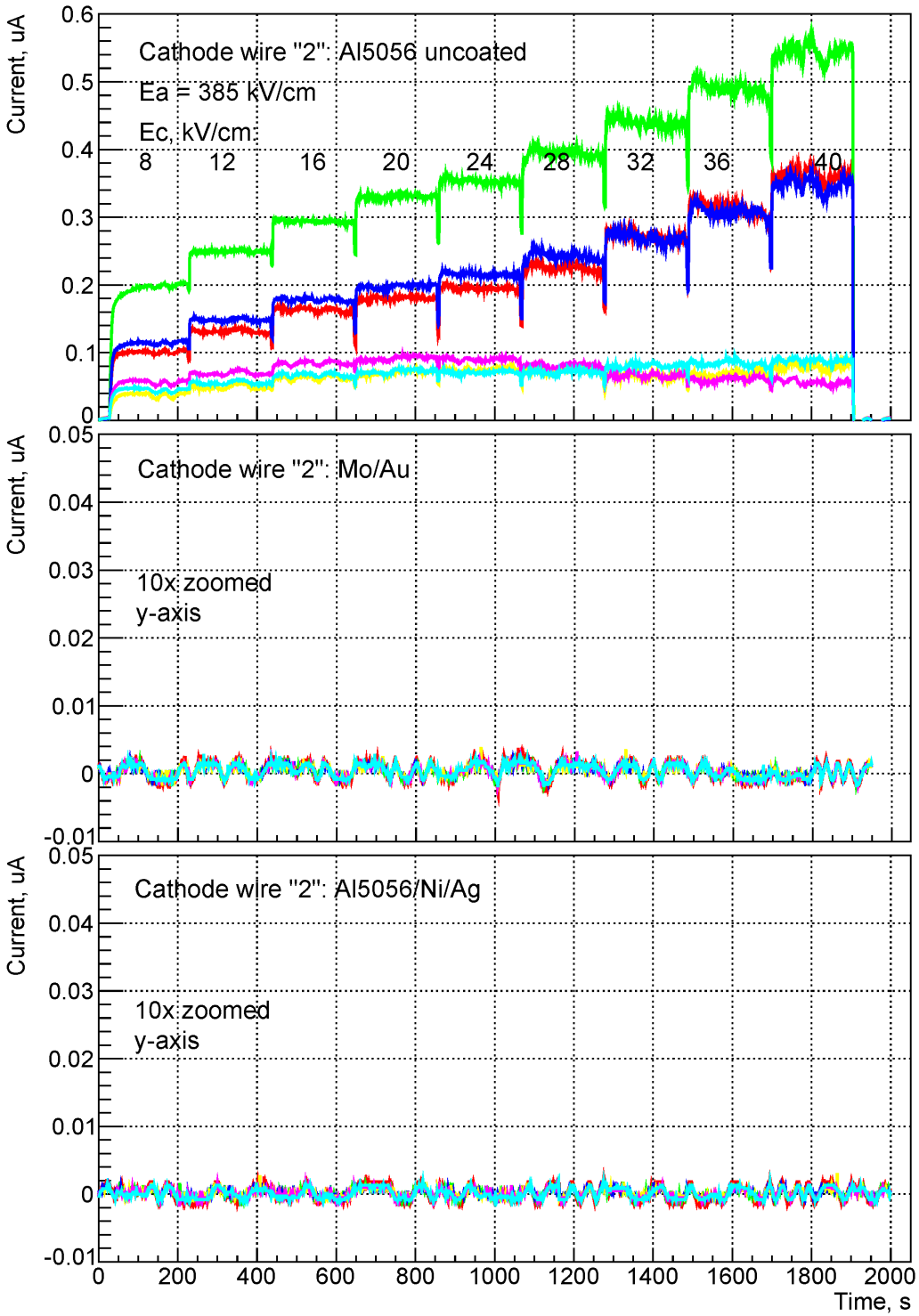


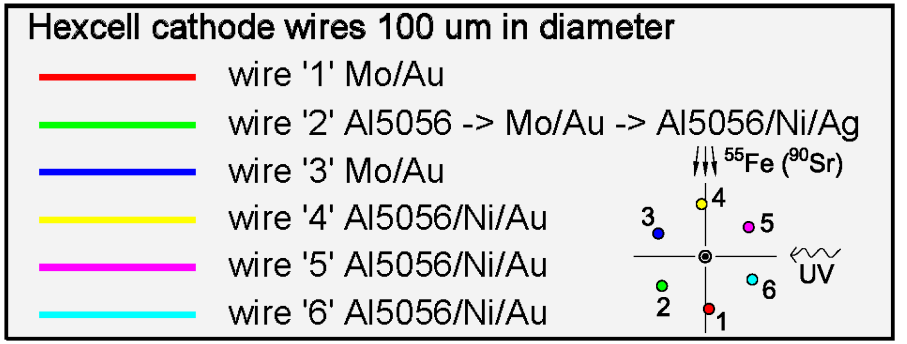
Study 1. Cell cathode currents under UV source irradiation ($E_{cathode}$ = const, E_{anode} = var)



- The photoelectric effect is most pronounced on uncoated aluminum cathode (wire ‘2’).
- At high gas gain, the intensities of the photoelectric effect on uncoated aluminum cathode (wire ‘2’) and on gold-coated aluminum cathodes (wires ‘4’, ‘5’, ‘6’ for the case of Mo/Au cathode wire ‘2’) differ by about 4 times.

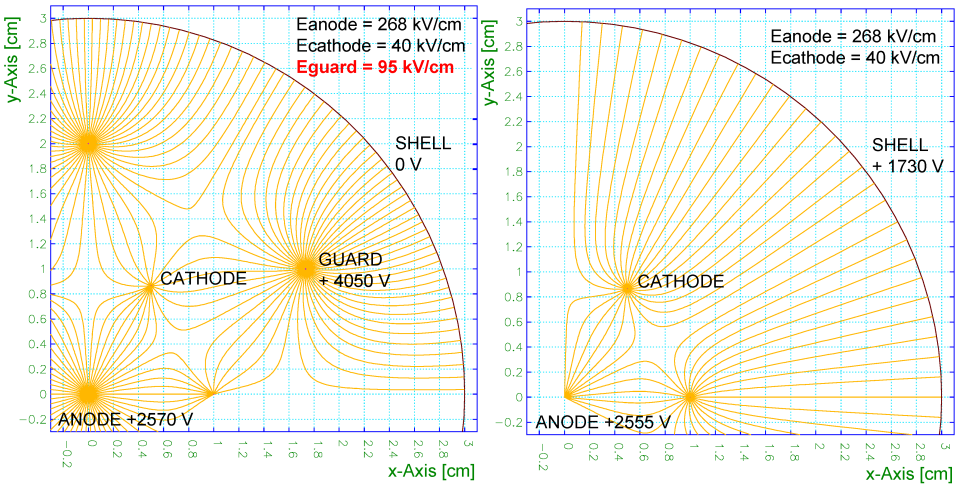
Study 1. Cell cathode currents under UV source irradiation (Eanode = const, Ecathode = var)

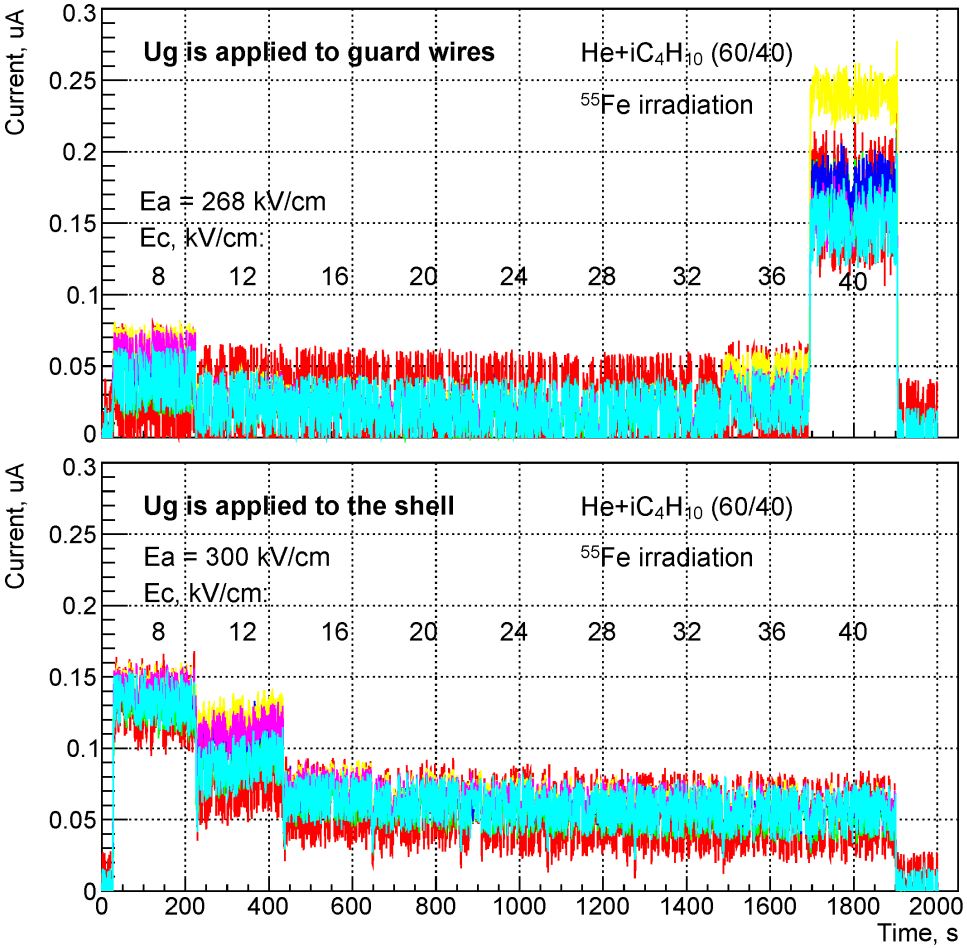


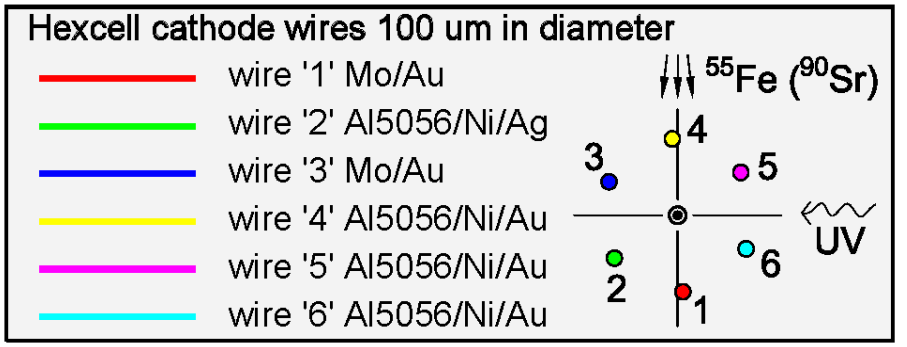


- A great difference between the uncoated aluminum wire compared to the gold-coated and silver-coated cathode is observed.
- The behaviors of Mo/Au and Al5056/Ni/Au cathodes in these tests are comparable.

Study 2. HV supply, E-U relations







- In helium mixtures, at too high voltages on the guard wires, due to gas amplification, an additional current flows from them to the cathodes. To eliminate this effect, voltage was applied to the shell of the prototype.

- Field matrices:

$$\begin{pmatrix} U_a \\ U_g \end{pmatrix} = \begin{pmatrix} 6.90 & -17.85 \\ -2.41 & -117.00 \end{pmatrix} \cdot \begin{pmatrix} E_a \\ E_c \end{pmatrix}$$ **Ug on wires**

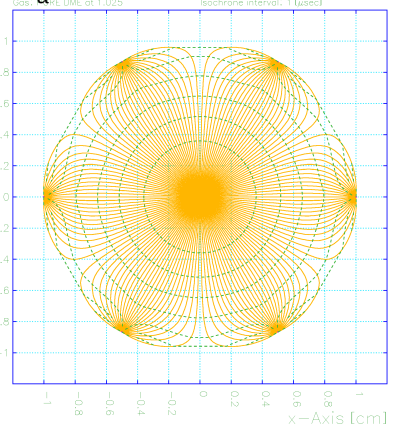
$$\begin{pmatrix} U_a \\ U_g \end{pmatrix} = \begin{pmatrix} 6.91 & -17.53 \\ -1.10 & -50.65 \end{pmatrix} \cdot \begin{pmatrix} E_a \\ E_c \end{pmatrix}$$ **Ug on shell**

U_a, U_g — anode and guard voltages, V;

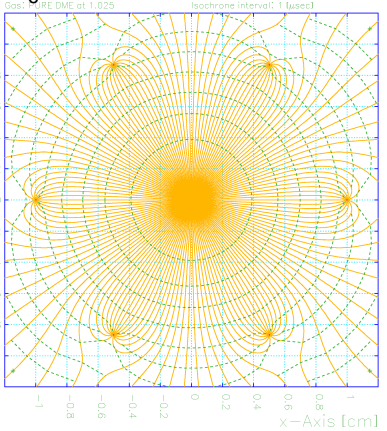
E_a, E_c — surface electric field strength on anode and cathode wires, kV/cm.

Study 2. Gas gain, drift lines

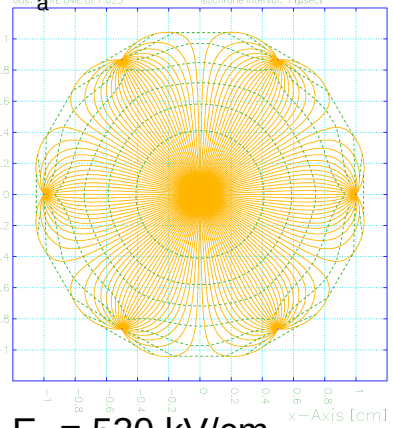
E_c = 20 kV/cm = const
E_a = 330 kV/cm



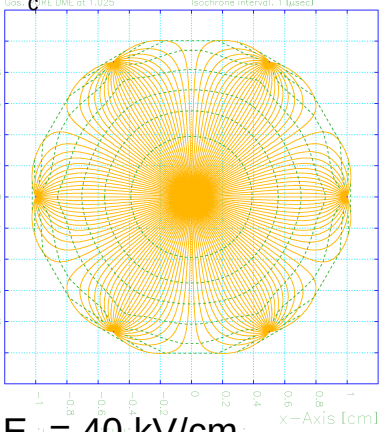
E_a = 385 kV/cm = const
E_c = 8 kV/cm



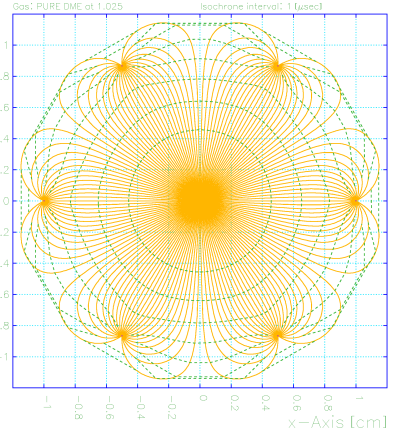
E_a = 430 kV/cm



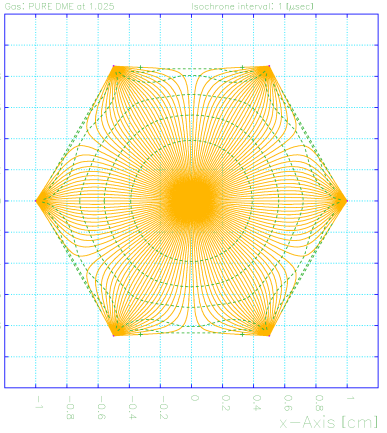
E_c = 20 kV/cm



E_a = 530 kV/cm



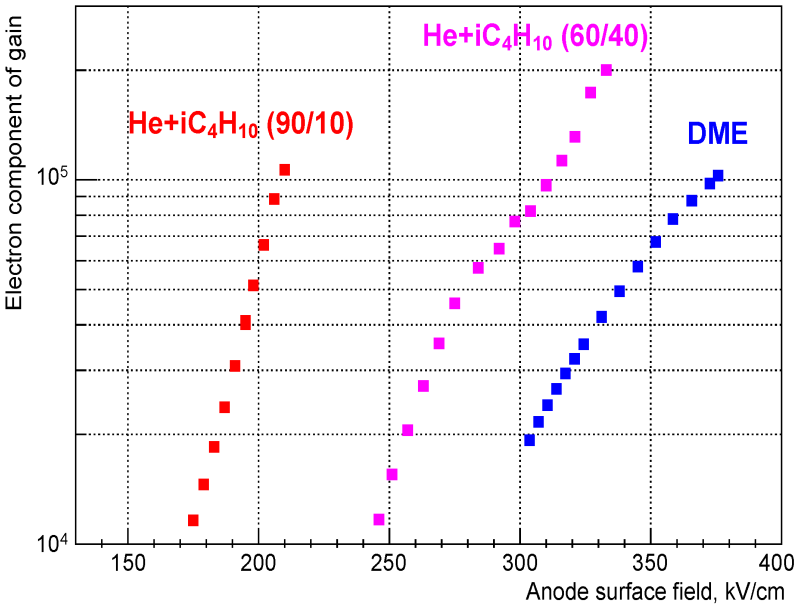
E_c = 40 kV/cm



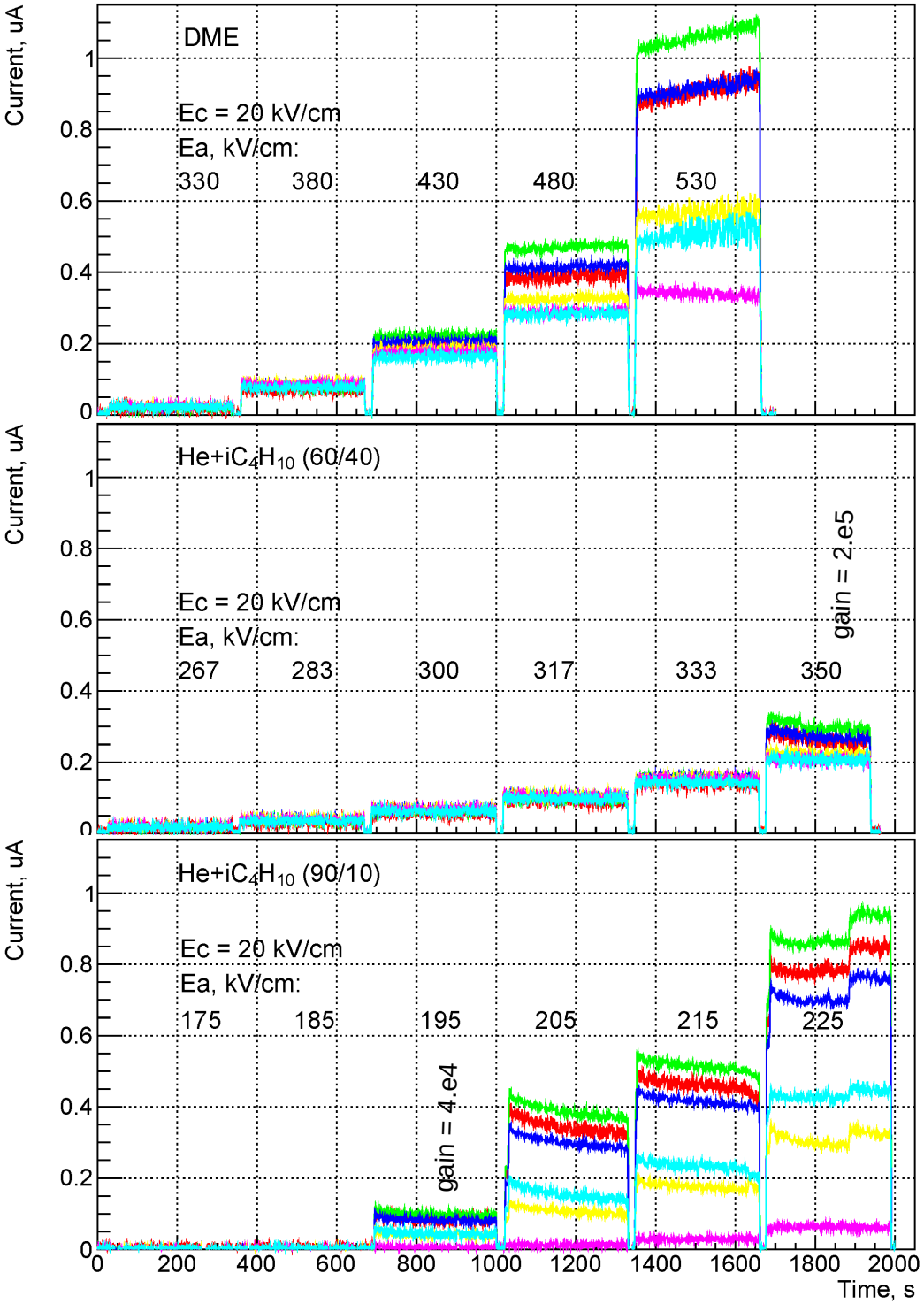
- At a constant field strength on cathode, with increasing gas gain, the field boundary in the cell expands, the primary ionization collection area increases, and also the cathode area, on which the field lines from the anode are ended, increases.

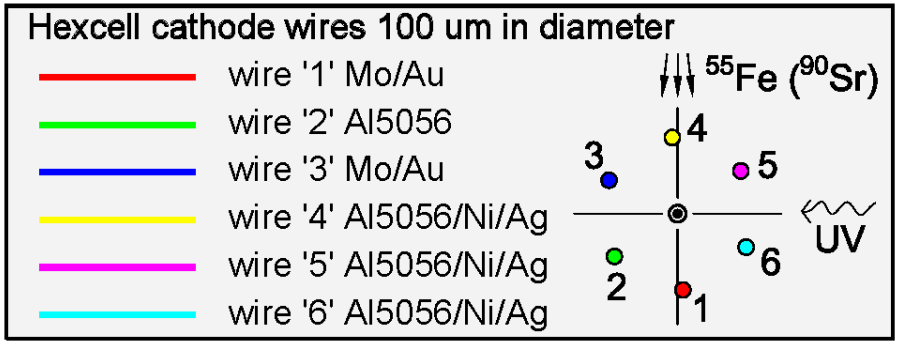
- At a constant gas gain, with an increasing field strength on cathode, in the cell the field region narrows, the cathode area, to which the field lines are ended, decreases, and the proportion of field lines that end to the shell decreases.

- Operating gases: dimethyl ether (DME) and helium-isobutane 60/40 and 90/10 mixtures (with collimator and low rate)



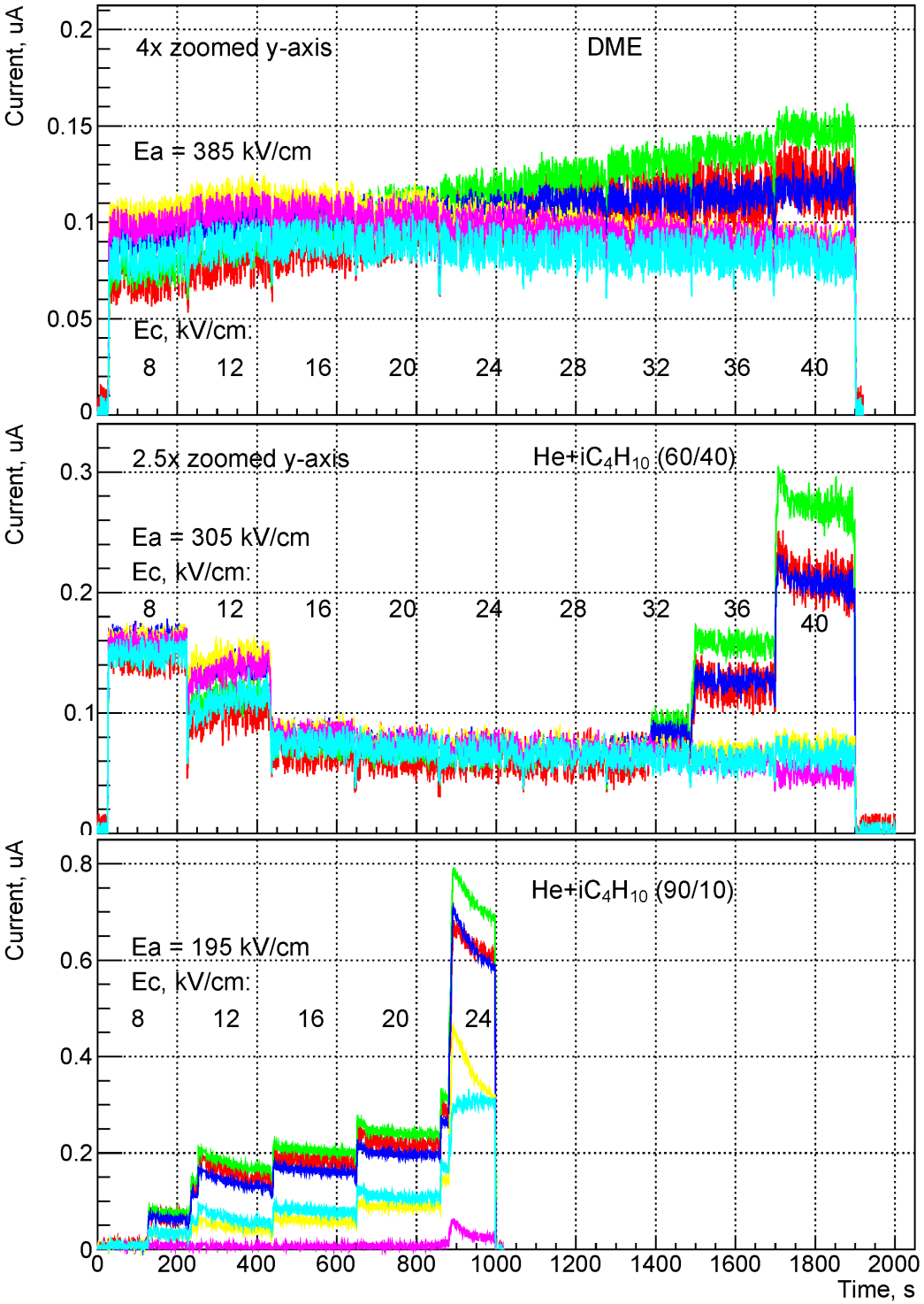
Study 2. Cell cathode currents under ^{55}Fe X-ray source irradiation ($E_{cathode}$ = const, E_{anode} = var)

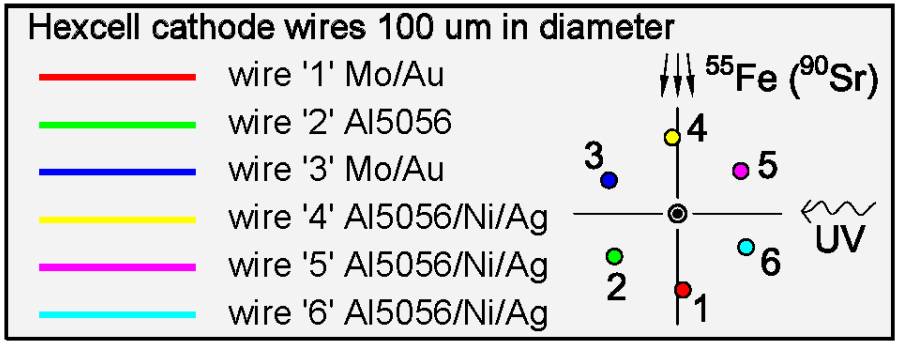




- For all gases, as the gas gain increases, the largest increase in current from the uncoated aluminum cathode (wire '2') is observed.
- The growth of currents from those adjacent to wire '2' is associated with space charge division in an avalanche between cathodes.
- Middle figure: at the last point, the film on cathode is charged enough to cause the Malter effect (the charging rate by the ion flow from the avalanche is higher than the film discharge rate).

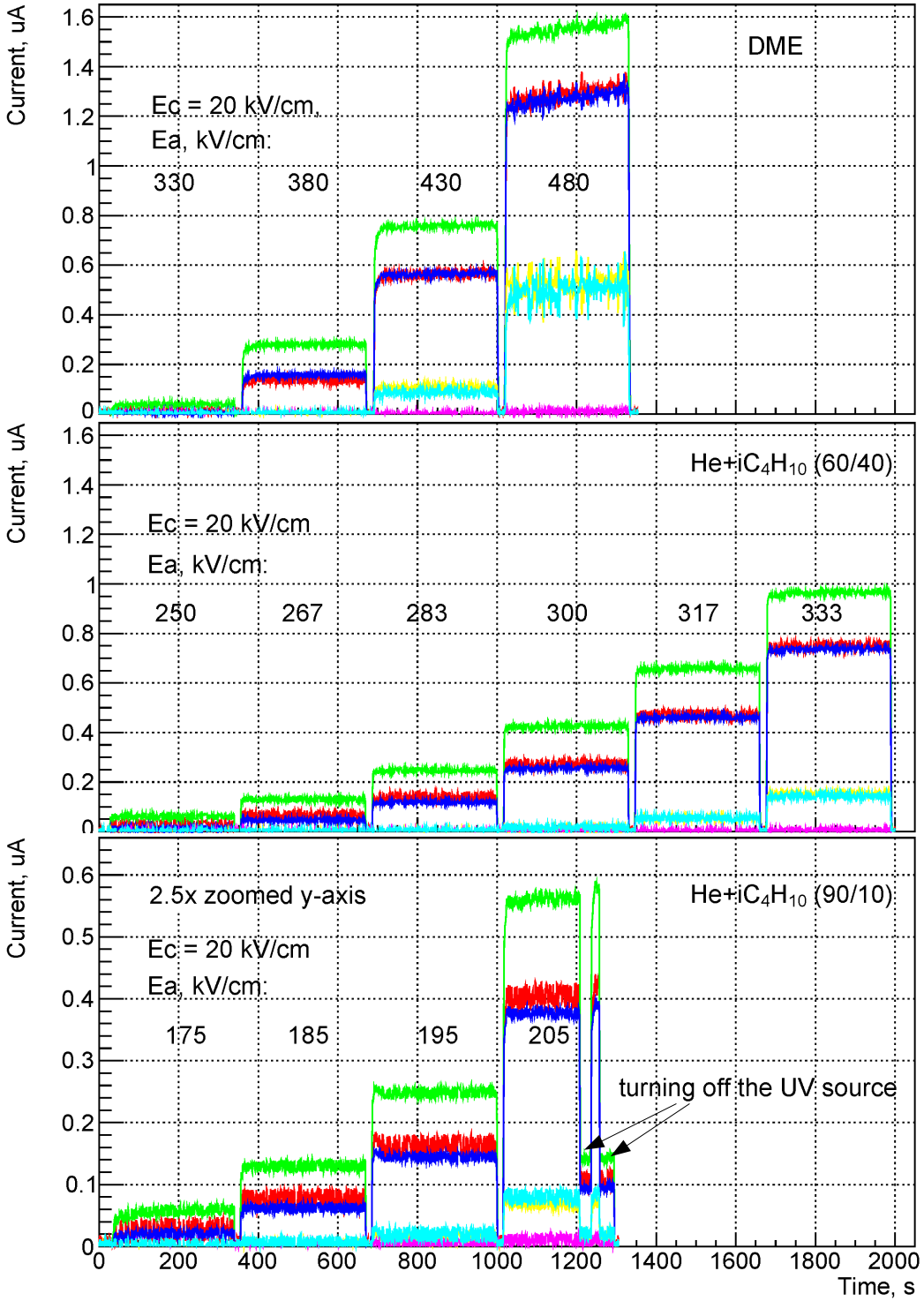
Study 2. Cell cathode currents under ^{55}Fe X-ray source irradiation (Eanode = const, Ecathode = var)

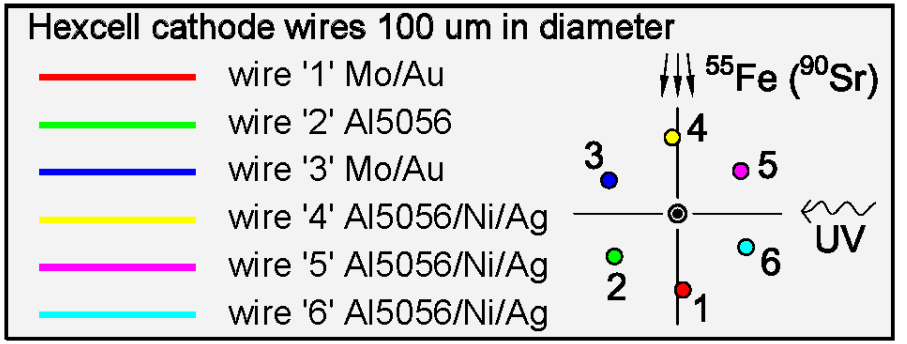




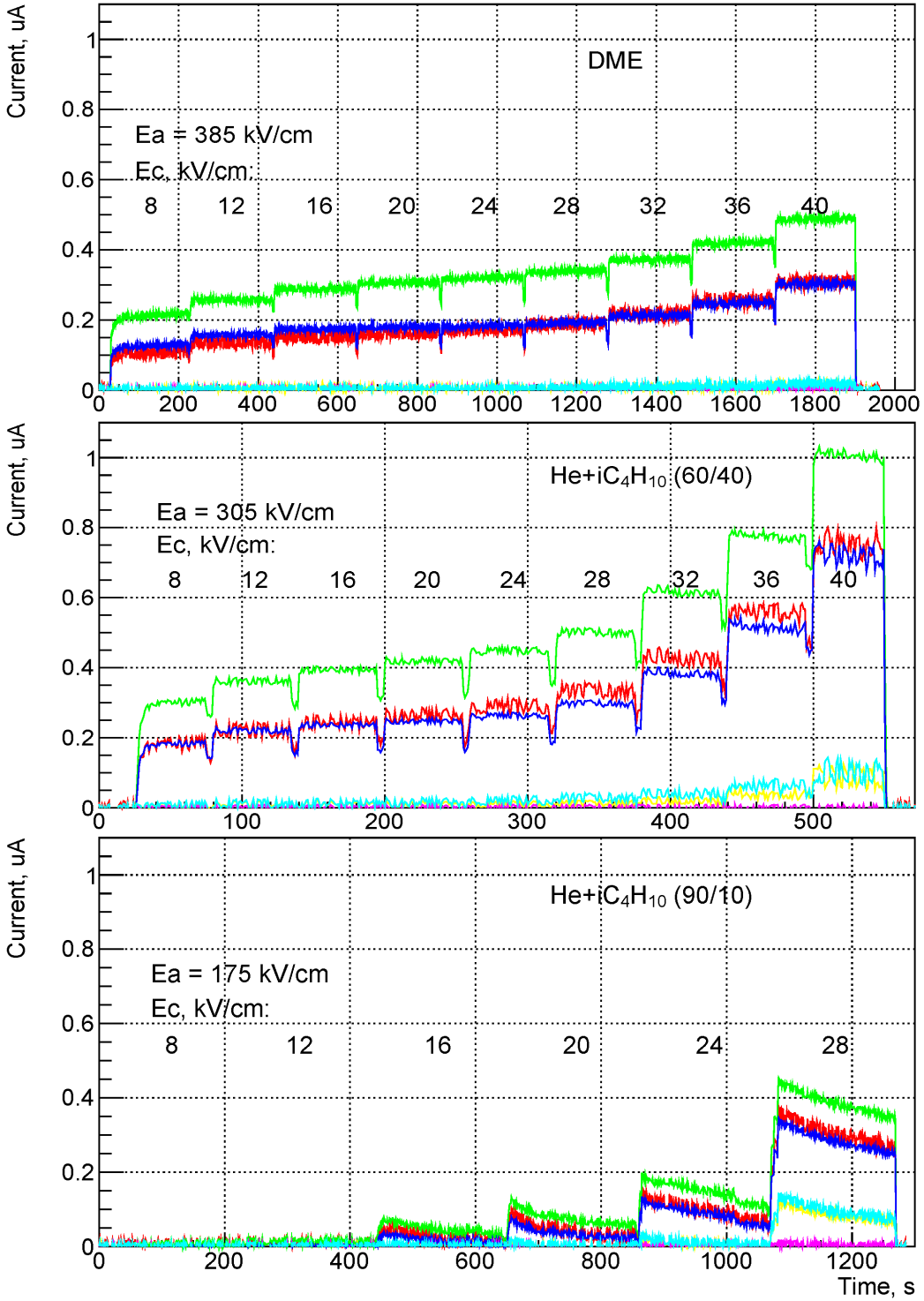
- An uncoated cathode (wire ‘2’) is characterized by a maximum current from it, provoking an increase in currents from neighboring cathodes.
- The relationship between currents is explained by the current source at wire ‘2’. The behavior of the current has a stick-slip nature.
- The current from wire ‘2’ is associated with the Malter effect, since no current appears without isotope initiation.
- In the bottom figure, there is a decrease in the emissivity of the tip located closer (to the side) to the wire, marked in blue (wire ‘3’).

Study 2. Cell cathode currents under UV source irradiation ($E_{cathode}$ = const, E_{anode} = var)

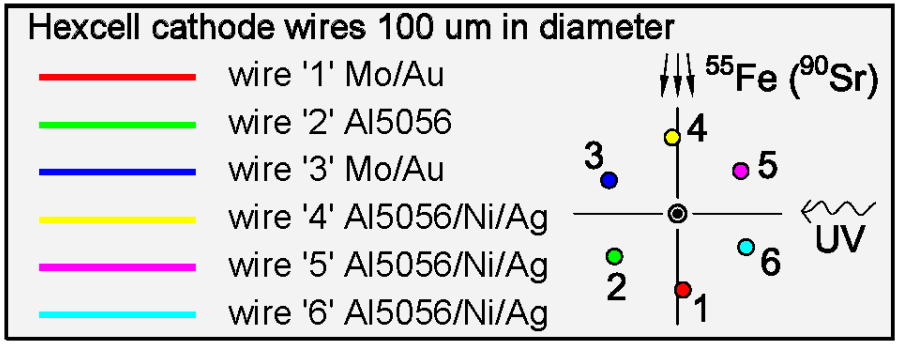




- Influence of the photoeffect (through the Malter effect arising) is maximum at the cathode ‘2’. The ion current from the avalanche area is distributed towards neighboring cathodes symmetrically with respect to the cathode ‘2’.
- Silver plating greatly suppresses the photoelectric effect or initiation of the Malter effect.
- At high gas gain and when UV source is turned off, a self-sustaining current is observed, which is most likely associated with the Malter effect on uncoated catode (wire ‘2’).



Study 2. Cell cathode currents under UV source irradiation (E_{anode} = const, $E_{cathode}$ = var)



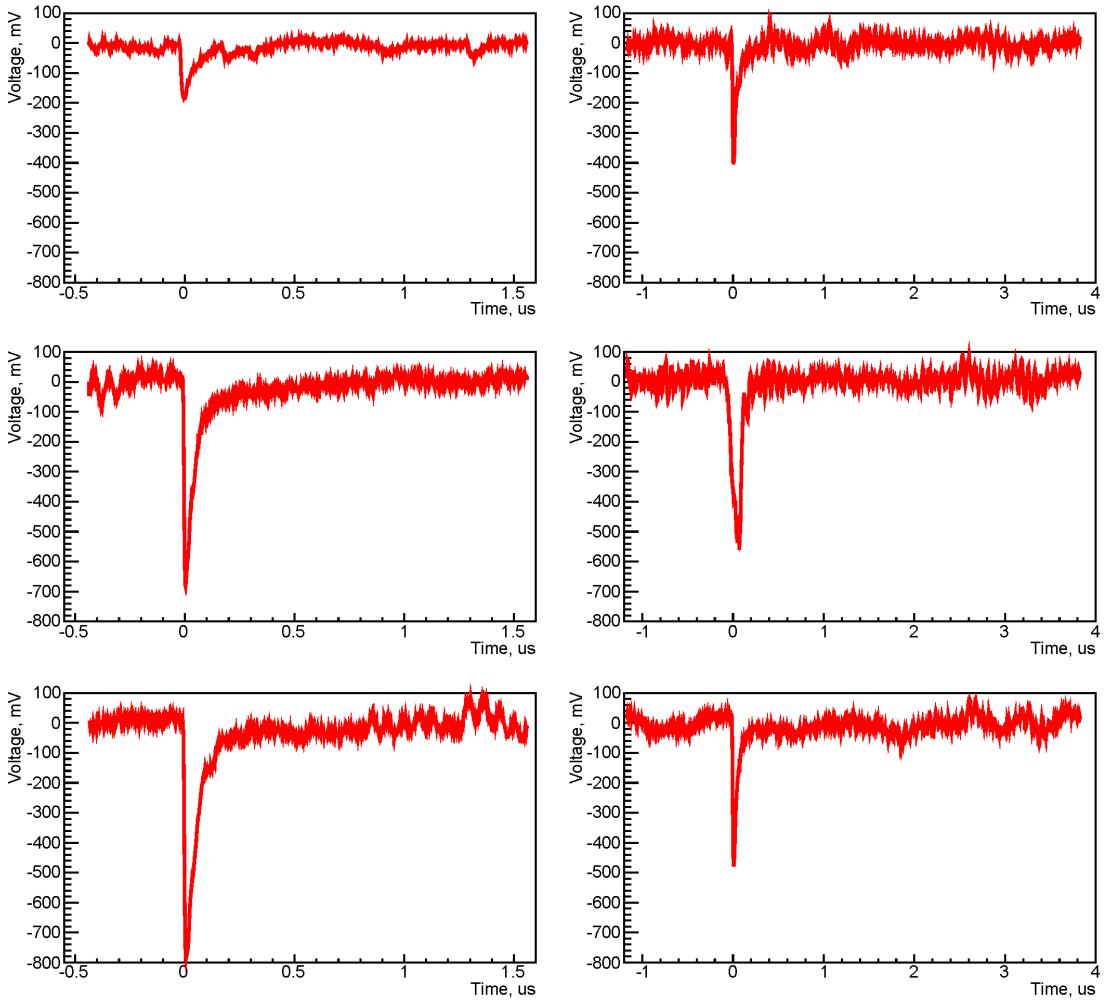
- In the picture of currents, uncoated cathode (wire ‘2’) stands out, the currents from other cathodes are consistent with the mutual arrangement.
- The behavior of the current with increasing field strength on cathode is influenced by 3 factors:

- an increase in the emission current density;

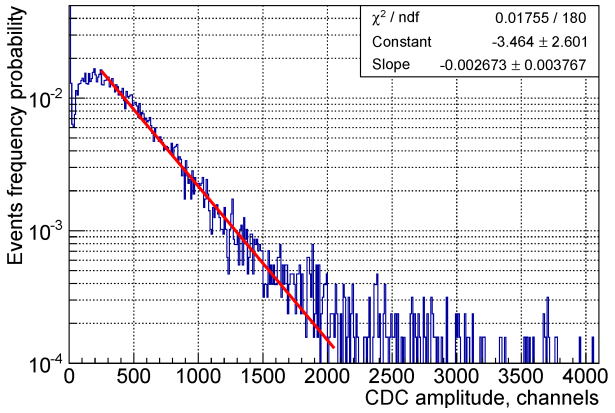
- reduction of the cathode area, on which the field lines from the anode are ended;

- a decrease in the proportion of field lines, that end to the shell, which leads to an increase in the ions flow to cathodes.

One-electron pulses under UV source irradiation (E_{anode} = 333 kV/cm, $E_{cathode}$ = 20 kV/cm)

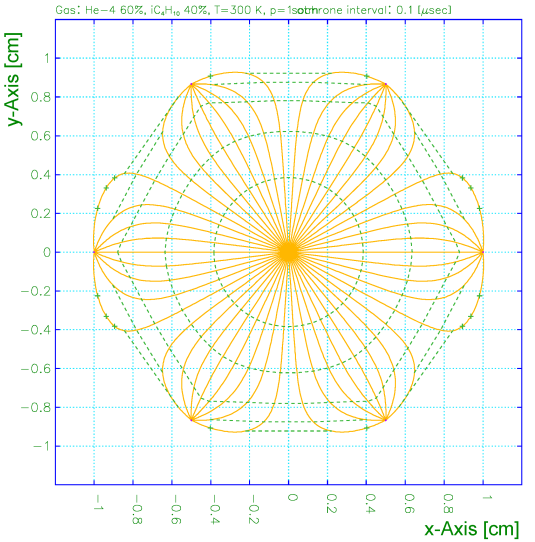


One-electron spectrum (normalized distribution)



Electron drift lines in **He+iC_4H_{10} (60/40)**

Isochrone interval = 0.1 usec



- The drift time of electrons from the cathode is about 0.5 usec.
- The oscillograms don“t show postpulses that could be associated with secondary photoelectrons from the light of avalanche.

Conclusions

- Coating of wire in a magnetron is possible without changing its mechanical properties.
- Two-layer coating with a nickel sublayer provides good wettability with solder.
- The magnetron coating of the wire with **Ag** or **Au** (~30 nm) with a **Ni** sublayer (~25 nm) suppresses emission from the cathode surface.
- The emission suppression effect is comparable for gold- and silver-coated wires.

Thank you for your attention