Wire Aging Test for the COMET CDC

Dec. 28th 2017

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COMET experiment

COherent Muon to Electron Transition

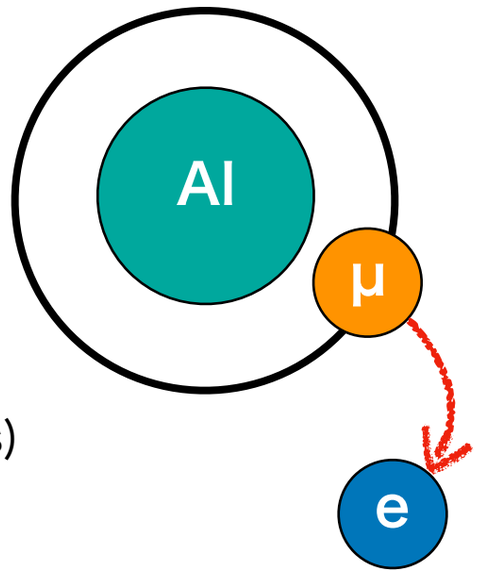
Search for the transition of a muon to an electron in a muonic atom (μ- e conversion)

Muon electron transition

$$\mu^- + N(A, Z) \rightarrow e^- + N\ (A, Z)$$

- Neutrinoless coherent process.
- This rare process violates lepton flavor conservation in the charged lepton sector.
- Blanching ratio($\mu \rightarrow e\ \gamma$) Standard model: O($10^{-54}$)

  Beyond standard model: O(10^{-15})



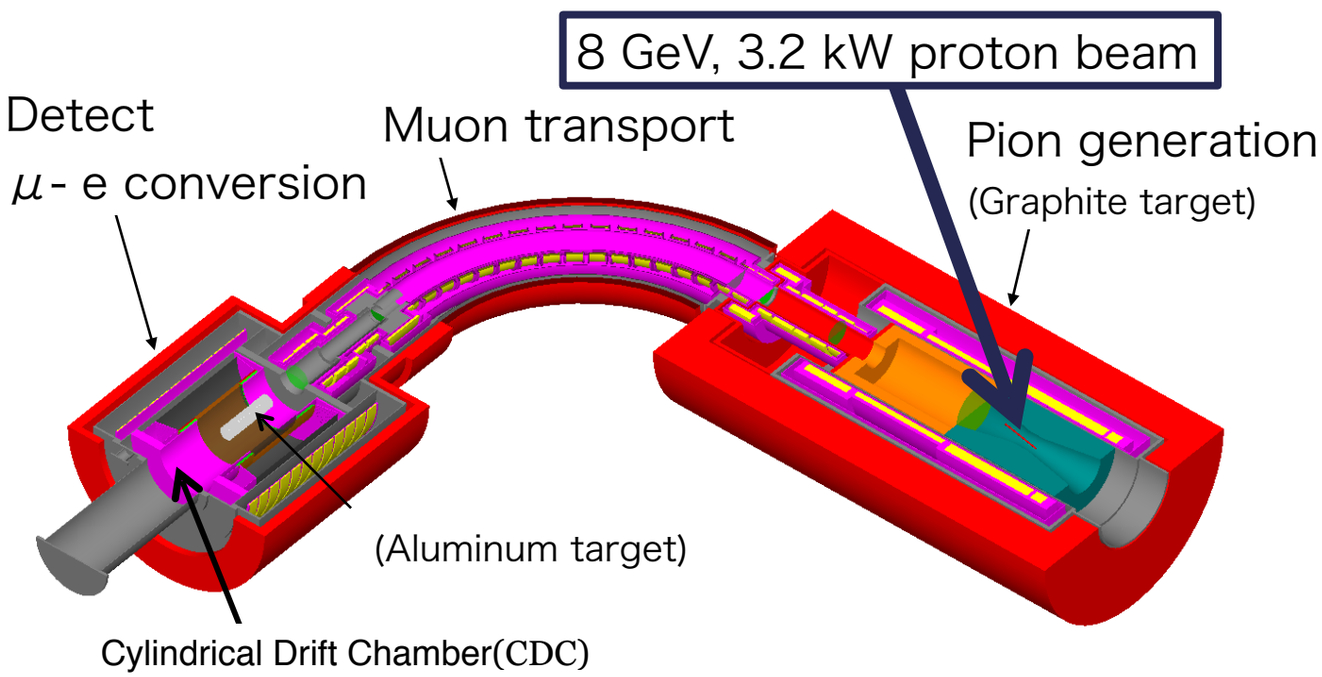
- Energy of muon electron transision $E_{\mu e}$

  $E_{\mu e} = m_\mu - B_\mu - E_{recoil}$

  (m_μ: Muon mass, B_μ: Binding energy of 1s state, E_{recoil}: recoil energy of nucleus)

- In aluminum nucleus: $E_{\mu e}$ = 104.97 MeV

CDC(Cylindrical Drift Chamber)



Layout of COMET Phase-I

Information of CDC

Inner wall	Length	1495.5 mm
	Radias	490.0 ~ 496.5 mm
Outer wall	Length	1577.3 mm
	Radias	835.0 ~ 840.0 mm
Cell size		16.8 mm × 16.0 mm
Sense wire	Material	Au-plated W
	Diameter	25 μm
	Number of wire	4986
Field wire	Material	Al
	Diameter	126 μm
	Number of wire	14562
Volume		2084 L

Maim motivation of Phase-I

- **Earlier physics measurement**

  Detector: **Cylindrical Drift Chamber(CDC)**

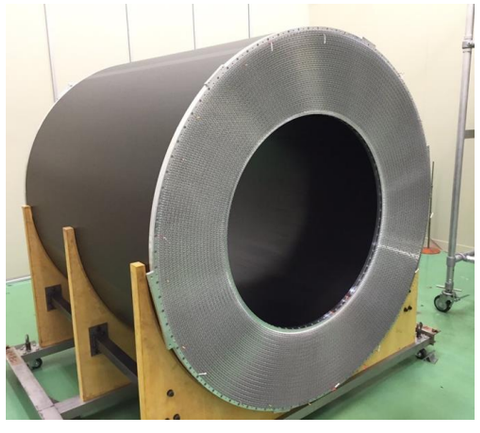
  (Single Event Sensitivity: 3×10^{-15})
  - search for the μ-e conversion
  - Background measurement of DIO

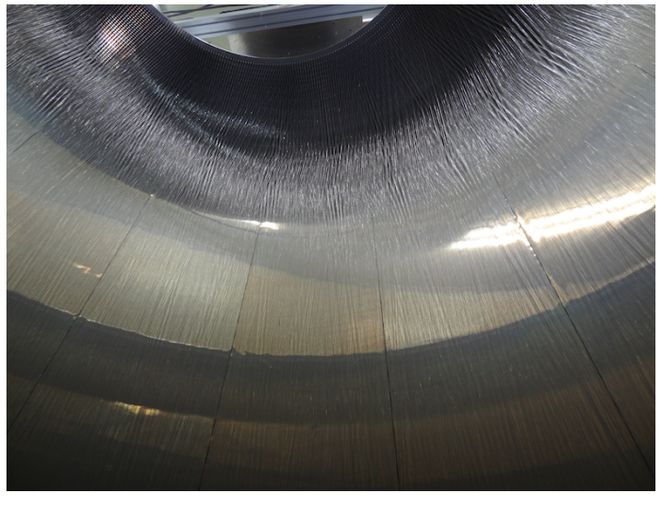
- **Background measurement**

  Detector: Straw-tube tracker, crystal electromagnetic calorimeter
  - Directly measuring of secondary particle (proton, neutron, photon, electron etc.)

Measurement period: 200 days

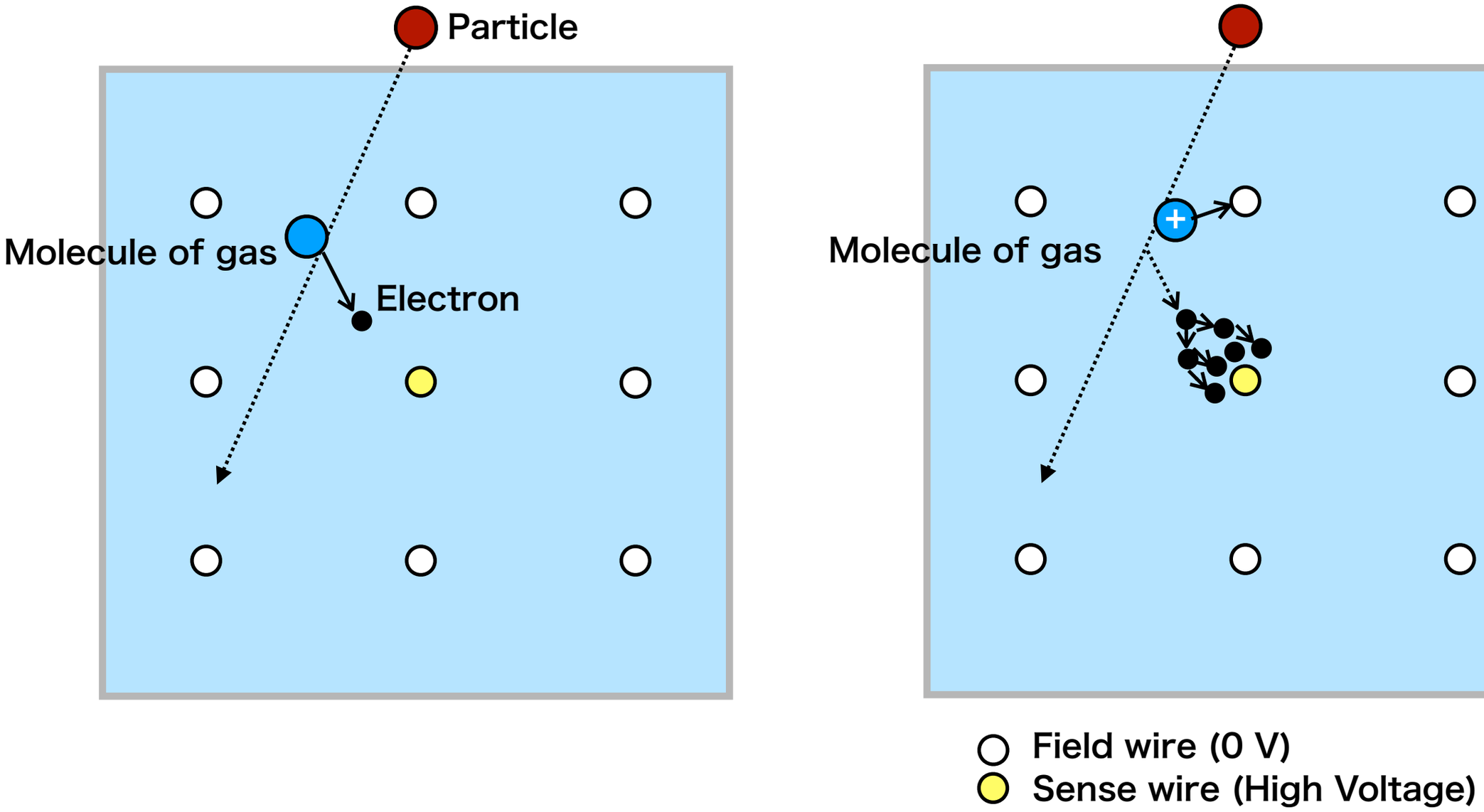
Energy of electron from μ-e conversion: 105 MeV





CDC and wires strung in the CDC

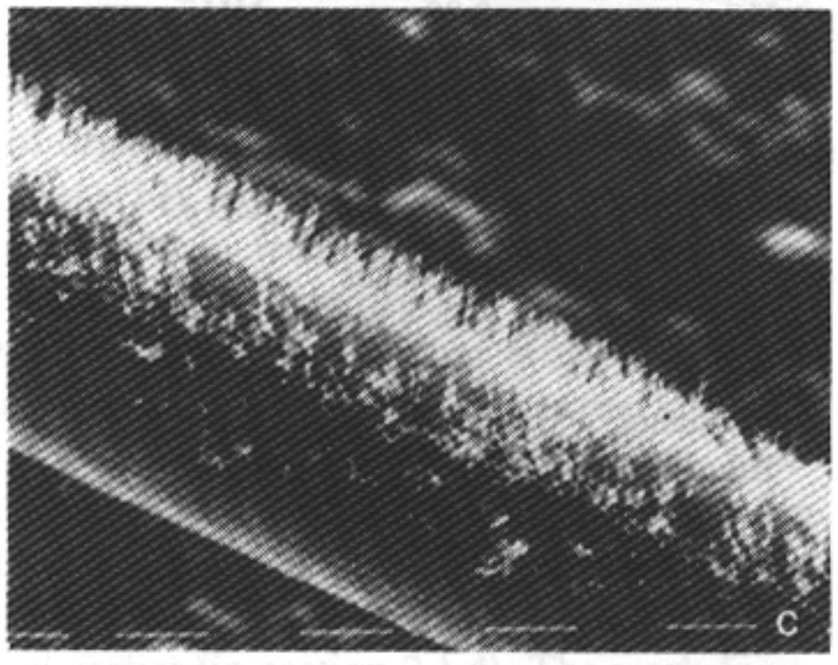
Drift Chamber



Cross section of drift chamber

Wire Aging Effect

Problem of drift chamber when using it in the radiation environment



Surface of the aged sense wire
(J.Va'var, DESY workshop, October 2, 2001)

Aging effect

Anode wire

- Compound deposits on the surface of the wire
- Diameter of the anode becomes effectively increases.

→ **It causes gain decrease, discharge, and noise increase.**

Cathode wire

- Insulating film is made on the cathode wire. Positron ion are charged around wire and make a high electric field.
- This electric field excite the electrons of the cathode which make an avalanche.

→ **The current continues to flow to the wire even when the radiation source is not placed. (Malter effect)**

→ **Deterioration of the performance of drift chamber**

Origin of chemical compound

- Atoms which consist gas (C, H etc).
- Out gas from silicone rubber used for adhesion (Si).

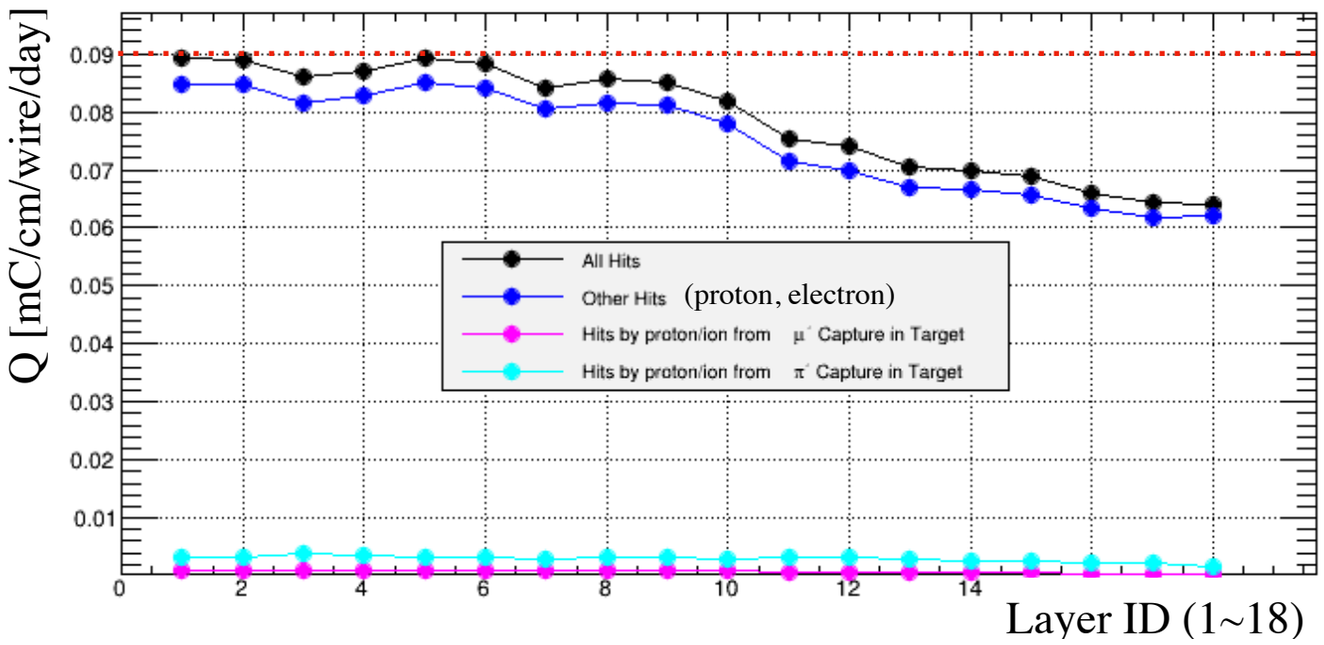
Some other experiment groups reported water vapor and alcohol can prevent and recover this effect.

→ even though it can be reduced, it is impossible to remove it completely.

We should know how effect this aging effect on the wires of the COMET CDC.

Accumulated charge of COMET CDC

The amount of radiation irradiated on the CDC wires are evaluated by the accumulated charge of the current flowing the wire.



Less than
0.09 mC/cm/wire/day

Accumulated speed of each layer (ref. COMET TDR)

Accumulated value of CDC simulated by Geant4 (COMET TDR)

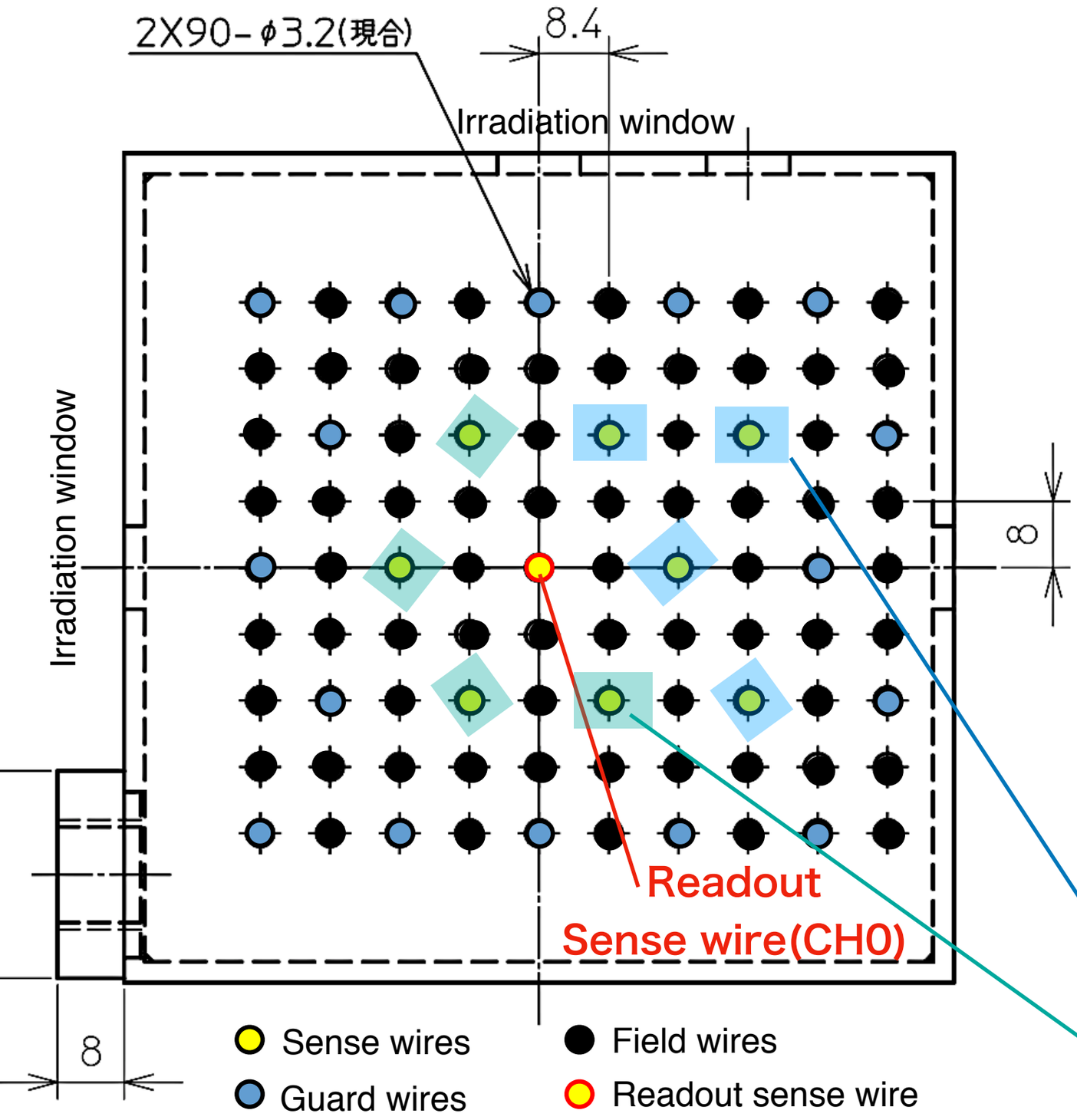
less than 20 mC/cm/wire during 200 days running period

Minimum target value: **20 mC/cm/wire**

Required value for gain reduction: **within 10%**

Correctable by software if it is within the required value.

Wire cross section



Wire cross section of 9cell test chamber

- Wire current is recorded by HV module every second.

HV channel

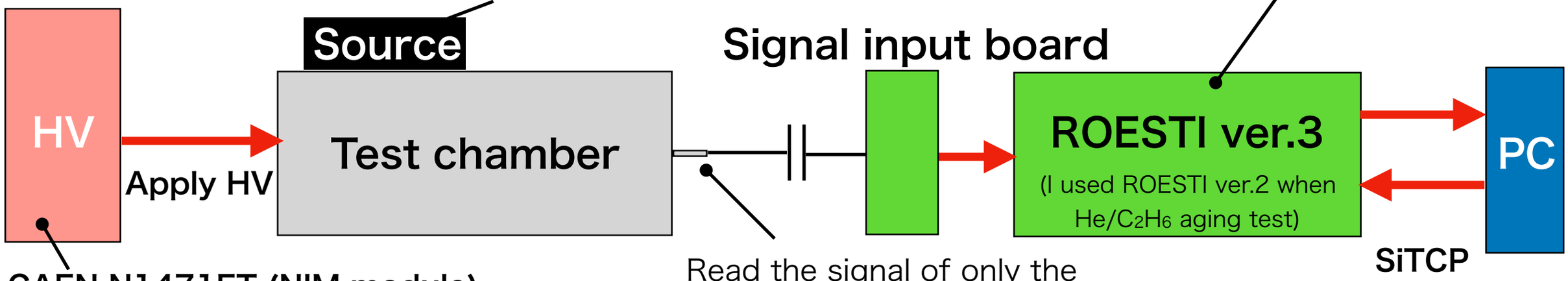
CH0: Readout sense wire
CH1: 4 sense wire
CH2: 4 sense wires
CH3: Guard wires

Set ups

Source at the time of aging: ^{90}Sr

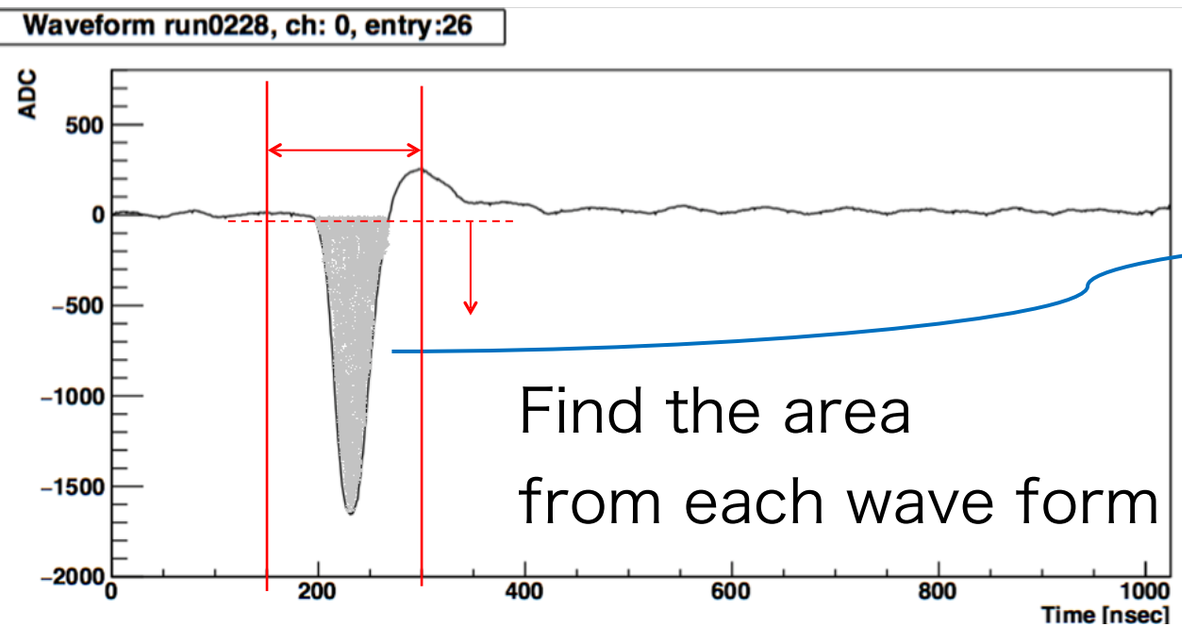
Source for gain measurement: ^{55}Fe

Circuit for waveform acquisition.
High-accuracy waveform acquisition by high-speed sampling is possible with DRS4.

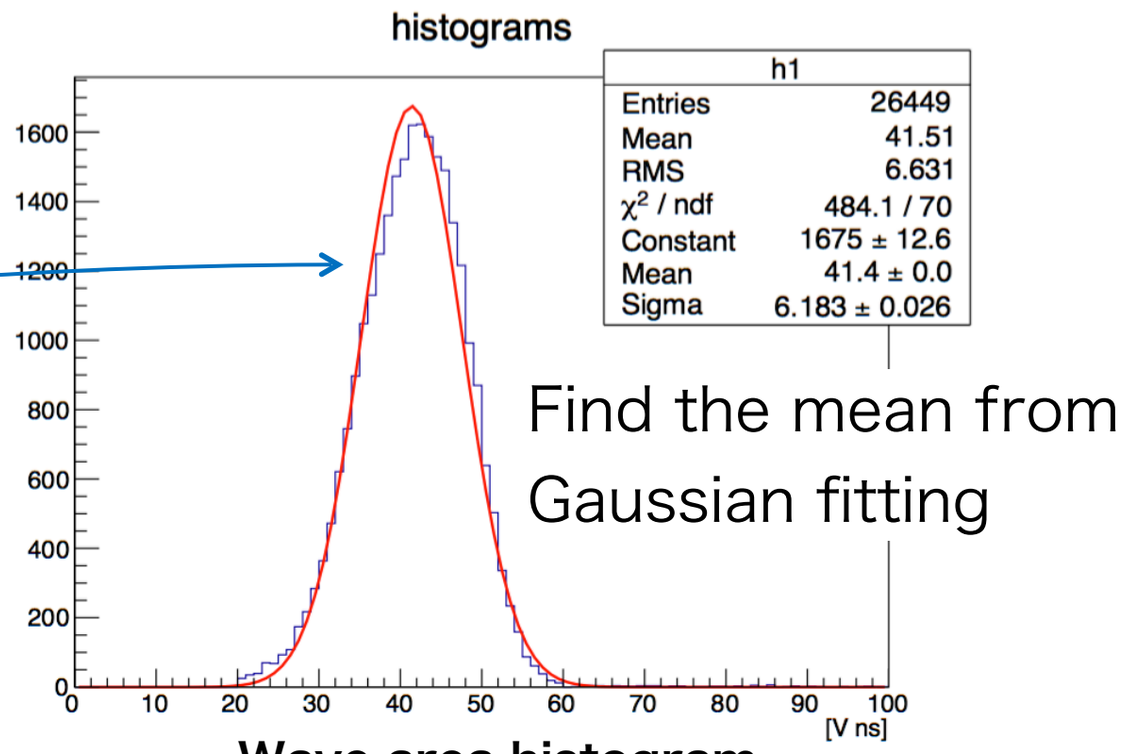


CAEN N1471ET (NIM module)
HV Control by PC.
The value of HV applied to the wire and the current flowing in the wire can be recorded,

Read the signal of only the central sense wire (ch 0)

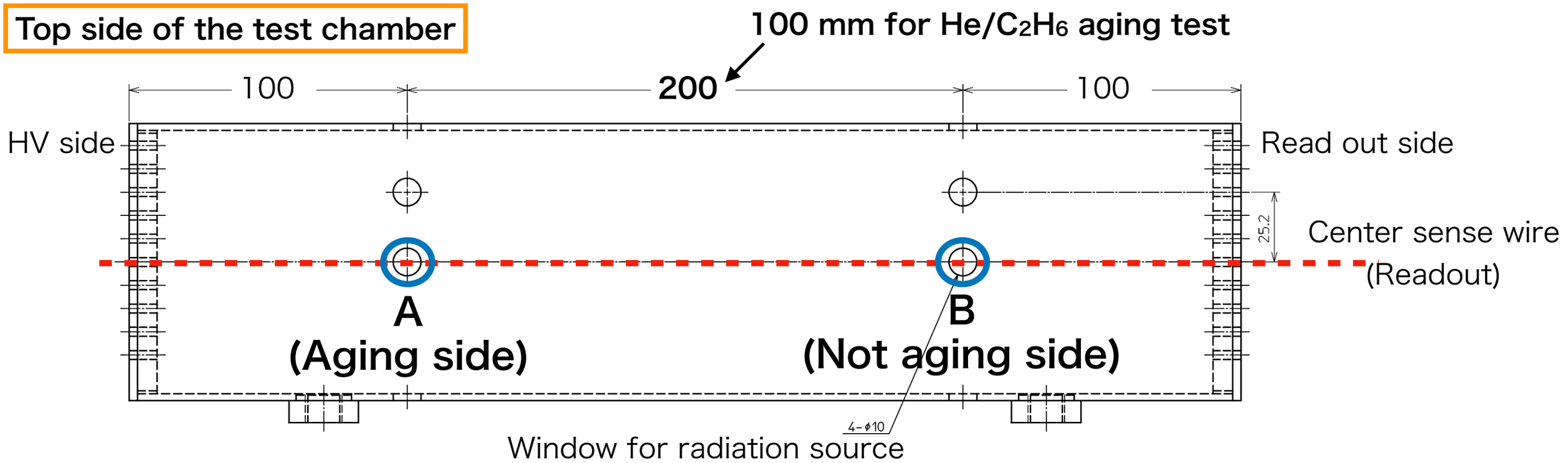


Typical wave form from acquired by ROESTI

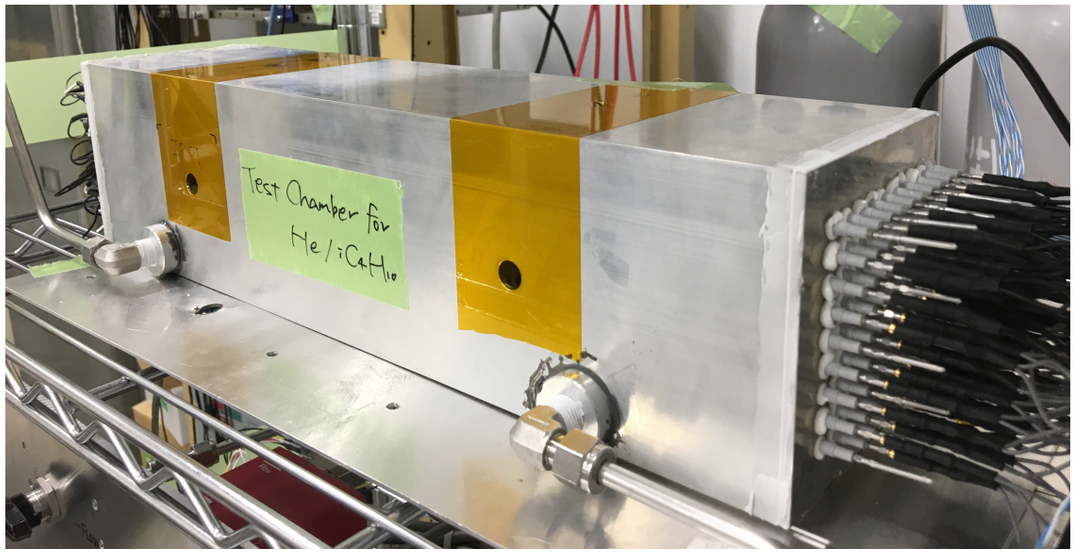


Wave area histogram

Gain evaluation method



- Put ^{90}Sr source on the A part when aging the wires.
- Gain measurement is done int the two point A part and B part using ^{55}Fe source.



- We measured gains at 2 parts;
  A: Aging part
  B: No aging part

$$\text{Ratio of gain} \equiv \frac{\text{Mean of wave area at } \mathbf{A}}{\text{Mean of wave area at } \mathbf{B}}$$

Result of the aging test $He/C_2H_6(50/50)$

Measurement condition

$He/C_2H_6(50/50)$ 40 mL/min

Wire aging conditions

Source: ^{90}**Sr**

HV (ch0~2): **2300 V**

HV (ch3): 1800 V

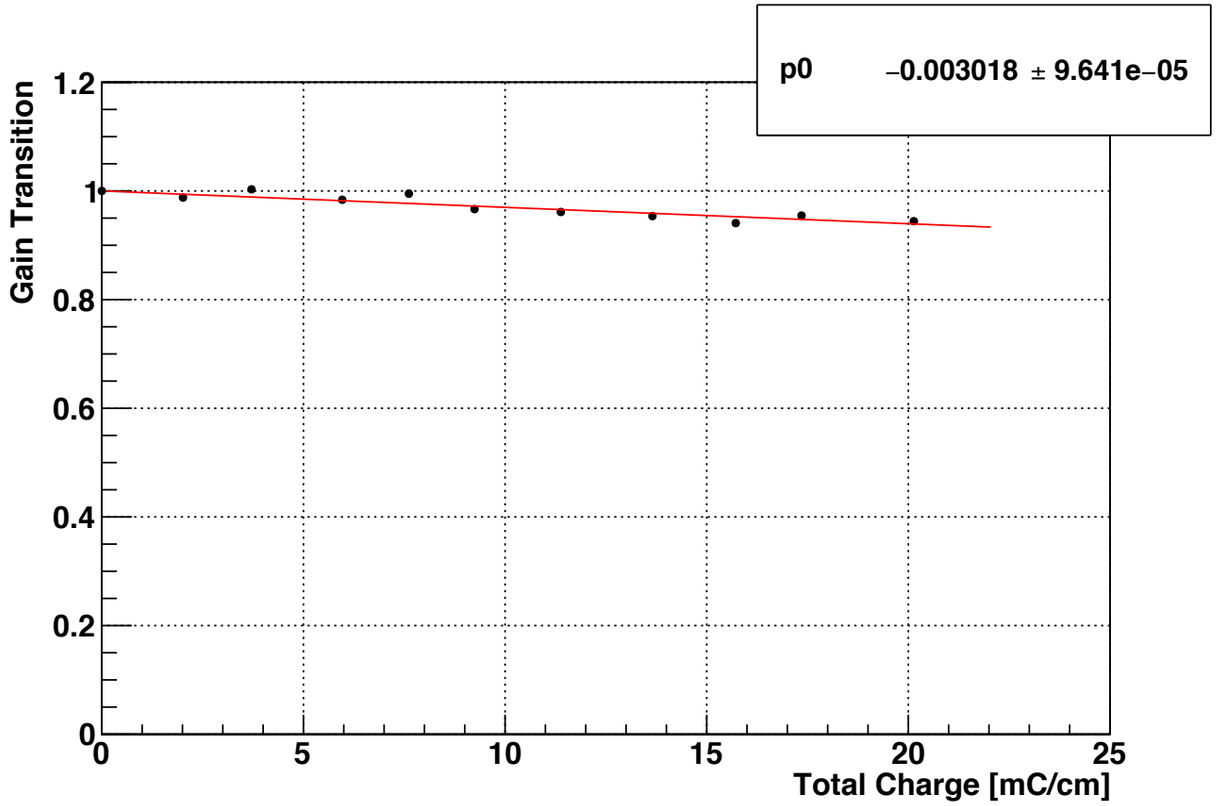
Gain measurement conditions

Source: ^{55}**Fe**

HV (ch0~2): **2120 V**

HV (ch3): 1800 V

Number of events: 10,000 event



Gain Transition (He/C_2H_6 (50/50))

- Gain decrease:
  About **6.0% at 20 mC/cm/wire**.
- Gain decrease rate:
  About **0.3% /mC/cm/wire**.

This is less than the required value of COMET (10%).

Result of the aging test $He/iC_4H_{10}(90/10)$

Measurement condition

$He/iC_4H_{10}(90/10)$ 40 mL/min

Wire aging conditions

Source: ^{90}**Sr**

HV (ch0~2): **1850 V**

HV (ch3): 1700 V

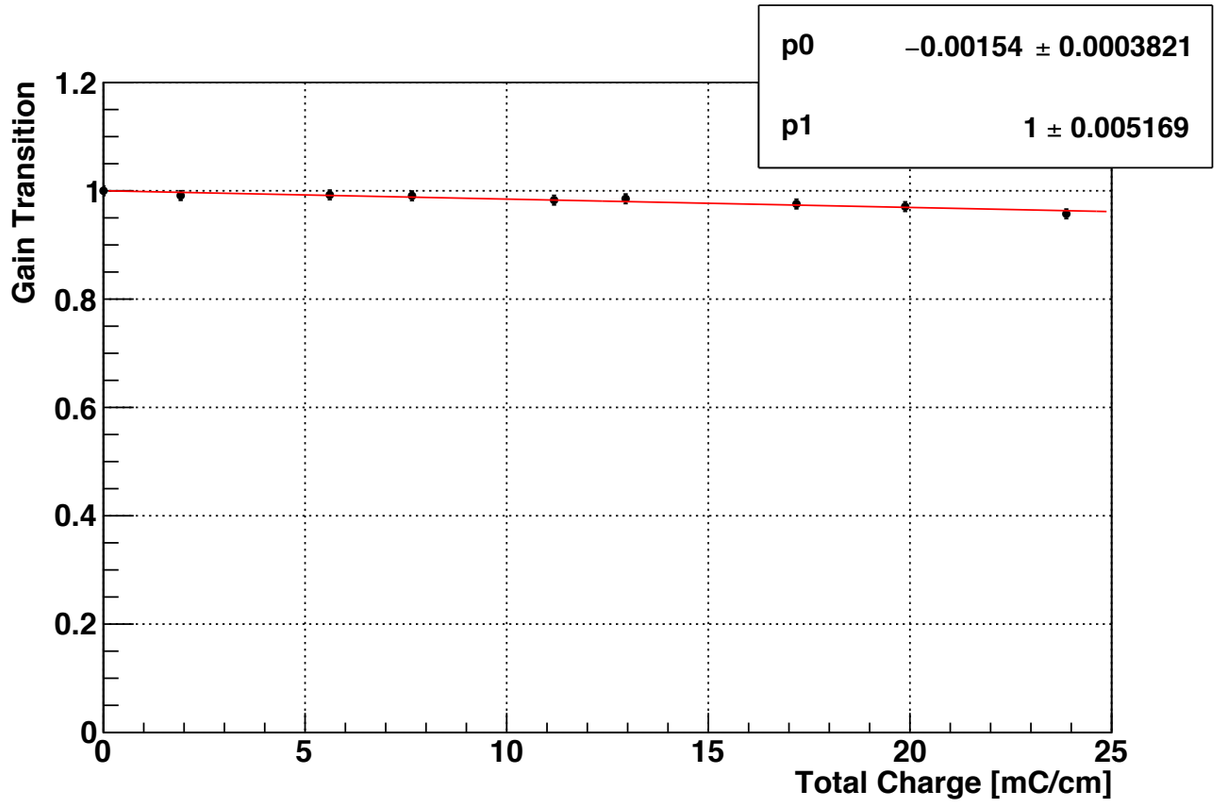
Gain measurement conditions

Source: ^{55}**Fe**

HV (ch0~2): **1750 V**

HV (ch3): 1700 V

Number of events: 10,000 event



Gain ration transition (He/iC_4H_{10} (90/10))

- Gain decrease:
  About **3.1% at 20 mC/cm/wire**.
- Gain decrease rate:
  About **0.15% /mC/cm/wire**.

- Gain decrease is better than the result of He/C_2H_6 aging test.
- I strung all wires again and second aging test is ongoing.

Study of the aged wire condition

Checked the surface of the aged wires.

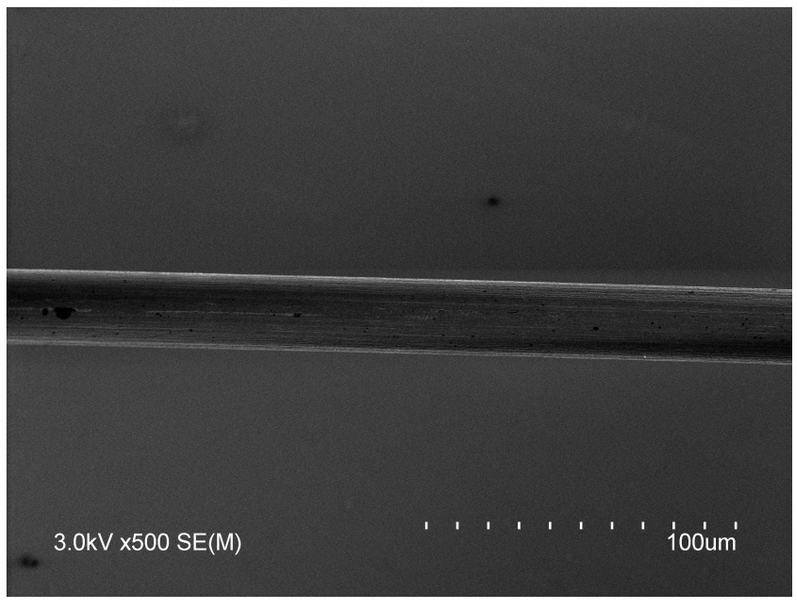
SEM S-4800

Photographing condition

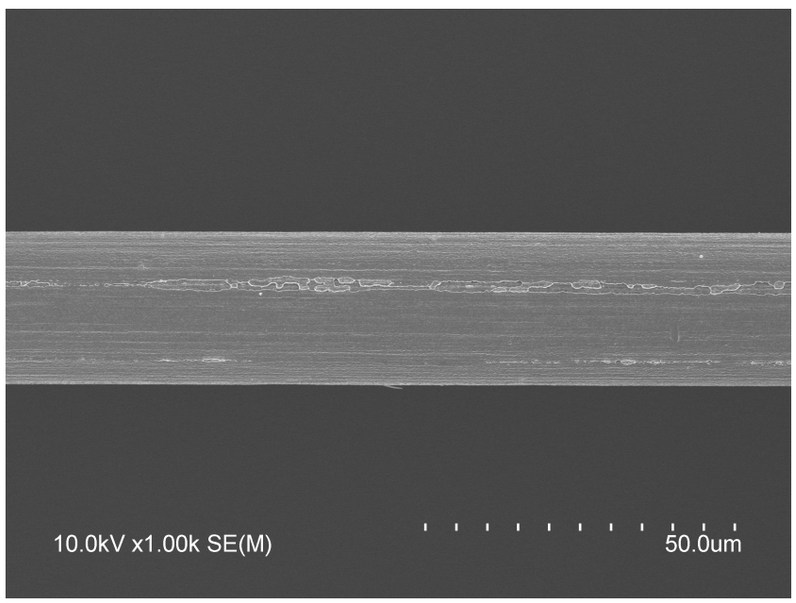
Scanning Electron Microscope: S-4800 (HITACHI)
Acceleration Voltage: 10 kV
Osmium Coter: Neoc-CS (MEIWAFOSIS)

- The samples are subjected to osmium coating treatment to avoid charge up.

Osmium coator

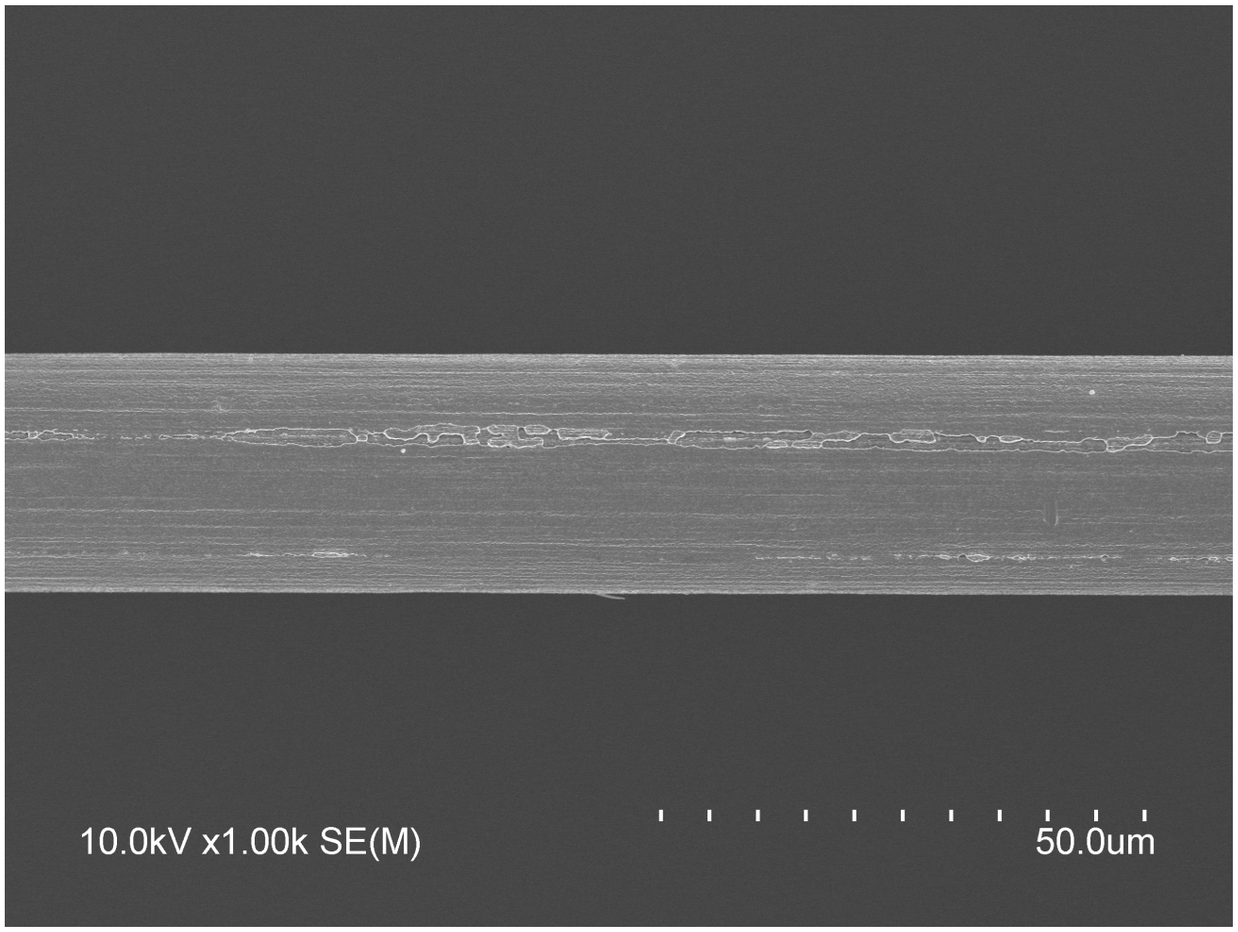


Before osmium coating

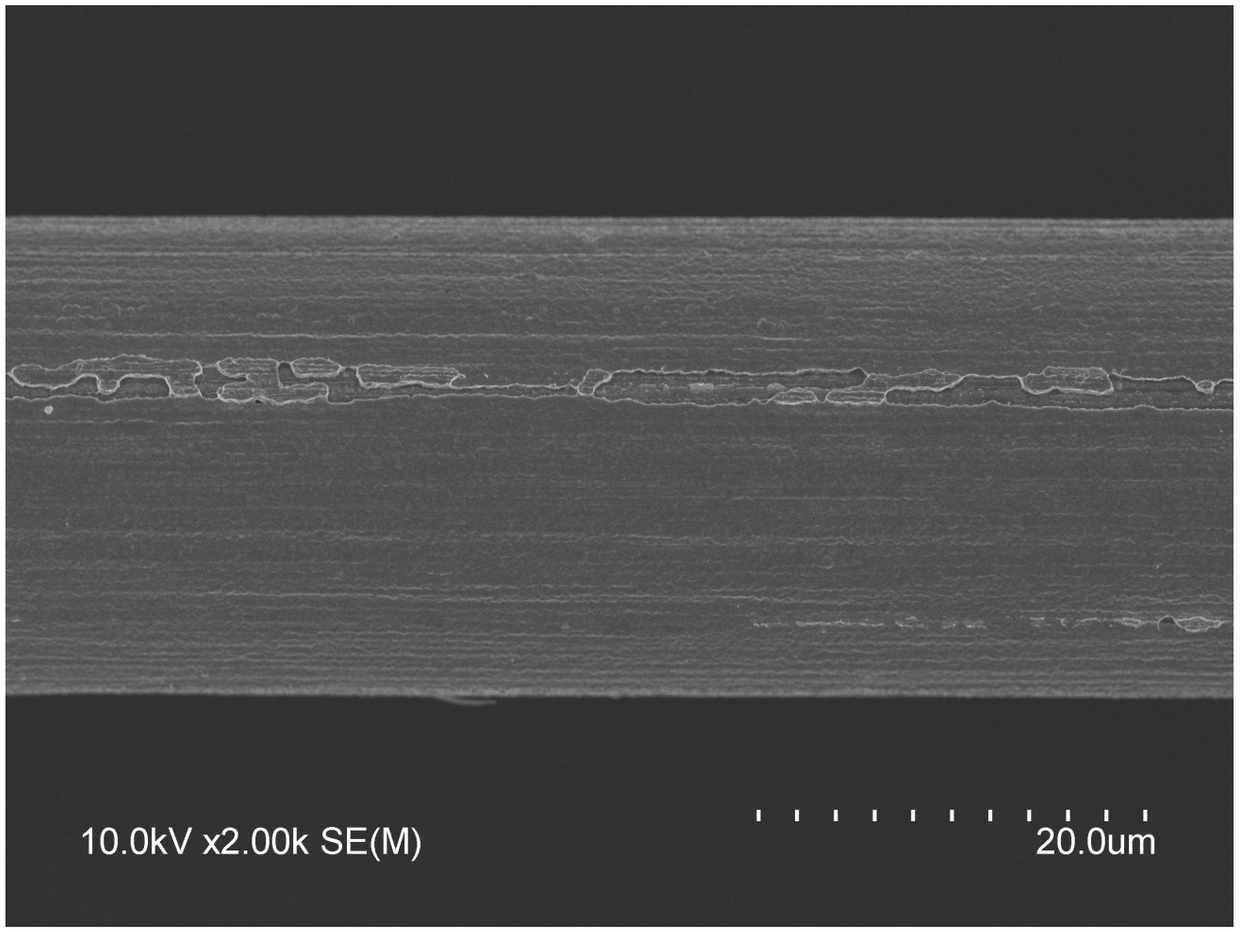


After osmium coating

Surface of NOT Aged Au-W Wire



Sense wire (Au-W)
Magnification: ×1,000

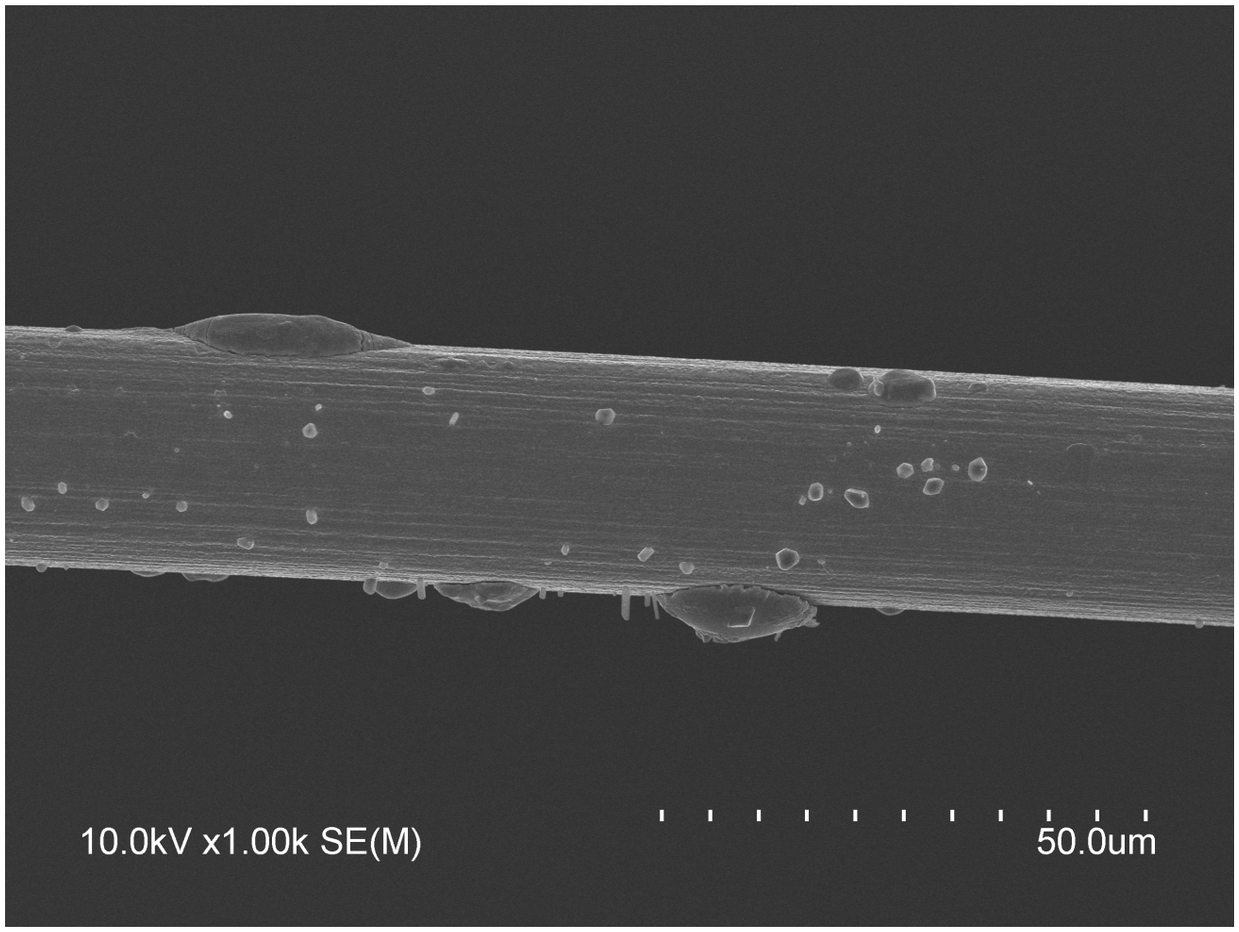


Sense wire (Au-W)
Magnification: ×2,000

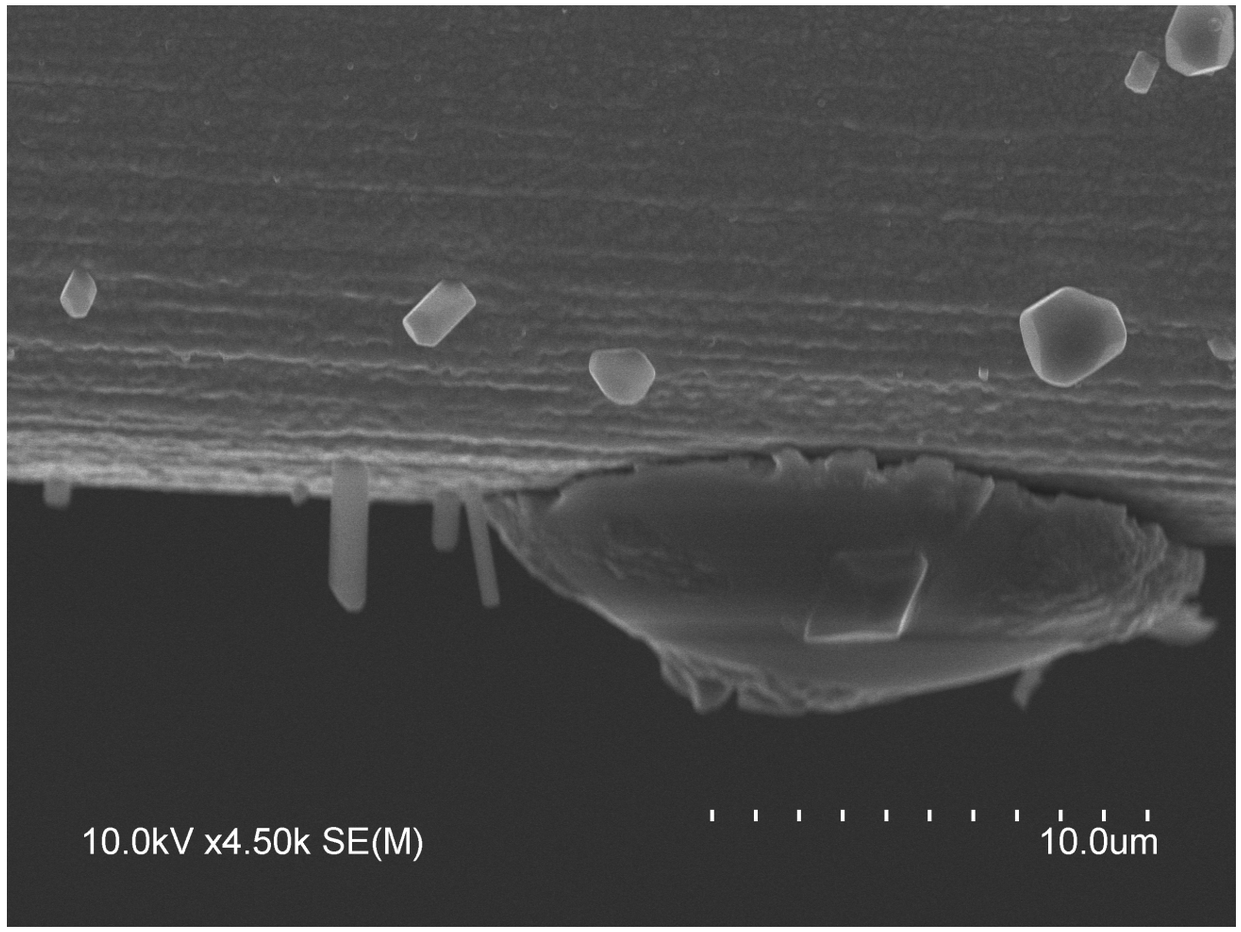
- These pictures are new sense wire.
- Both pictures are the same part of the wire, but the magnification is changed on the left and right.
- There is NO deposit on the sense wire.

Surface of Aged Sense Wire (Readout)

He/C_2H_6 aging test



Magnification: ×1,000

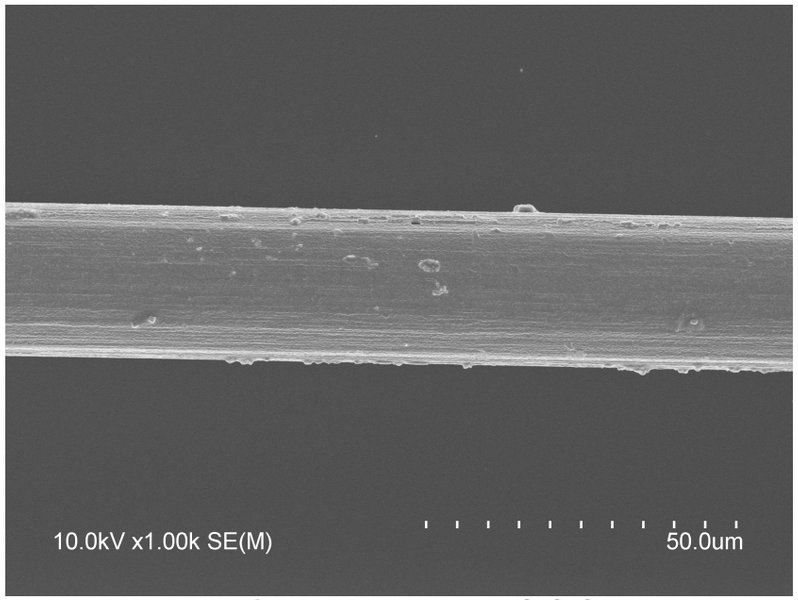


Magnification: ×4,500

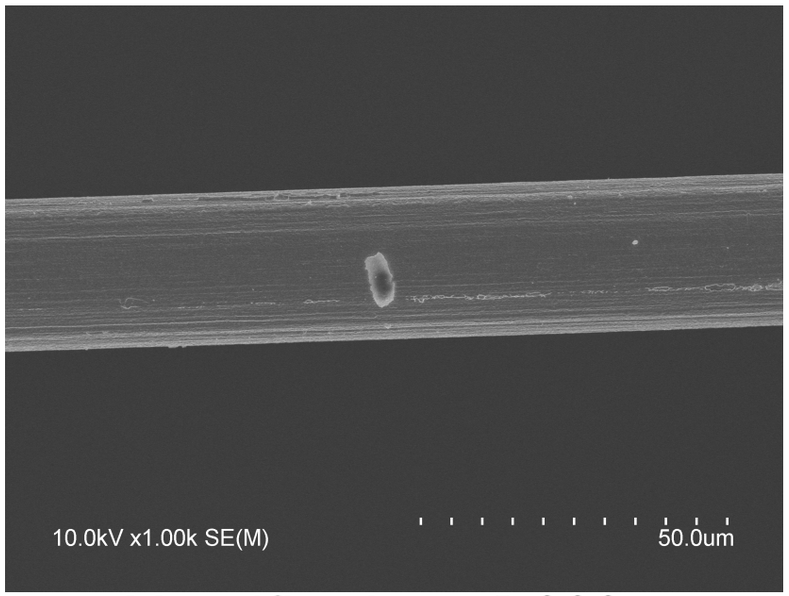
- This is the readout sense wire.
- The pictures shows the aged side (A part) of the aged wire.
- The spiked compounds and the gum-like compounds are on the wire.

Surface of Aged Sense Wire (Readout)

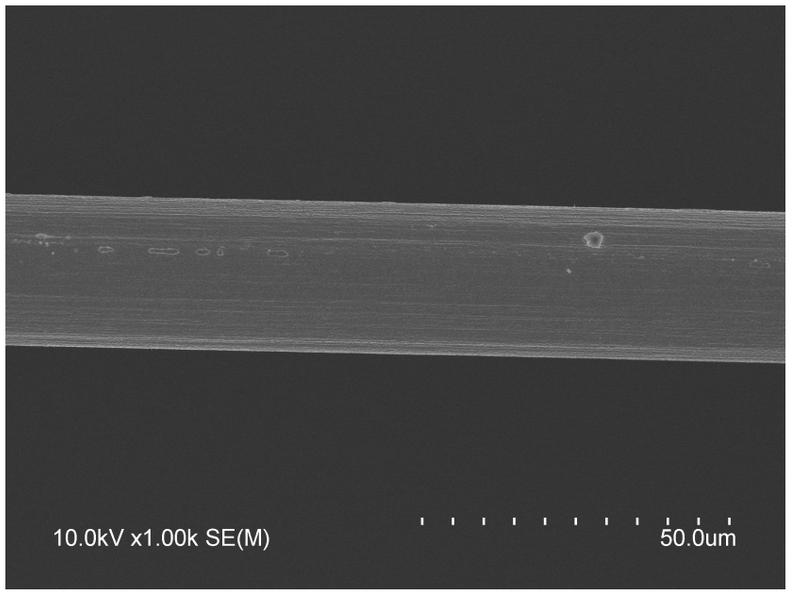
He/iC_4H_{10} aging test



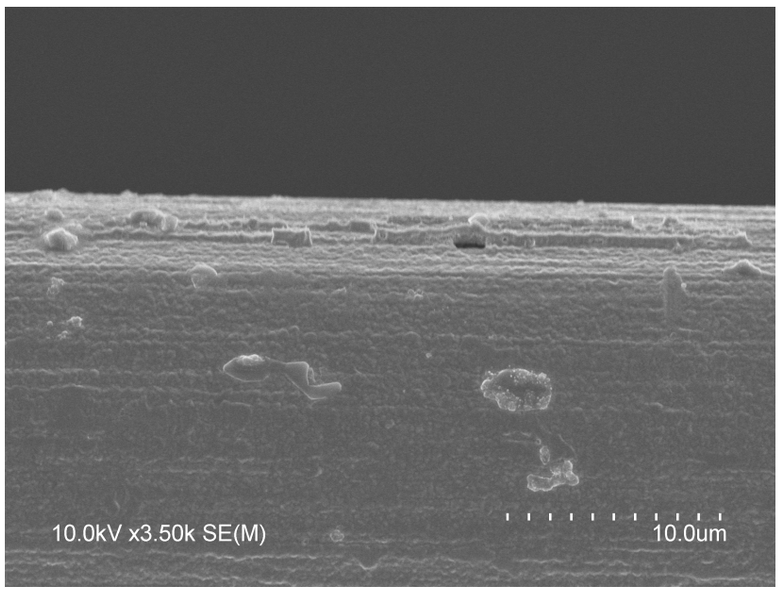
Magnification: ×1,000



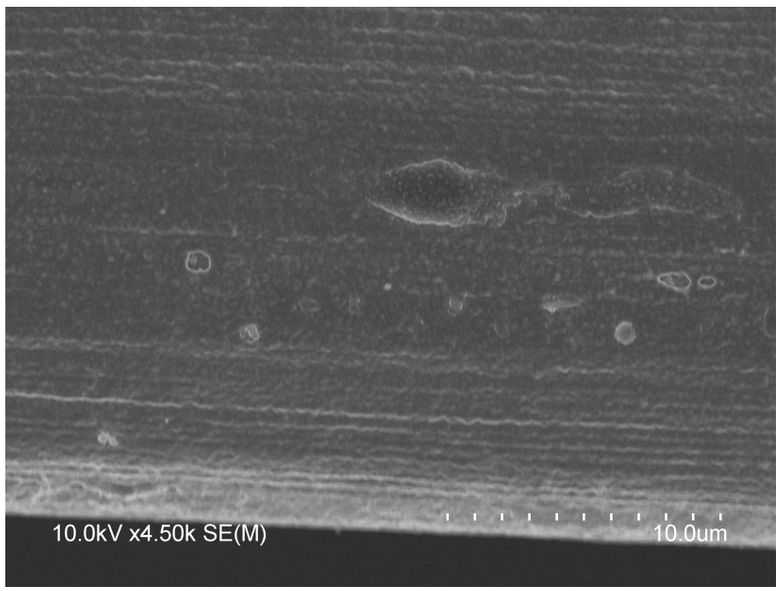
Magnification: ×1,000



Magnification: ×1,000



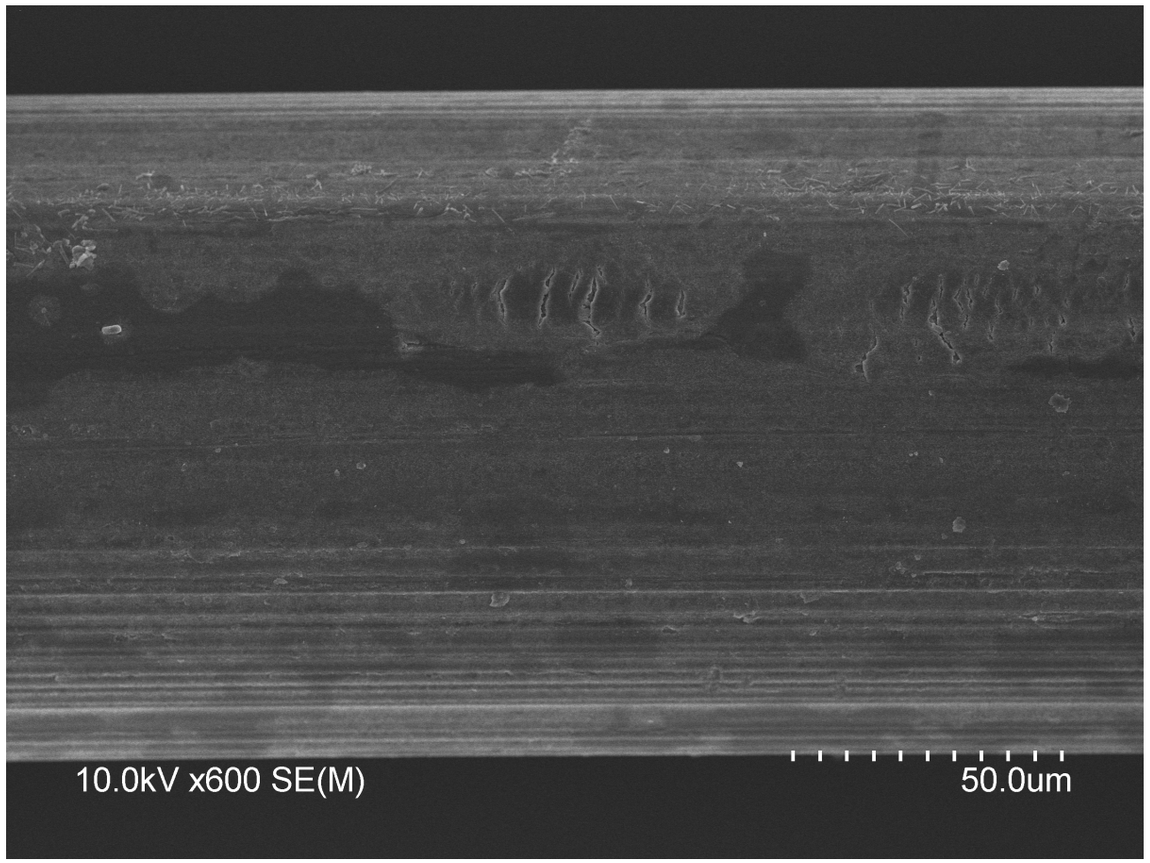
Magnification: ×35,000



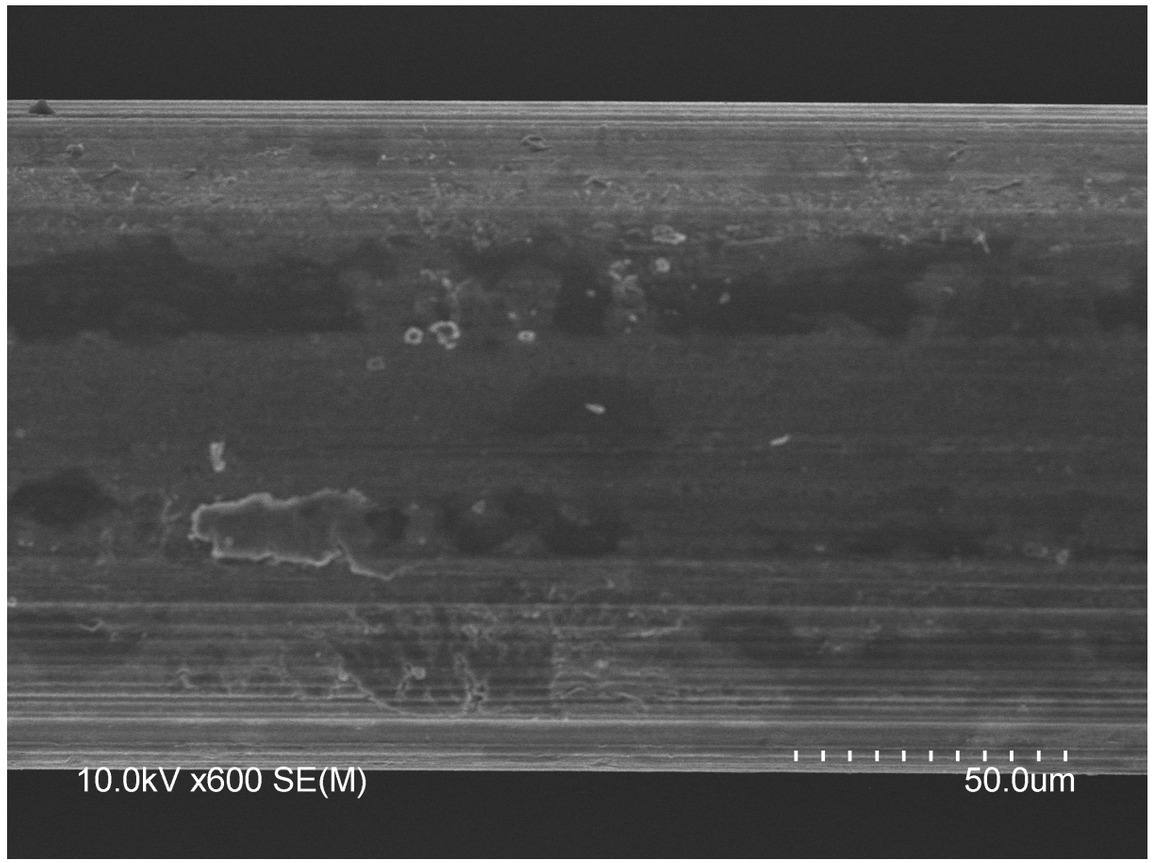
Magnification: ×35,000

- There is less deposits than aged center sense wire of He/C_2H_6.
- The decrease in gain was also about twice as good as the result of ethane.

Surface of the not aged Al wire



Field wire (Al)
Magnification: ×600

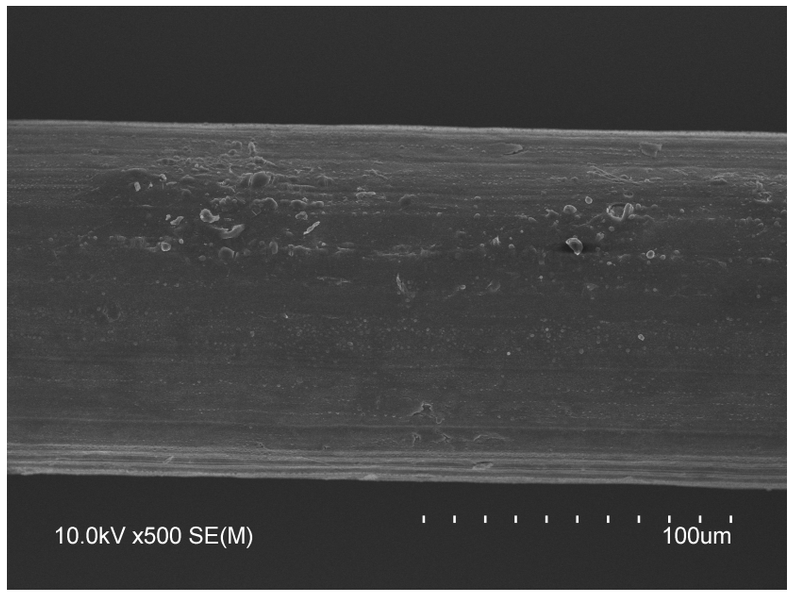


Field wire (Al)
Magnification: ×600

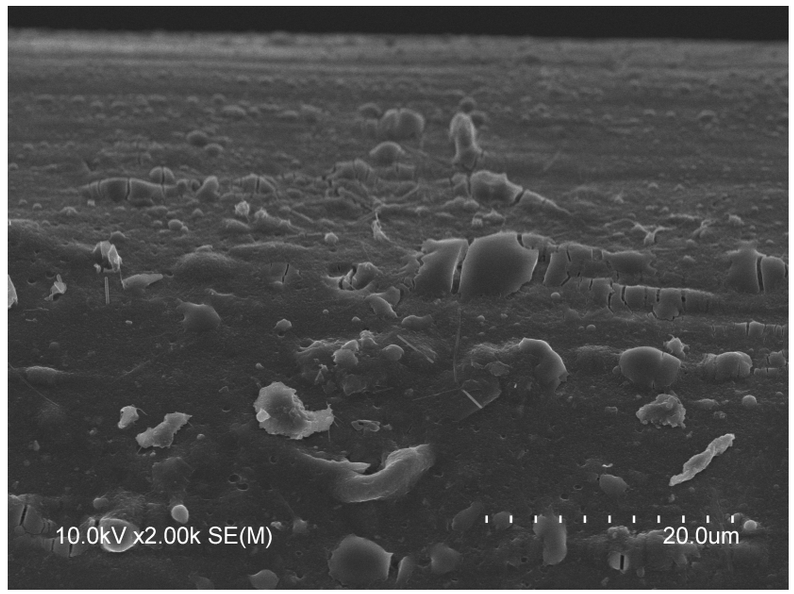
- These pictures are new field wire.
- We can see any deposit on the new field wire.

Surface of Aged Field Wire (next to the center sense wire)

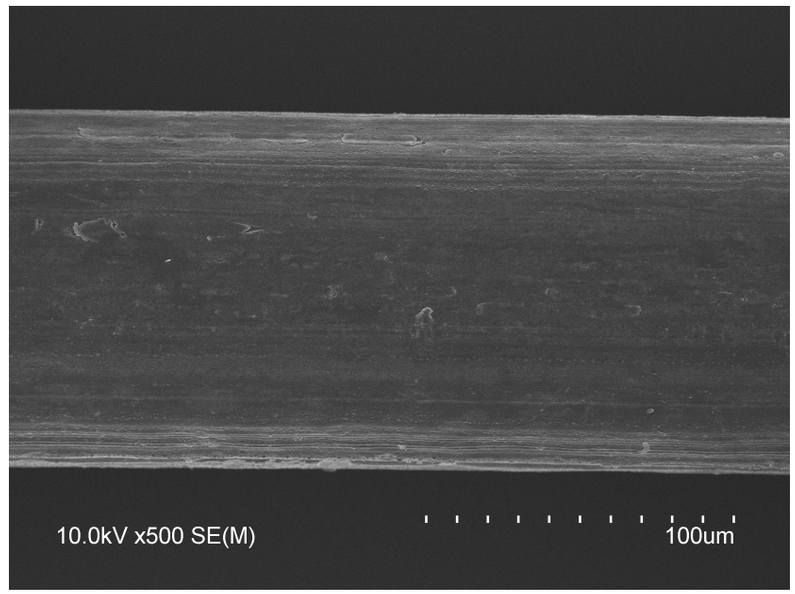
He/C_2H_6 aging test



Magnification: ×500

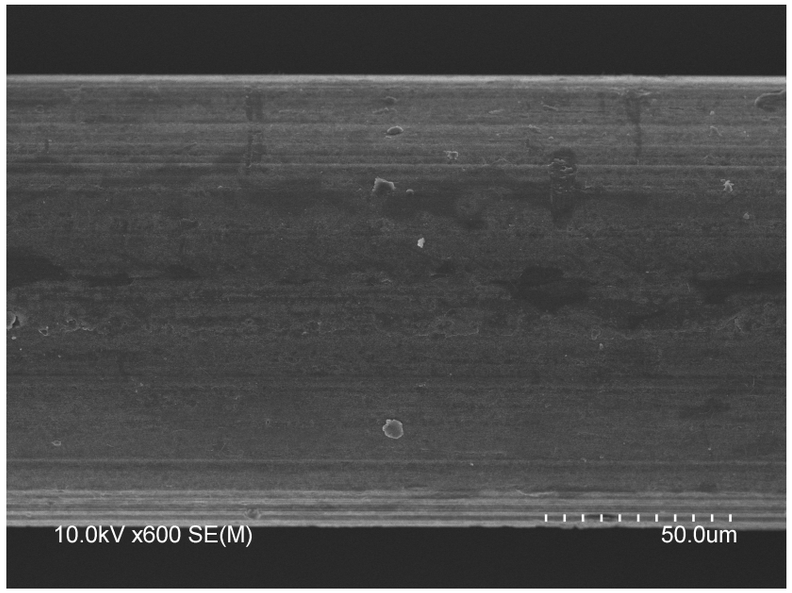


Magnification: ×2,000

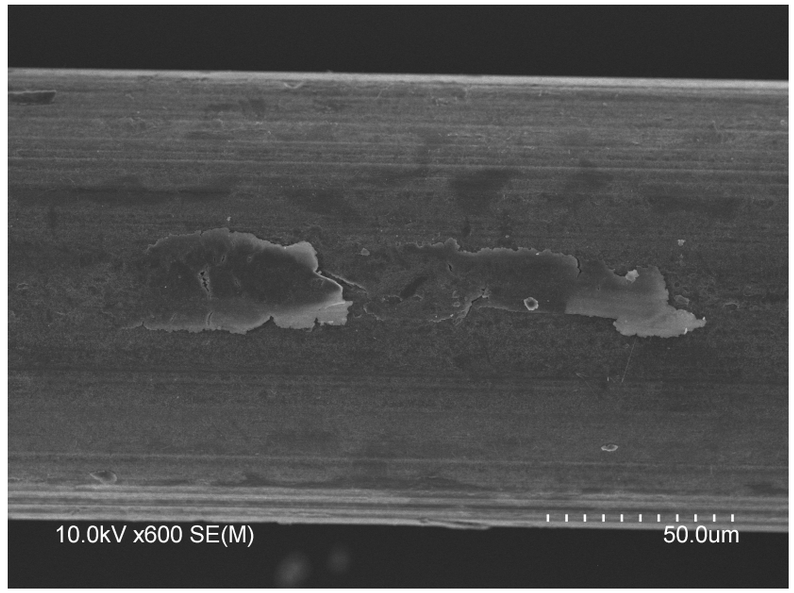


Magnification: ×500

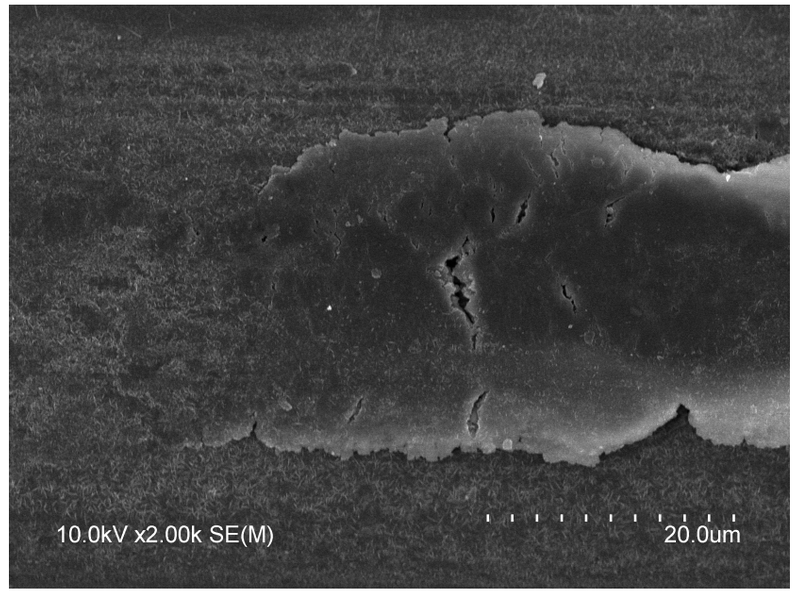
He/iC_4H_{10} aging test



Magnification: ×600



Magnification: ×600

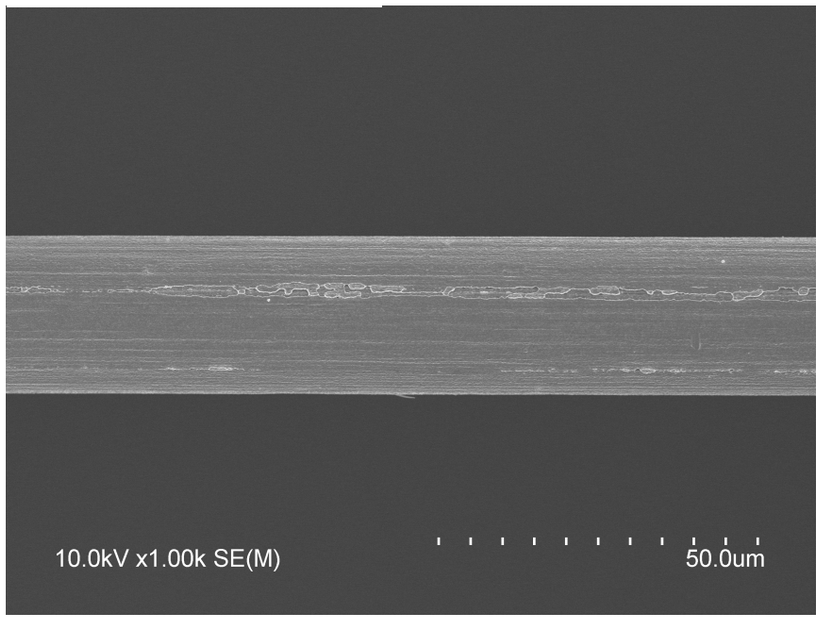


Magnification: ×2,000

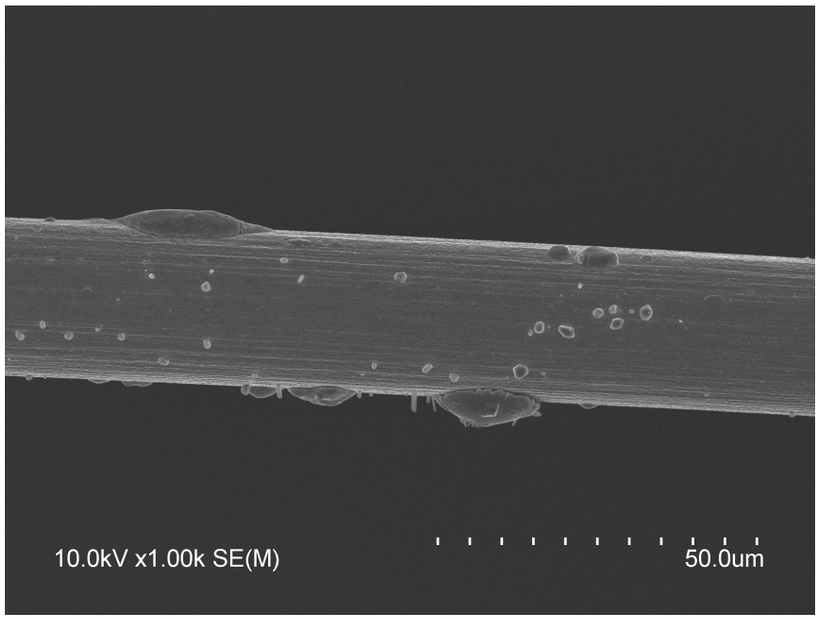
It looks like something sticks to the surface and it cracks on the field wire of the He/C_2H_6 aging test.

Surface of the wires (summary)

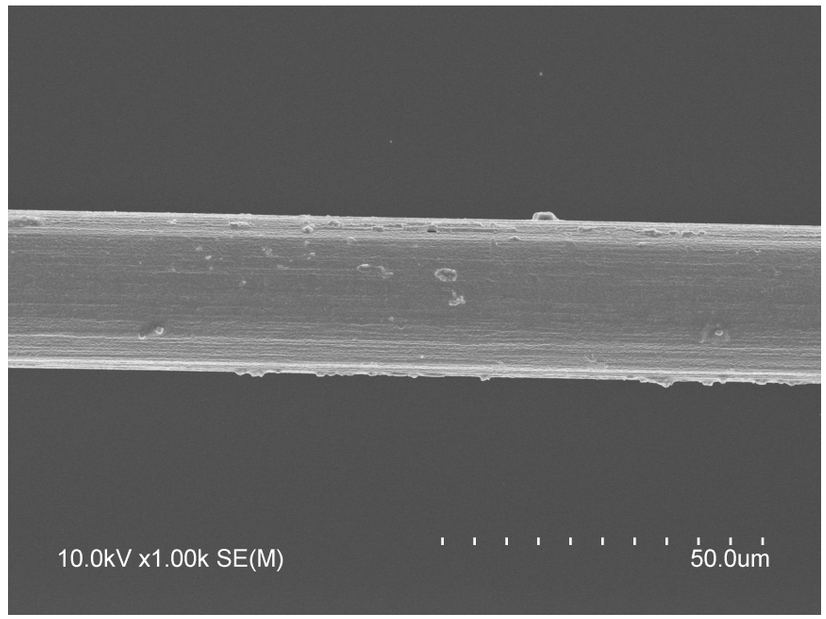
Sense wire



New sense wire

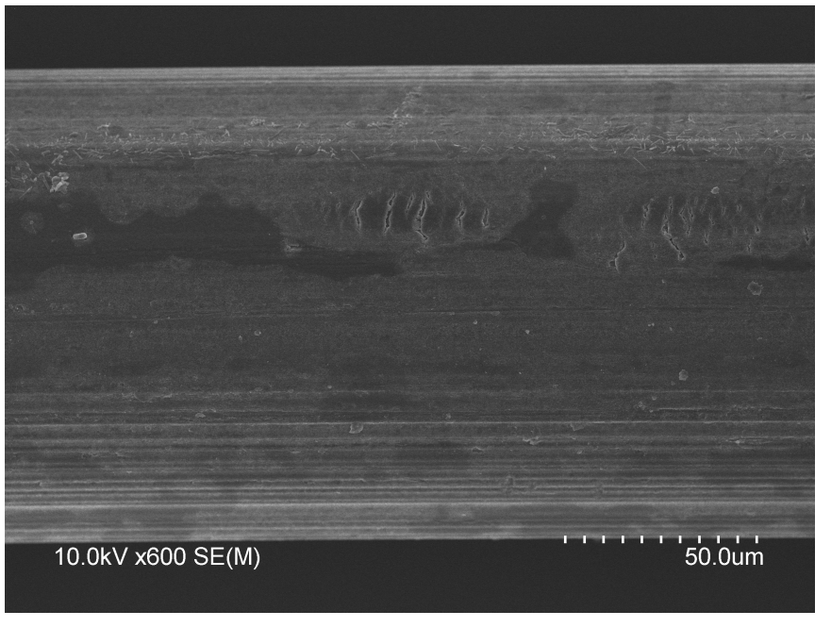


Aged center sense wire (He/C_2H_6)

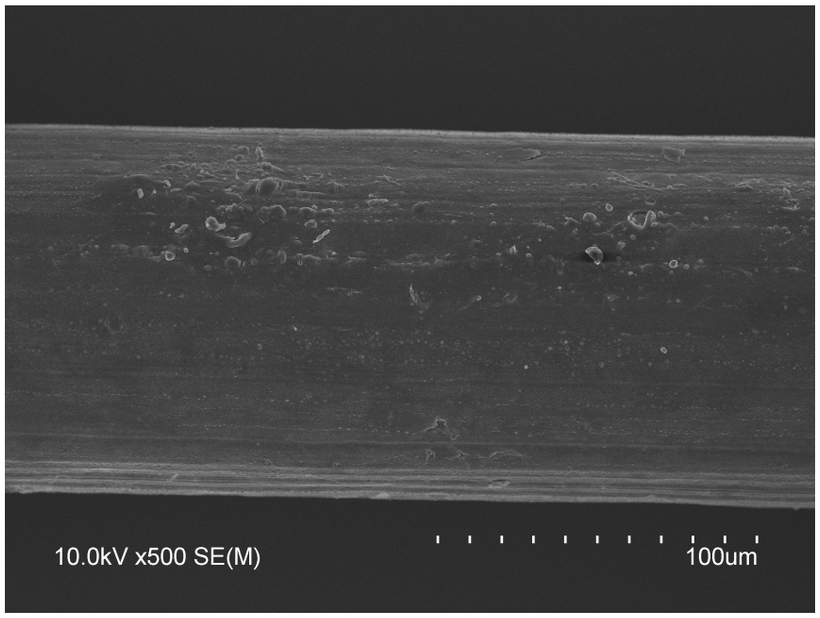


Aged center sense wire (He/iC_4H_{10})

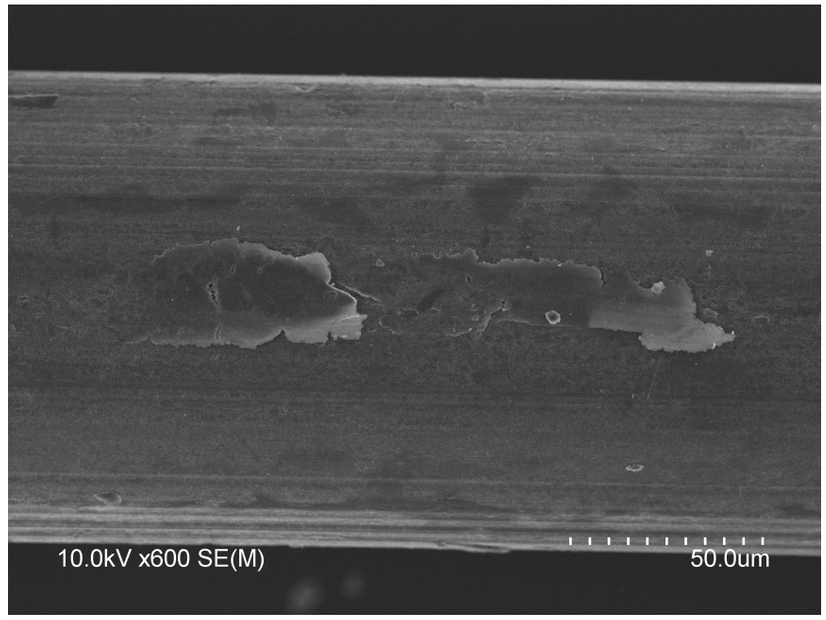
Field wire



New field wire



Aged field wire (He/C_2H_6)
(next to the center sense wire)



Aged field wire (He/iC_4H_{10})
(next to the center sense wire)

Scanning Electro Microscope: S-4800 (HITACHI)

Elemental Analysis

What are the deposits made of?

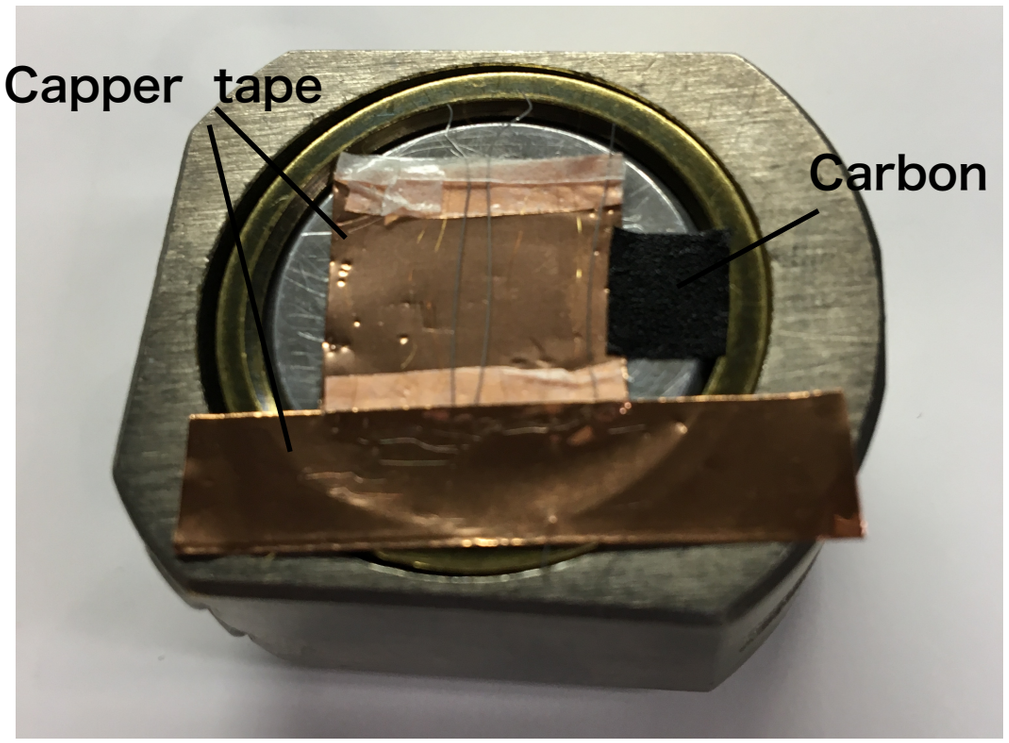
FE-SEM(Field Emission Scanning Electro Microscope): 日本電子 JSM-6335

EDS(Energy Dispersive x-ray Spectroscopy): 日本電子 JED-2300F

*EDS energy resolution: about 160 eV

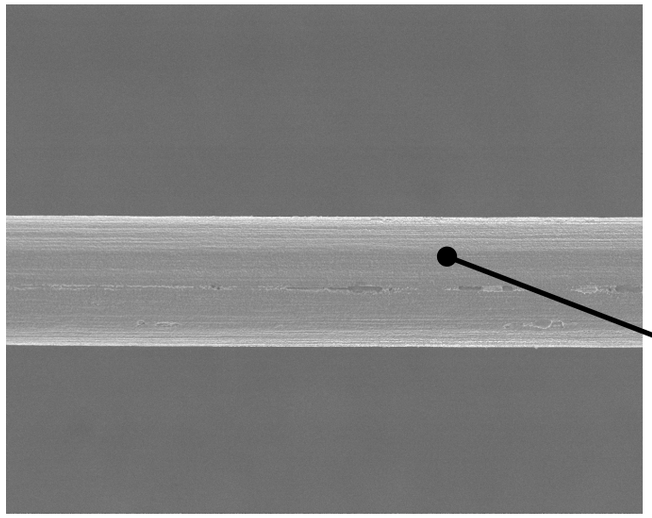
Place: The Institute of Science and Industrial Research, Osaka Univ.

SEM/EDX

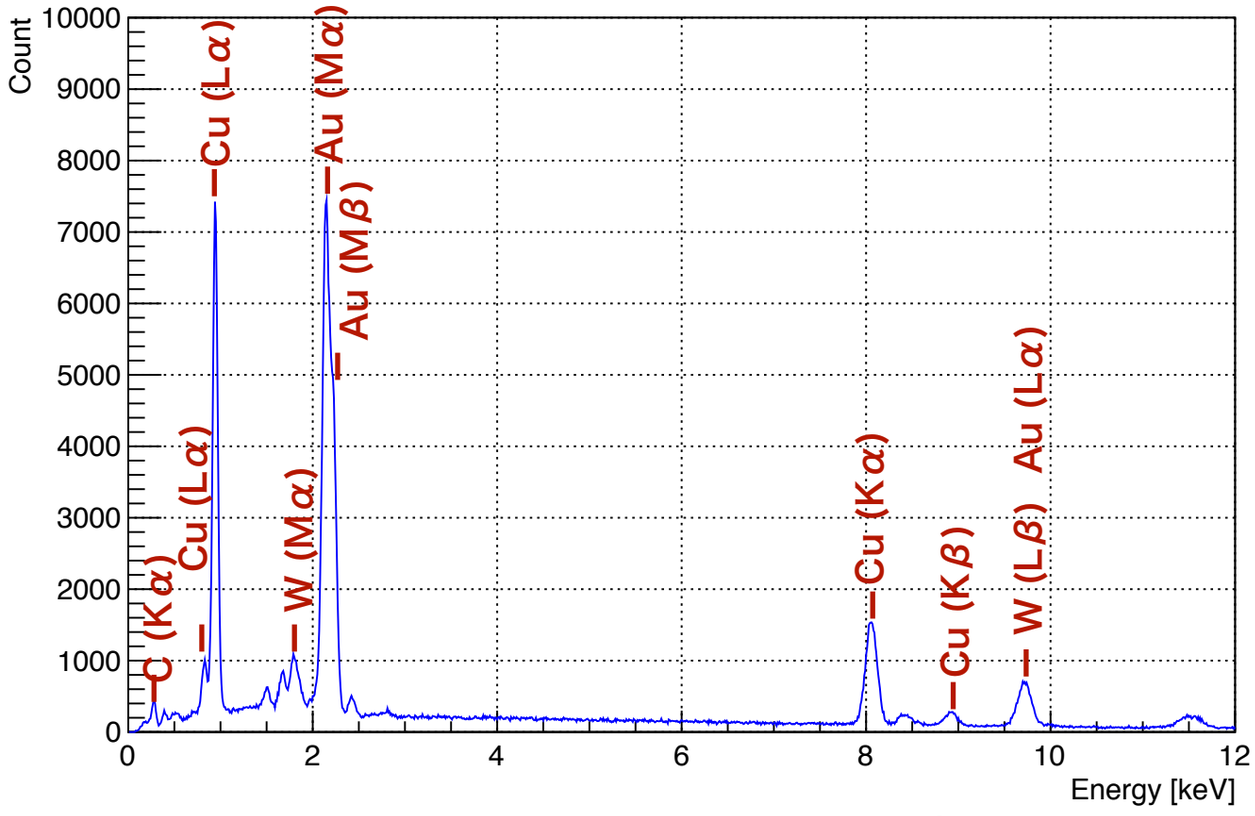


Sample and Sample holder

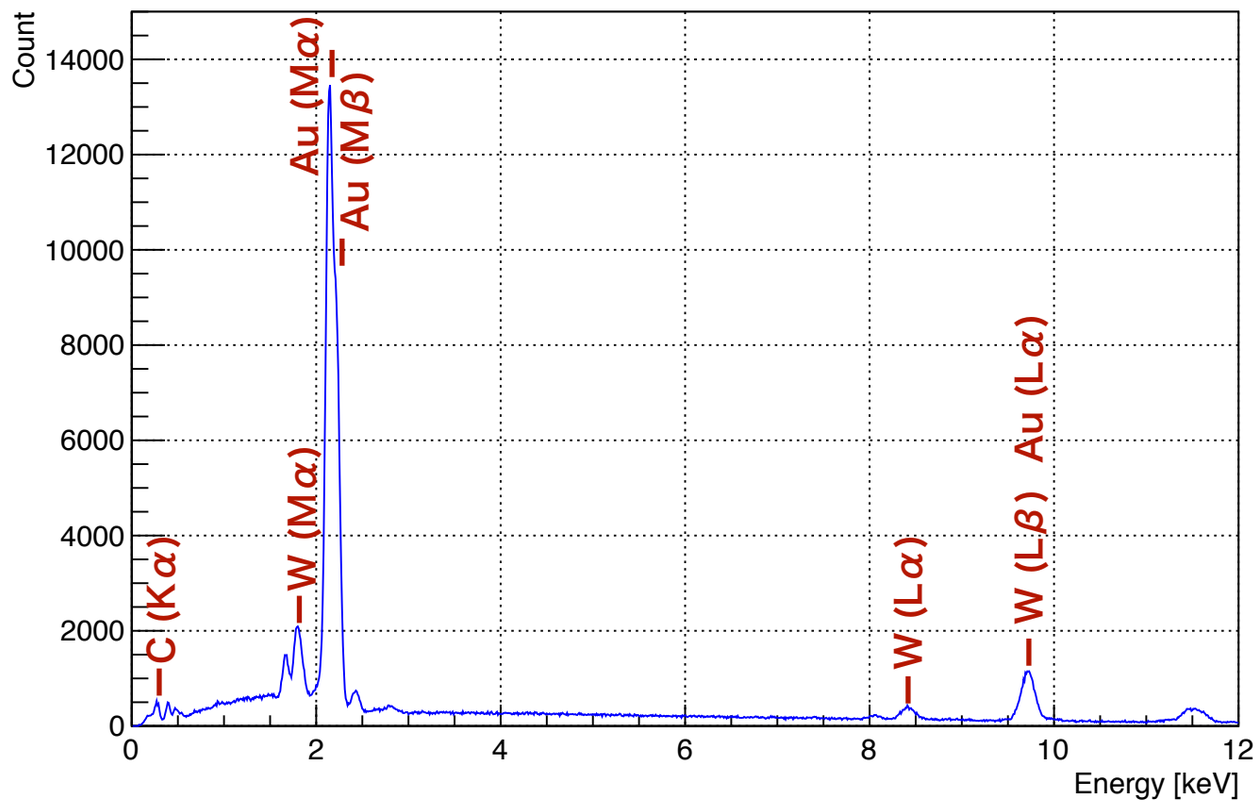
Elemental analysis of Clean Au-W wire



As a result of point analysis with Au-W wire, there are gold peak and weak tungsten peak.



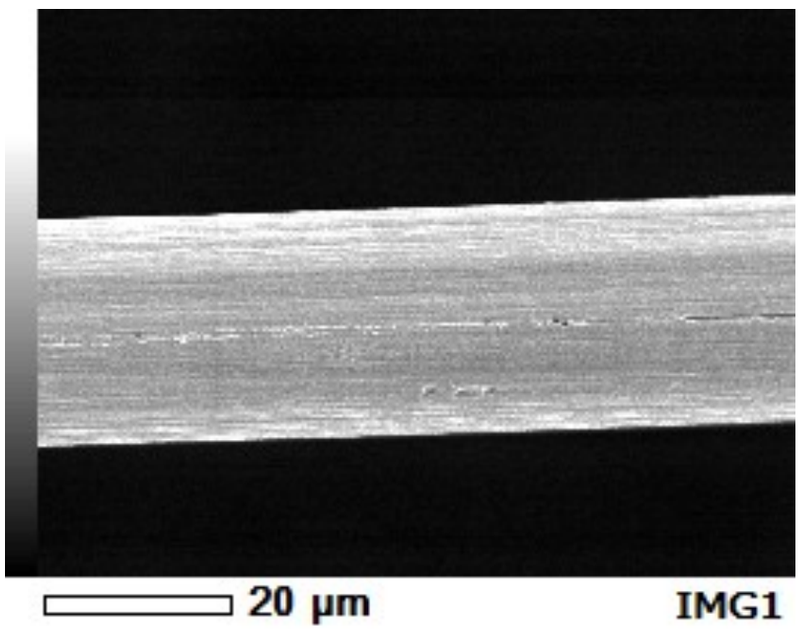
The elemental analysis result of the whole picture screen

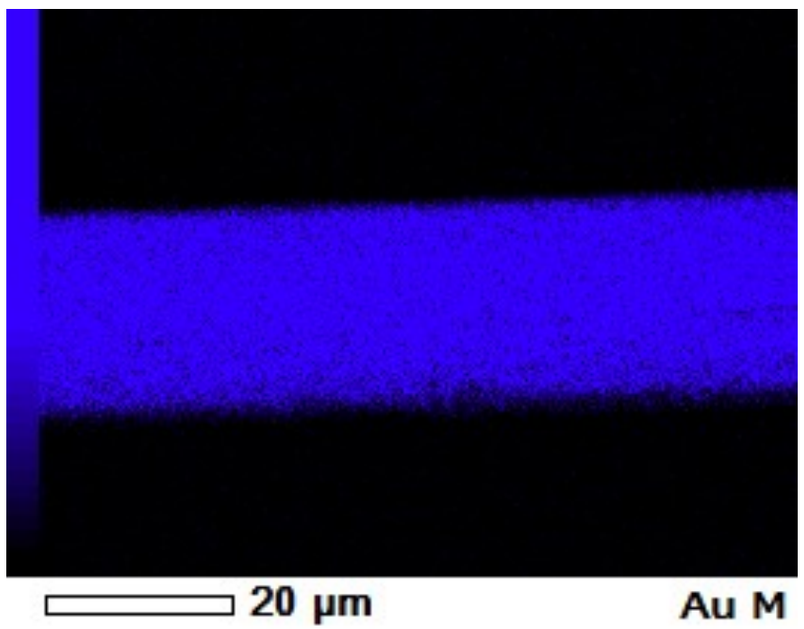


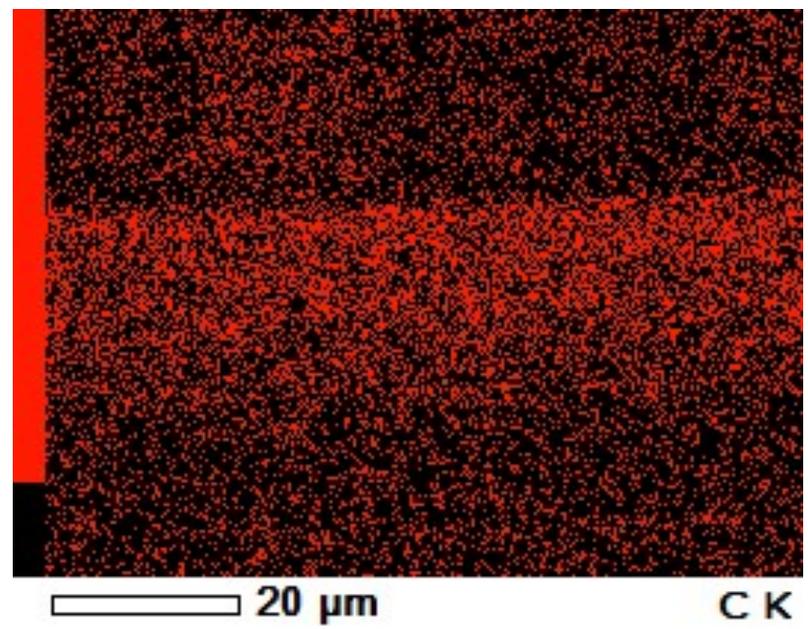
The point analysis result of surface of the Al wire

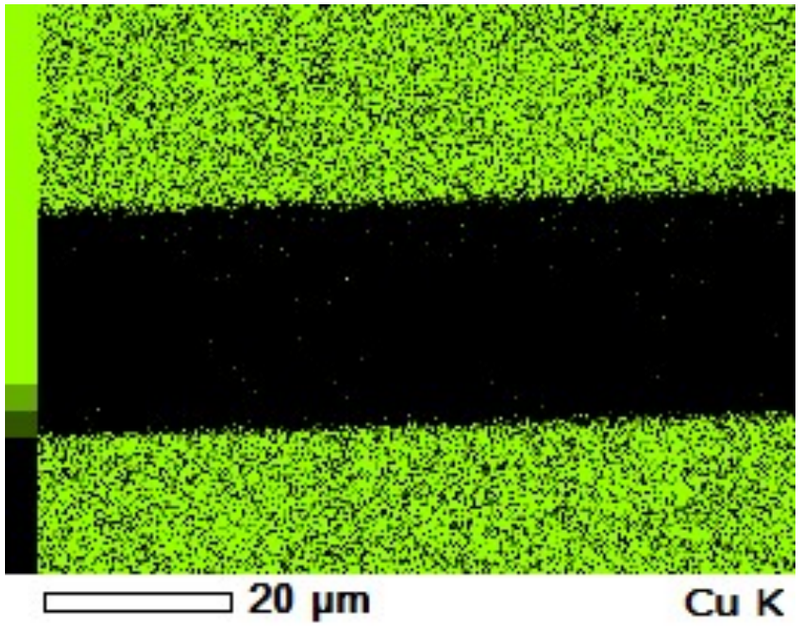
Resolution of point analysis: 1 μm radius

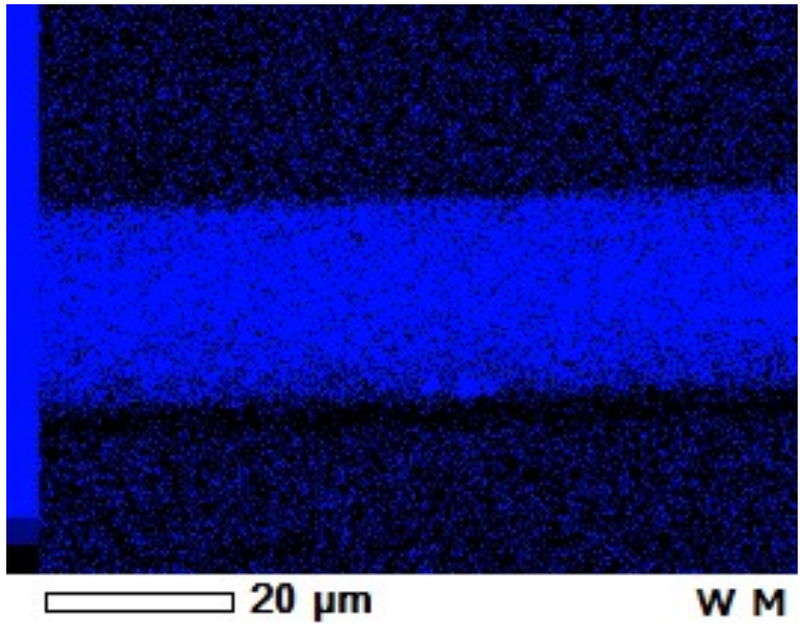
Elemental analysis of Clean Au-W wire







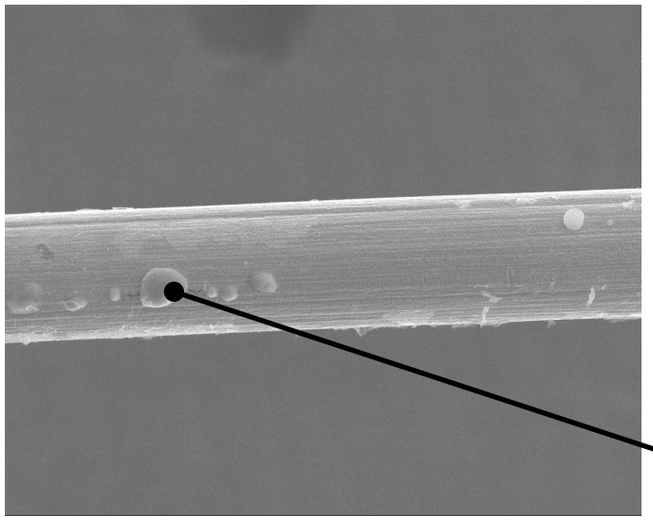




Results of element mapping

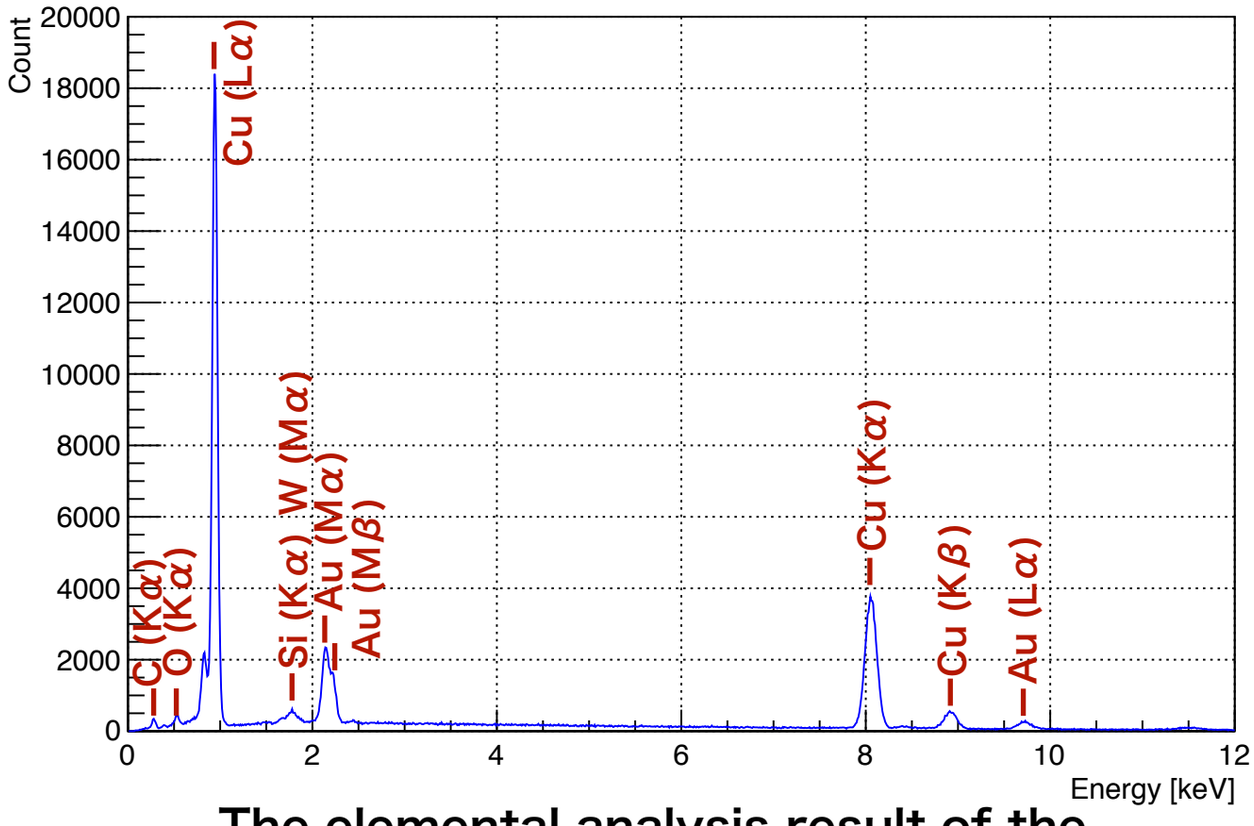
Gold and tungsten are seen clearly.

Elemental analysis of the center sense wire (He/C_2H_6)

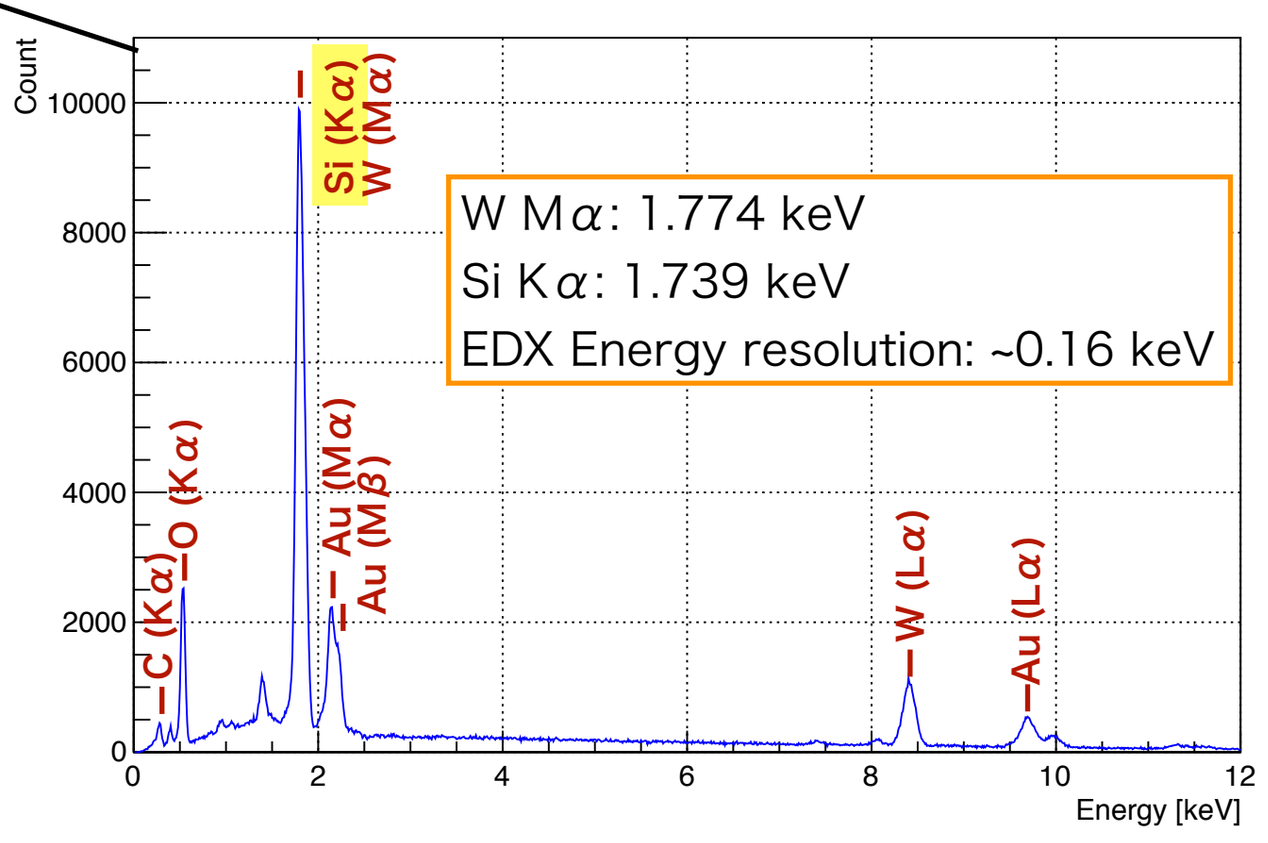


- The characteristic X-ray peak of tungsten and silicon are nearly identical, that it can not be determined by the energy resolution of EDX.
- However, with the new wire, the gold peak was 7.1 times stronger than tungsten peak, whereas this silicon peak is 5 times stronger than the gold peak compared to the gold peak.

→ **Is it considered to be a peak of silicon?**

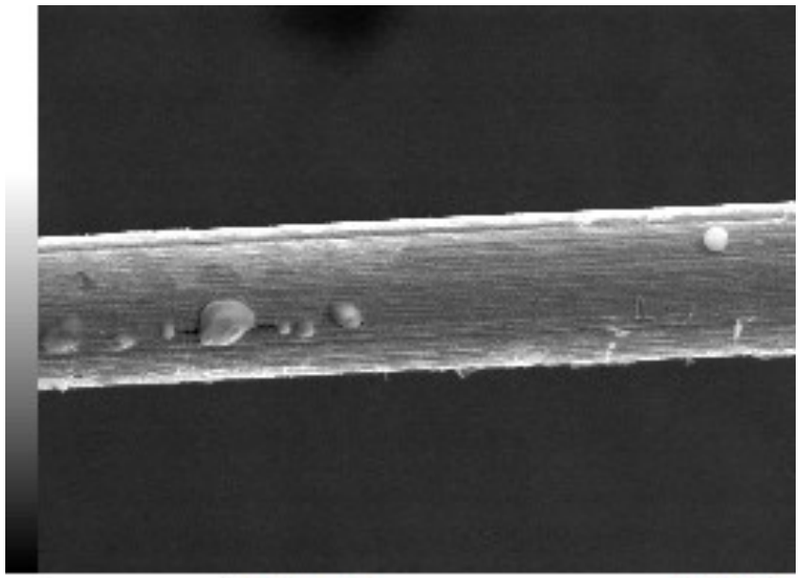


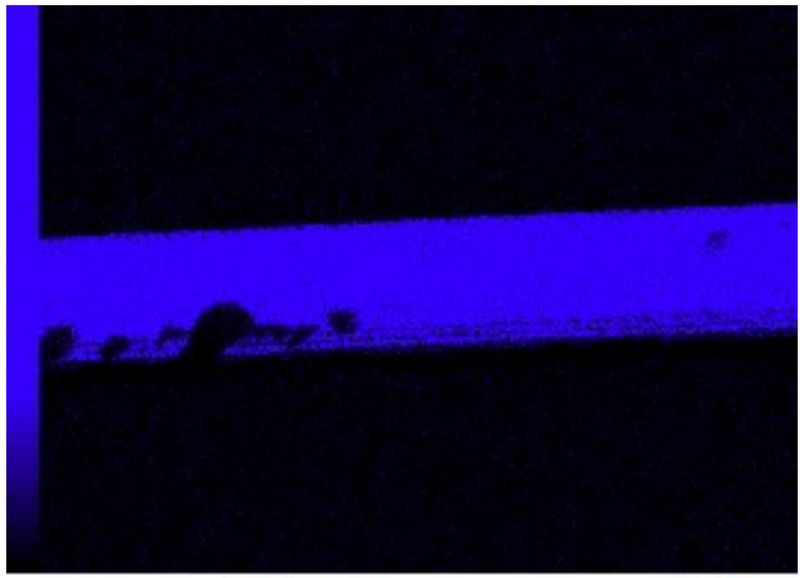
The elemental analysis result of the whole picture screen

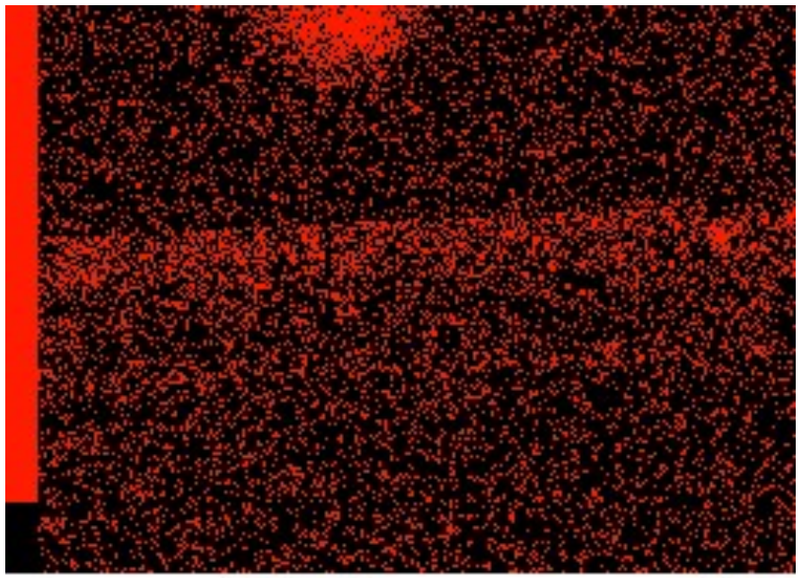


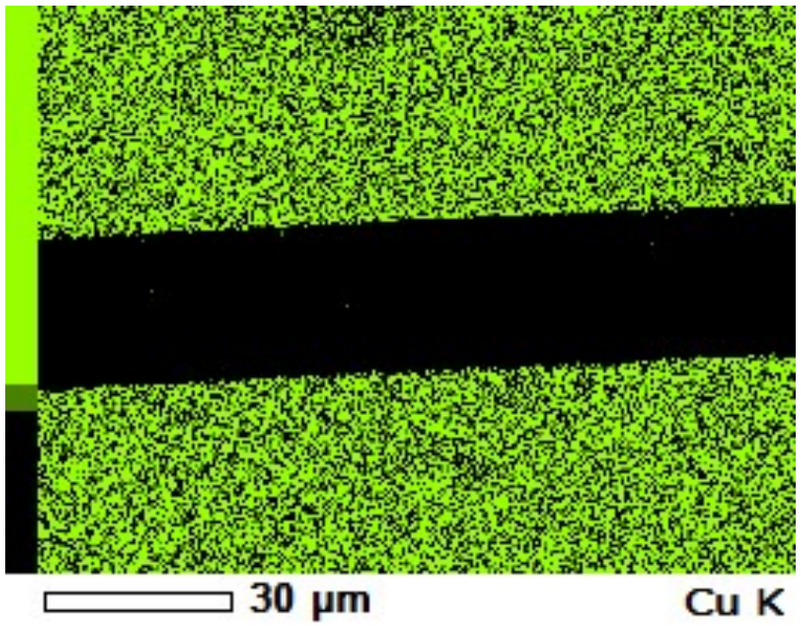
The point analysis result of deposits

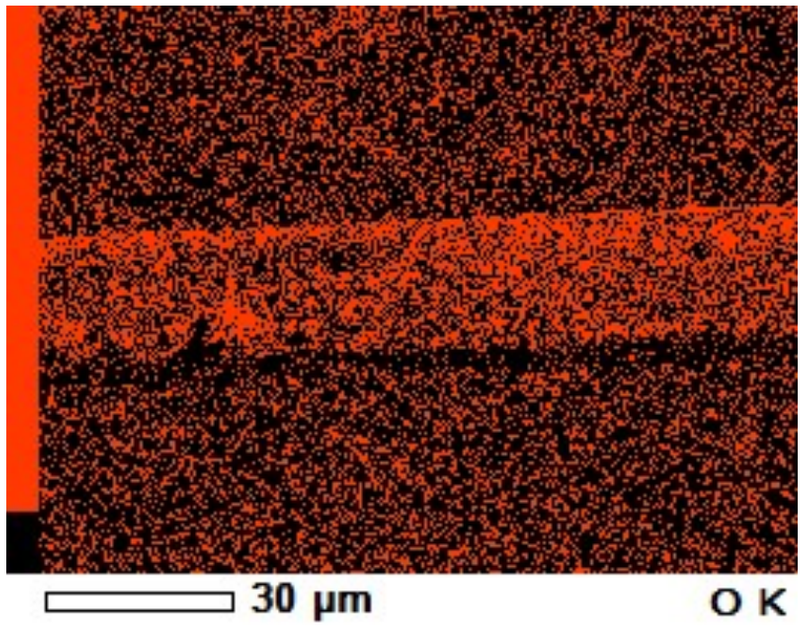
Elemental analysis of the center sense wire (He/C_2H_6)

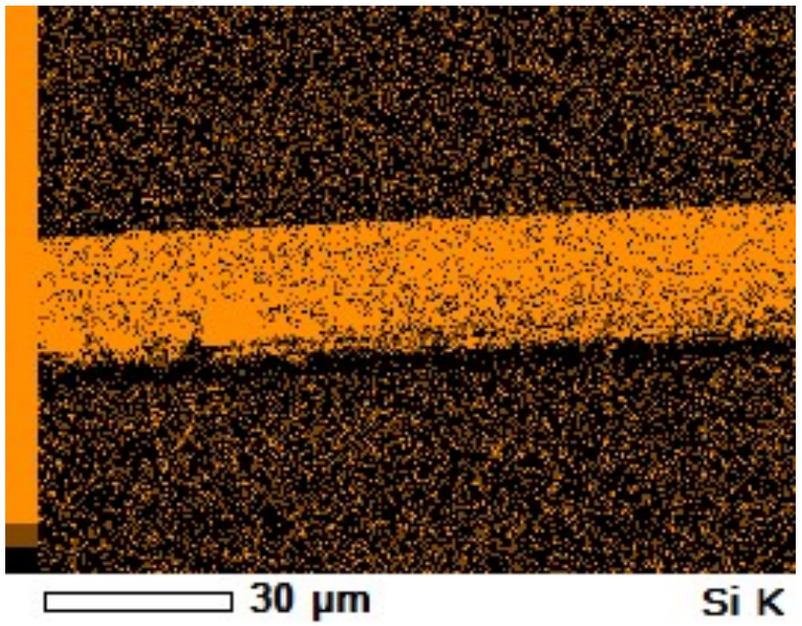












Results of element mapping

- The compound attached to the wire seems to be composed of silicon and oxygen.
- Are they silicone (…-O-Si-O-Si-O-…)?

Summary

- Drift chamber is one of the main detector of the COMET Phase-I.

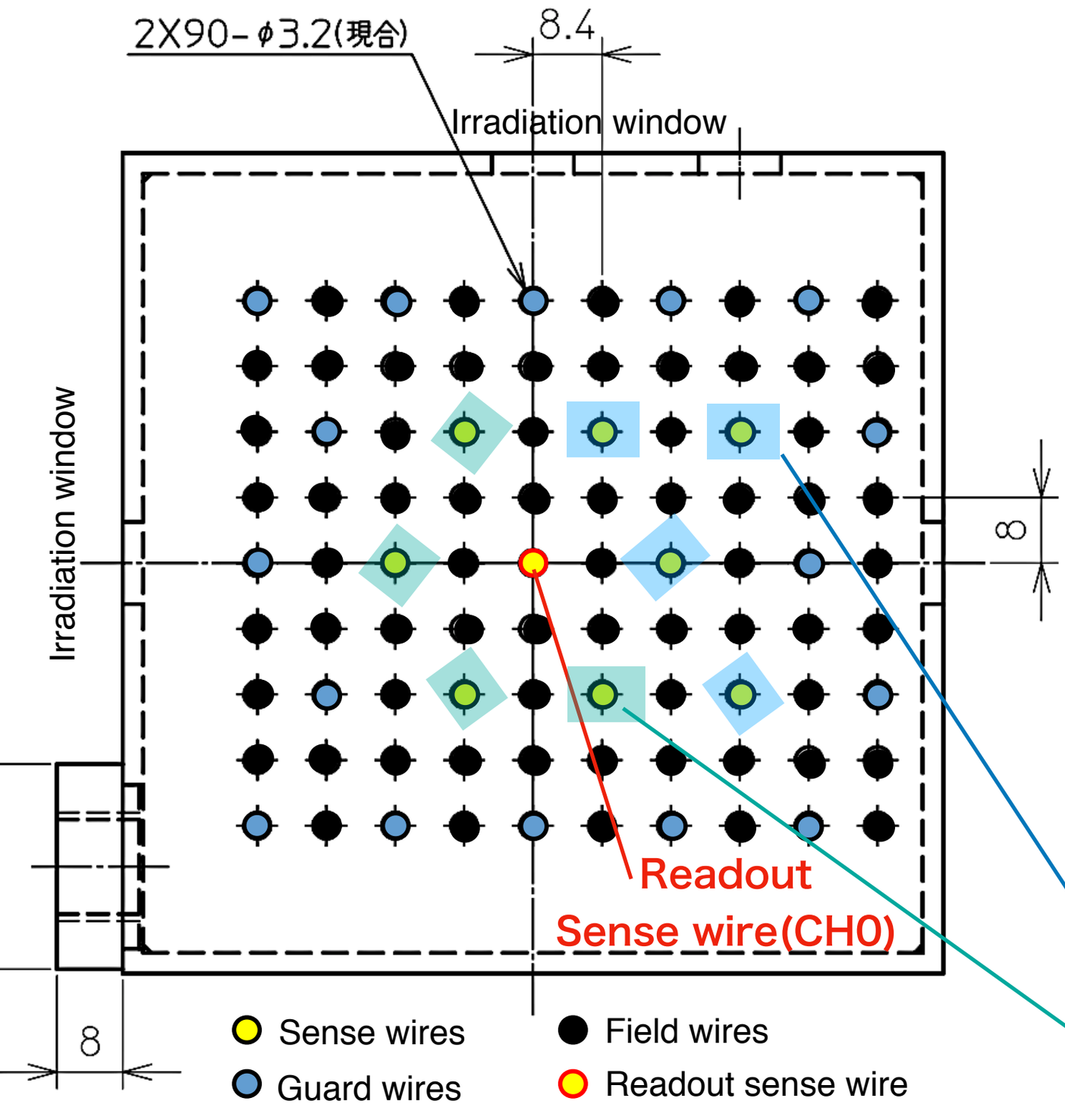
- Chemical compound covers sense and field wire when we use drift chamber in the radiative environment. And it causes gain decrease and increase dark current etc. (Wire aging effect).

- Studying how effect this aging effect on the wires of the COMET CDC.
- Gain decrease is
  - About 6.0% at 20 mC/cm/wire for He/C_2H_6 (50/50).
  - About 3.1% at 20 mC/cm/wire for He/iC_4H_{10} (90/10).

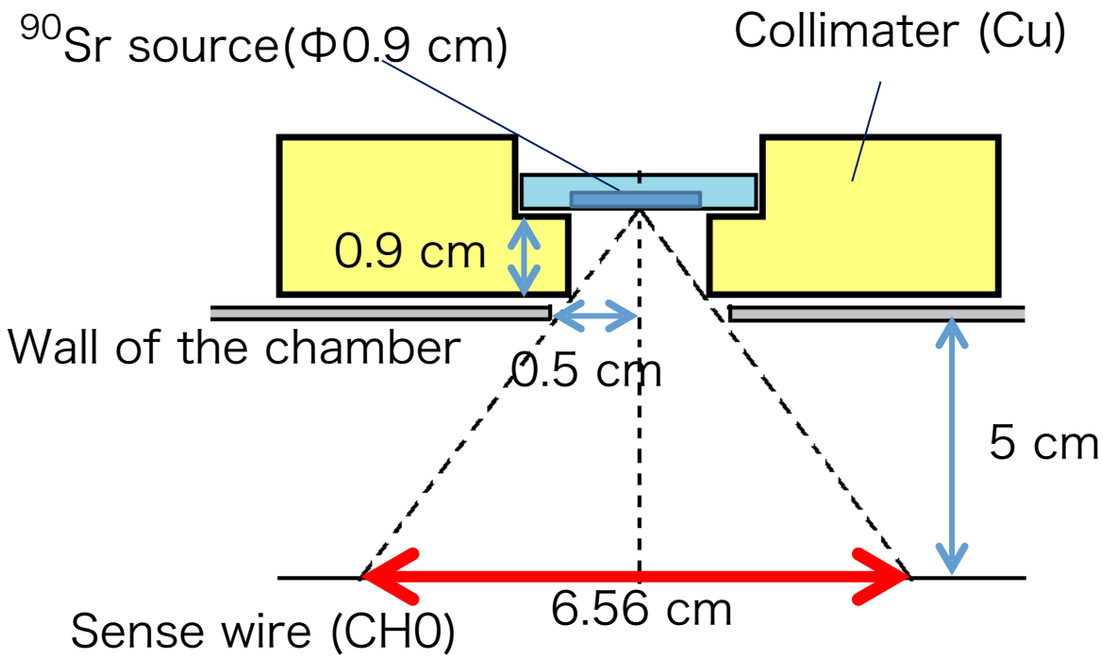
- From the picture of SEM, it was found that there was compounds on the aged sense wires.
- Compounds of the sense wires seem to be made of Si and C according to the results of element.

Back Ups

Wire cross section



Wire cross section of 9cell test chamber



Estimation of the Radiation range of the center sense wire (CH0)

- Wire current is recorded by HV module every second.

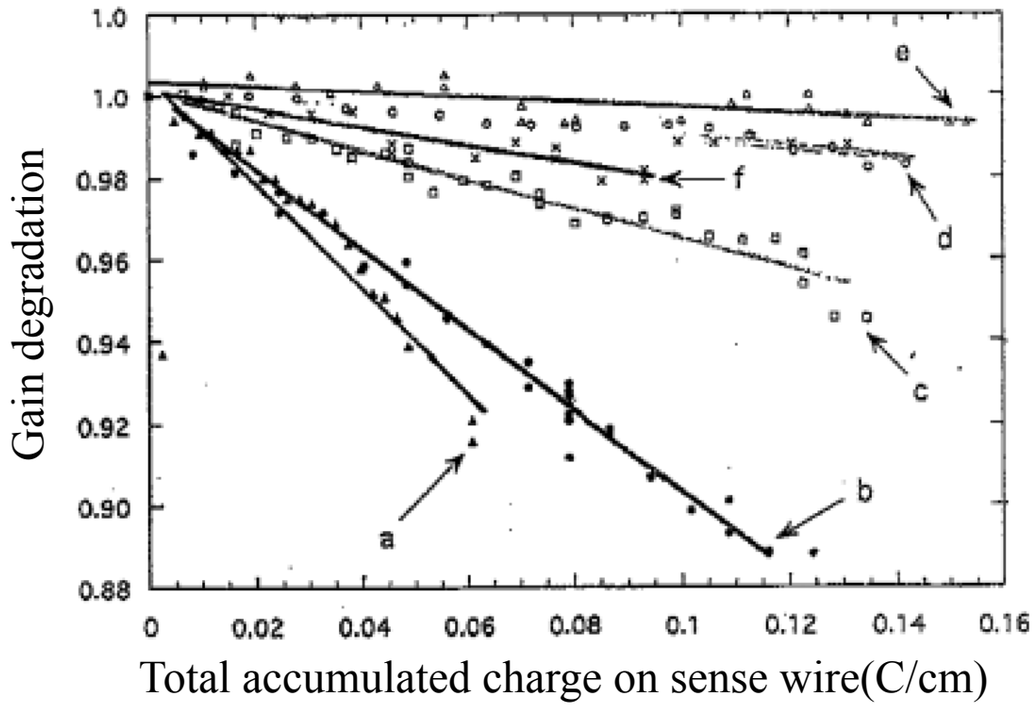
HV channel

CH0: Readout sense wire
CH1: 4 sense wire
CH2: 4 sense wires
CH3: Guard wires

Result and past study

The Aging effect can be evaluated by examining the reduction of the wire current and gain.

	COMET CDC		KLOE Drift Chamber	Belle II CDC
Gas mixture	**He/iC_4H_{10} (90/10)**	**He/C_2H_6 (50/50)**	He/iC_4H_{10} (90/10)	He/C_2H_6 (50/50)
Accumulated charge (max)	**20 mC/cm/wire**	**20 mC/cm/wire**	3.1 mC/cm/wire	155 mC/cm/wire
Decrease of current and gain	**3.1% (gain)** (results of the first measurement)	**6.0% (gain)** (results of the first measurement)	≈0% (current) (KLOE note n.143, April 1995)	Less than 1% (gain) (Shoji Uno, Jan-20th, 2003 at at Super B-factory WS in Hawaii)



Left figure: Results of Belle II aging test

(Shoji Uno, Jan-20th, 2003 at Super B-factory WS in Hawaii)

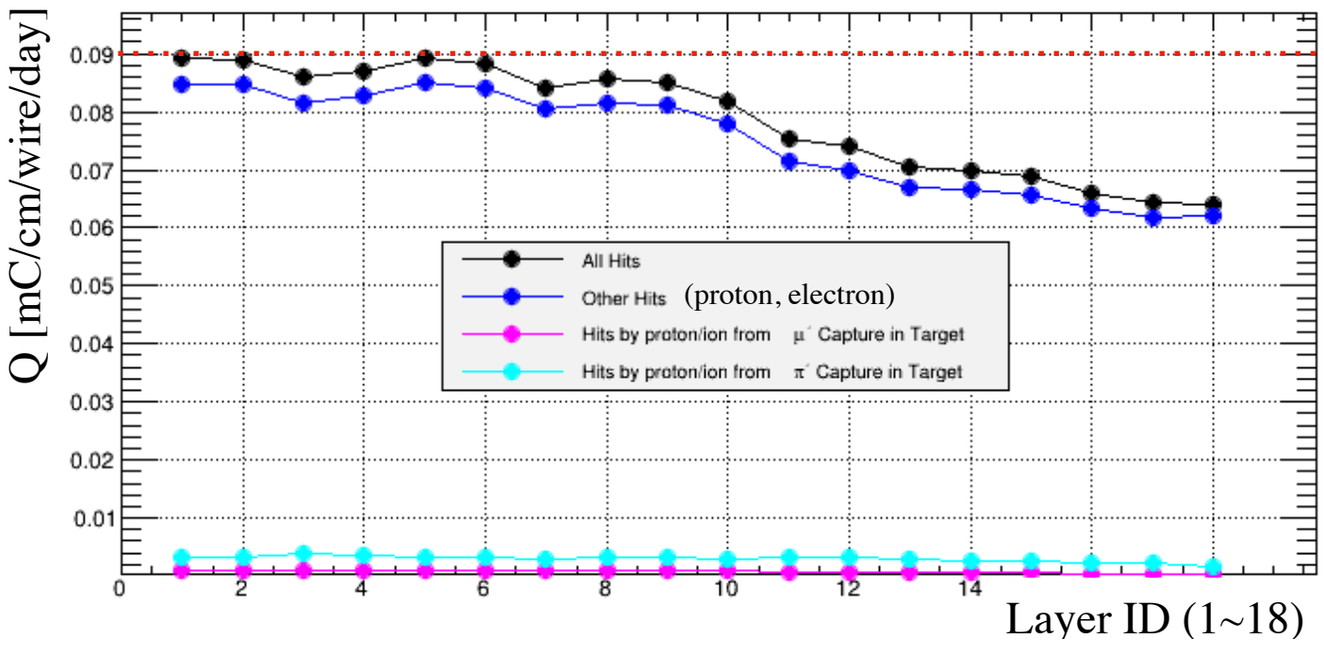
a: '93 Plastic tube
b: '93 Plastic tube + O2 filter
c: '94 Plastic tube
d: '94 SUS tube
e: '94 SUS tube + O_2 filter
f: '94 Plastic tube

Belle group concluded the major cause of aging effect is "out gas".

Less gain drop was observed when using chambers which passed a year after making it.

Accumulated charge of COMET CDC

The amount of radiation irradiated on the CDC wires are evaluated by the accumulated charge of the current flowing the wire.



Accumulated speed of each layer (ref. COMET TDR)

Accumulated value of CDC simulated by Geant4 (COMET TDR)

less than 20 mC/cm/wire during 200 days running period

Minimum target value: **20 mC/cm/wire**

Required value for gain reduction: **within 10%**

Correctable by software if it is within the required value.

Result of the aging test $He/C_2H_6(50/50)$

Measurement condition

$He/C_2H_6(50/50)$ 40 mL/min

Wire aging conditions

Source: ^{90}**Sr**

HV (ch0~2): **2300 V**

HV (ch3): 1800 V

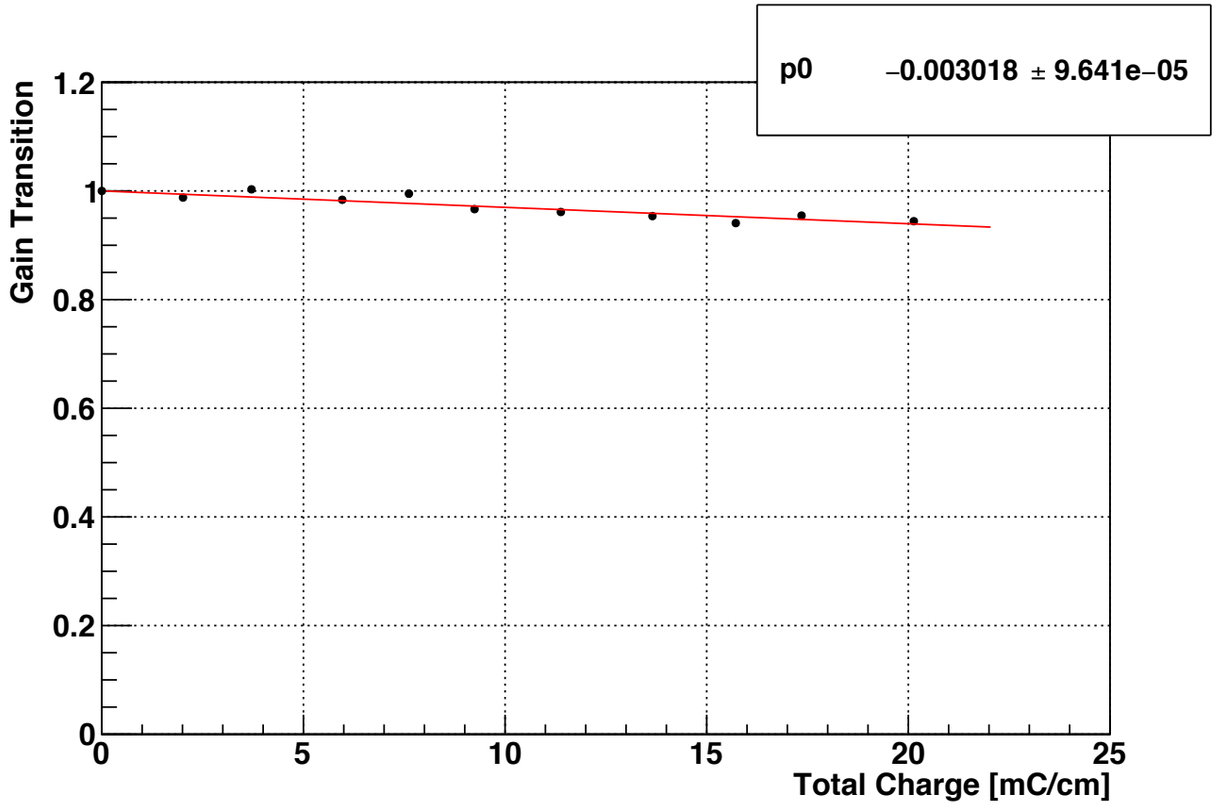
Gain measurement conditions

Source: ^{55}**Fe**

HV (ch0~2): **2120 V**

HV (ch3): 1800 V

Number of events: 10,000 event



Gain Transition (He/C_2H_6 (50/50))

- Gain decrease:
  About **6.0% at 20 mC/cm/wire**.
- Gain decrease rate:
  About **0.3% /mC/cm/wire**.

This is less than the required value of COMET (10%).

Gain decrease of the Belle's study: about 2% at 20 mC/cm/wire.

→ gain decrease rate is **worse** than Belle.

Because HV is higher than operation HV of Belle, and Anode wire diameter is smaller than Belle CDC?

Result of the aging test $He/iC_4H_{10}(90/10)$

Measurement condition

$He/iC_4H_{10}(90/10)$ 40 mL/min

Wire aging conditions

Source: ^{90}**Sr**

HV (ch0~2): **1850 V**

HV (ch3): 1700 V

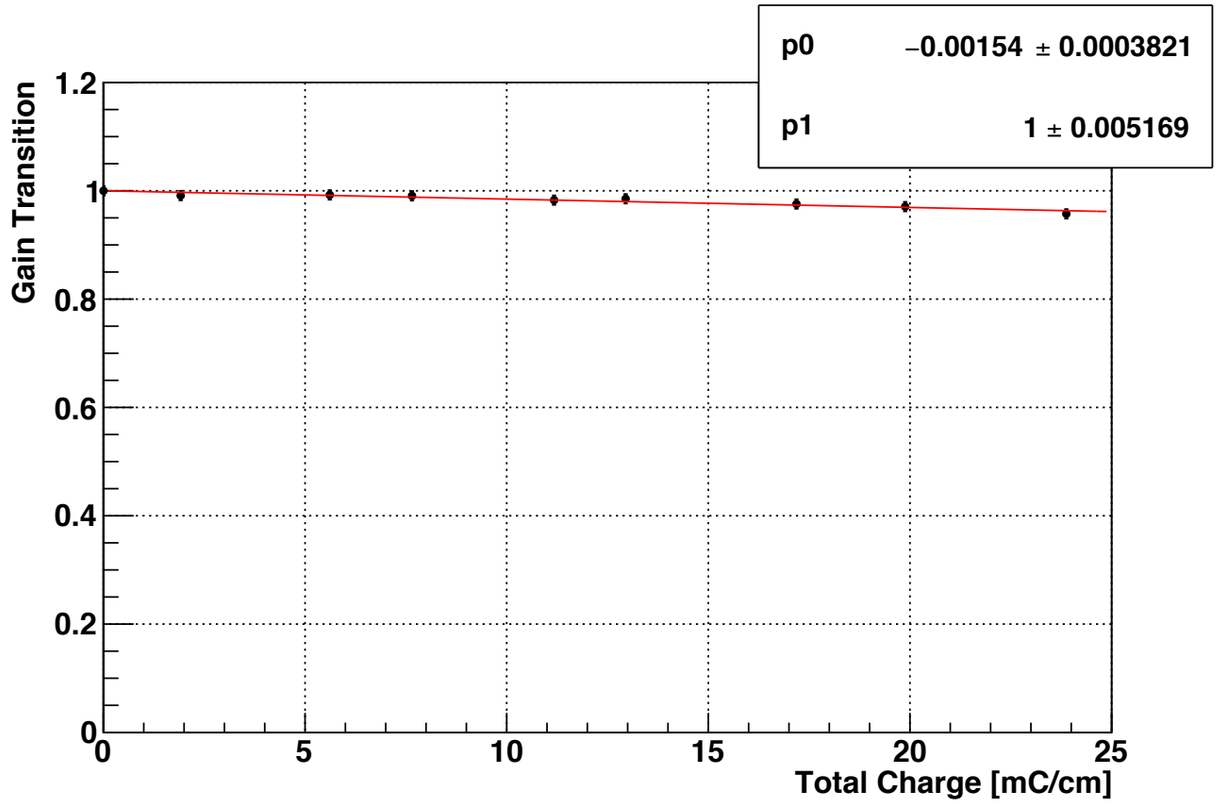
Gain measurement conditions

Source: ^{55}**Fe**

HV (ch0~2): **1750 V**

HV (ch3): 1700 V

Number of events: 10,000 event



Gain ration transition (He/iC_4H_{10} (90/10))

- Gain decrease:
  About **3.1% at 20 mC/cm/wire**.
- Gain decrease rate:
  About **0.15% /mC/cm/wire**.

- Gain decrease is better than the result of He/C_2H_6 aging test.
- I strung all wires again and second aging test is ongoing.