Development of the micro pixel chamber based on MEMS technology

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Outline

- Introduction

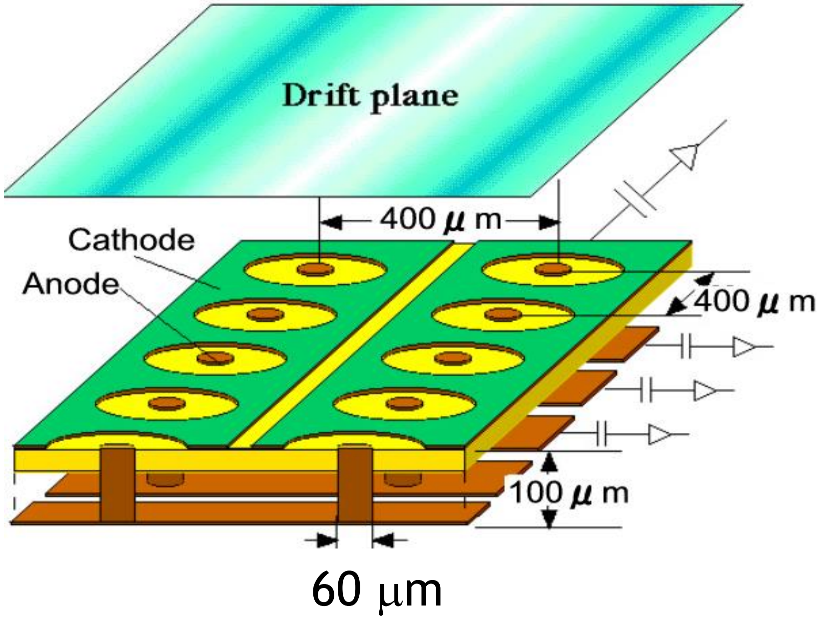
-Micro pixel chamber (μ-PIC) and its application

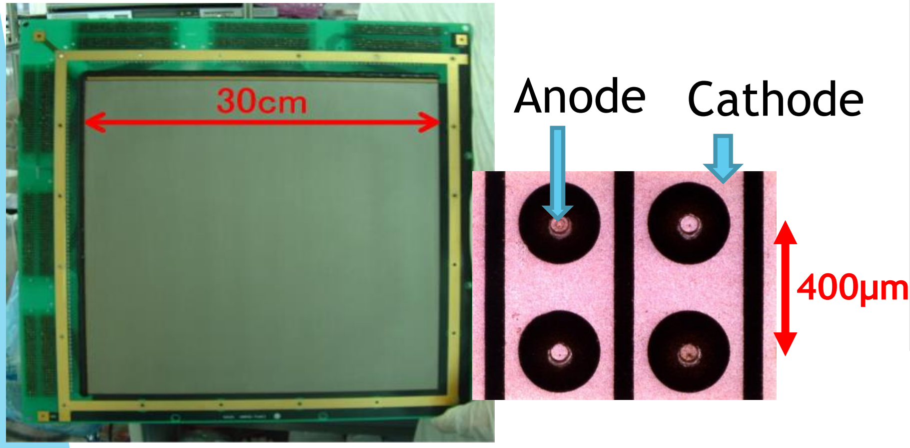
-Requirements for μ-PIC

- μ-PIC based on MEMS Technology
- Gain Simulation of MEMS μ-PIC with Garfield++
- Measured spectrum and gain of MEMS μ-PIC

- Summary

Micro pixel chamber (μ-PIC)





- A gaseous 2D imaging detector
  with strip read out
- Manufactured with PCB(Printed Circuit Board) technology
  Cu electrodes and polyimide substrate
- Each pixel is place with
  a pitch of 400 μm
- Gas gain: Max ~ 15,000
  stable operation ~ 6,000
- Fine position resolution(RMS ~ 120 μm)
- Large detection area:
  10 x 10 cm^2, 30 x 30 cm^2
- Time of operation:
  \> 2 years (30 x 30 cm^2)

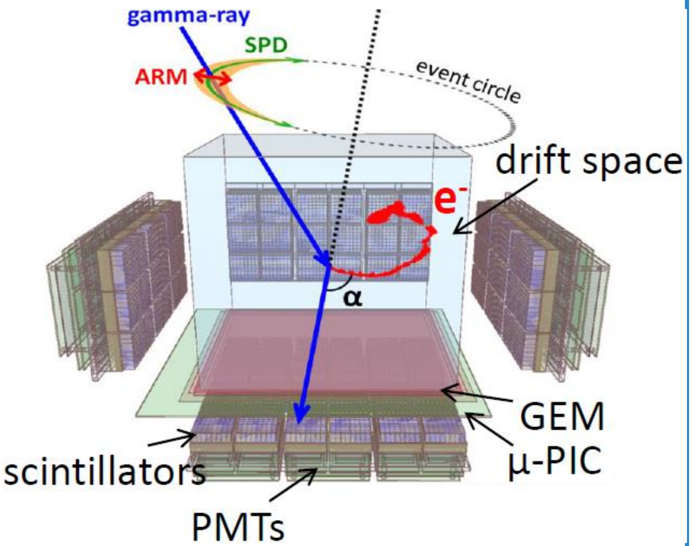
T. Nagayoshi+ (NIMA, 2003)

μ-PIC Application

Application for MeV

Gamma-Ray astronomy

ETCC (Electron-Tracking Compton Camera)

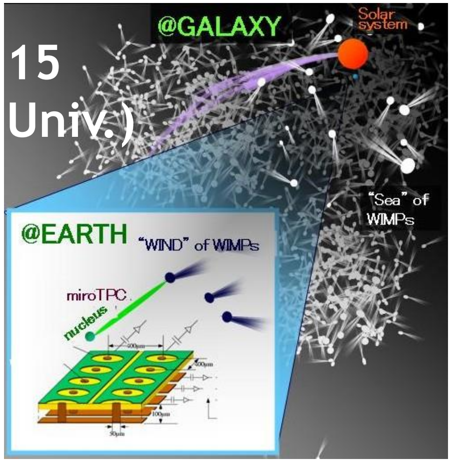


T. Tanimori+

(Astrophysical Journal 2015)

Application for Dark Matter Search

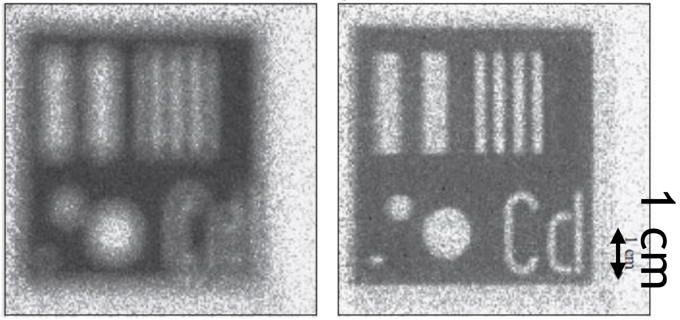
talk id[108] Thursday 15
10:25~ Mr. IKEDA (Kobe Univ.)



K. Nakamura+

(PTEP 2015)

Application for neutron imaging



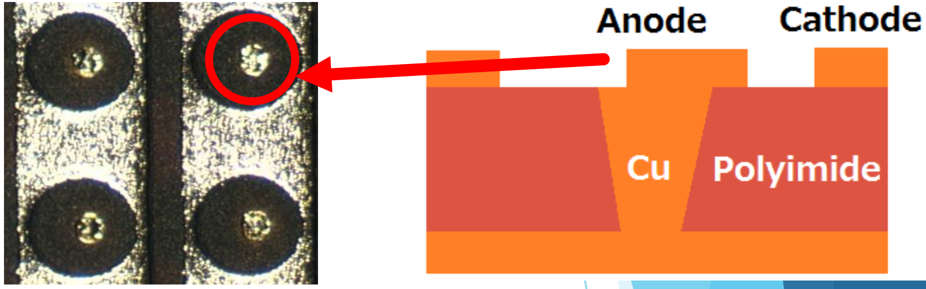
J.D. Parker+ (NIMA 2013)

Using μ-PIC as TPC

Requirements of μ-PIC for TPC

- ① Higher gas gain
- ② Suppression of discharge
- ③ Precise 3D tracking

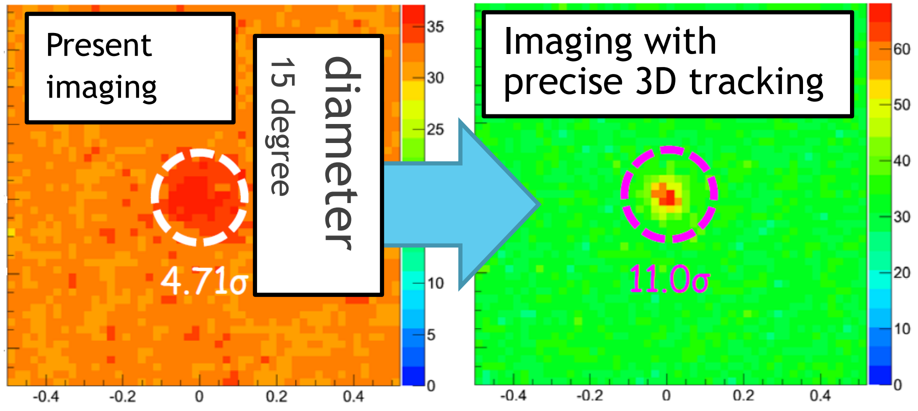
A gap of anode cap makes discharge easily



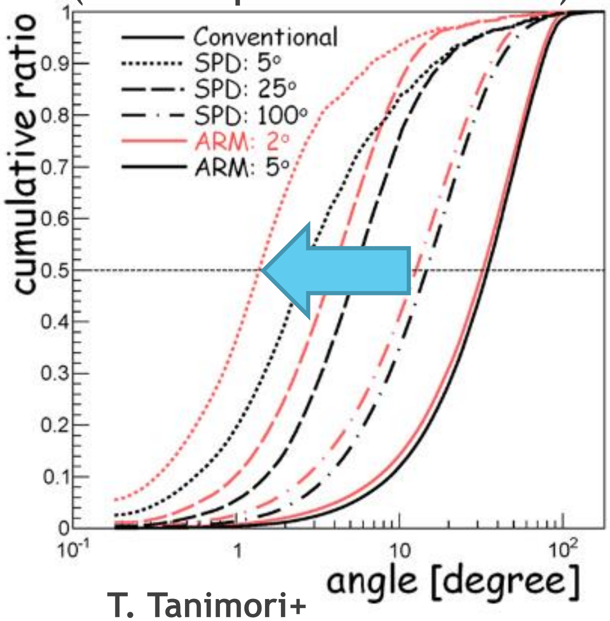
For Gamma-ray imaging

The precision 3-D tracking is essential to determine the Point Spread Function for gamma ray

S : N = $10^3 : 10^6$ (simulation)



Cumulative ratio in PSF (Point Spread Function)



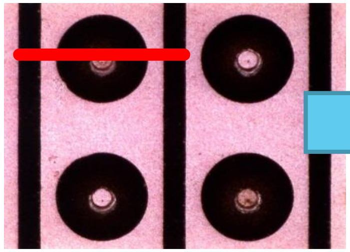
T. Tanimori+

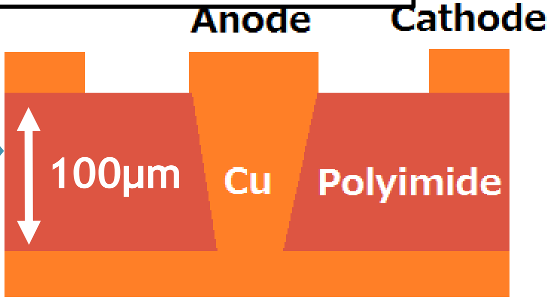
(Astrophysical Journal, 2015)

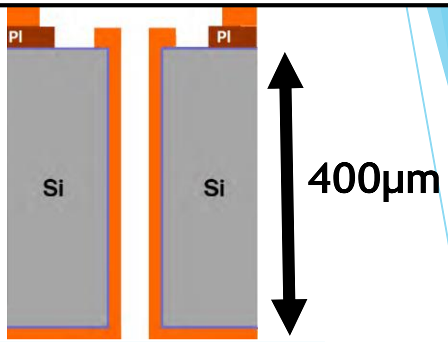
PCB Technology & MEMS Technology

μ-PIC based on PCB technology

μ-PIC based on MEMS (Micro-Electro-Mechanical Systems) technology







	PCB μ-PIC	MEMS μ-PIC
Substrate (dielectric constant)	Polyimide (PI: 3.2)	Silicon (+ thin SiO_2) (Si: 11, SiO_2: 4.5)
Aspect ratio of anode (height/diameter)	~ 2 (100 μm/60 μm)	~ 8 (400 μm/50 μm)
Processing accuracy	~ 10 μm	~ several μm
Pitch length	> 400 μm	> 200 μm
Cost		~ PCB (if 10 x 10 cm^2)

Higher gas gain

Suppression of discharge & Uniformity

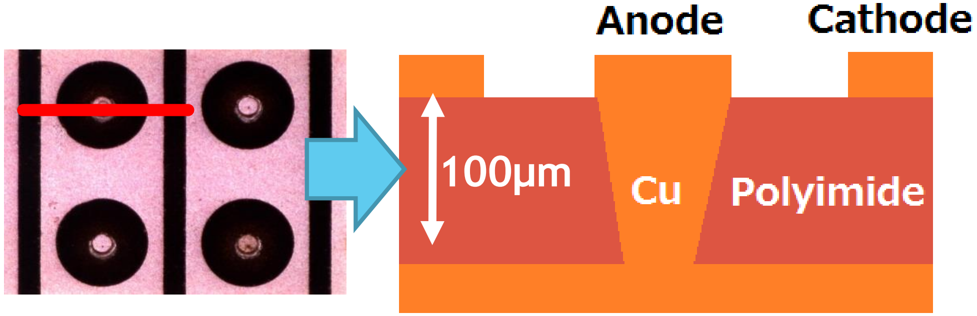
Precise 3D tracking

We studied MEMS -PIC with ever the same pitch

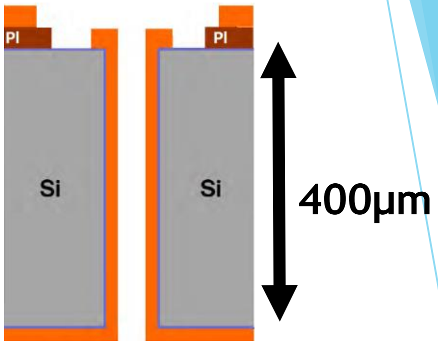
to focus on only the difference between PCB and MEMS

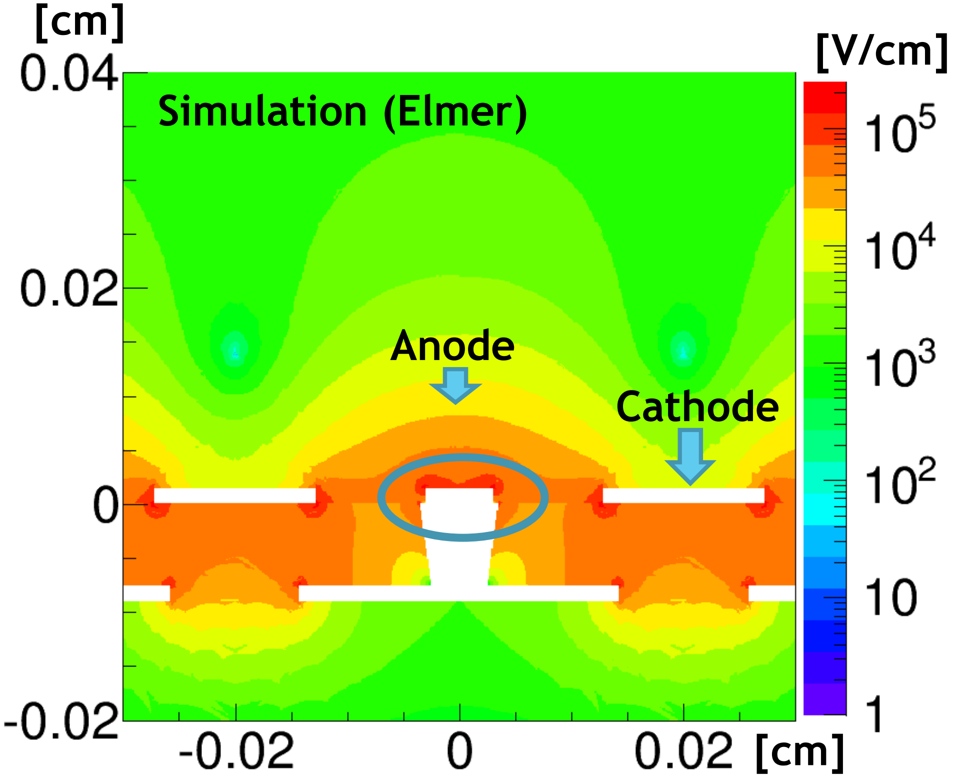
Electric Field

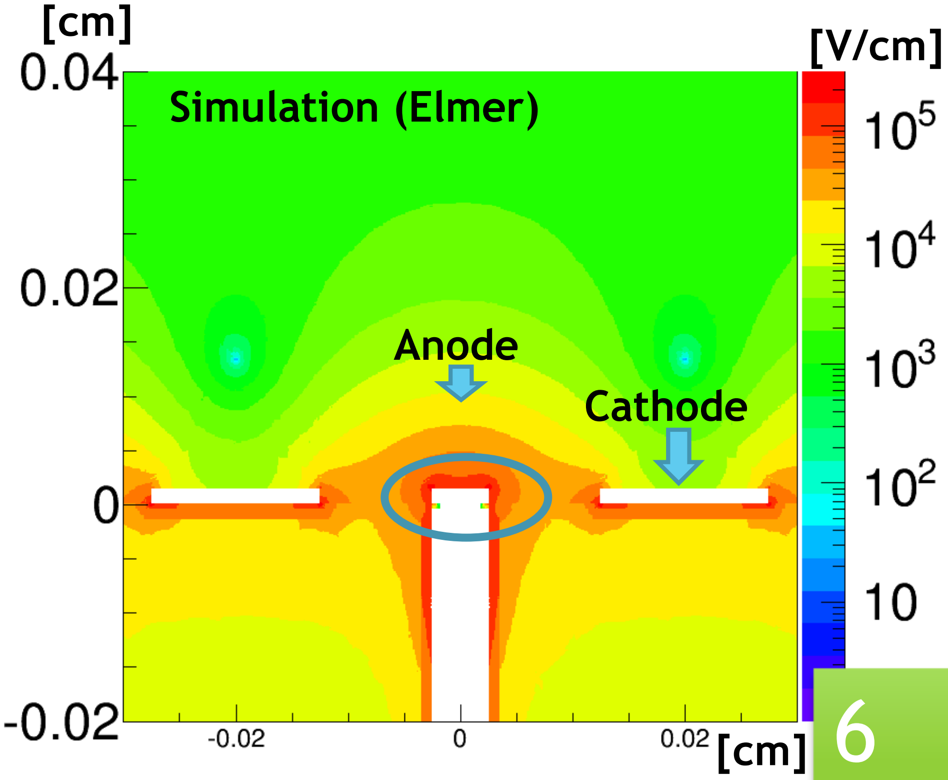
PCB



MEMS

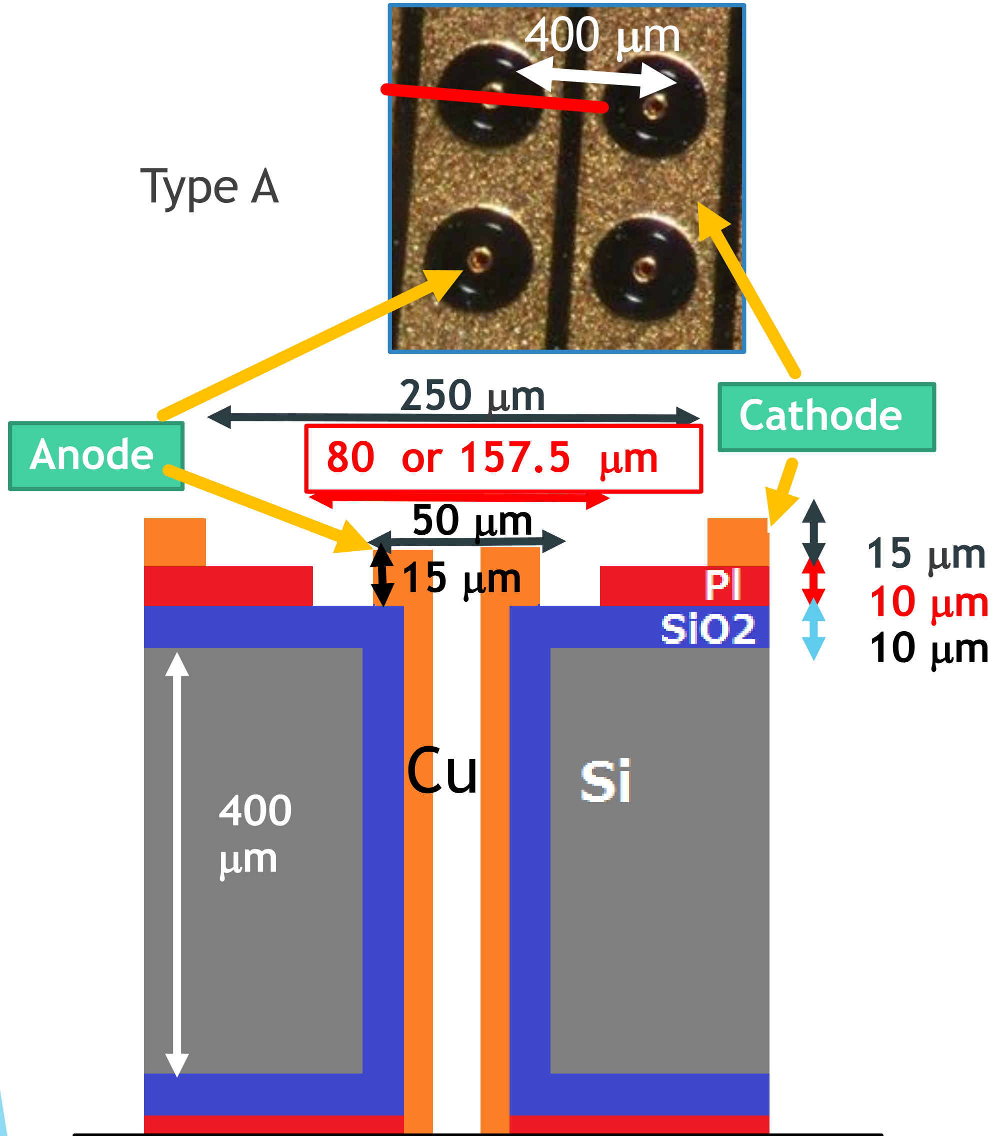




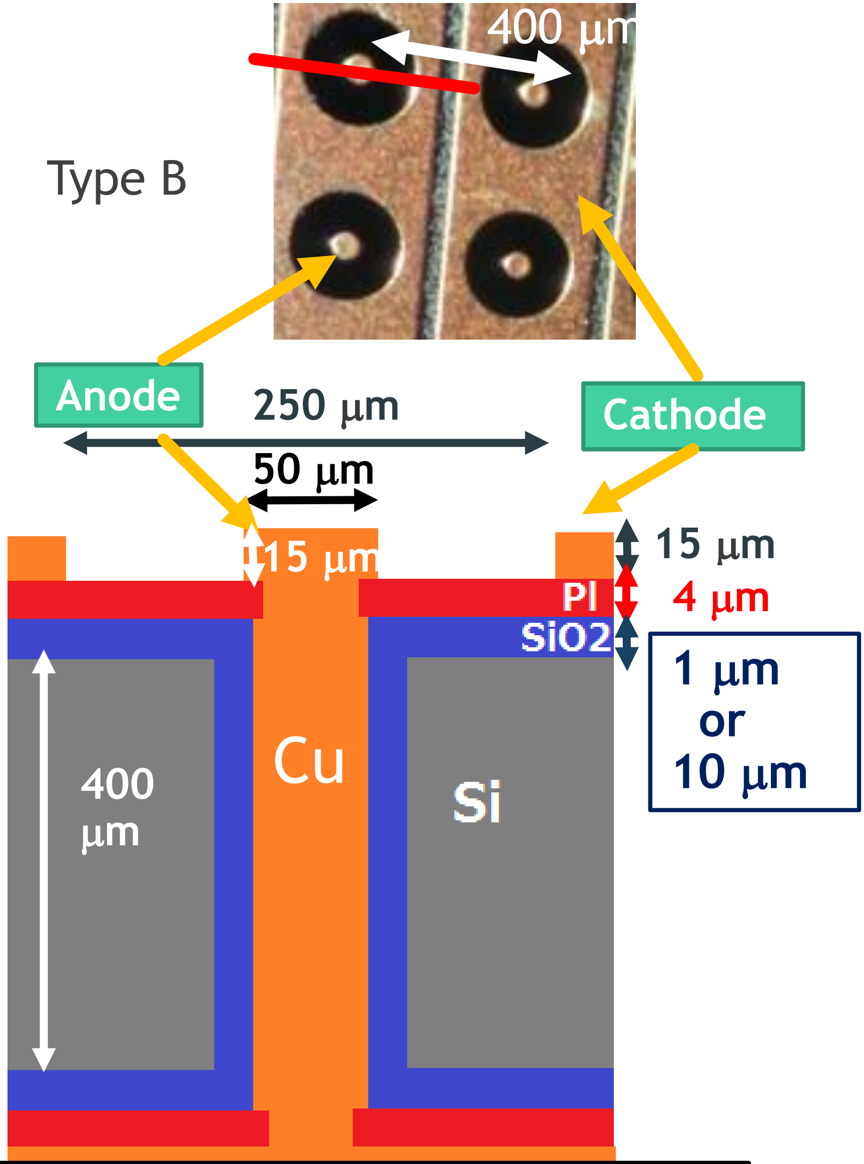


Simulation

MEMS μ-PIC structures and types

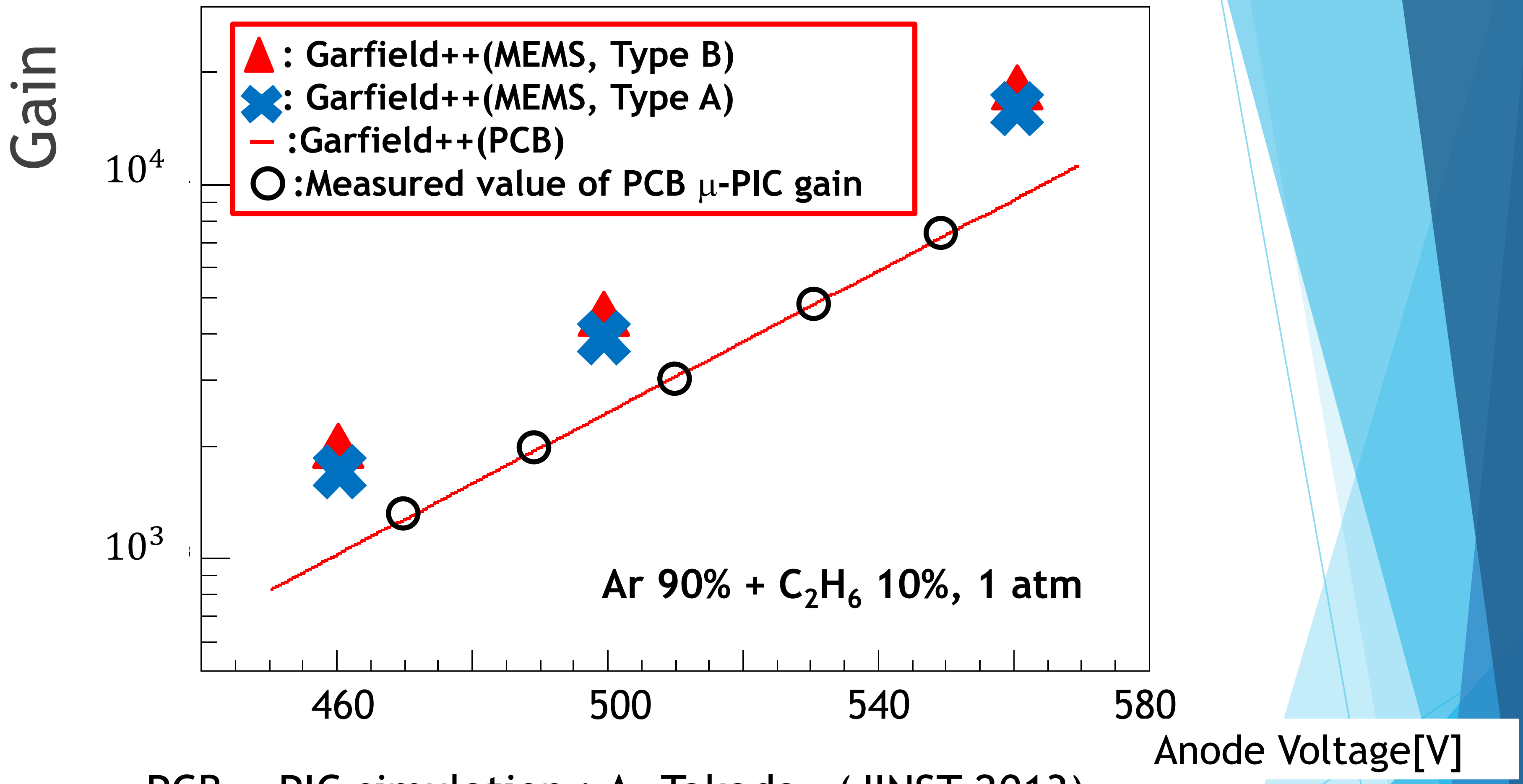


The structure is manufactured by basic MEMS technology (through-hole technology)



The Structure is similar to that of present μ-PIC

Gas Gain of MEMS μ-PIC in Simulation



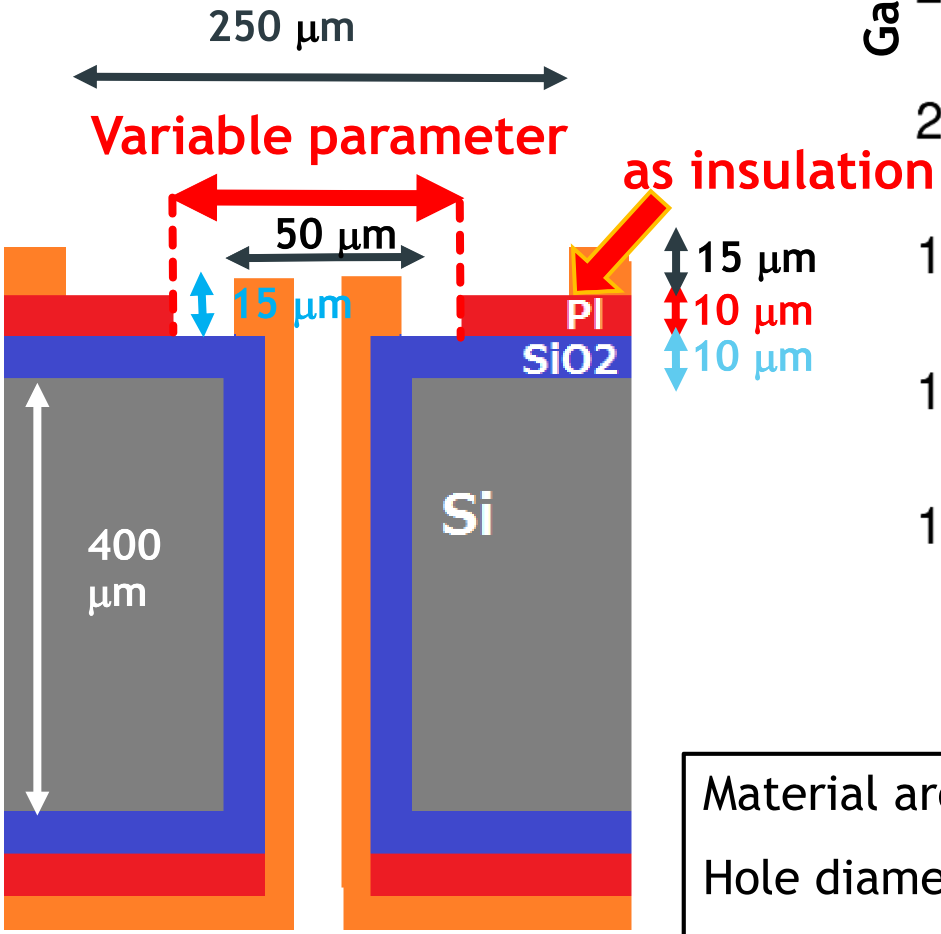
PCB μ-PIC simulation : A. Takada+ (JINST 2013)

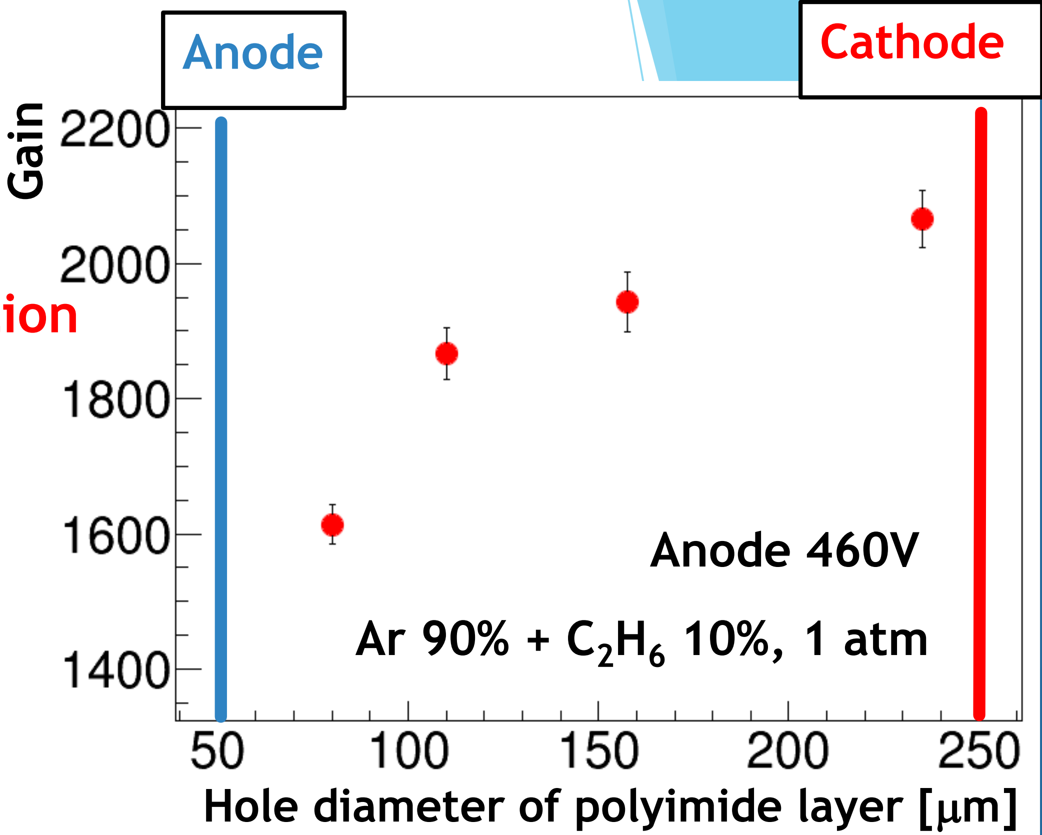
Simulation suggests

① the gain of MEMS μ-PIC is 2 times higher than that of PCB μ-PIC

② the gains of two types MEMS μ-PIC are same

Dependence on polyimide layer of gain (MEMS μ-PIC type A)





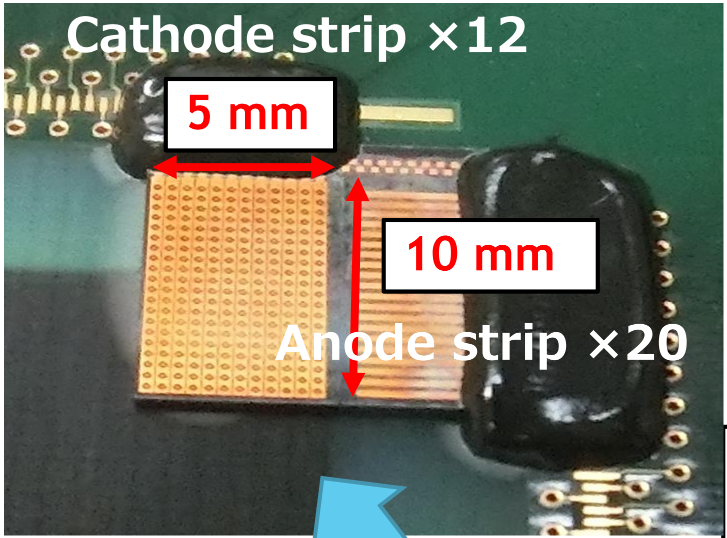
Material around anode disturb electric field

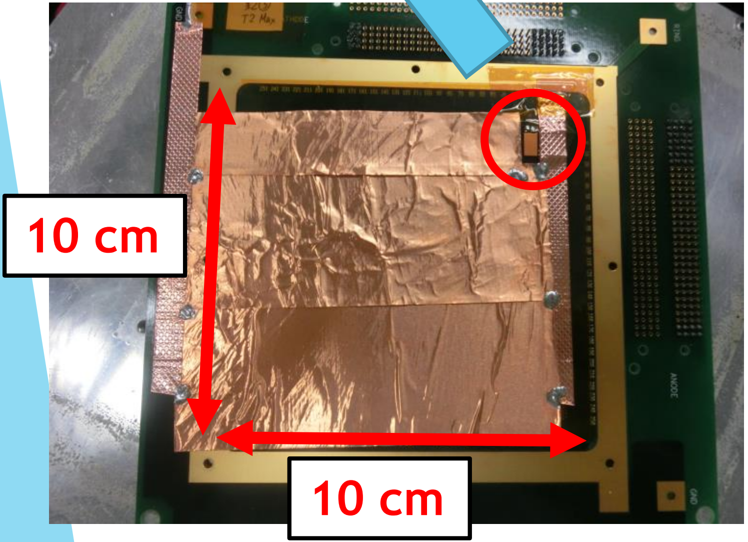
Hole diameter of polyimide should be large

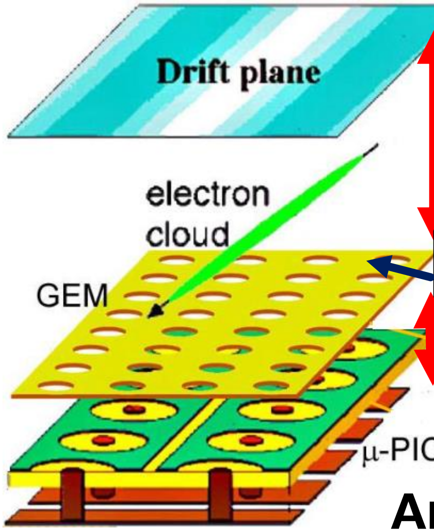
Measurement

Setup of Experiment MEMS μ-PIC

MEMS μ-PIC







Drift Voltage 250[V/cm]

Drift Space ~3mm

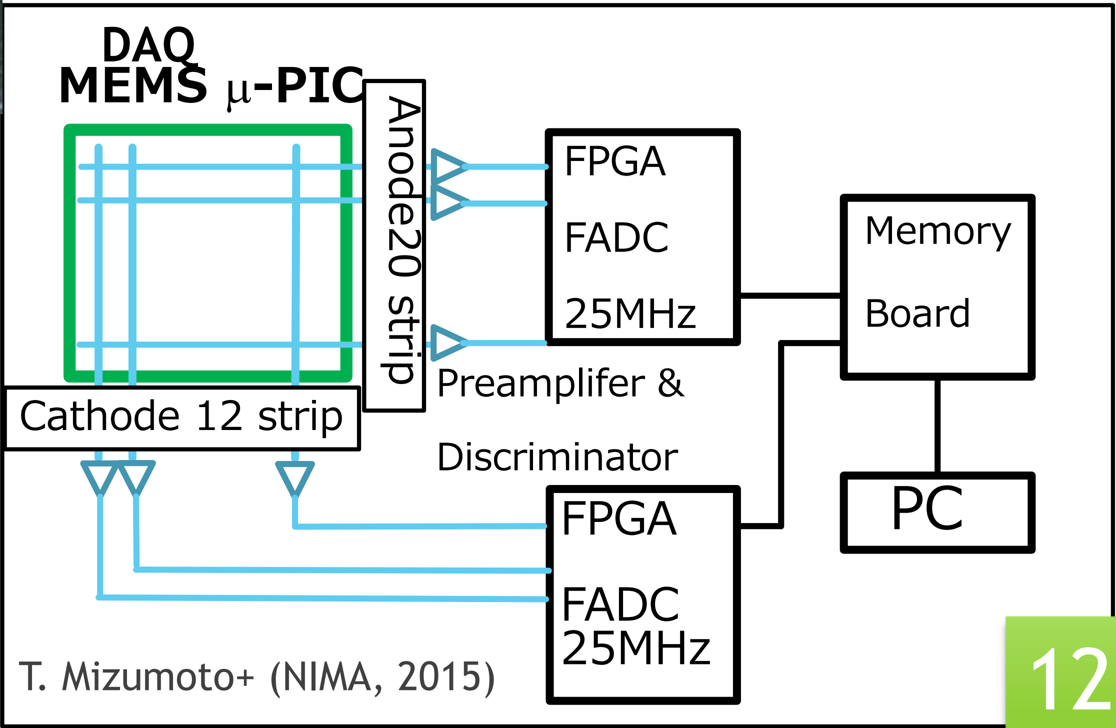
ΔGEM 300V(Gain ~ 20)

Induction field

1[kV/cm] ~3mm

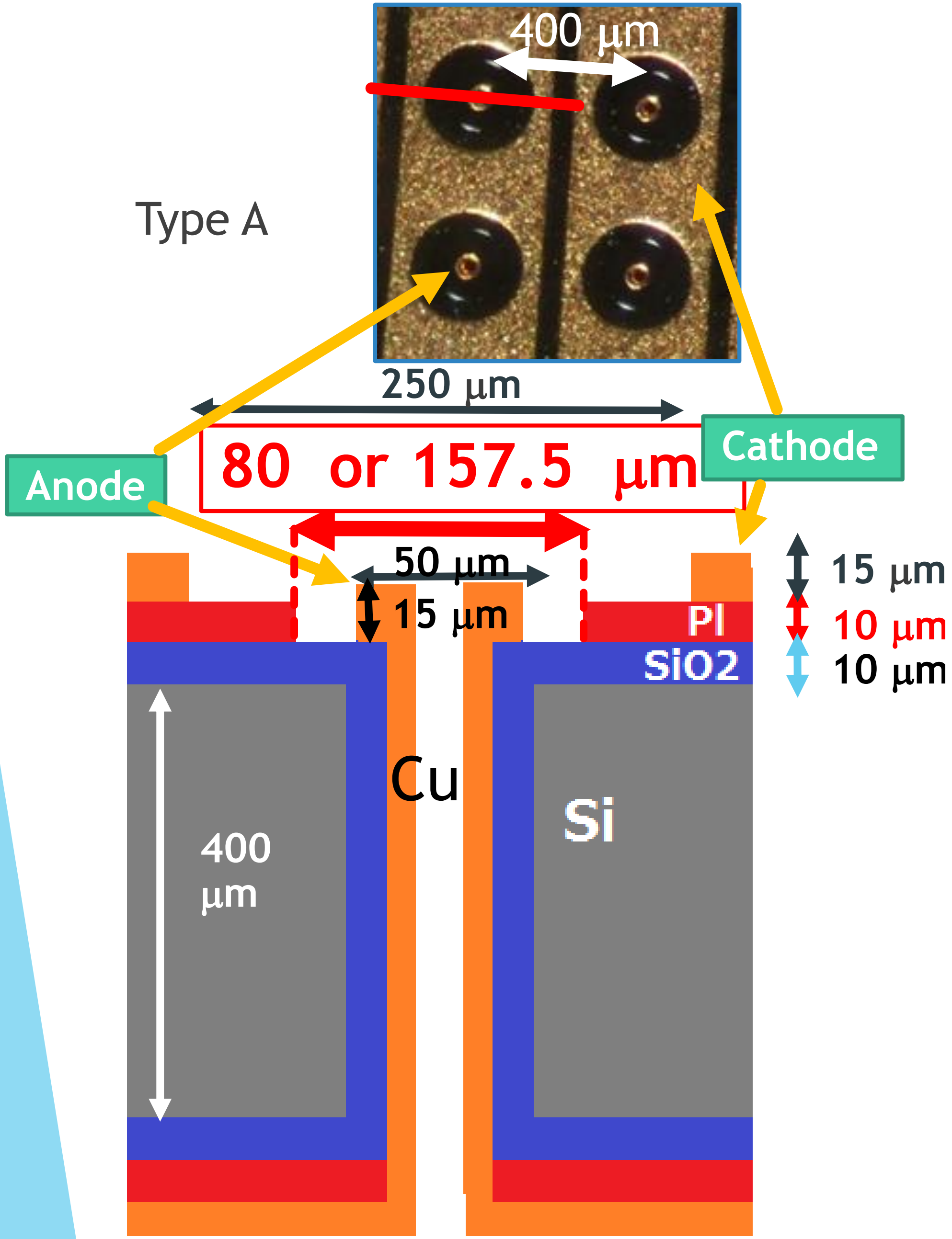
Ar:90%,C_2H_6:10%,1atm

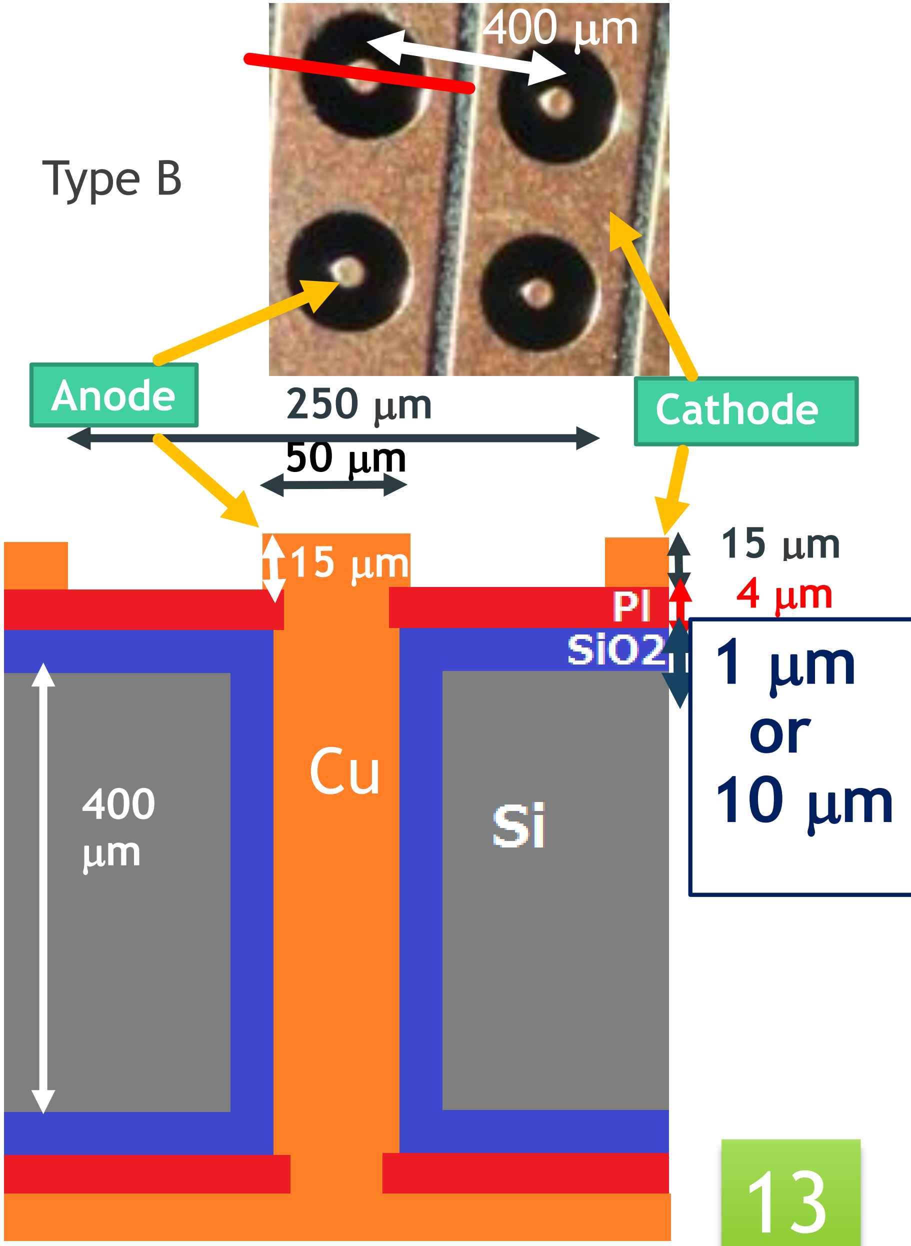
DAQ



T. Mizumoto+ (NIMA, 2015)

MEMS μ-PIC structure and types





Discharging Voltage

Type	Discharging Voltage [V] Ar90% $C_2H_6$10%, 1 atm	Gain
PCB	~550	~10,000
Type A (Anode Hole; Pl 157.5 μm)	570	~8,000
Type A(Anode Hole; Pl 80 μm)	590	~10,000
Type B(like PCB; SiO_2 10 μm)	570	~10,000
Type B(like PCB; SiO_2 1 μm)	530	~1,700

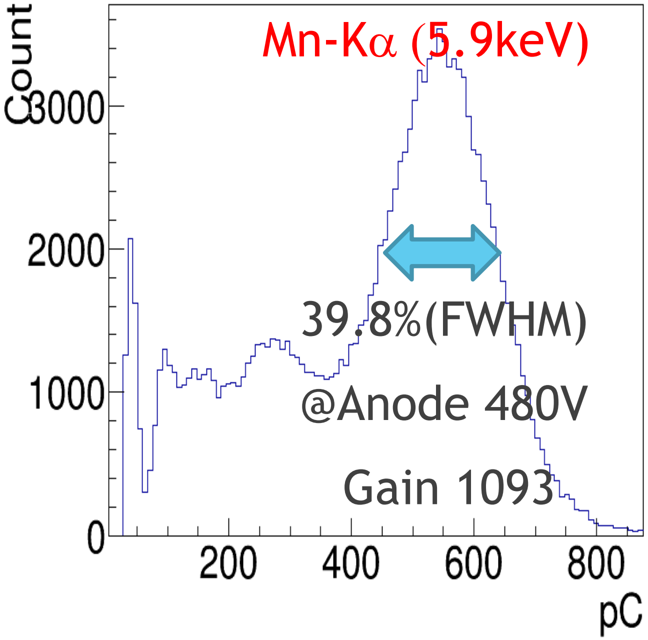
It took a long time that current of SiO2 1 μm MEMS u-PIC settle down

(SiO_2 1 μm: >20nA ~4h)

(Other u-PICs: >20 nA ~1 min)

PCB and MEMS μ-PIC spectra

PCB



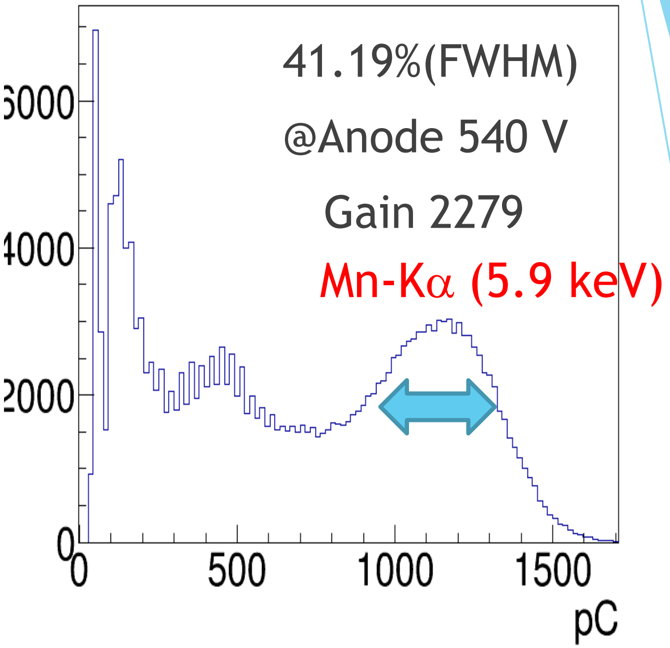
Mn-Kα (5.9keV)

39.8%(FWHM)

@Anode 480V

Gain 1093

MEMS (Type A)



41.19%(FWHM)

@Anode 540 V

Gain 2279

Mn-Kα (5.9 keV)

For the first time, we succeed in test operation of MEMS μ-PIC

GAS Ar90% $C_2H_6$10%, 1 atm

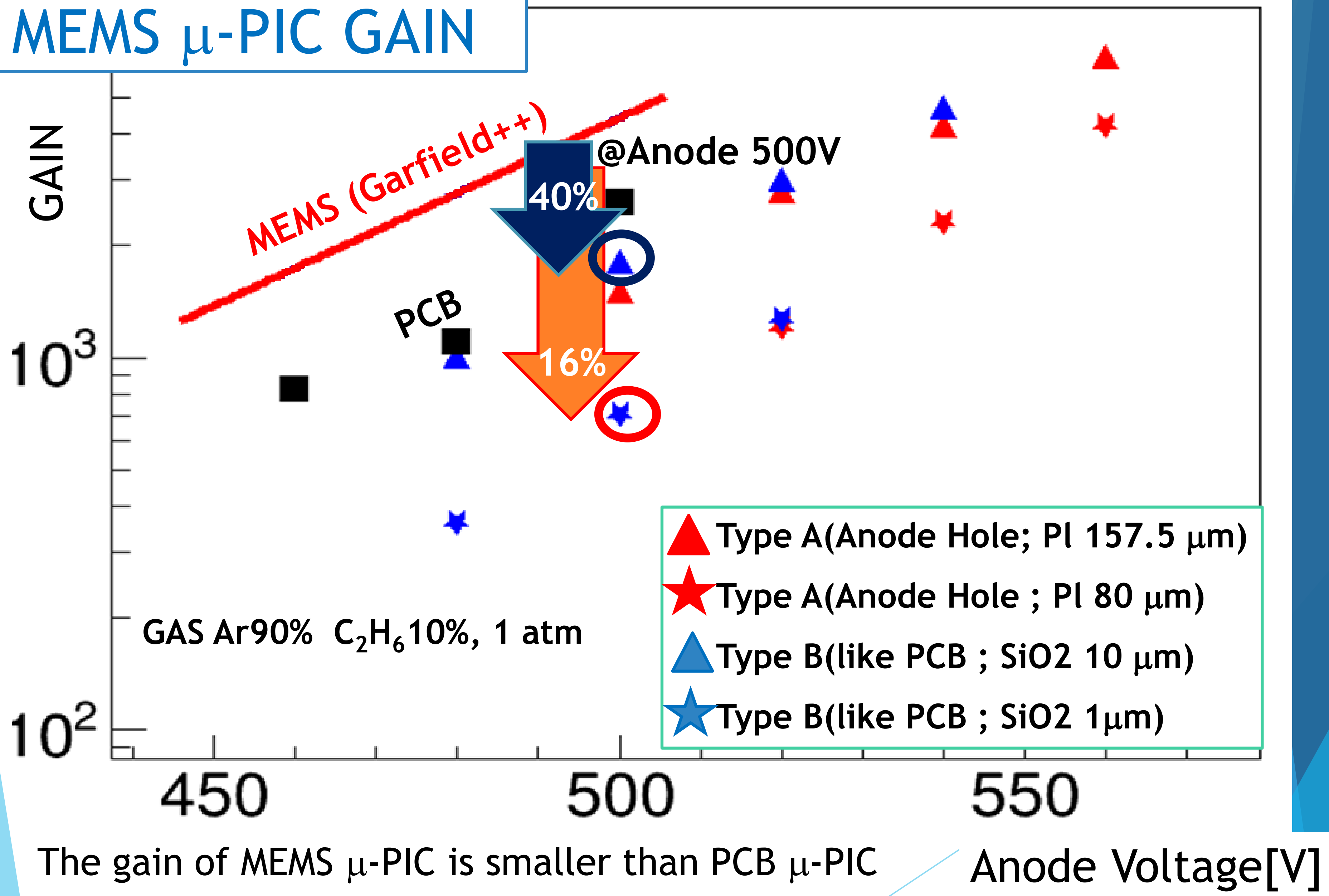
X-ray source Fe-55

Bad Energy resolution

probably due to much small detection area(10 mm x 5mm)

→ A lot of electrons escape from detection area

MEMS μ-PIC GAIN



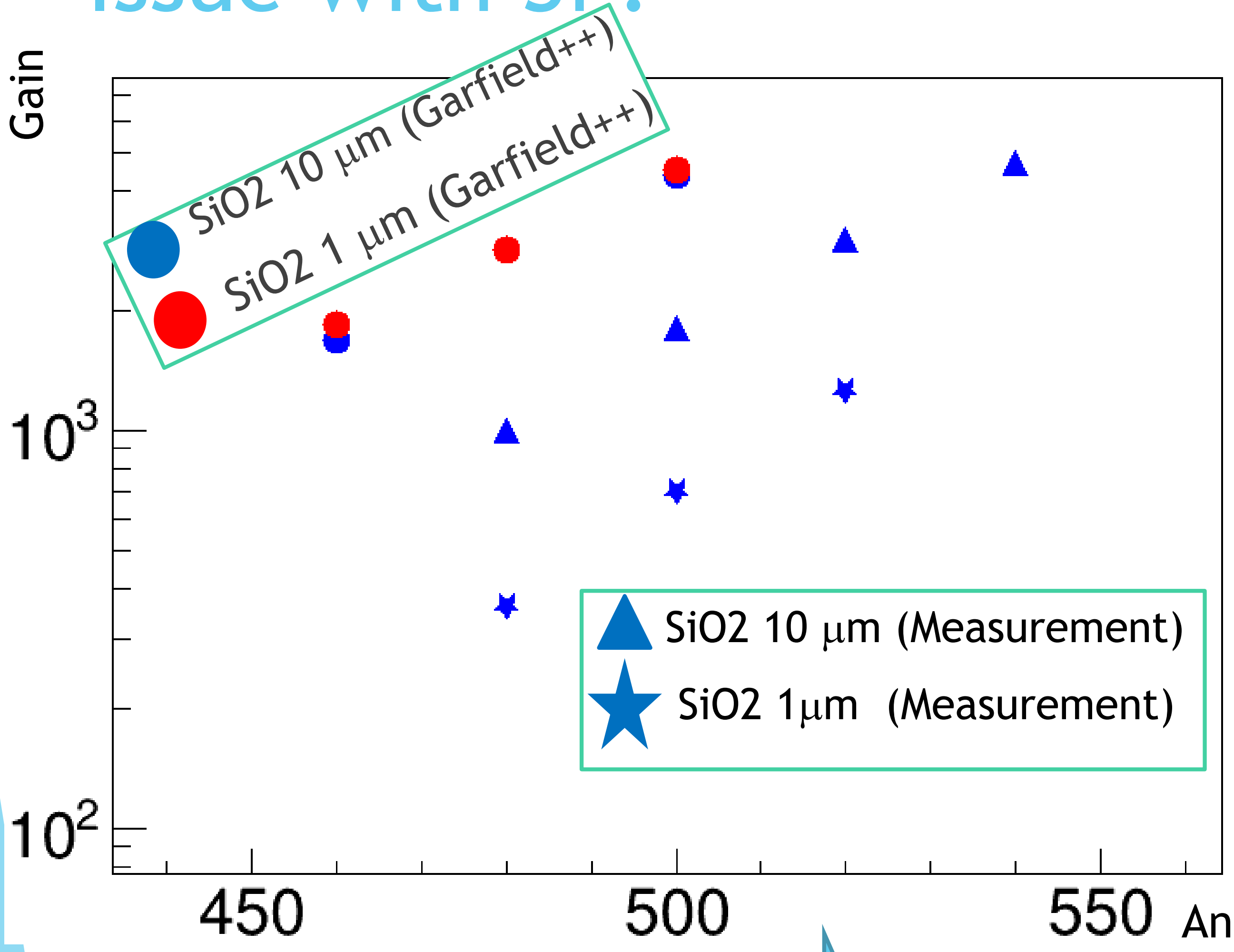
The gain of MEMS μ-PIC is smaller than PCB μ-PIC

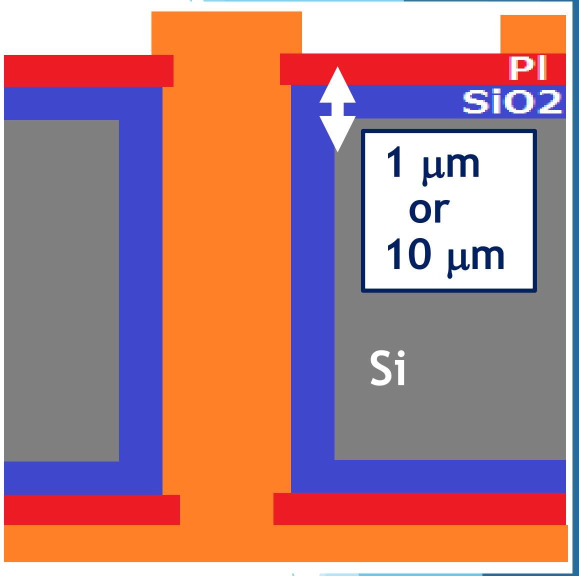
This results is inconsistent with Garfield++ simulation

]

Issue with Si ?

MEMS Type B





By the experiment,

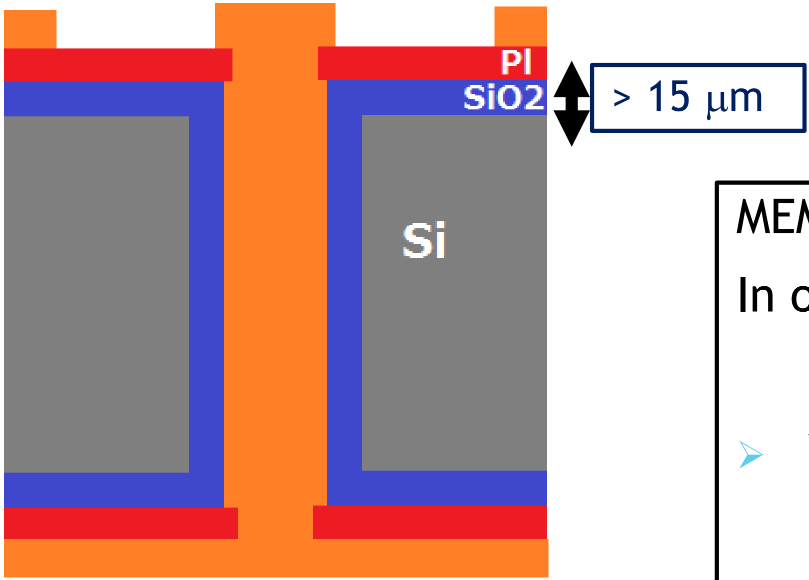
MEMS μ-PIC with SiO_2 1 μm has a much lower gain than MEMS μ-PIC with SiO_2 10 μm

Assumption

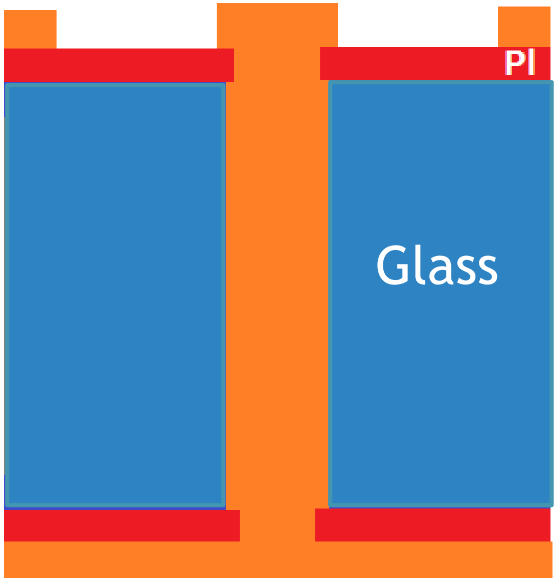
Deterioration of gain against simulation is caused by Si near anode working as semiconductor

Future prospect

Type B MEMS μ-PIC



MEMS μ-PIC with glass substrate



MEMS μ-PIC

In order to study the effect of

Si near anode

- Various thickness of SiO2 layer (≥ 15 μm)

  we'll experiment with MEMS μ-PIC

  with SiO_2 15 μm soon

- GALASS substrate

⇩

Both MEMS μ-PIC can be manufactured

Summary

- We expect MEMS technology improves gas gain, suppression of discharge and precise tracking capability of u-PIC
- Garfield++ simulation suggests that

  the gain of MEMS μ-PIC is twice higher than that of PCB μ-PIC
- For the first time, we succeed in test operation of MEMS μ-PIC
- Measured gain of MEMS μ-PIC is 16 % - 40% of simulation value

  (@ Anode 500 V, GAS: **Ar 90% + C_2H_6 10%, 1 atm**)
- We assume the deterioration is caused by Si working as semiconductor

  (We hope Garfield++ include semiconductor working)

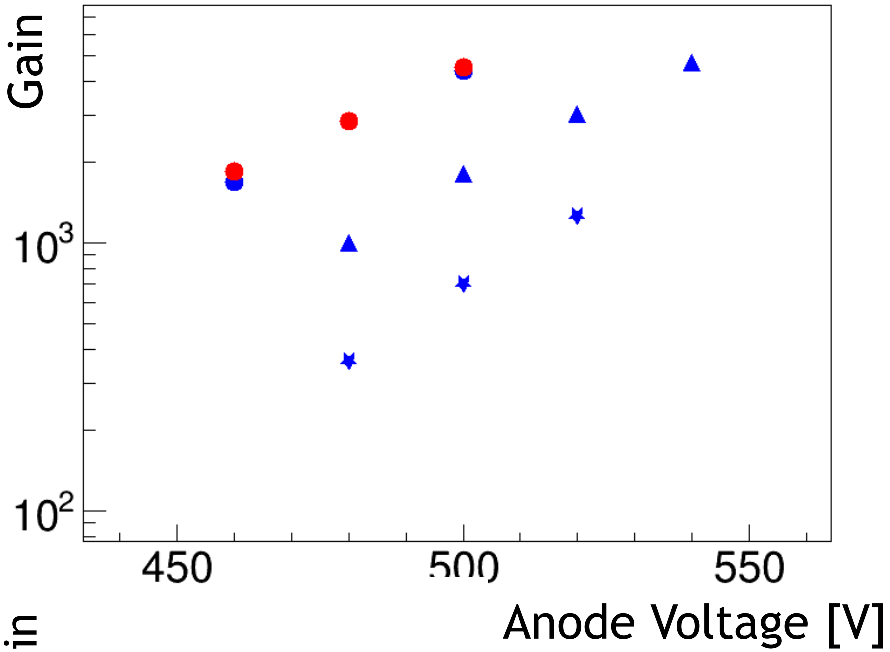
Future

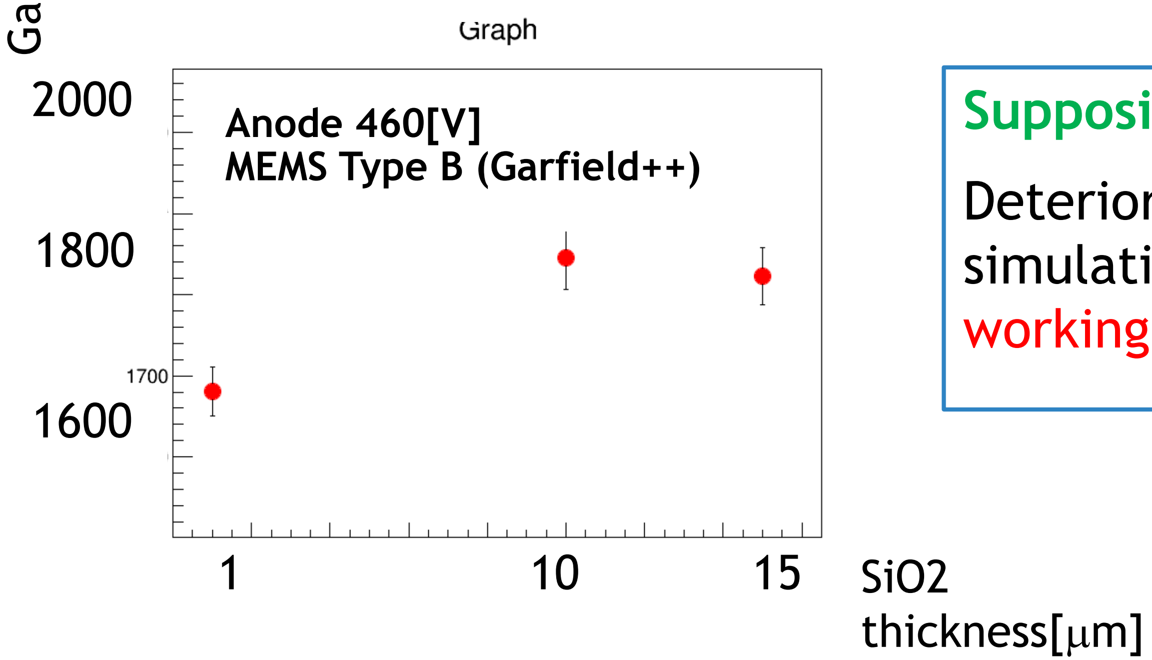
- We'll investigate relation SiO_2 thickness and gas gain,

  and we'll experiment with MEMS μ-PIC with SiO_2 15 μm soon
- We have started study of MEMS μ-PIC with short pitch in simulation

Supplemental Slides

Problem of Si ?





By the experiment,

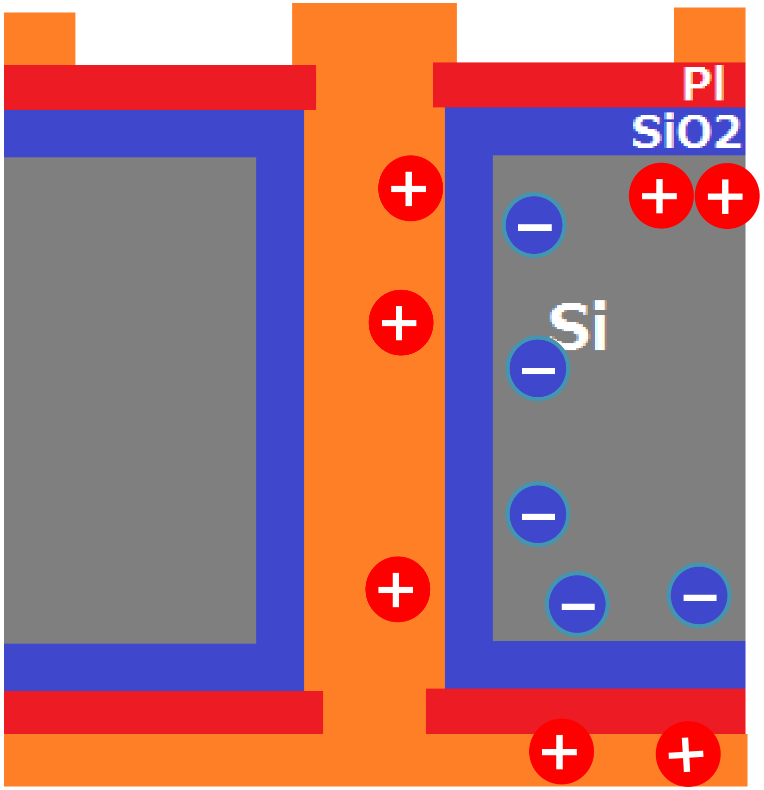
MEMS μ-PIC with SiO_2 1 μm has a much lower gain than MEMS μ-PIC with SiO_2 10 μm,

though gain of MEMS μ-PIC in simulation has no relation between gain and SiO_2 thickness

Supposition

Deterioration of gain against simulation is caused by Si near anode working as semiconductor

Si working as semiconductor

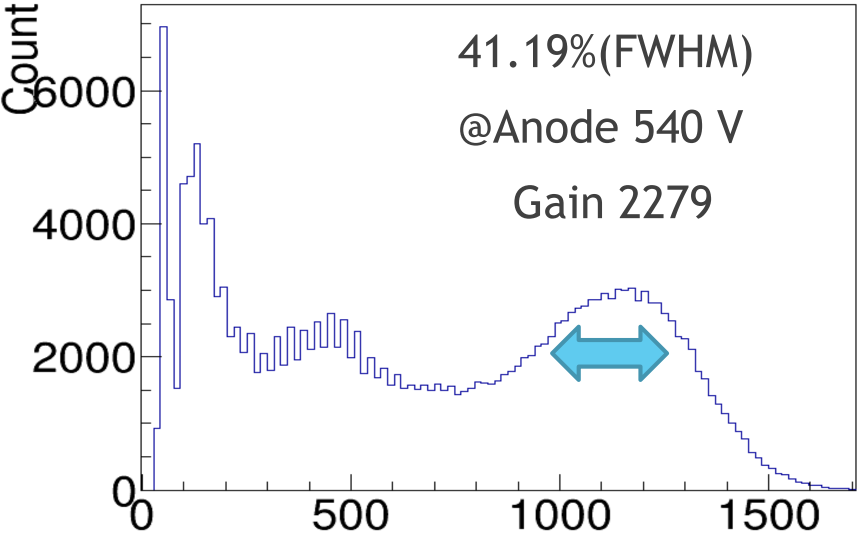


MEMS spectrum

GAS Ar90%.$C_2H_6$10%, 1 atm

X-ray source Fe-55

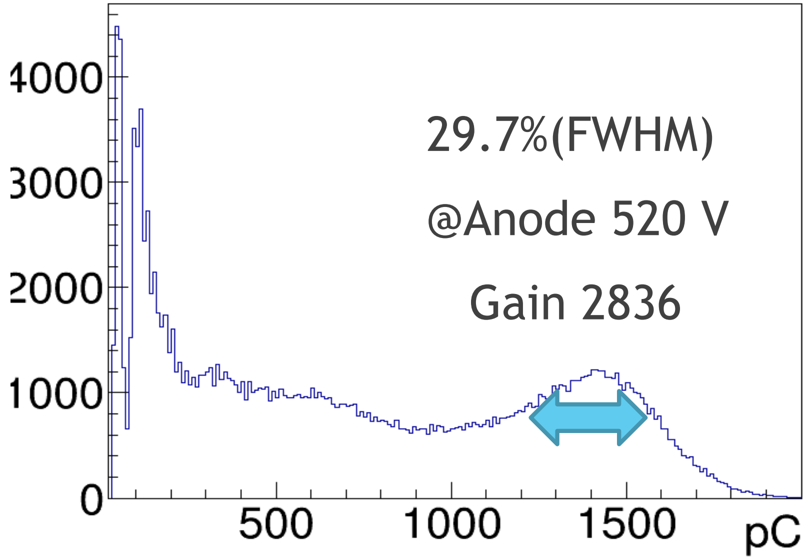
MEMS Type A (Pl 80 μm)


41.19%(FWHM)

@Anode 540 V

Gain 2279

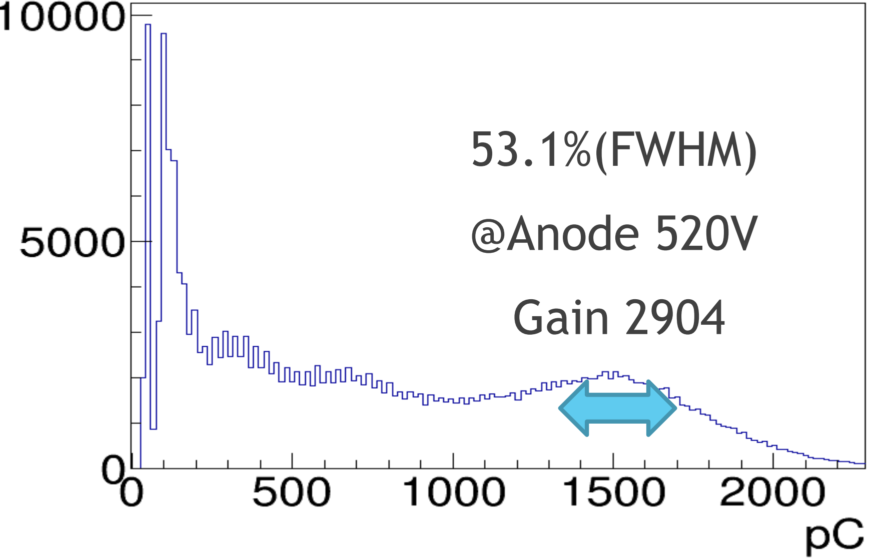
MEMS Type A (Pl 157.5 μm)


29.7%(FWHM)

@Anode 520 V

Gain 2836

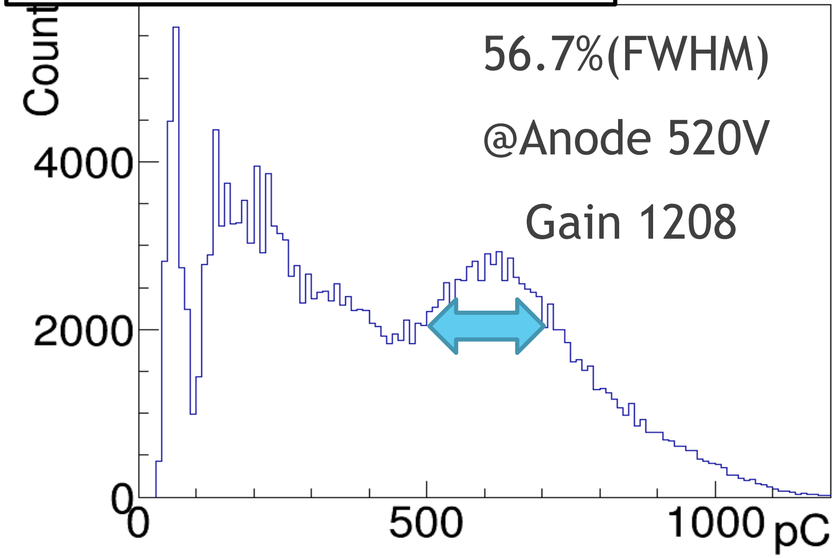
MEMS Type B (SiO_2 10 μm)


53.1%(FWHM)

@Anode 520V

Gain 2904

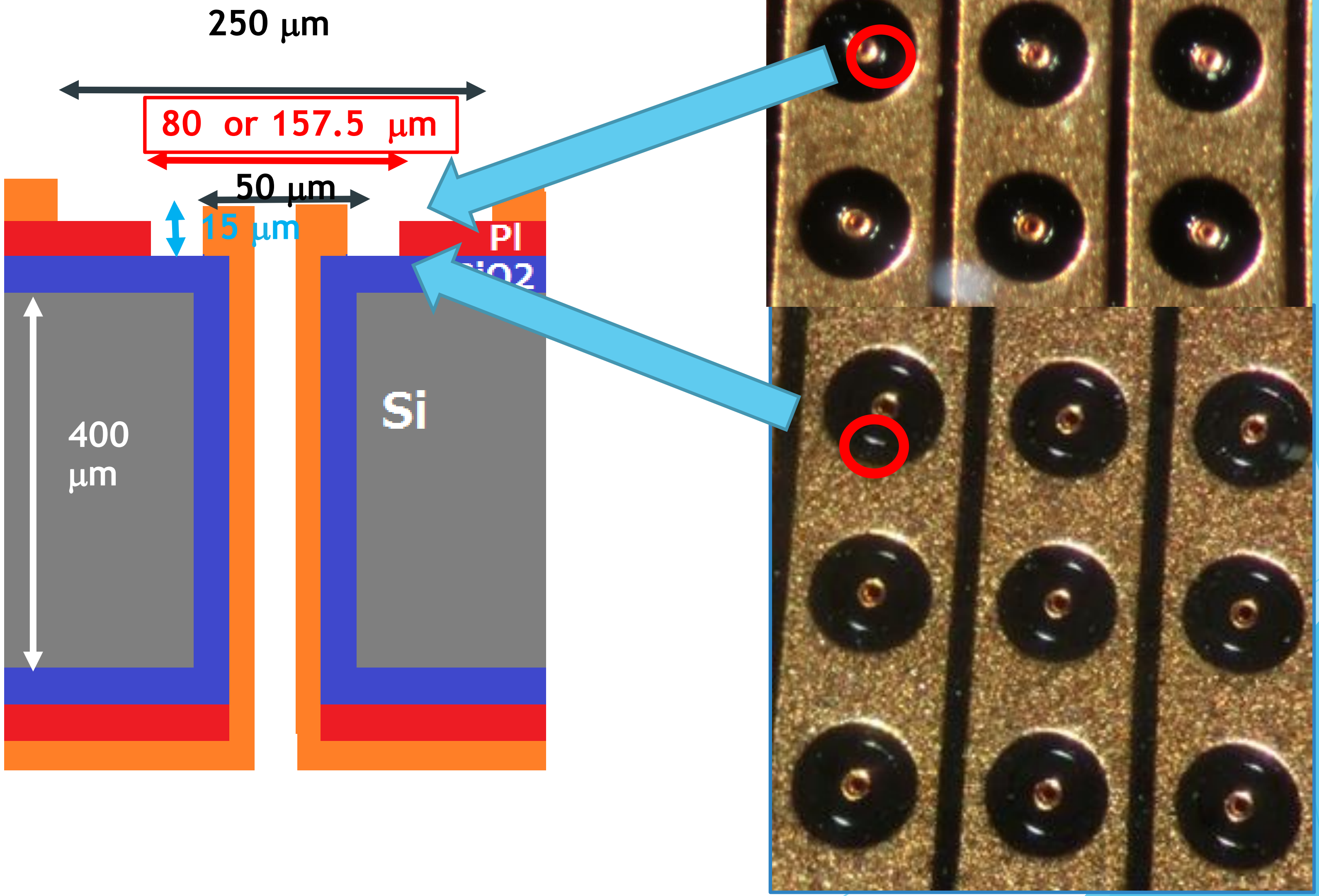
MEMS Type B (SiO2 1 μm)


56.7%(FWHM)

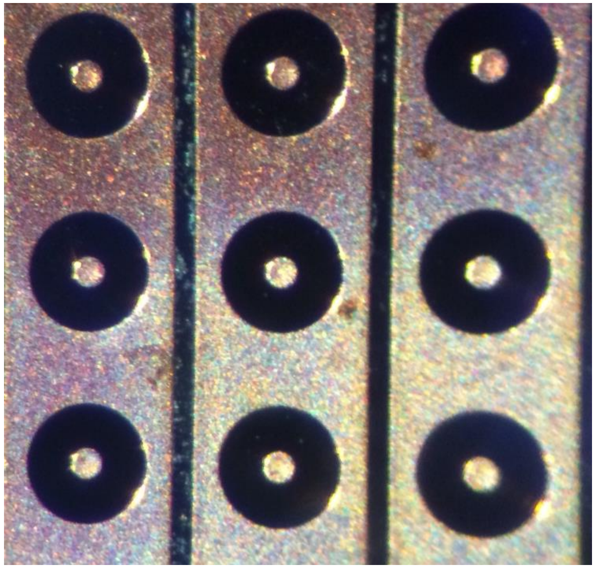
@Anode 520V

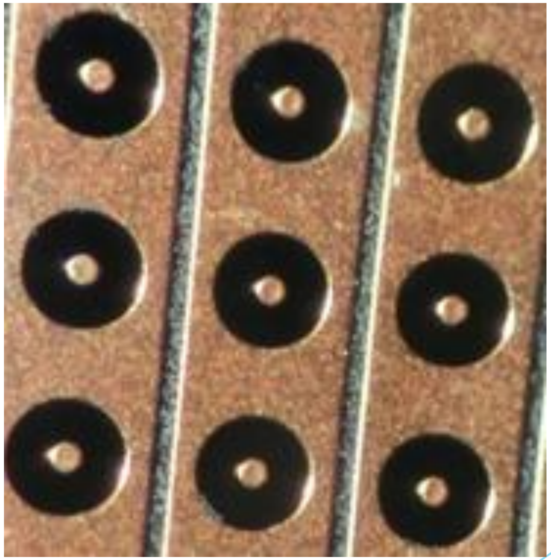
Gain 1208

Polyimide Edge

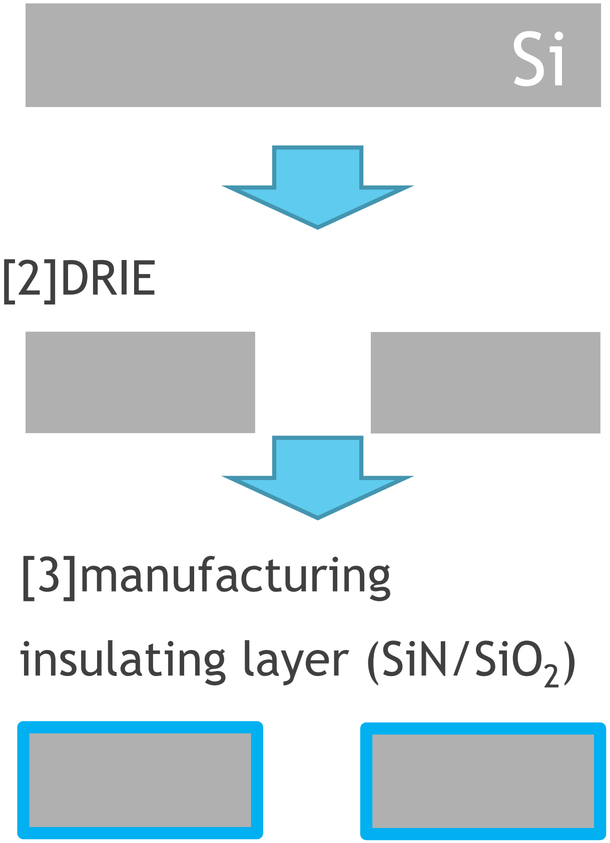


Type B u-PIC





Manufacturing process of MEMS μ-PIC [1]



[1]manufacturing alignment

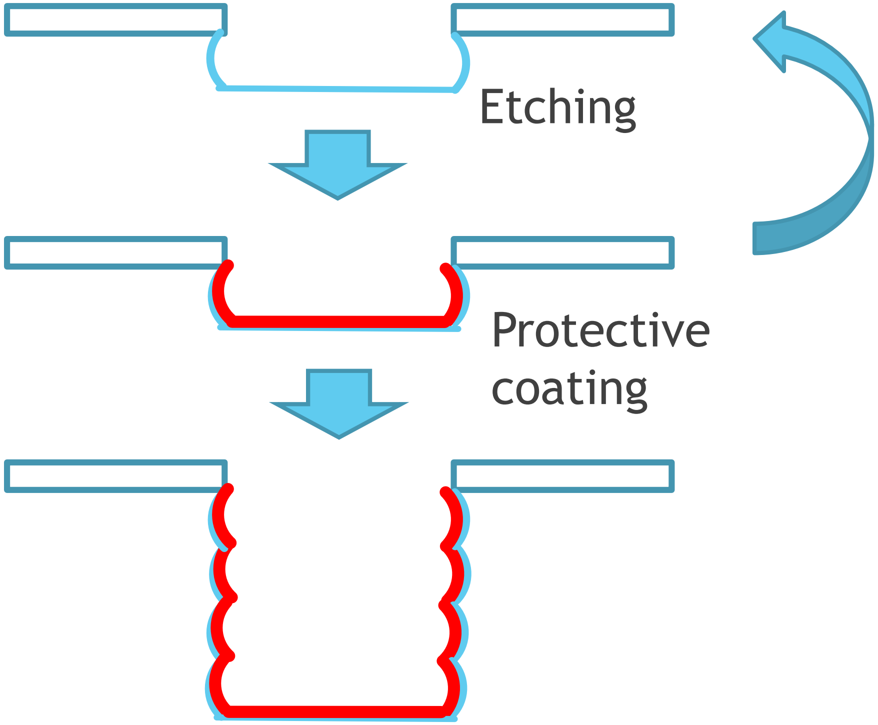
[2]DRIE

[3]manufacturing

insulating layer (SiN/SiO_2)

DRIE(Deep- Reactive Ion Etching)

Bosch process

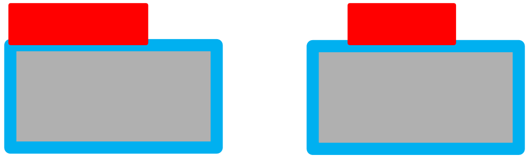


This process enable to make high aspect ratio

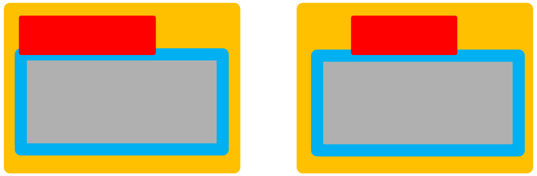
Manufacturing process MEMS μ-PIC [2]

Type A

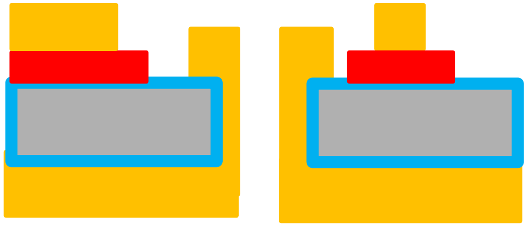
[1]manufacturing surface insulating layer (Polyimide)



[2]manufacturing seed layer

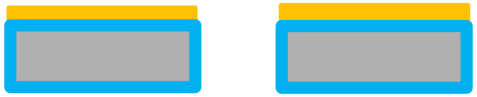


[3] photolithography, metal plating, seed etching

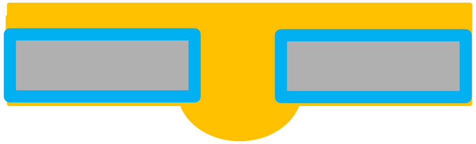


Type B

[1]manufacturing seed layer



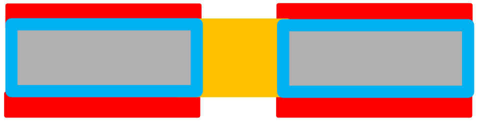
[2]Filling plating metal



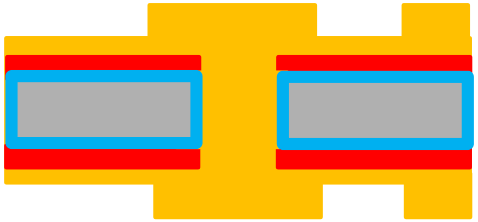
[3]CMP

(Chemical Mechanical Polishing)

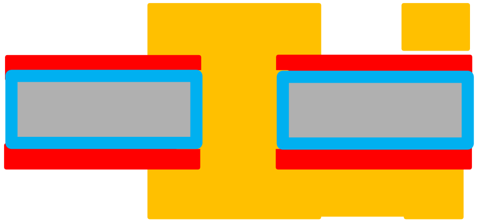
[4] manufacturing surface insulating layer (Polyimide)



[5] photolithography, metal plating, seed etching

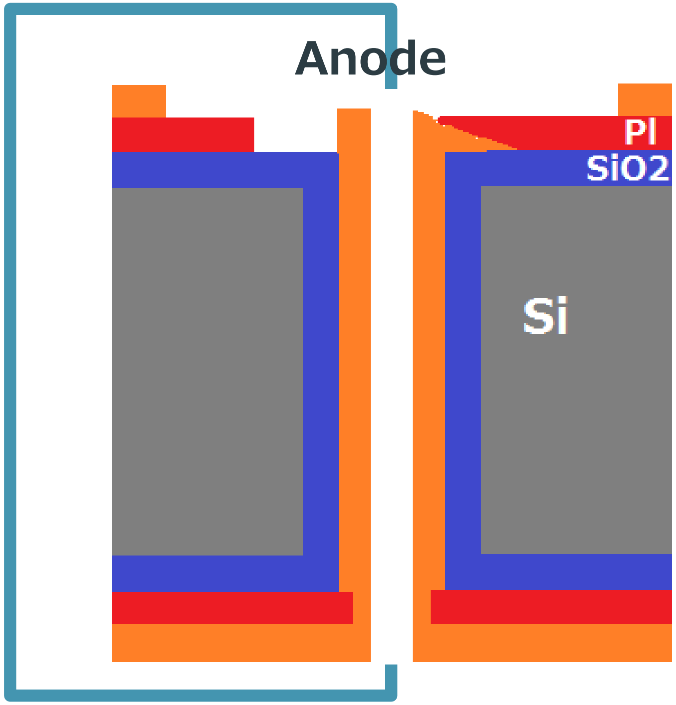


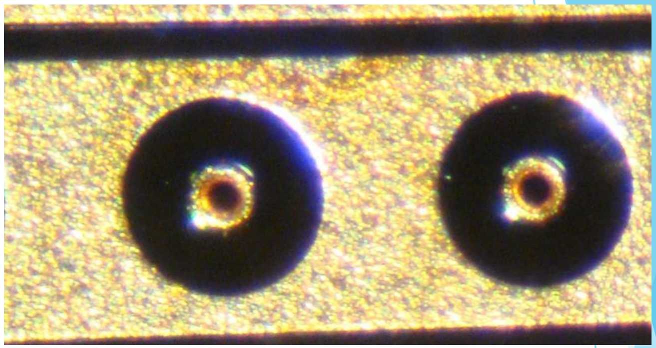
[6] seed etching



1st MEMS μ-PIC

理想形





Anodeの山形の崩れ　と

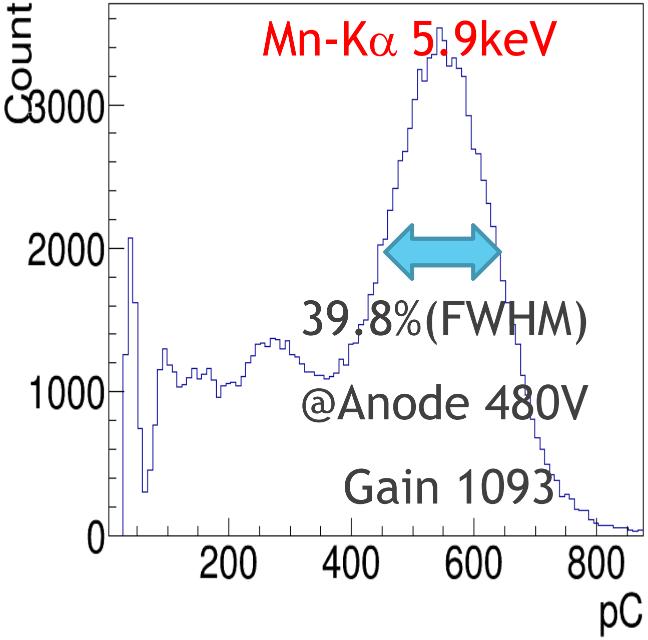
ポリイミド層形成の制御が失敗によりゲインが出なかった

放電が1度起こると、とまらなくなった(SiO2の放電による傷が原因か？)

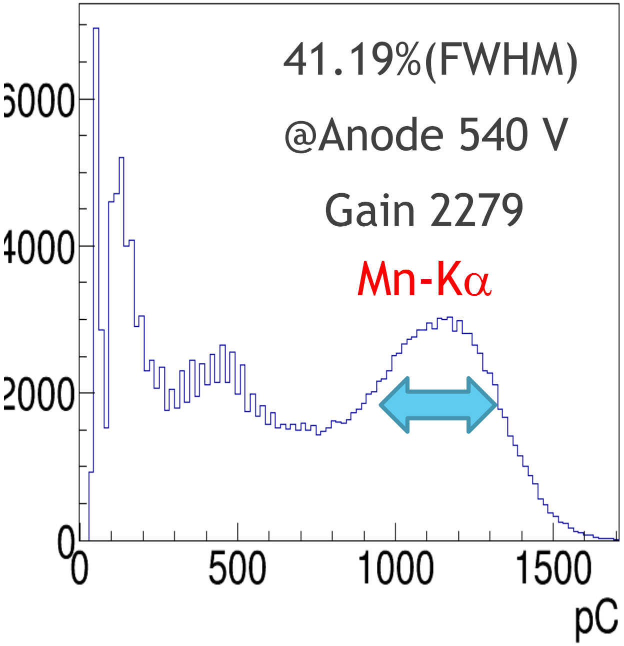
次タイプのMEMSはSiO_2膜を厚く

PCB and MEMS μ-PIC spectrum

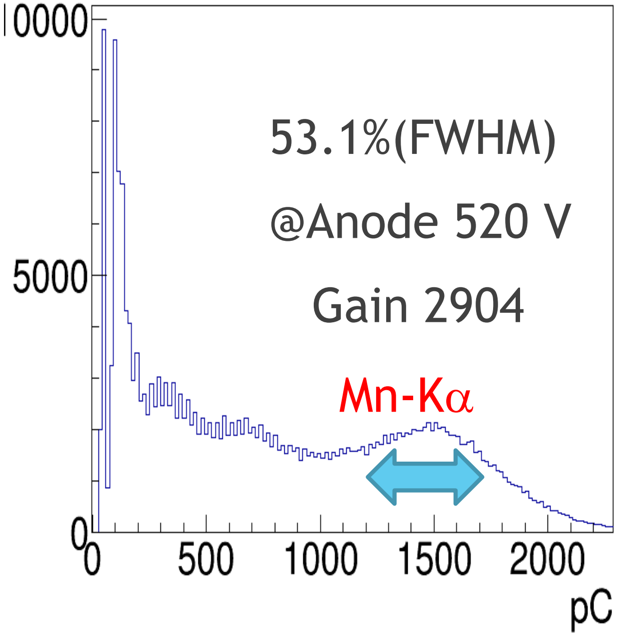
PCB



MEMS TypeA



MEMS TypeB



For the first time, we succeed in test operation of MEMS μ-PIC

GAS Ar90%.$C_2H_6$10%, 1 atm

X-ray source Fe-55

Bad Energy resolution

probably due to much small detection area(10 mm x 5mm)

⇨ A lot electrons escapes from detection area