



Measurements of LGAD

3rd.
CiRfSE
Workshop

23-24 Jan. 2017

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The University of Tsukuba, B4

+ Talk Outline

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- ▣ Brief Introduction of LGAD
- ▣ IV Measurements (Pixel)
 - ▣ Setup description / Samples
 - ▣ Wavelength Dependence of IV (Strip CV)
 - ▣ Temperature Dependence of IV
- ▣ IV After Irradiation (Pixel)
 - ▣ γ -ray
 - ▣ Neutron

+ Low Gain Avalanche Detector

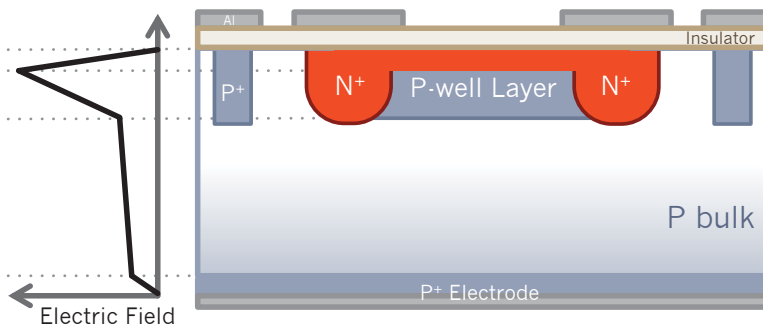
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□ N⁺-on-P \ggg N⁺-P⁺-P⁻-P⁺

□ Uniform high electric field

@ N⁺-P⁺-junction (Thin multiplication layer) \ggg Avalanche

\ggg Good time resolution (~50ps)



□ Low Gain (~10)

\ggg Optimum S/N

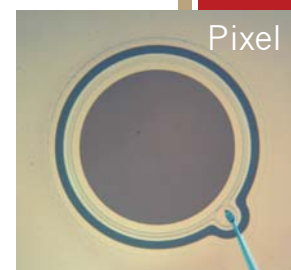
\ggg Thinner detector possible

+ Samples from HPK

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□ Strip (chip size 6mm×12mm, strip 80 μm pitch)

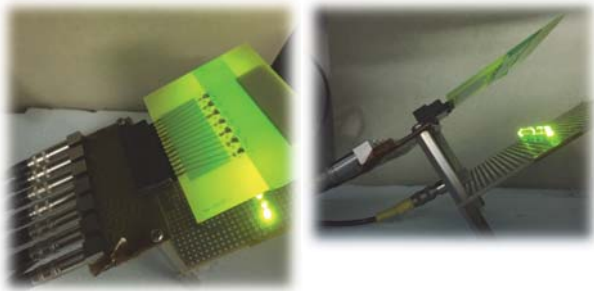
□ Pixel (chip size 2.5mm×2.5mm, window 1mm φ)



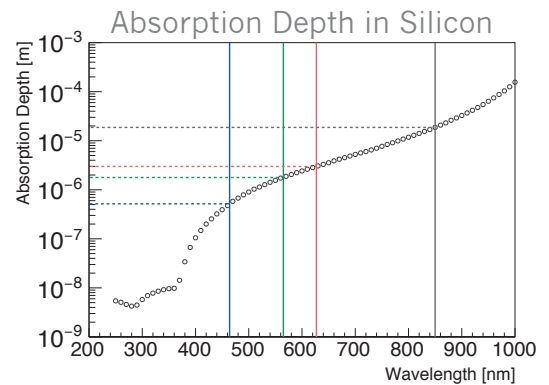
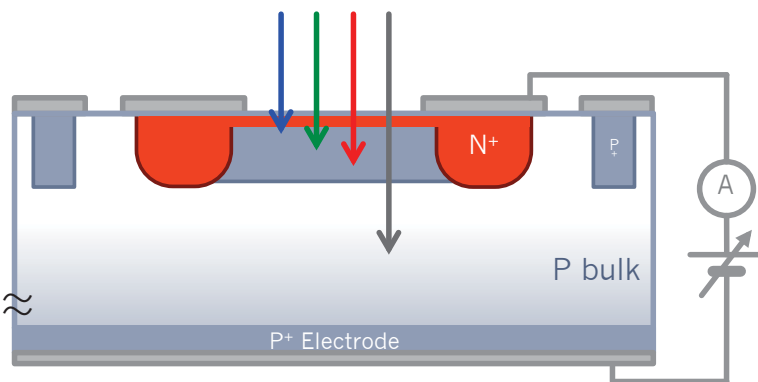
Wafer No.	Dose Gradations	Physical Thickness (μm)	Active Thickness (μm)	Sample Name
W02	A	150	50 (3~8kΩcm)	50A
W04(05)	B			50B
W07(08)	C			50C
W10(11)	D			50D
W13(14)	A		80 (1kΩcm)	80A
W16(17)	B			80B
W19(20)	C			80C
W22(23)	D			80D

+ IV Measurements ~ Setup

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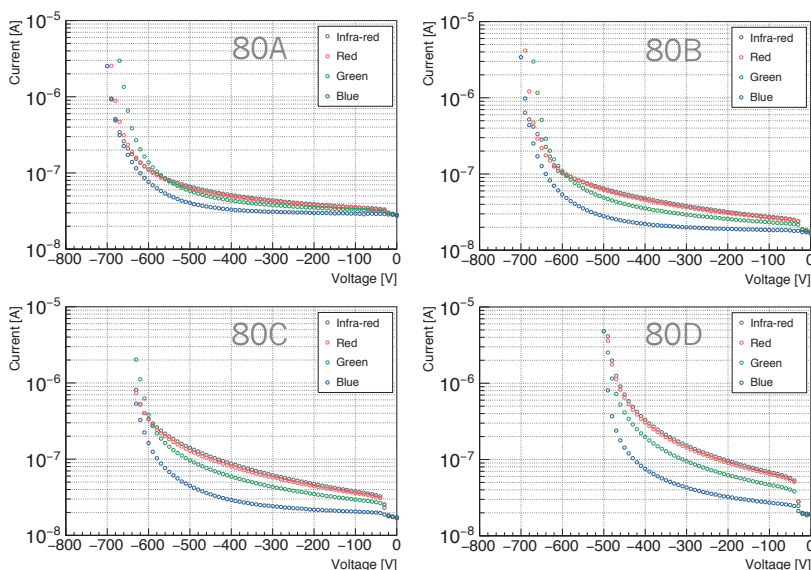
- Leakage
- LED Light Response
 - Blue ($\lambda = 464\text{nm}$, $D = 0.5\ \mu\text{m}$)
 - Green ($\lambda = 565\text{nm}$, $D = 2\ \mu\text{m}$)
 - Red ($\lambda = 627\text{nm}$, $D = 3\ \mu\text{m}$)
 - Infra-red ($\lambda = 850\text{nm}$, $D = 20\ \mu\text{m}$)



+ Wavelength Dep. of IV (0~700V)

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Pixel (active thickness $80\ \mu\text{m}$) @ 20°C



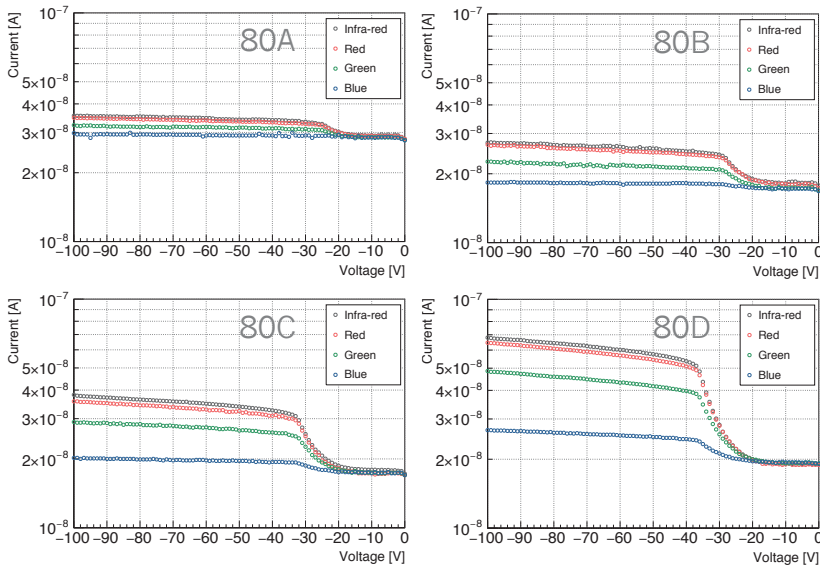
Dose : $A < B < C < D$

- Curves normalized @ 10V (Gain~1)
- Gain
 - Longer wavelength, higher gain
 - Jumps @ ~30V
- Breakdown Voltage
 - No Wavelength dep.

+ Wavelength Dep. of IV (0~100V)

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Pixel (active thickness $80 \mu\text{m}$) @ 20°C



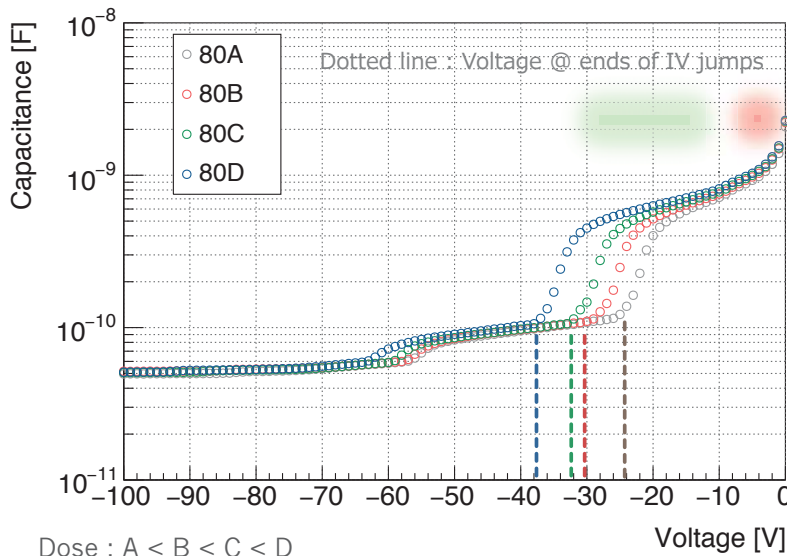
Dose : A < B < C < D

- Curves normalized @ 10V (Gain~1)
- More dose & Longer wavelength, Higher gain
- More dose, Higher voltage @ ends of jumps

+ P+ Dose Dependence of CV

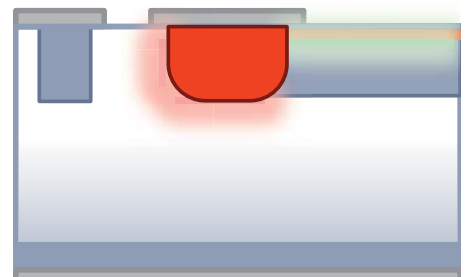
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Strip $80 \mu\text{m}$ @ 1500Hz



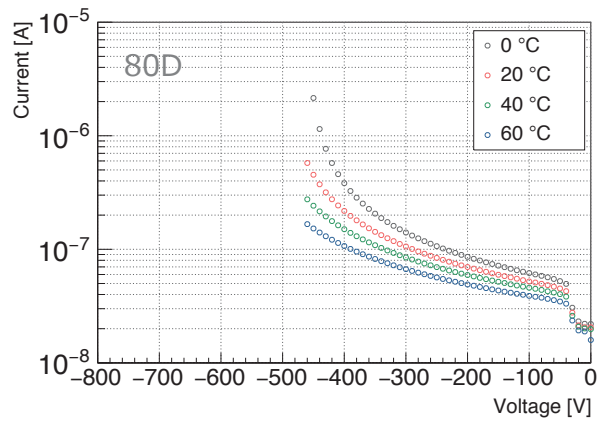
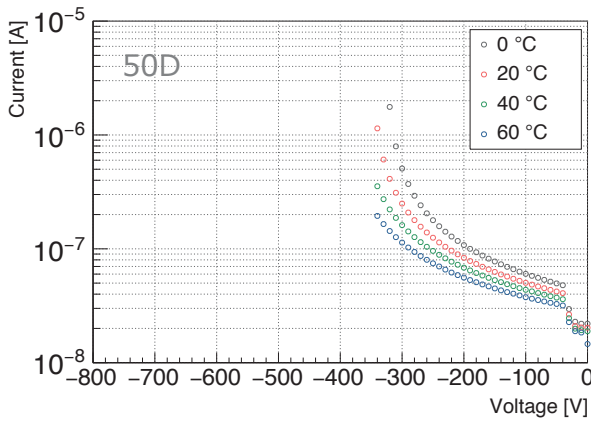
Dose : A < B < C < D

- Depletion voltage
- in agreement with IV
- 1st. Depletion
 - Electrode side way
- 2nd. Depletion
 - Multiplication layer
- 3rd. Depletion
 - Bulk's depletion



+ Temperature Dependence of IV

Pixel 50 μm & 80 μm @ 20°C

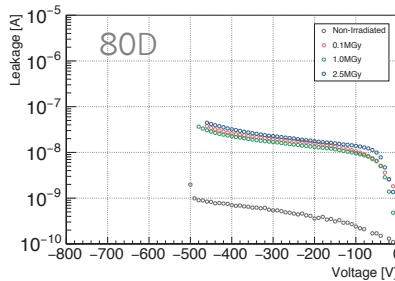
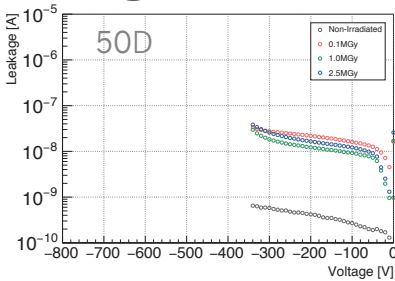


- Green LED Light Response
- Lower temp., larger current ➤➤➤ Avalanche

+ IV After γ -ray Irradiation

@ 20°C

Leakage

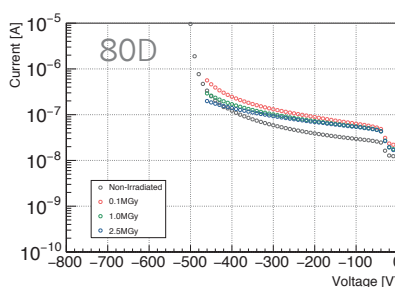
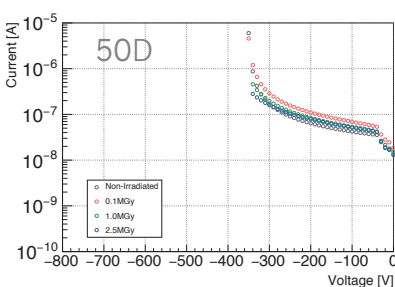


TARRI(QST), Japan

24 Nov. - 20 Dec. 2016

- 0.1MGy
- 1.0MGy
- 2.5MGy

Green Light Response



- Leakage increase
- no dose independence because of surface damage
- Green LED response not changed

➤➤➤ Gain retain

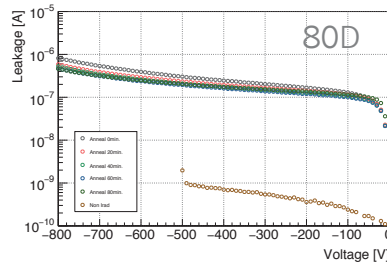
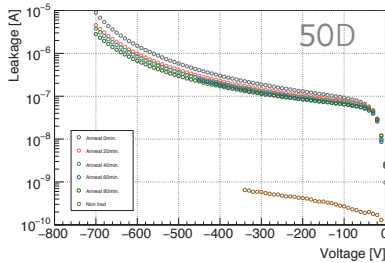
+ IV Annealing After Neutron Irradiation

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$$1.0 \times 10^{15} n_{eq}/cm^2$$

@ -20°C

Leakage



Ljubljana, Slovenia

15 Dec. 2016

$$0.3 \times 10^{15} n_{eq}/cm^2$$

$$1.0 \times 10^{15} n_{eq}/cm^2$$

$$3.0 \times 10^{15} n_{eq}/cm^2$$



Leakage increase

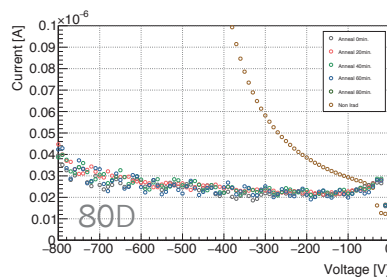
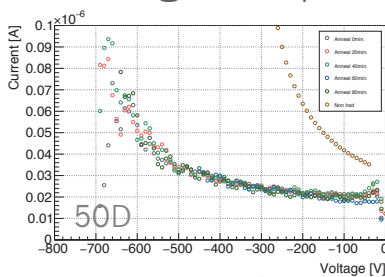
Gain retain

appear @ higher voltage

e.g. 50D (280V → 700V)

Gain ~5

Green Light Response



Annealing @ 60°C

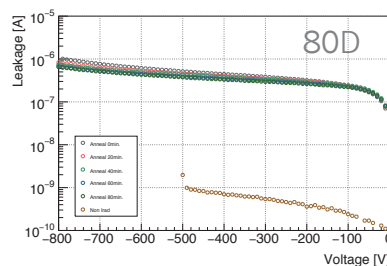
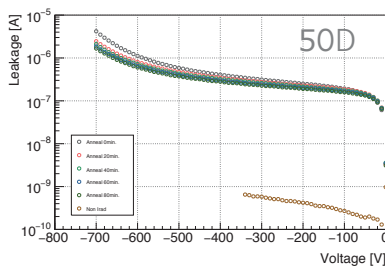
+ IV Annealing After Neutron Irradiation

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$$3.0 \times 10^{15} n_{eq}/cm^2$$

@ -20°C

Leakage



Ljubljana, Slovenia

15 Dec. 2016

$$0.3 \times 10^{15} n_{eq}/cm^2$$

$$1.0 \times 10^{15} n_{eq}/cm^2$$

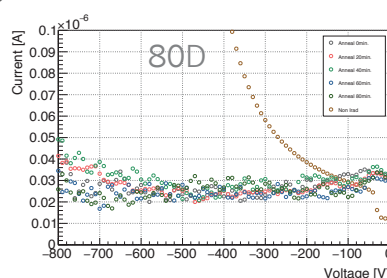
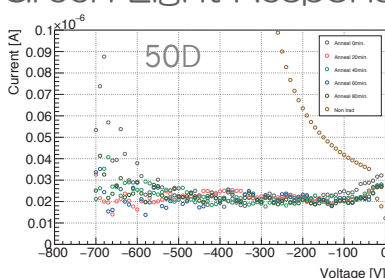
$$3.0 \times 10^{15} n_{eq}/cm^2$$



Leakage increase

Gain disappear? (< 800V)

Green Light Response



Annealing @ 60°C

+ Conclusions / Future Work

- ▣ Understood the structure of LGAD from HPK
- ▣ Gain retain after γ -ray irradiation (2.5MGy)
- ▣ After neutron irradiation, ($1.0 \times 10^{15} n_{eq}/cm^2$) gain retain
($3.0 \times 10^{15} n_{eq}/cm^2$) gain disappear ($< 800V$)

- ▣ Measure Laser & β -ray Response
- ▣ Proton Irradiation (Feb. 2017 @ CYRIC)