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Hamamatsu silicon detectors for high energy physics experiments

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HAMAMATSU PHOTONICS K.K.

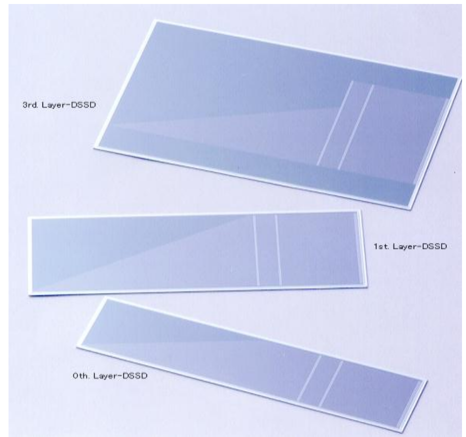
Outline

1. Development and production history of Hamamatsu SSD (Silicon Strip Detector)
2. Production flow of SSD
3. Failure analysis
4. New dicing technology
5. Design examination of SSD for HL-LHC

Hamamatsu Si detectors for HEP

Direct detector

- Silicon Strip Detector(SSD)
- Silicon Pixel Detector



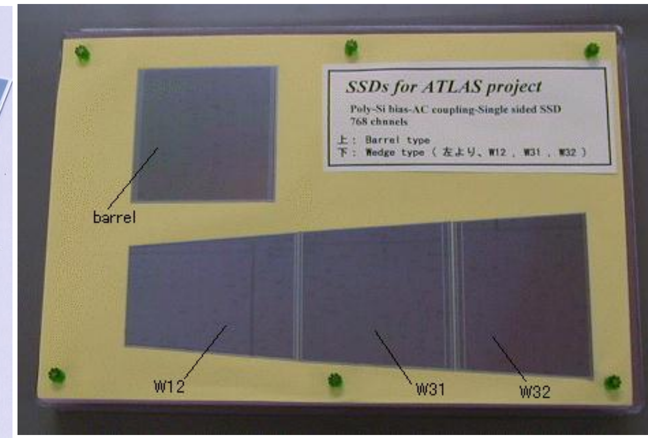
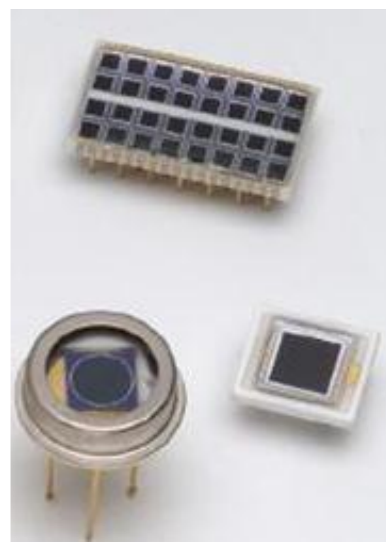
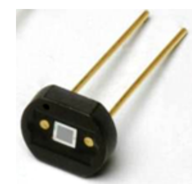
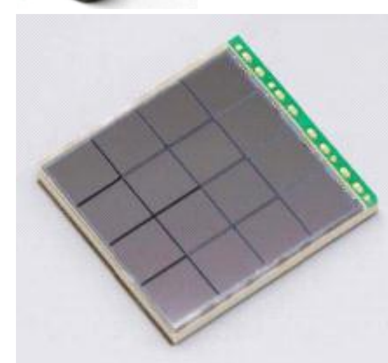


Photo detector

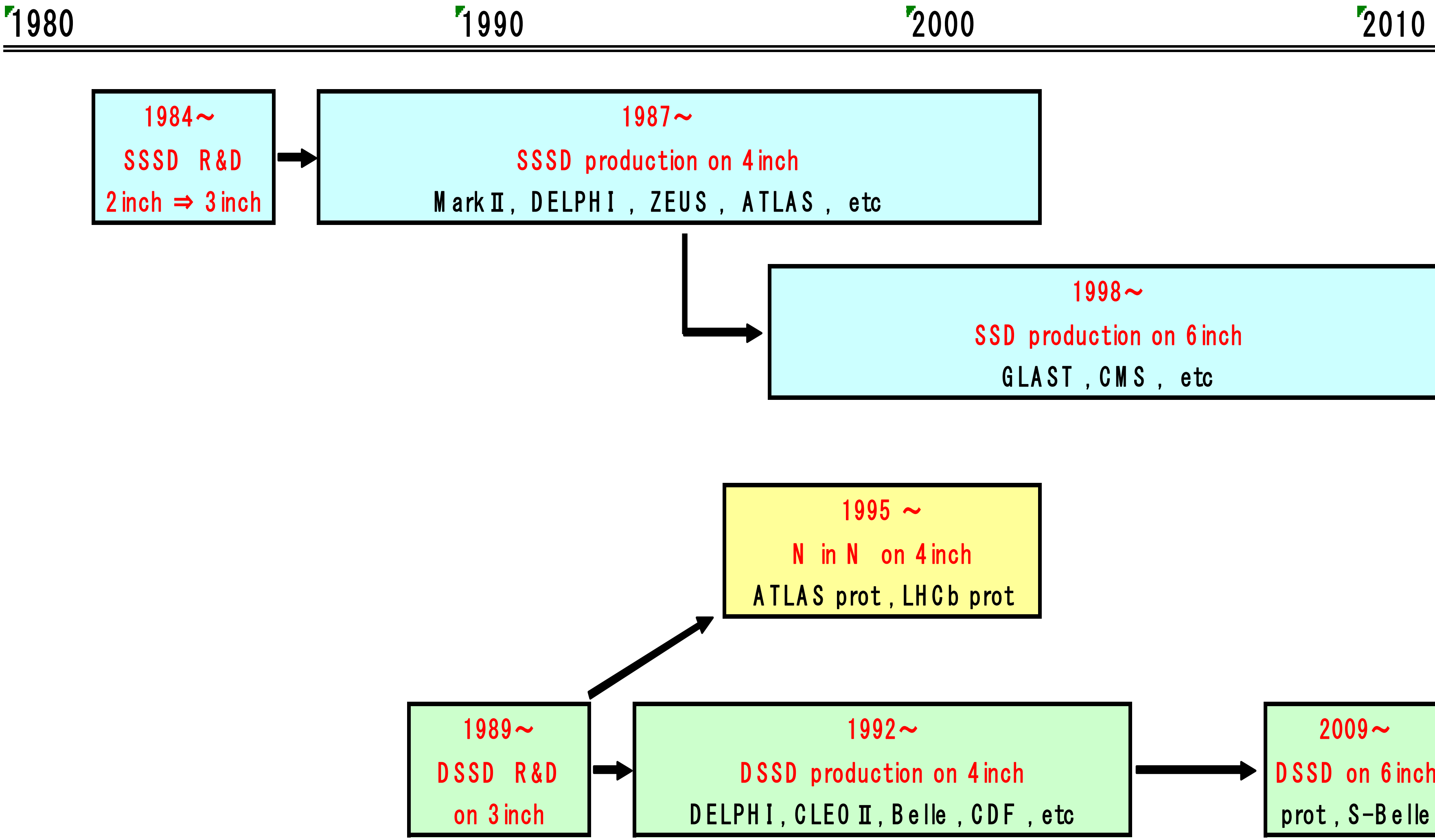
- Silicon Photo Diode(PD)
- Silicon Avalance Diode(APD)
- Multi Pixel Photon Counter(MPPC)







Development and production history of SSDs at Hamamatsu



Review of main SSDs made by Hamamatsu for HEP projects

PROJECT	DETECTOR TYPE	size	QTY.	period
MARK Ⅱ	DC-SSSD 3type	3chip/4inch	44	1987
CLEO Ⅱ	AC-DSSD 3type Pside: punch-through , Nside: poly-Si & DML	1chip/4inch 2chip/4inch	122	1993～1994
DELPHI	AC-DSSD 2type both-side: poly-Si , Nside: DML	2chip/4inch	130	1993～1994
DELPHI up grade	AC-SSSD , FOXFET	2chip/4inch	330	1994
NOMAD	AC-SSSD , FOXFET	2chip/4inch	650	1996～1997
CLEO Ⅲ	DC-DSSD , Pside: DML	2chip/4inch	550	1997～1999
CDF-SVX Ⅱ	AC-DSSD 3type both-side: poly-Si , Nside: DML	1chip/4inch 2chip/4inch	360	1997～1999
CDF-ISL	AC-DSSD both-side: poly-Si , Pside: stereo	1chip/4inch	550	1998～1999
PAMELA	AC-DSSD Pside: punch-through , Nside: poly-Si & DML	2chip/4inch	60	1997
KEK-B(BELLE)	AC-DSSD both-side: poly-Si , Nside: DML	2chip/4inch	180	1998
ZEUS	AC-SSSD 3type , poly-Si	1chip/4inch	950	1999
AGILE	AC-SSSD , poly-Si	1chip/6inch	500	2000
PAMELA	DC-SSSD	1chip/6inch	300	2000
BELLE up grade	AC-DSSD , both-side: poly-Si	2chip/4inch	250	2000～2002
ATLAS	AC-SSSD 6type , poly-Si	1chip/4inch	16000	2001～2003
GLAST	AC-SSSD , poly-Si	1chip/6inch	11500	2001～2003
CMS	AC-SSSD 14type , poly-Si	1chip/6inch	24000	2003～2006

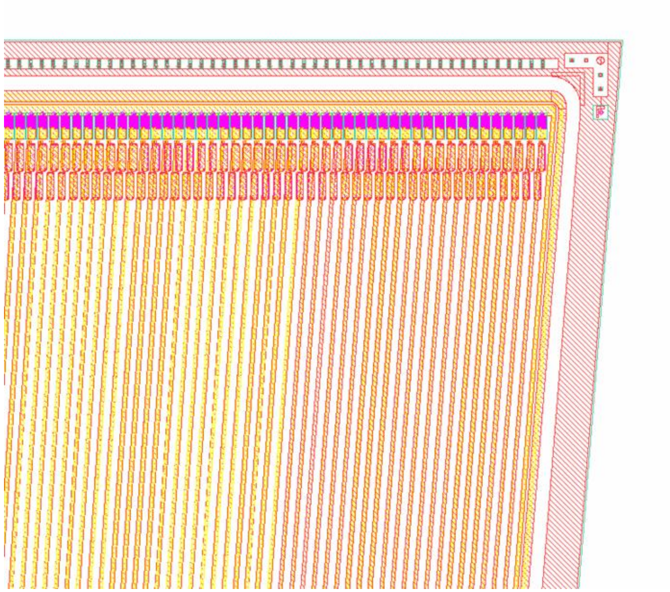
Production flow of SSDs

1) Design of Photo masks
2) Wafer process
3) Wafer inspection
4) Dicing
5) Chip proving
6) Visual inspection
7) Packing
8) Test of long time stability

Design of Photo masks

CAD soft on PC is mainly used for Si detectors.

Each coordinates of figures can be inputted by macro program made by EXCEL etc.



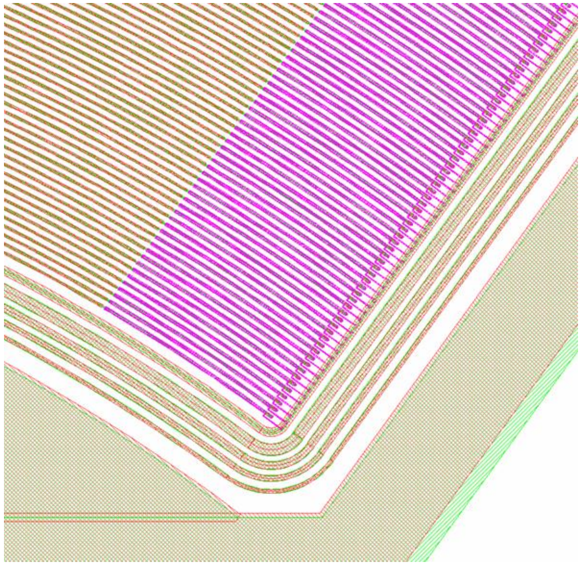


Photo-mask design of complicated shape like any angle or rounded strips pattern are acceptable.

Wafer process

About 10,000 of 6 inch wafers are processed per month.

We have kinds of process (PDs , Bipolar photo IC , CCDs, C-MOS).

For SSDs

2,000 wafers per month were processed for LHC mass production.

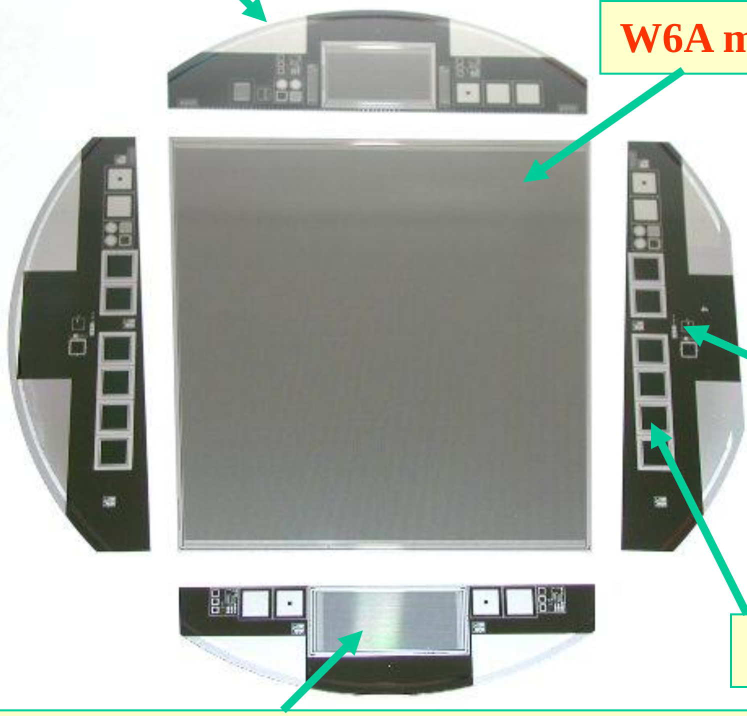
Available type : SSSD or DSSD, AC or DC-coupling , Single or Double-metal

Available thickness : 150 to 650um for SSSD , 320um for DSSD

- Oxidation
- Photolithography
- Ion Implantation
- Poly-Si process
- Metal Evaporation
- Passivation

CMS-W6A chip & Cut-offs from 6inch wafer

CMS-std Cut-off (on all CMS wafers)
contains
Std-Baby detector , Test structures designed by CMS ,
Mos diode , CMS-Monitor diode (CMS-MD) , etc.



W6A main detector

ALL cut-offs are kept in envelop and delivered with main detector

HPK test structure
contains
test structures of poly-Si resistance ,
implant resistance , coupling capacitance , etc.

HPK-Monitor diode (HPK-MD)

W6A-baby detector (the same design of W6A main detector)

Wafer proving

1) Lot check using TEG
by manual or auto prober

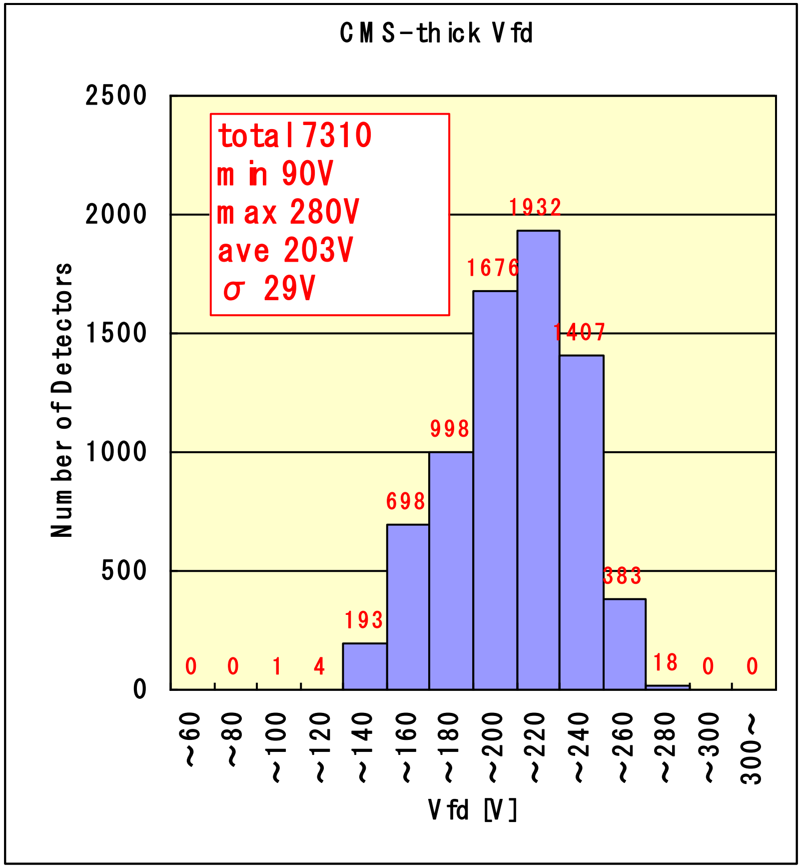
- implant resistance
- poly-Si resistance
- Flat-band voltage
- capacitance of Cc
- IV & CV of Monitor PD

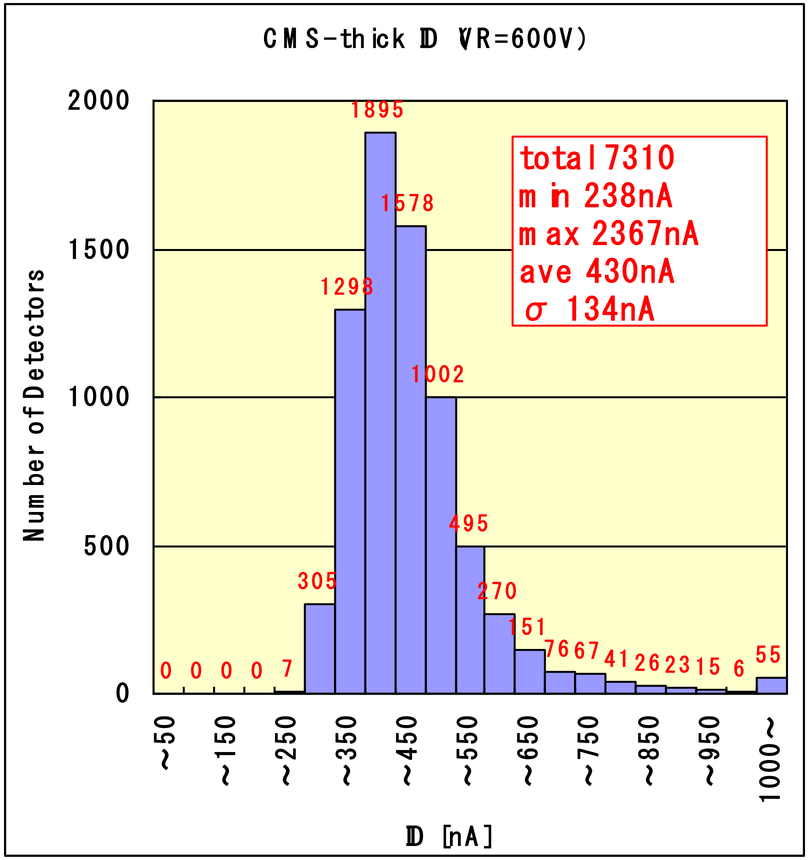
2) IV curve of main chips
Chose good wafers

3) Put chip serial number
Binary notation at
Scratch PADs on chip

< Auto prober system >

Vfd and Leakage current for CMS-thick type SSSDs

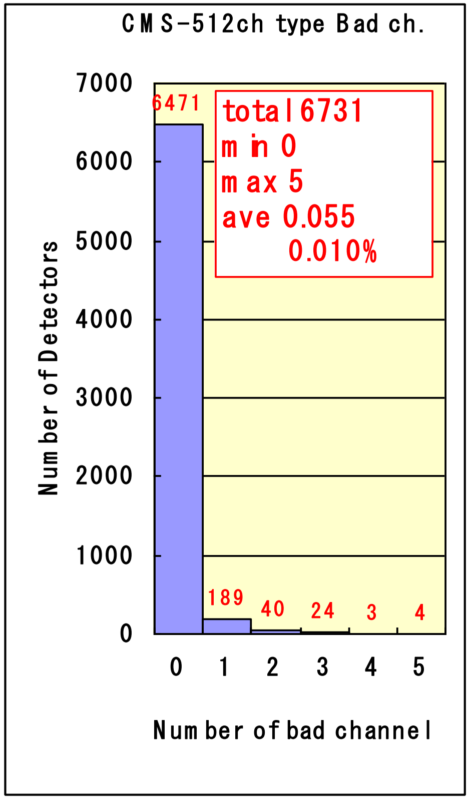


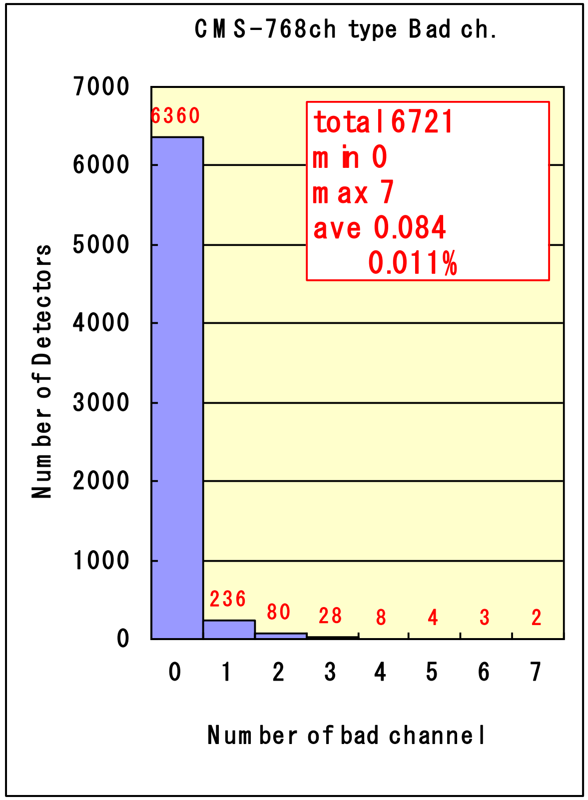


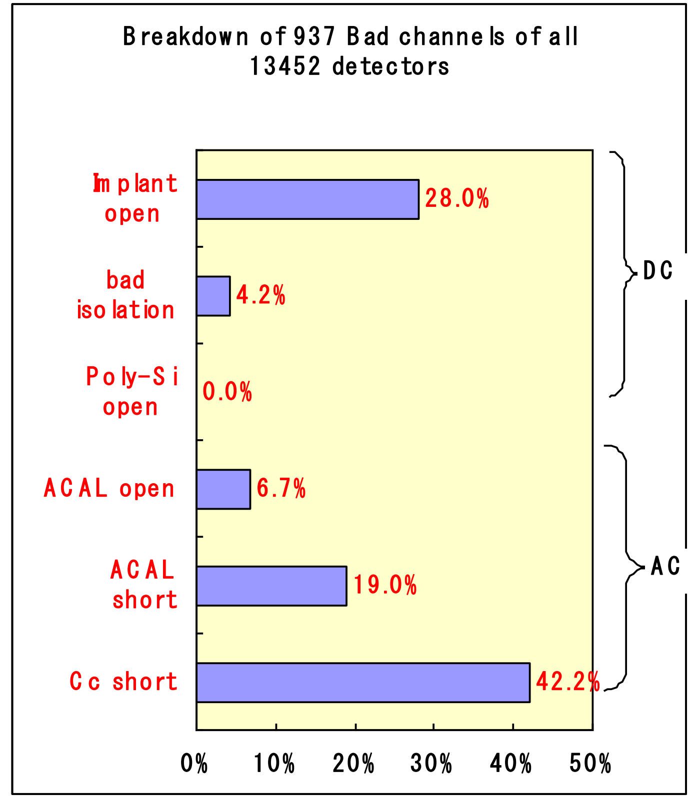
Vfd distribution is due to
the resistance variation of wafer

Relatively small leakage current
though big and 500um thickness

Bad channel rate for CMS-SSDs

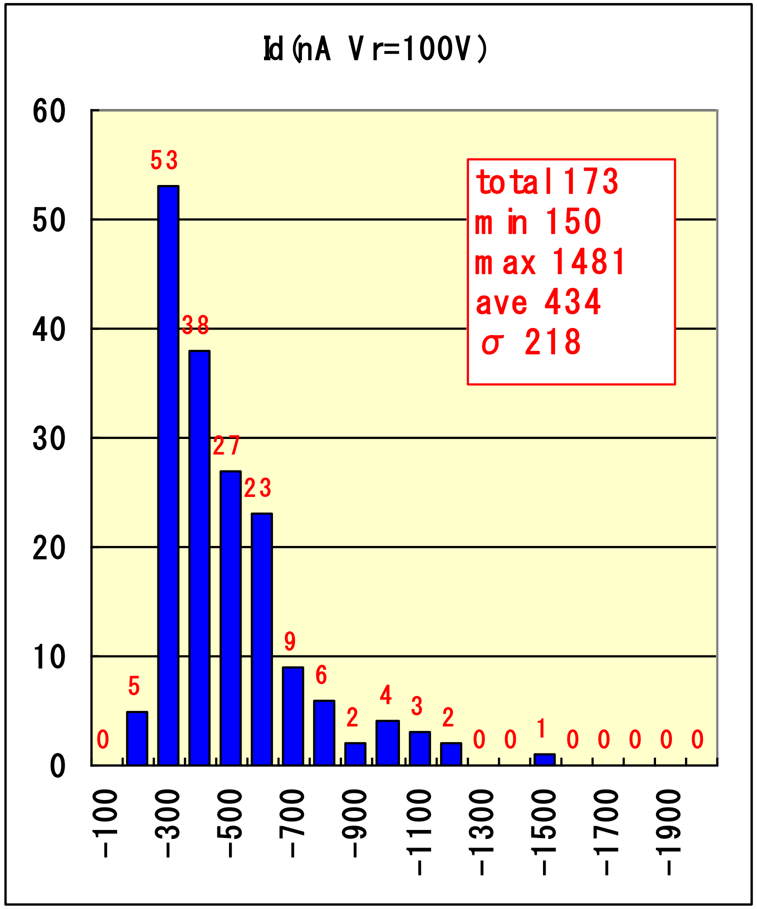


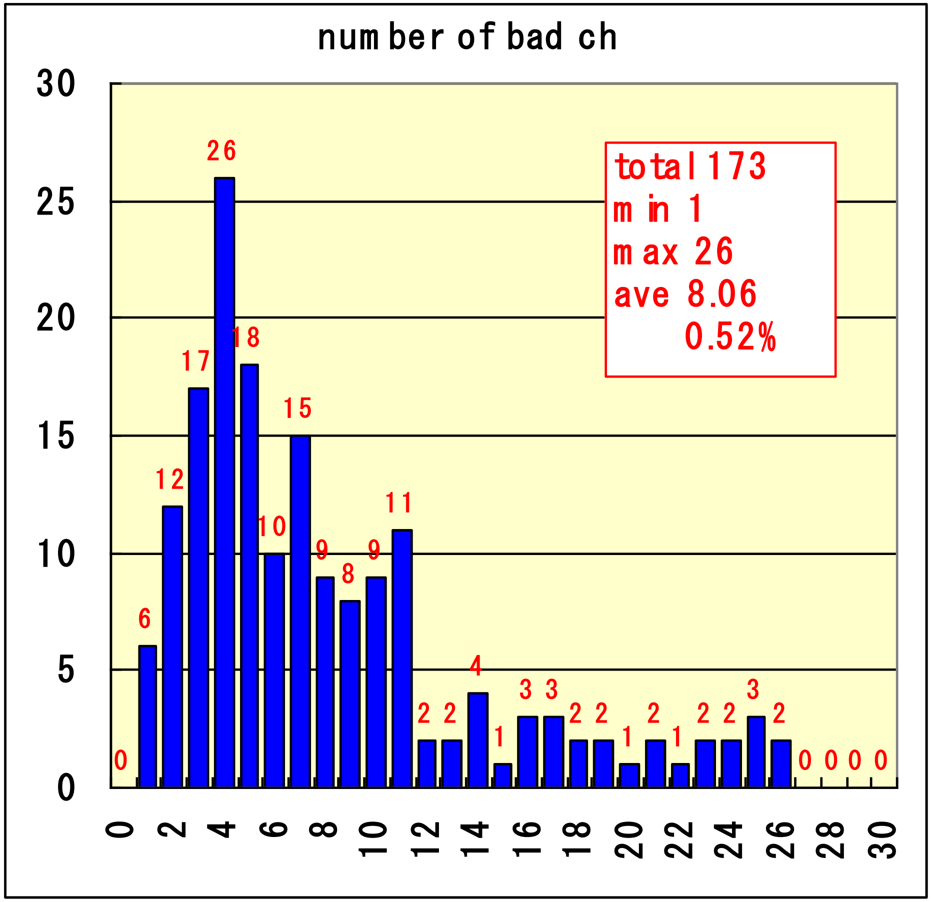




More than 95% of detector have no bad channels.
The average of bad channel rate is around 0.01%.
Short of Cc, Open of strip implant, short of AC AL are main factors of bad channel.

Leakage current and bad channel rate for Belle-L5-DSSDs

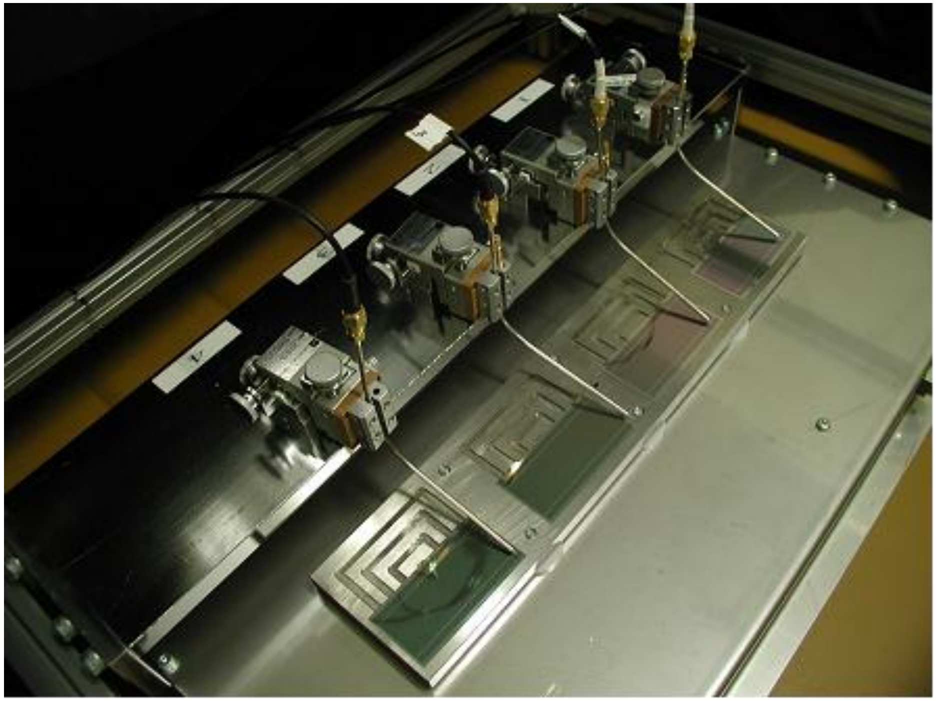




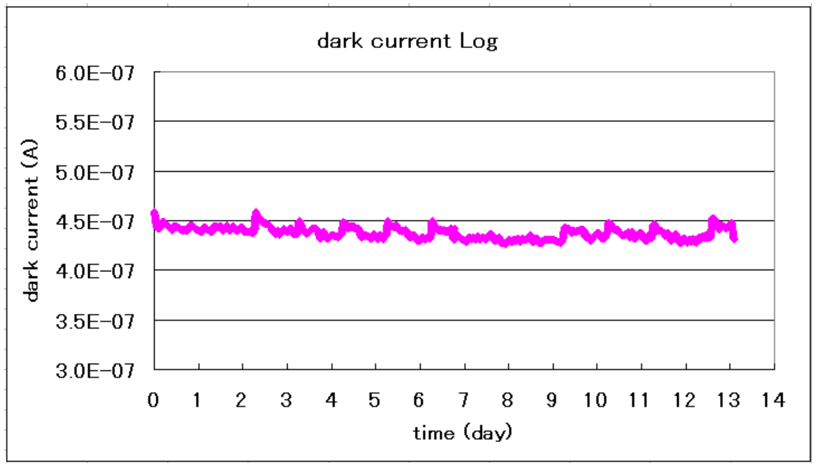
Relatively small leakage current though DSSD

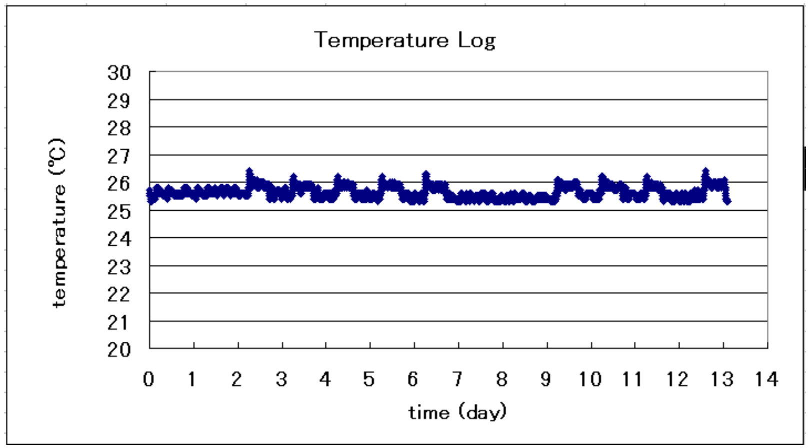
The average of bad channel rate is 0.52% and larger than SSSD

Long time stability of ATLAS proto-type SSSD



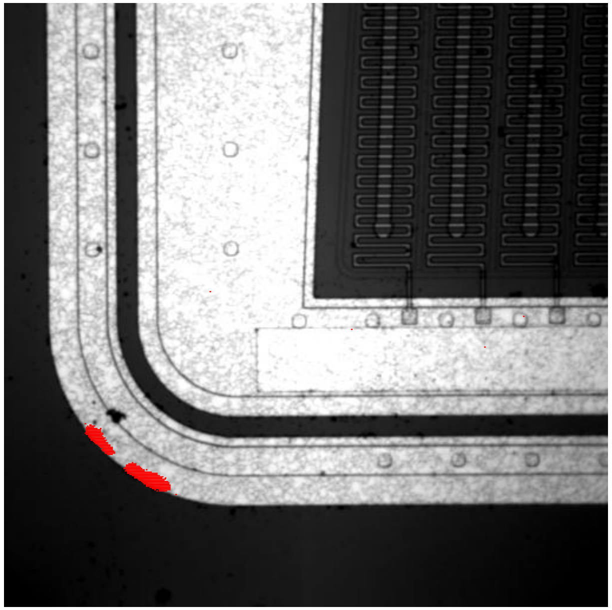
< 4 probers for checking long time stability>

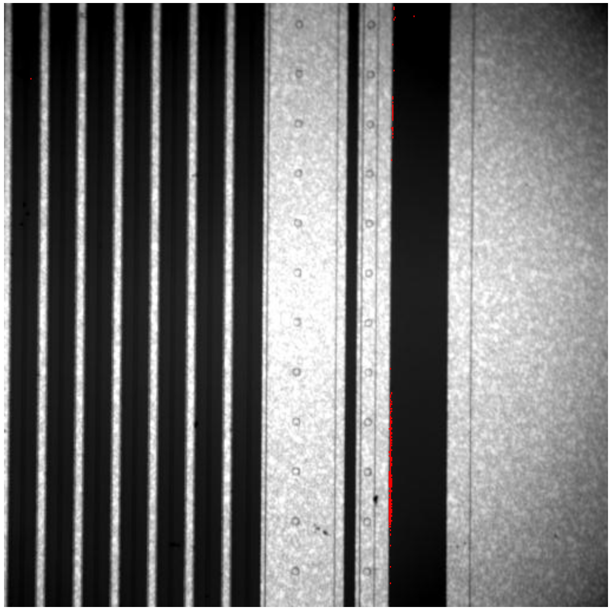




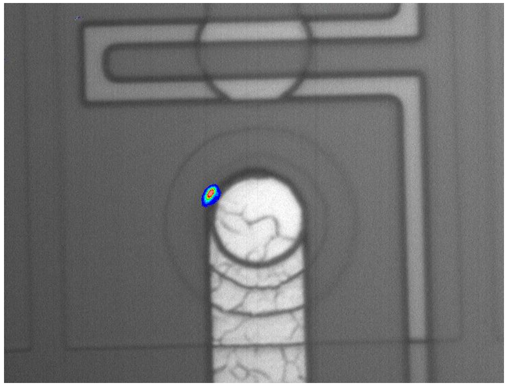
- Long time stability of dark current under operating at 600V.
- For 13 days biasing, no abnormalities have been identified.

Failure Analysis





Hamamatsu PHEMOS200



・A picture of delivered sensor, whose voltage tolerance came to be bad during the evaluation at the customer.

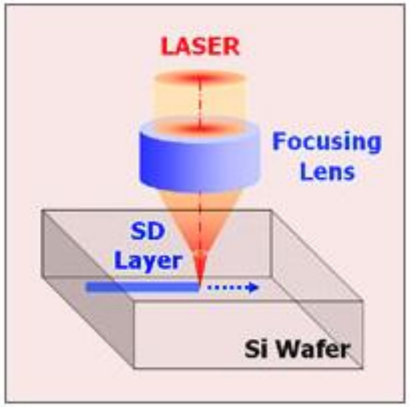
・Hot electron emission was observed at the edge of guard ring.（reported by customer）

・We will check whether there are some weak points at the structure of guard ring.

New Dicing Technology

We also have Stealth dicer in addition to the traditional blade dicer.
Cut as narrow as 1μm width without chipping.

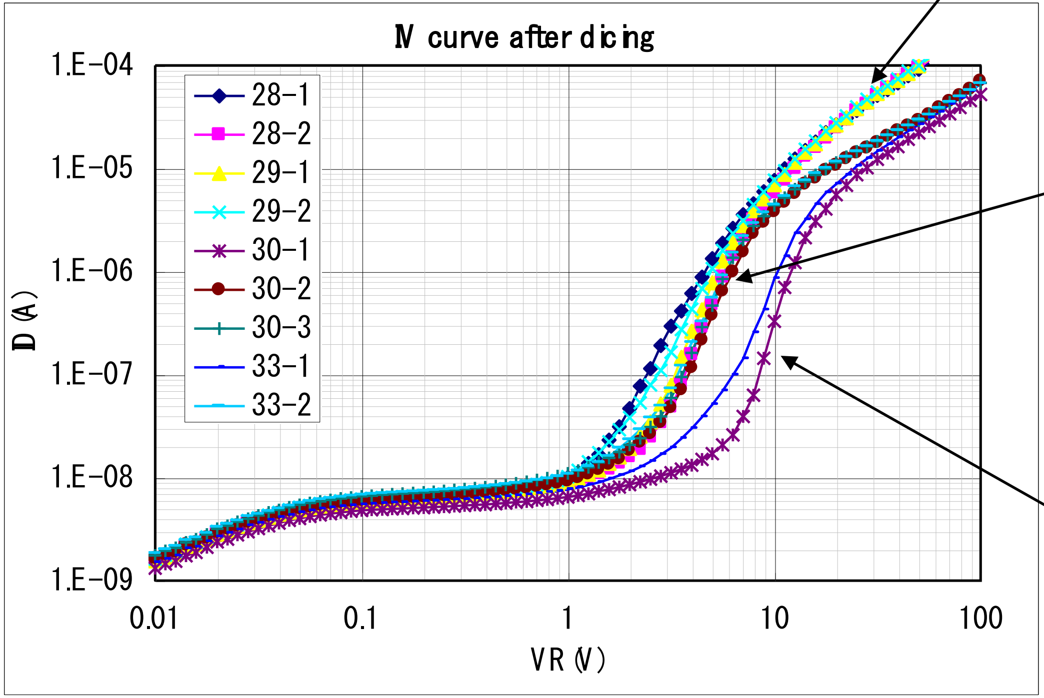
［from Hamamatsu homepage］

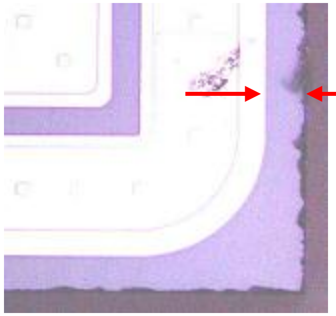


Baby detectors, Test structures, Mos diodes , Monitor diodes can be cut by stealth dicer in one set and one program.

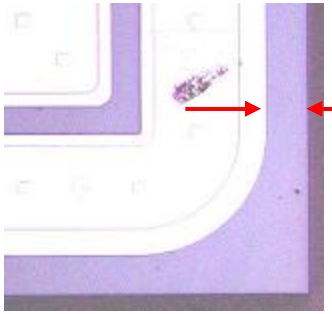
Comparison between cut edge and leakage current

Leakage current of stealth diced sample are smaller than that of blade diced one.

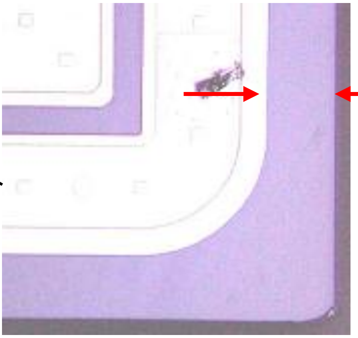




Blade 30um

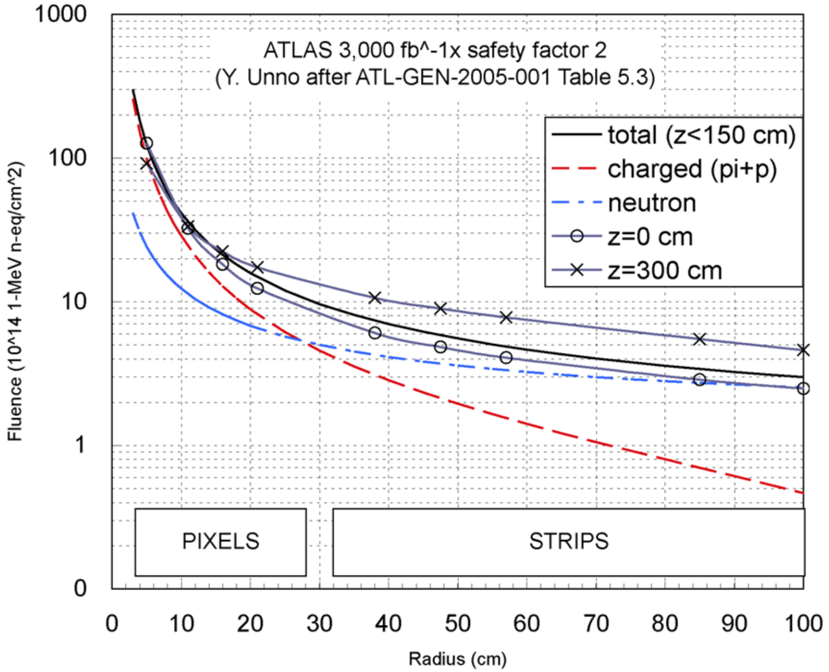


Stealth 30um



Stealth 50um

Requirement of Silicon detector for HL-LHC



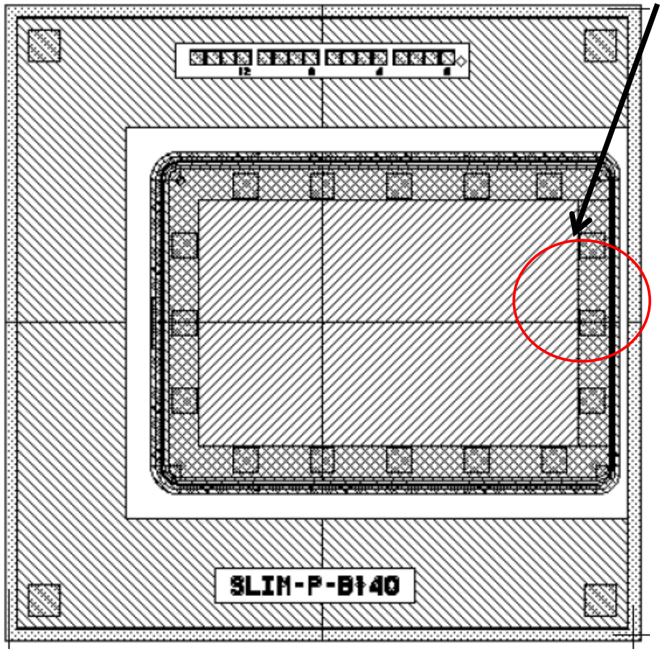
- **HL-LHC radiation environment**
  SSDs (R=30cm)> 1E15【1MeVn-eq/cm2】
  PIXELs (R=10cm) > 4E15【1MeVn-eq/cm2】

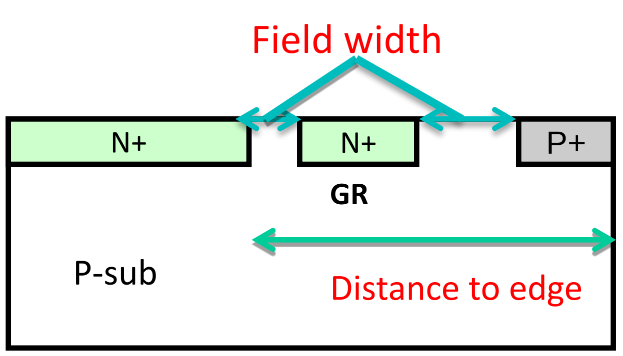
- **Radiation damages**
  - **Increase in leakage current**
  - **Change of the full depletion voltage(Vdep)**
    N type Si : decrease Vdep ⇒ invert to P type ⇒ increase Vdep
    P type Si : increase Vdep
  - **Decrease in charge collection efficiency**

- **Higher bias tolerance to use in HL-LHC condition for long time.**
- **Small dead space**

We are now doing experiment for edge design of slim edge and GR on 320um thickness P type Si material (initial Vfd is around 200V)

Experiment for Slim Edge design



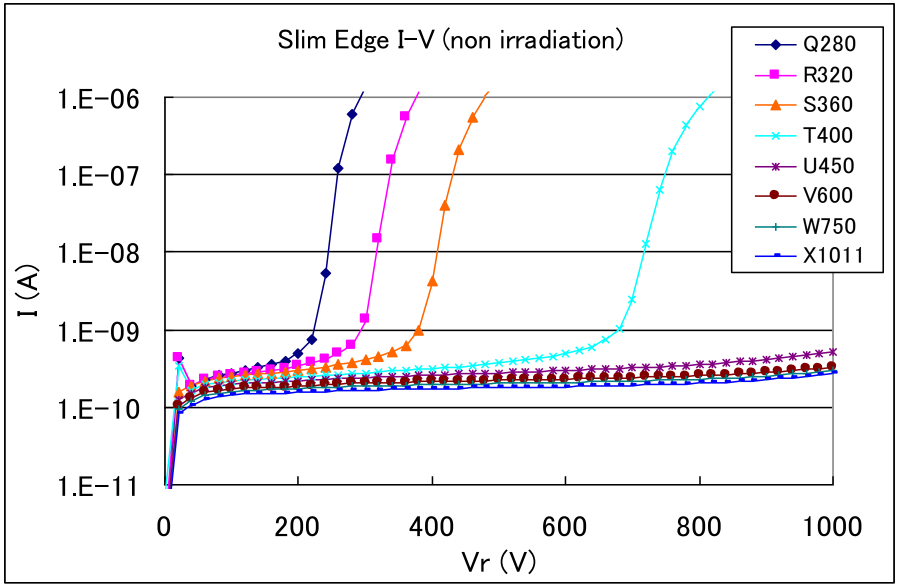


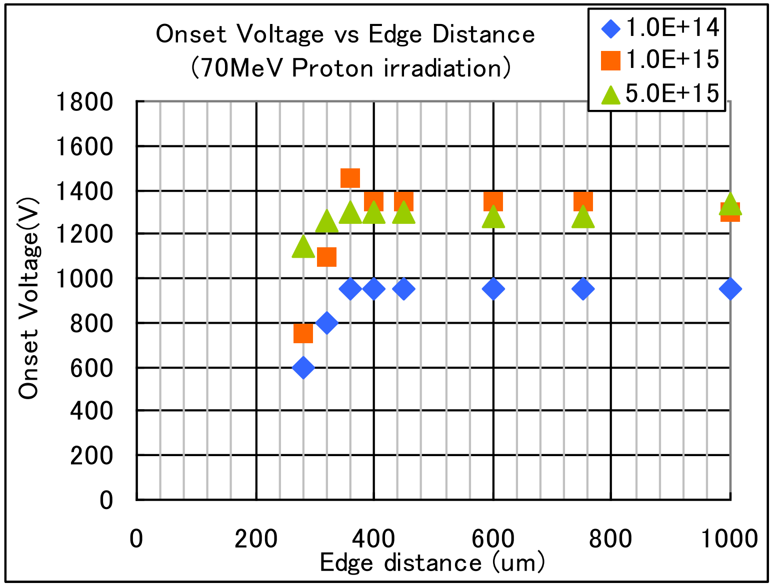
Sample No	Field width	Distance to edge
Q	160	280
R	200	320
S	240	360
T	240	400
U	240	450
V	240	600
W	240	750
X	240	1011

- **Sample No. Q to S**
  N+GR width & P+ width are the same
  Distance to edge are changed

- **Sample No. T to X**
  Field width are the same
  Distance to edge are changed

Experiment for Slim Edge design



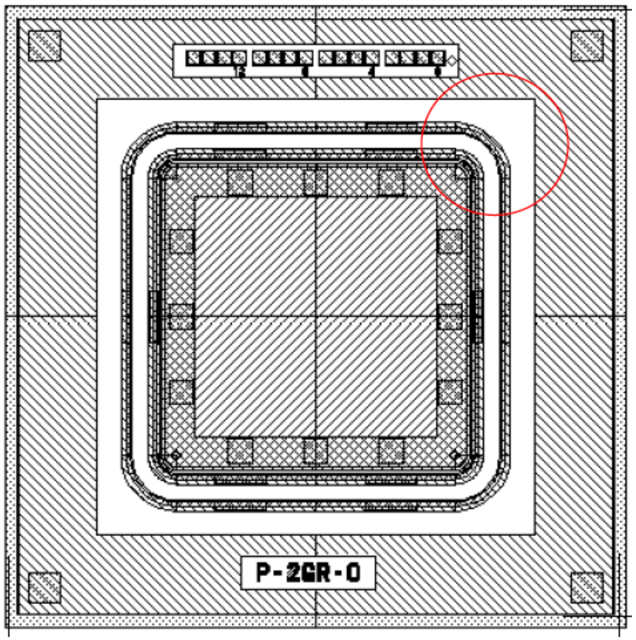


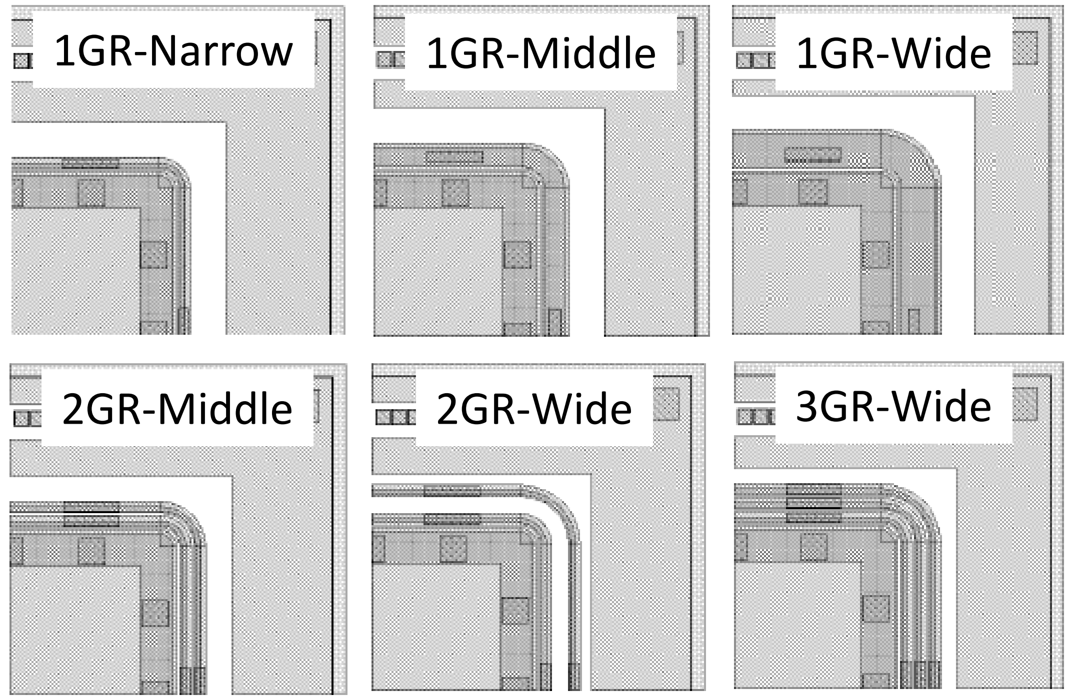
(※annealed for 80min@60℃)

[data from Mitsui et al 2011]

- Before irradiation, the sensor of edge distance lager than 450um hold over 1000V tolerance.
- After irradiation, the voltage tolerance tends to rise.
- So, if the sensor meets high voltage tolerance before irradiation, It also meets high voltage tolerance after irradiation.

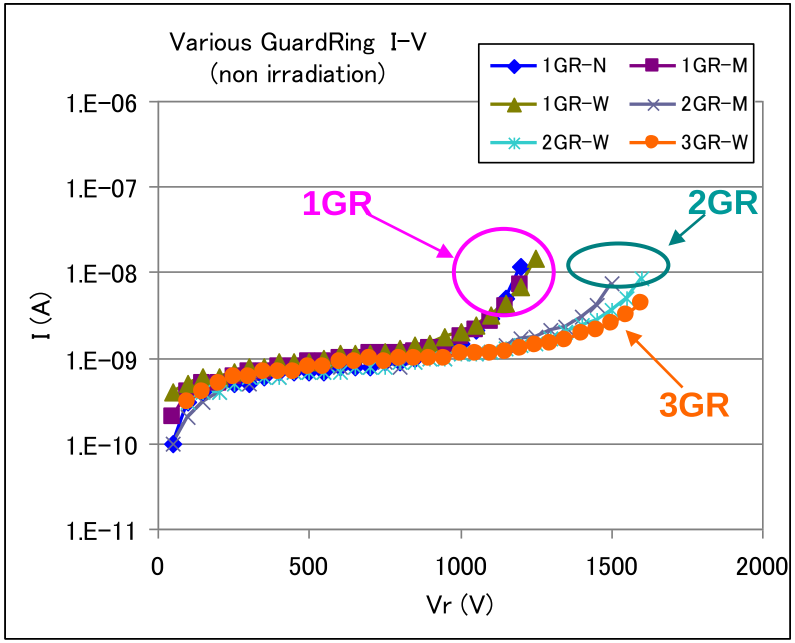
Experiment for Guard Ring design

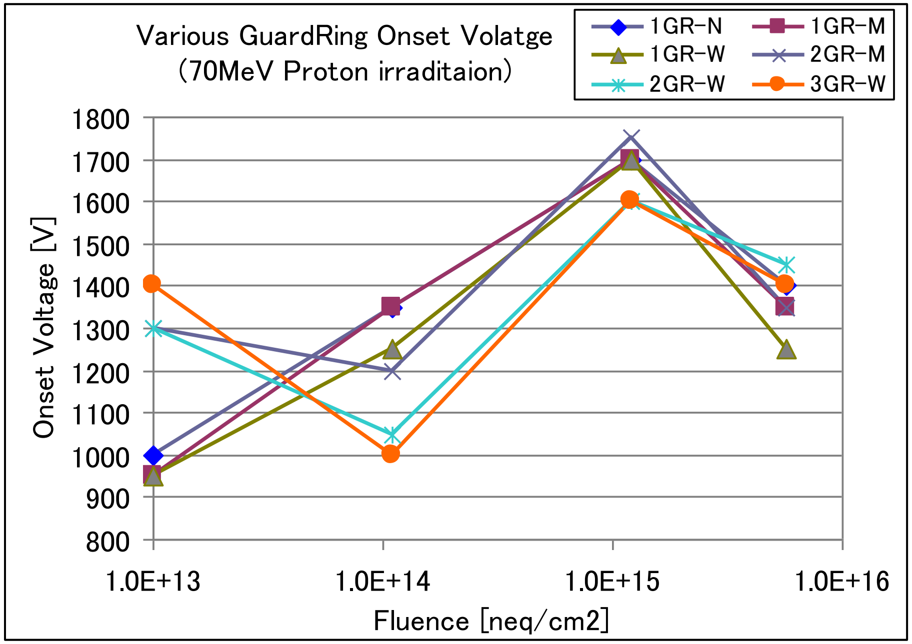




- **Distance to edge are the same, field width are the same**
- **Number of GR and total width of GR are changed.**
  1GR (Narrow , Middle , Wide)
  2GR (Middle , Wide)
  3GR (Wide)

Experiment for Guard Ring（GR） design





（※annealed for 80min@60℃）

[data from Mitsui et al 2011]

- Before irradiation, multi GR（2GR,3GR） holds higher voltage tolerance than single GR.
- Width of single GR doesn't influence I-V characteristic.
- After irradiation, the difference between single GR and multi GR tends to disappear.
- As mentioned before, GR problem (degradation of voltage tolerance) is reported.
  So, we must consider from viewpoint of both slim edge design and reliability.

Summary

1. The history of Hamamatsu SSD is more than 25 years, and have been used for many HEP experiment.
2. We have enough capability to design, process, inspection and check reliability for Si detector for HEP.
3. We have a stealth dicer and will be useful for Si detectors.
4. Now we are studying the experiment to design Si detector for the next HEP experiment. And we got following results.

   ・In design of edge distance of over 450um,
   the detector can hold over 1000V tolerance, both before and after irradiation.

   ・Before irradiation, multi GR（2GR,3GR） holds higher voltage tolerance than single GR but after irradiation, the difference between single GR and multi GR tends to disappear.

   ・As for GR design, we must consider from viewpoint of both slim edge design and reliability.

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We Hamamatsu are proud of the fact that our Si-detectors are being used in many physics experiments.

We are continuously making efforts to provide a better Si detectors.

Thank you for your attention !

www.hamamatsu.com