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Development of next-generation, no-gain Si photodiode array for HL-LHC

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Topic

- Contribution to the LHC
- Development of next-generation sensor for HL-LHC
- Developing technology

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Contribution to the LHC

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Hamamatsu sensor for the LHC

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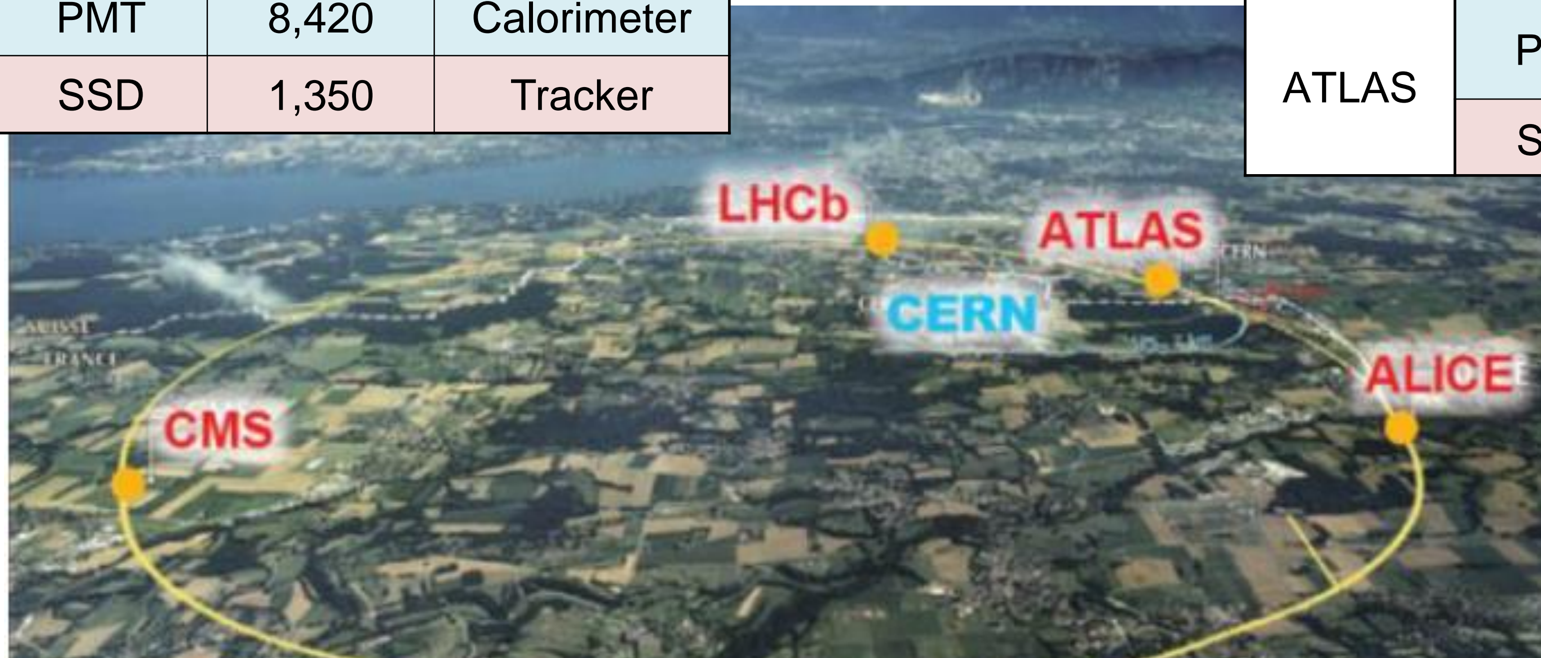
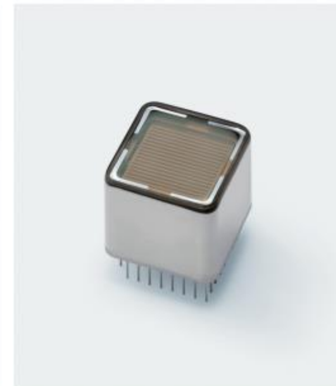
Group	Name of detector	quantity	Application
LHCB	PMT	8,420	Calorimeter
	SSD	1,350	Tracker

Group	Name of detector	quantity	Application
ATLAS	PMT	10,540	Calorimeter, Luminance meter
	SSD	15,570	Tracker





Group	Name of detector	quantity	Application
CMS	PMT	2,425	Calorimeter
	SSD	24,500	Tracker
	APD	140,000	Calorimeter

Group	Name of detector	quantity	Application
ALICE	PMT	70	V0 DETECTOR
	APD	24,000	Calorimeter
	SSD	100	Tracker

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Award from CERN research group

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- Plaque at the CERN entrance

- The CMS Gold Award 2003/2005， Crystal Award
- ATLAS Supplier Award for Hamamatsu Photonics
- LHCb industry Award

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Development of next-generation sensor for HL-LHC

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Development items for HL-LHC

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HL-LHC upgrade requires significant improvements from the previous product specification.

- High radiation hardness
  → Change wafer material from n-substrate to p-substrate.
- Better chip size accuracy and clean edge
  →Stealth dicing
- Reduction of dead area
  →Establishment of 8-inch process line
- Request for Pixel sensor and ASIC modules
  →Flip Chip Bonding

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For high radiation hardness

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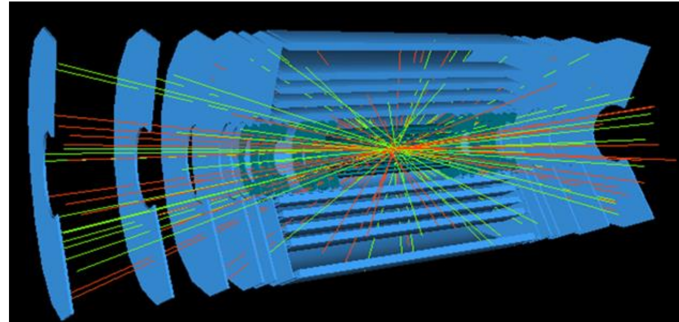
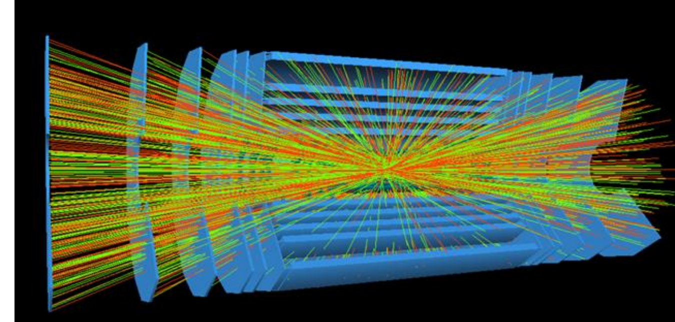
<simulation of collision event>

LHC
$10^{34} cm^{-2} s^{-1}$



HL-LHC
$10^{35} cm^{-2} s^{-1}$



※Thanks to Atlas group simulation

As HL-LHC upgrade, higher radiation hardness is required.
The effects of higher radiation on silicon sensors induce bulk inversion and oxide layer charge up.

	LHC		**HL-LHC**
■ Luminosity (/cm2・s) :	1E34	→	**1E35**
■ Radiation fluence(neq/cm2) :	2E14	→	**1.5E16**

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For high radiation hardness --Bulk inversion--

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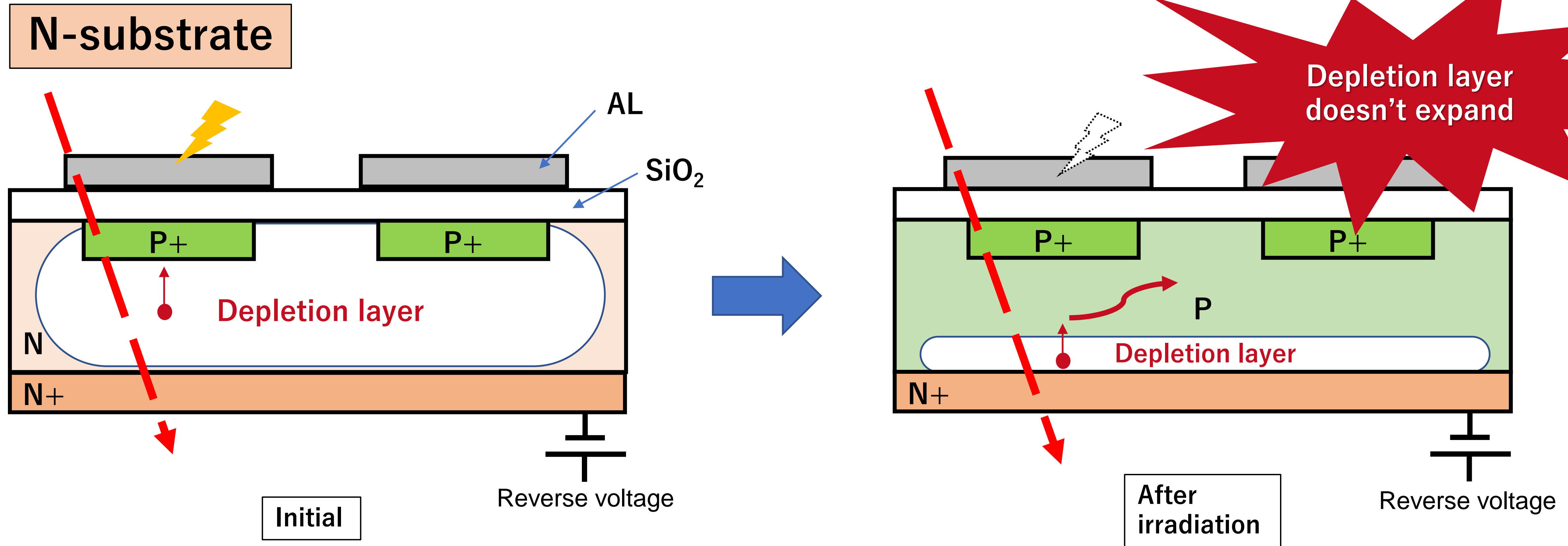

- The Si covalent bond is broken by radiation.
- Accepter level is increased, and substrate is converting to p-type.
- In case of N-substrate, quite high voltage is needed to expand the depletion layer.
  ⇒Changed to p-substrate that can detect with partial depletion.

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For high radiation hardness --Bulk inversion--

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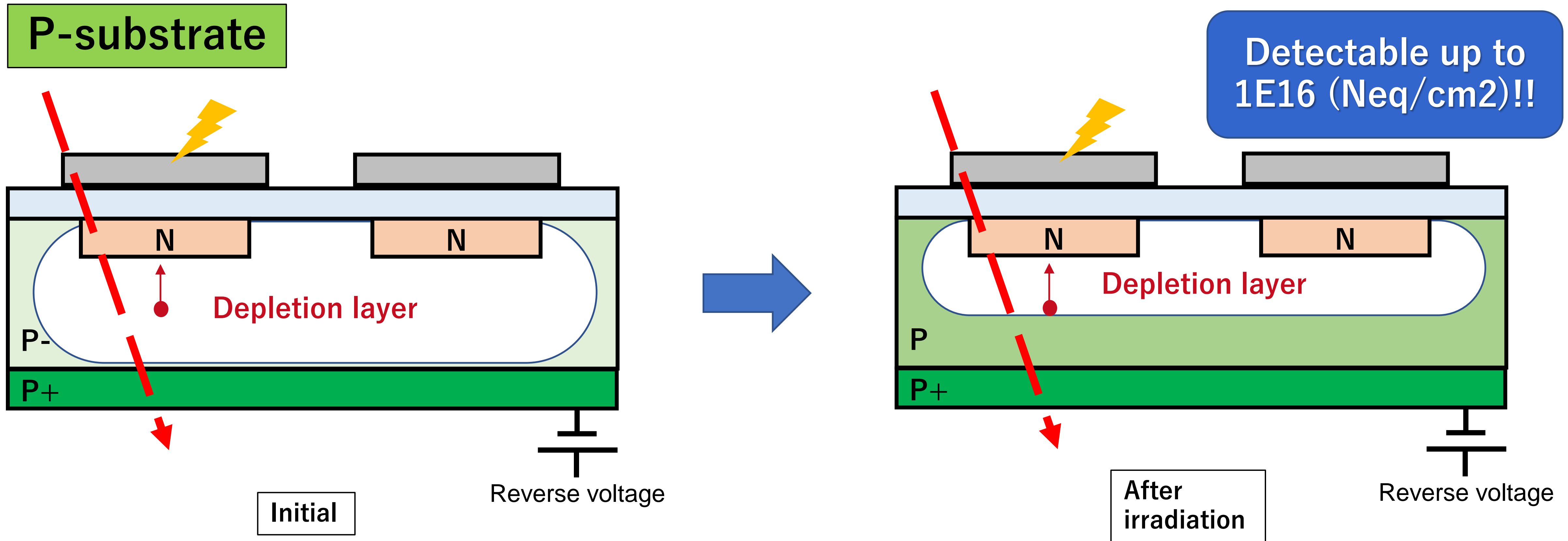

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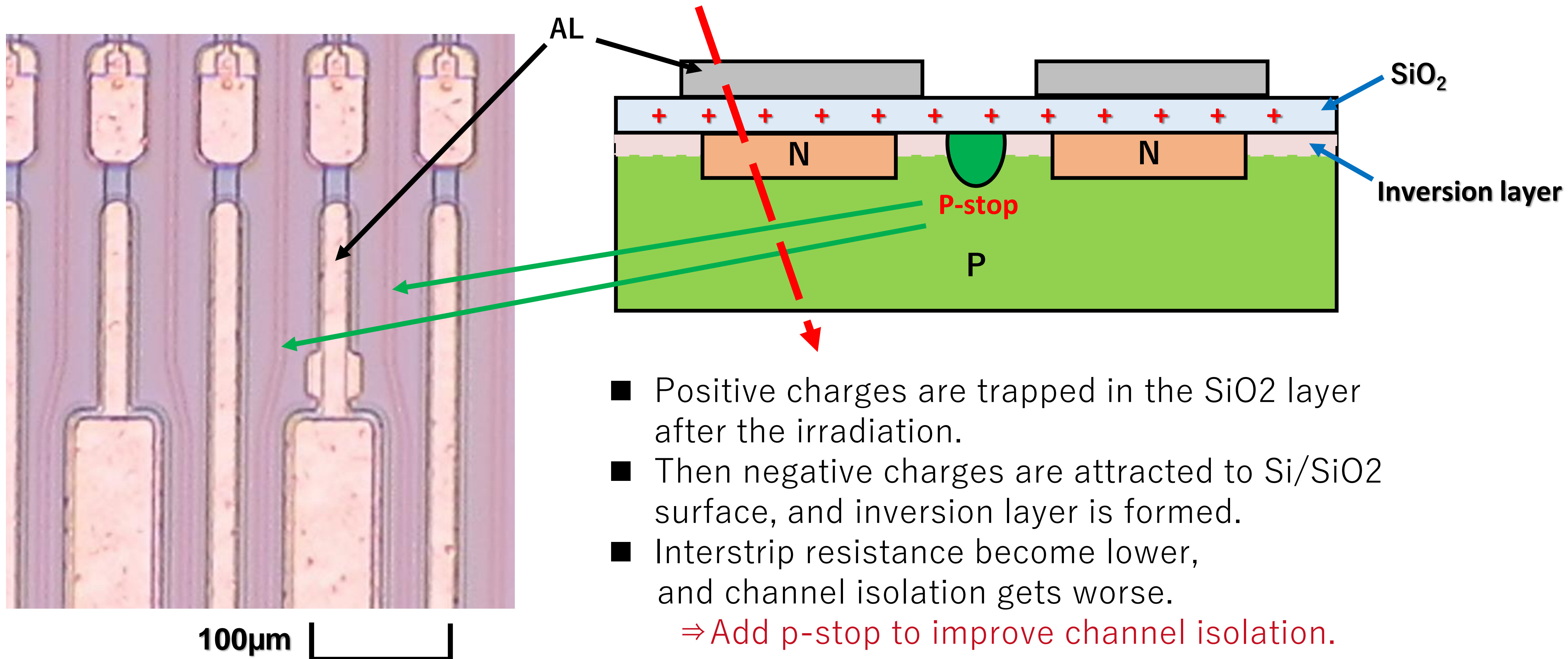
For high radiation hardness --Charge up--



- Positive charges are trapped in the SiO2 layer after the irradiation.
- Then negative charges are attracted to Si/SiO2 surface, and inversion layer is formed.
- Interstrip resistance become lower, and channel isolation gets worse.

⇒Add p-stop to improve channel isolation.

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Stealth dicing --clean edge--

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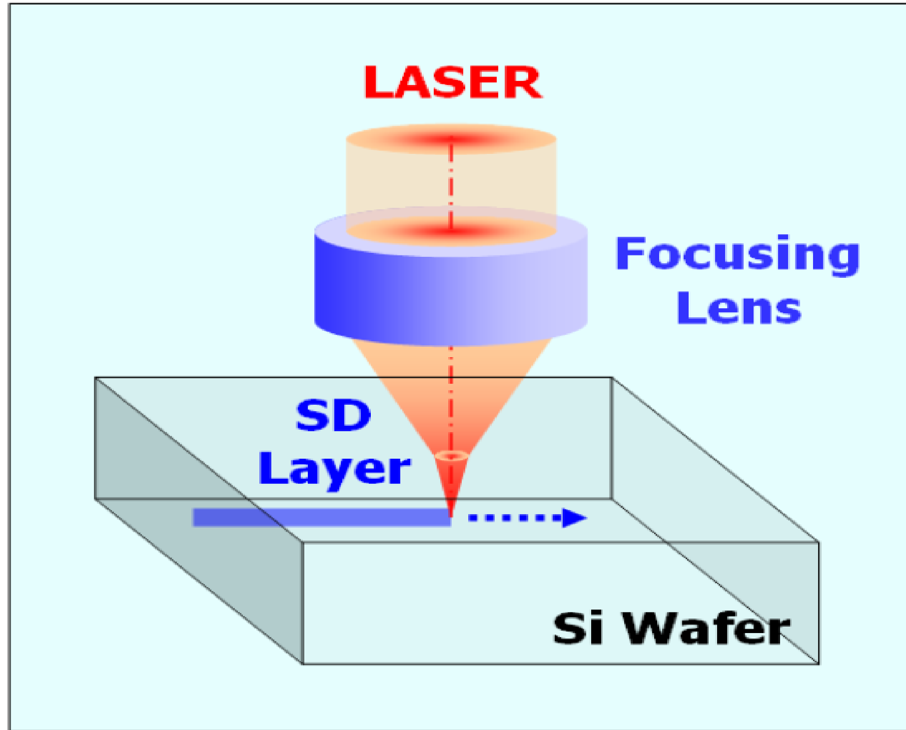
Wafer Dicing by Laser Light

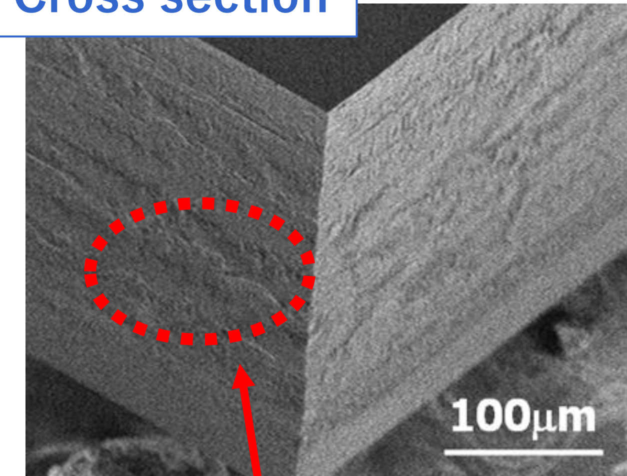


Stealth dicing is high-quality method for cutting and separating wafers internally by laser processing.

Blade dicing

Stealth dicing

Stealth dicing
Cross section



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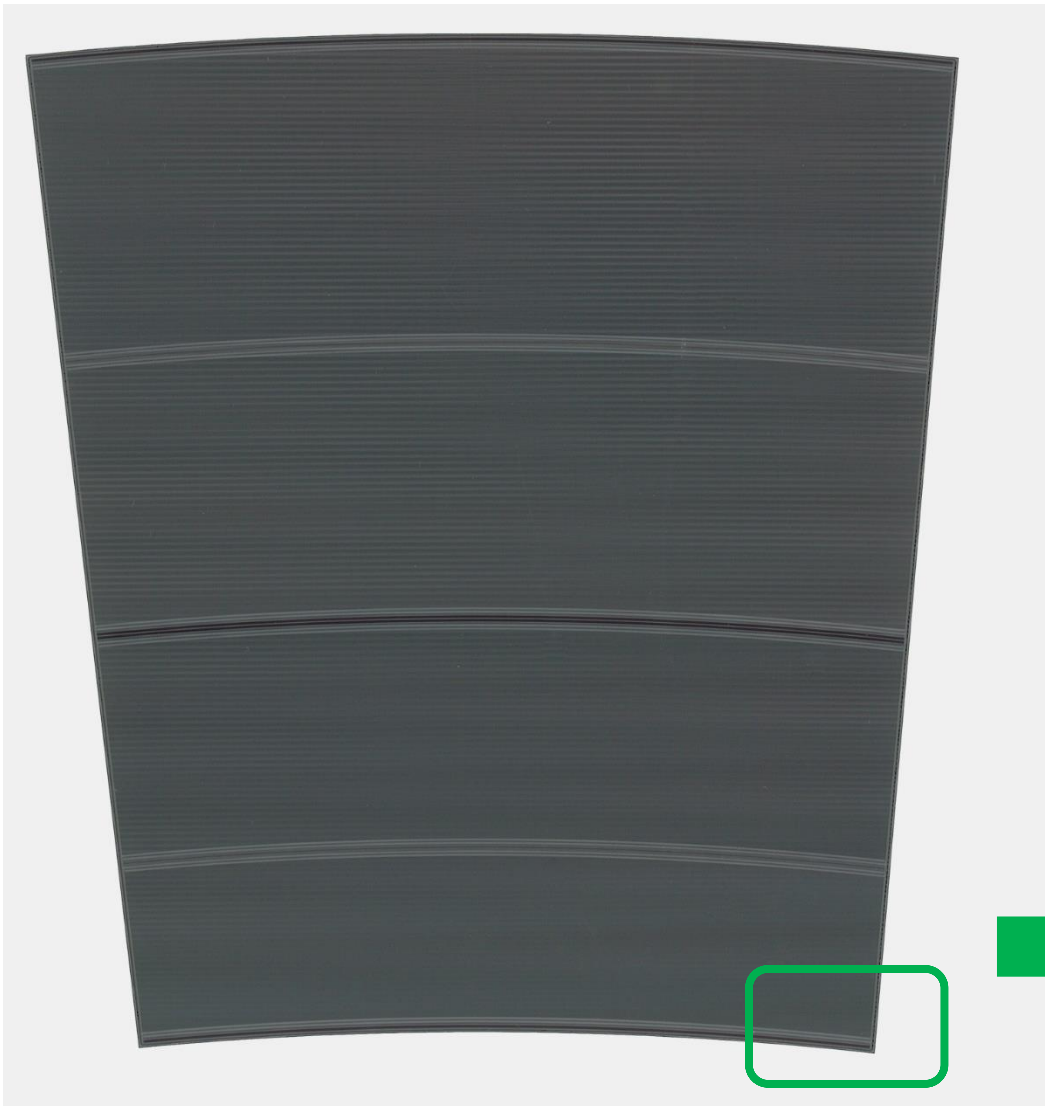
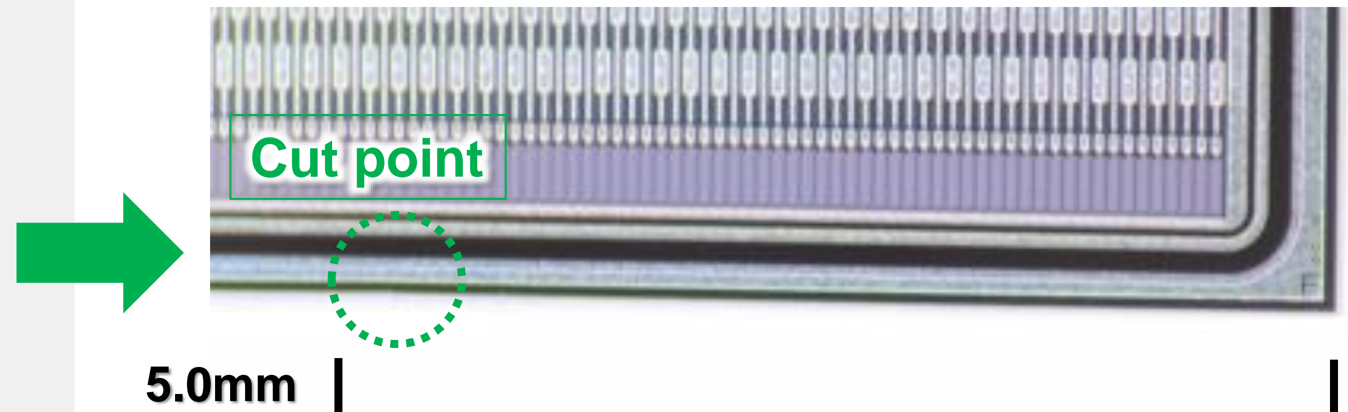
Stealth dicing --round cut--



The arc shape can reduce the dead area of endcap.
→Achieved by polygonal approximation dicing!



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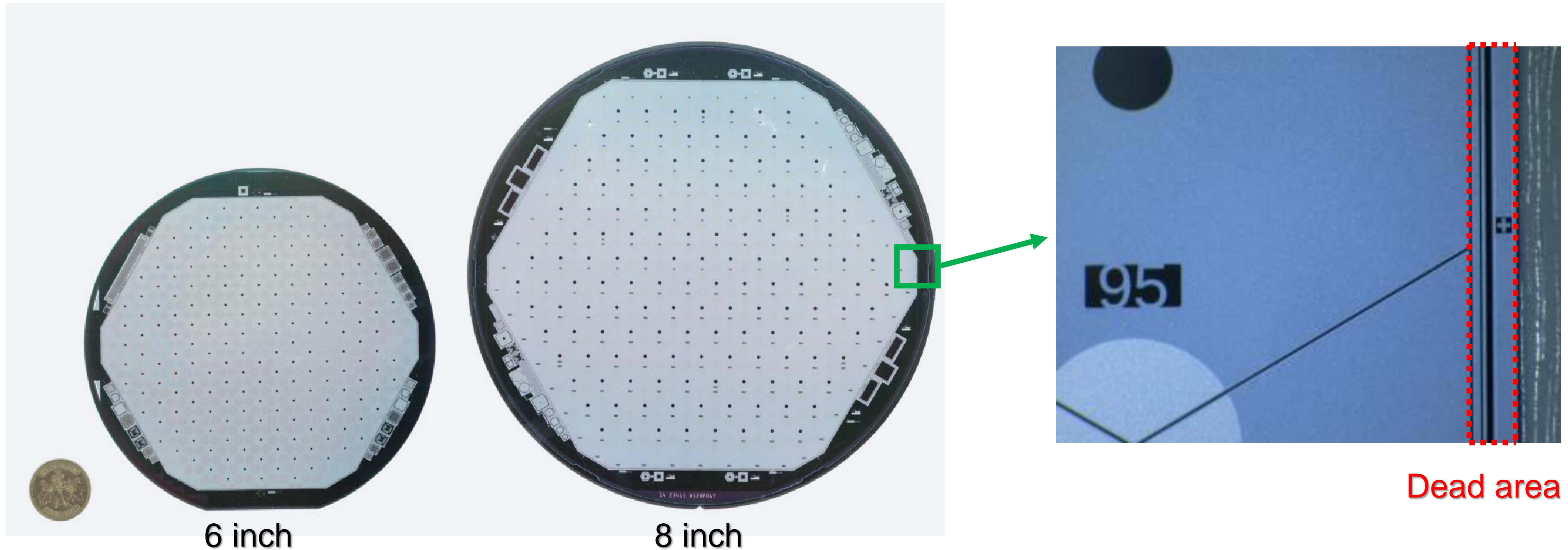
8-inch Pixel Array Detector



- The main object is the reduction of the dead area.
- Approximately twice the sensor size compared to 6-inch prototype.
- Mass production has already started since 2023 Feb. (until 2025 Jun)
- 1,000pcs/M capacity, and totally about 27,000pcs delivery.

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8-inch Pixel Array Detector

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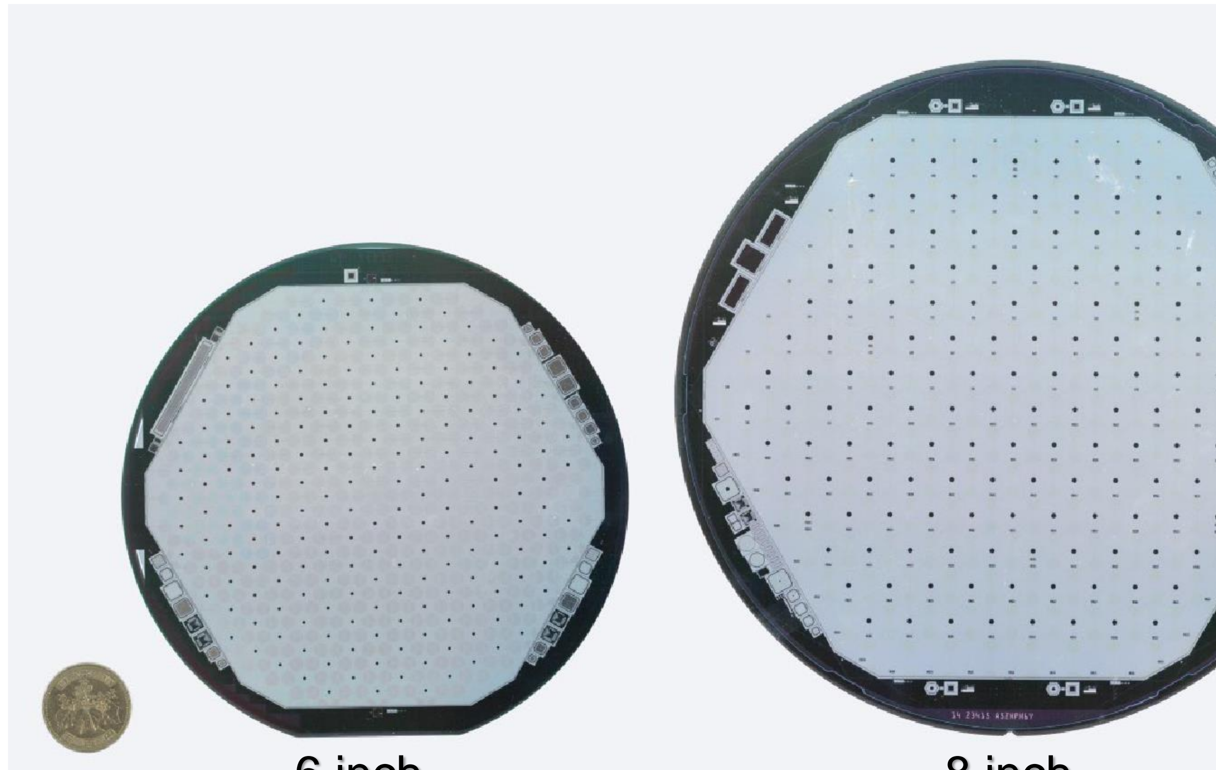


6 inch　　8 inch

あなたの静岡新聞

知っとこ　追っかけ　全国新着

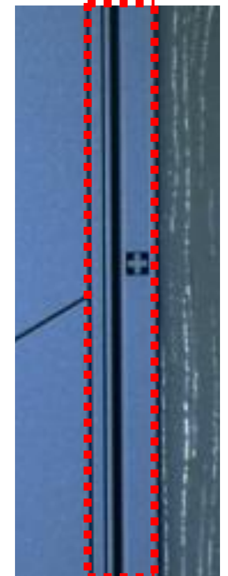
浜松ホトニクス　欧州加速器に新製品　宇宙の謎迫る研究貢献

2023.2.15

浜松総局　日本俊樹

浜松ホトニクスは１４日、スイスの大型ハドロン衝突型加速器（ＬＨＣ）の性能強化に向けた世界最大のフォトダイオード（ＰＤ）アレイの量産体制が整い、契約を結ぶ欧州合同原子核研究所（ＣＥＲＮ）に２７日から本格供給を始めると発表した。大面積化を図り、高い放射線耐性を備えた新製品で、宇宙の謎に迫る実験に貢献する。

試作品（左）から大面積化を図った世界最大のＰＤアレイ＝１４日午前、浜松市中区



ead area

※Thanks to Shizuoka Shinbun

- The main object is the reduction of the dead area.
- Approximately twice the sensor size compared to 6-inch prototype.
- Mass production has already started since 2023 Feb. (until 2025 Jun)
- 1,000pcs/M capacity, and totally about 27,000pcs delivery.

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8-inch Pixel Array Detector
Various issues with past prototypes

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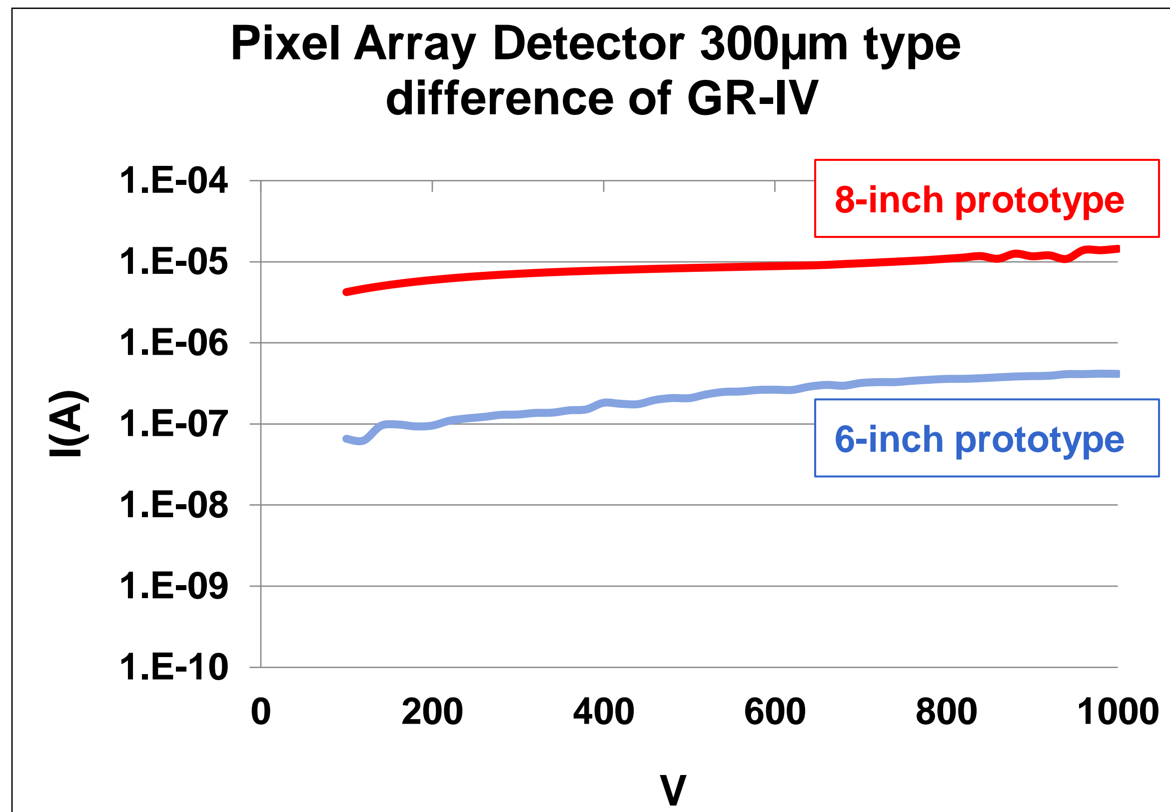

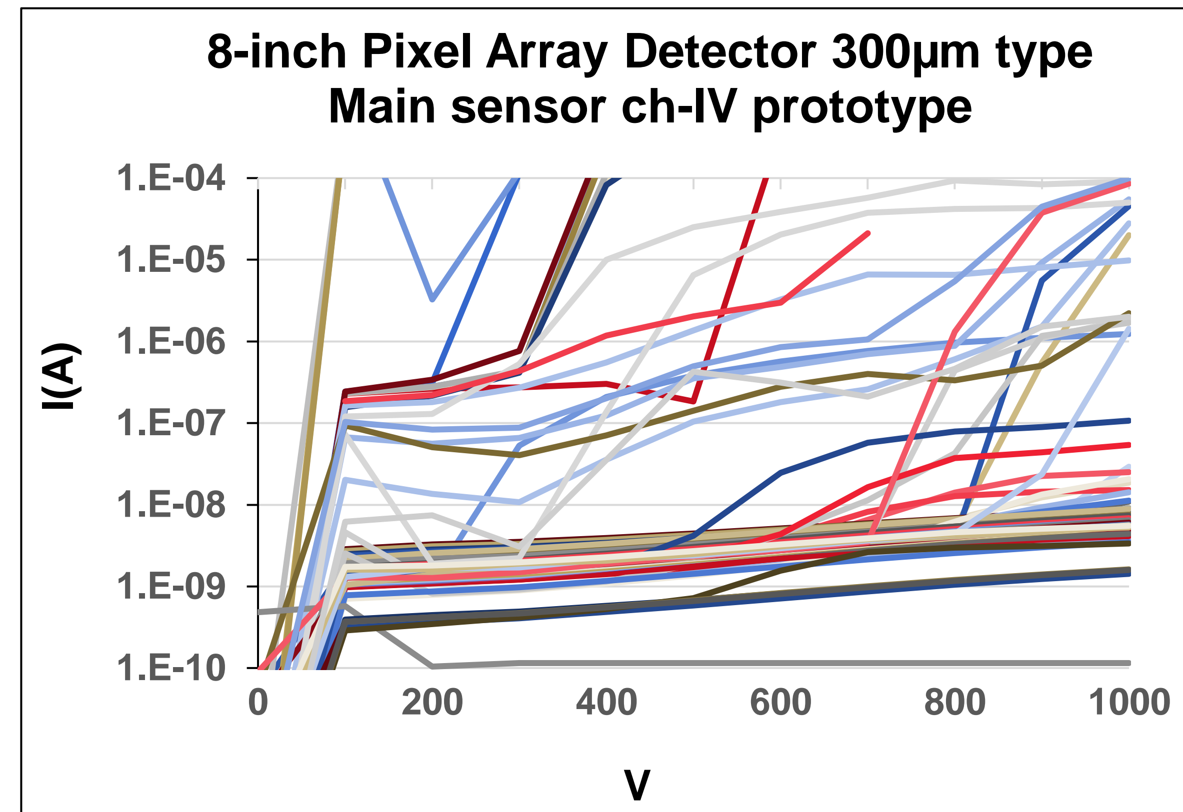

- High leakage current, low breakdown voltage, bad channel isolation, etc…
- We have investigated the cause for some years. And finally, we determined that the condition between channels should be improved.

  →All problems are resolved and become better than 6-inch line products!

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8-inch Pixel Array Detector
Leakage current reduction

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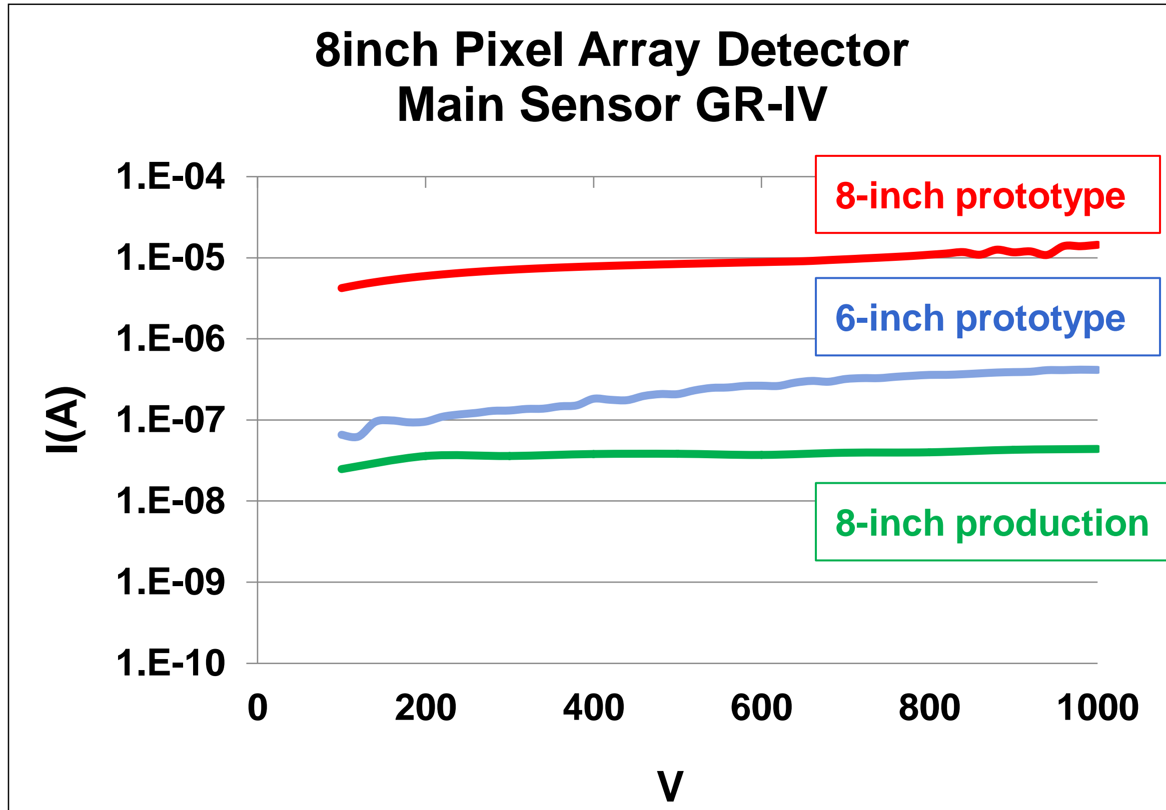

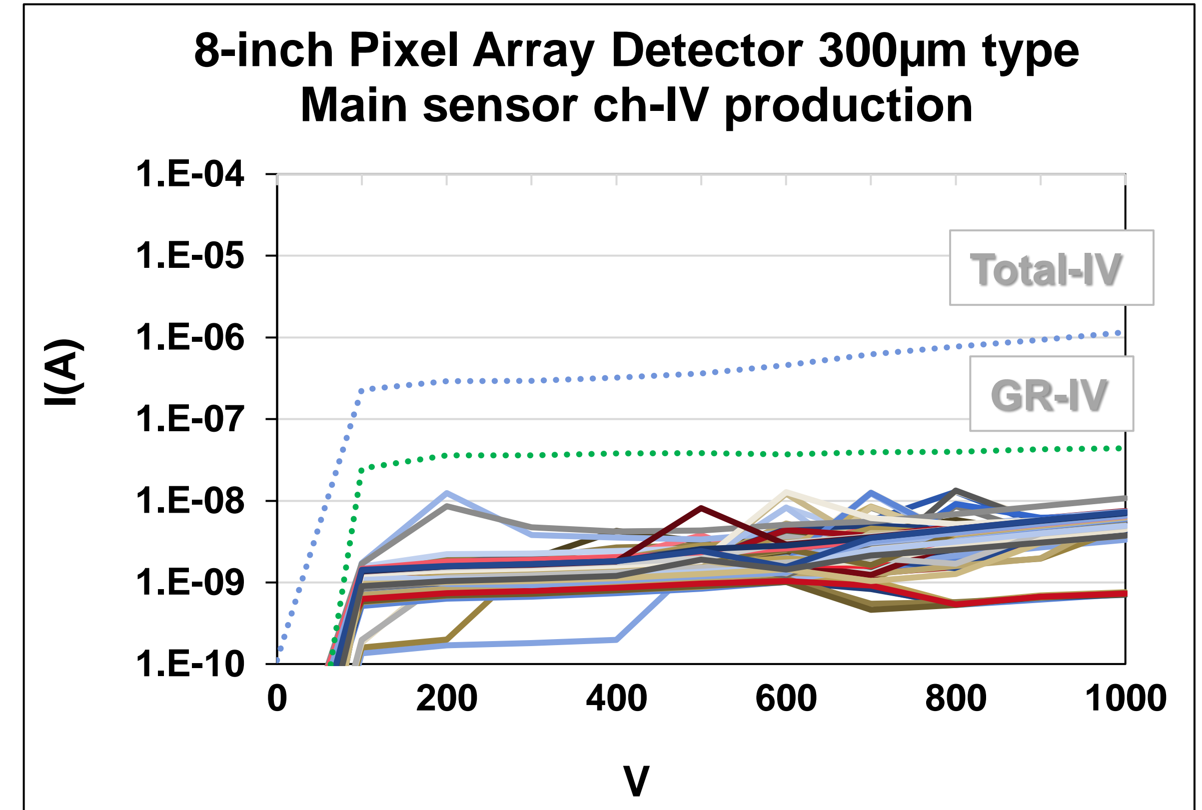

Succeeded in reducing the GR leakage current by more than 2 digits!
1,000V breakdown voltage, and quite low bad ch rate(~1%) are achieved!

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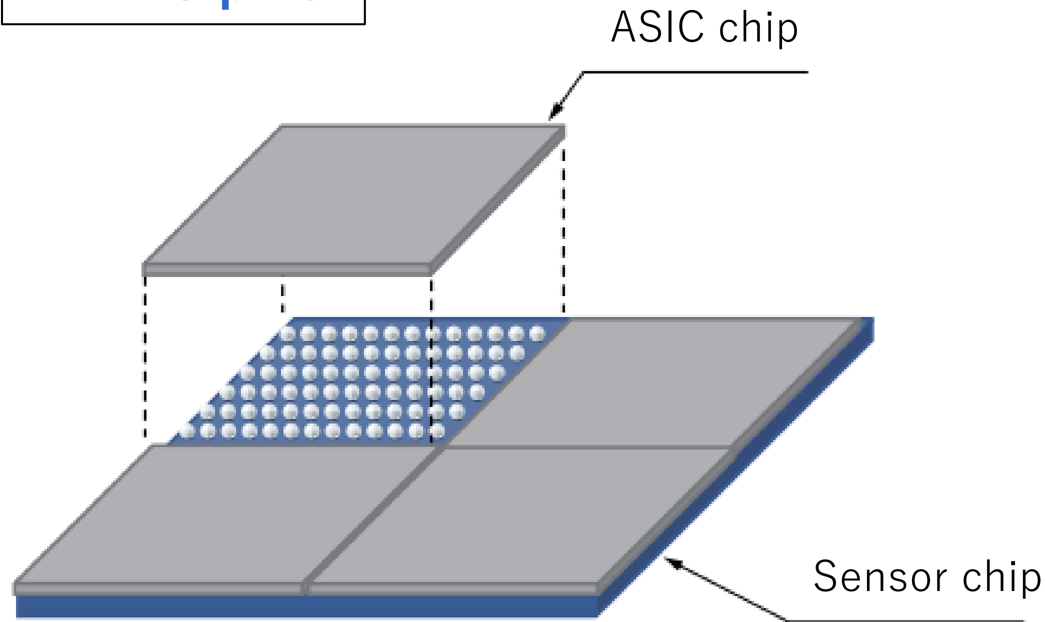
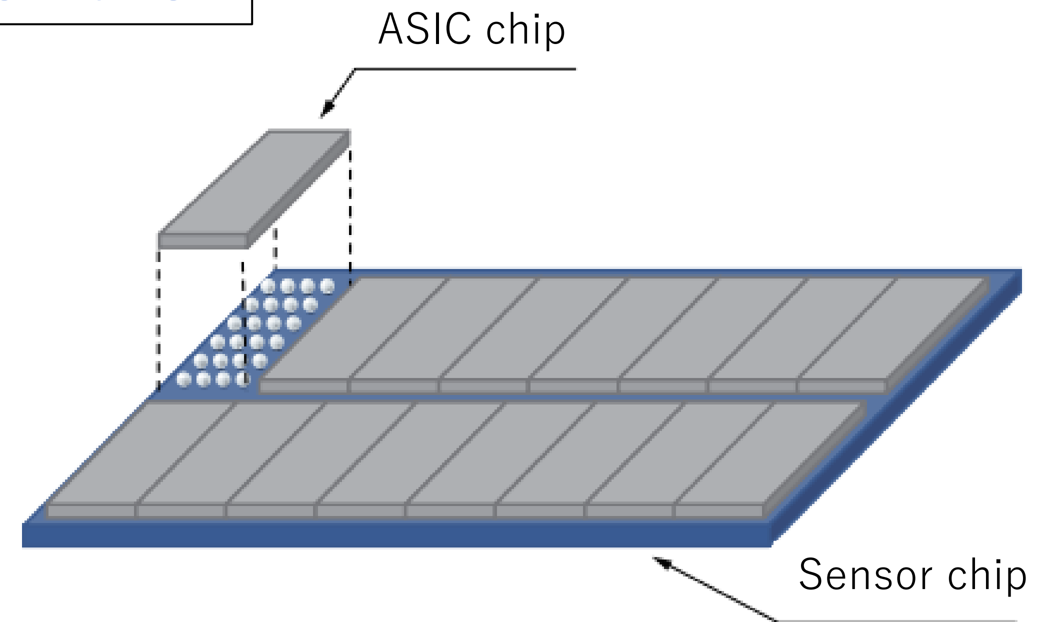
Pixel sensor & ASIC hybridization
Flip Chip Bonding





- HPK sensors for tracker have been shipped as bare chip.
- From HL-LHC, we develop the flip chip bonding technology to meet the demands of ATLAS and CMS.

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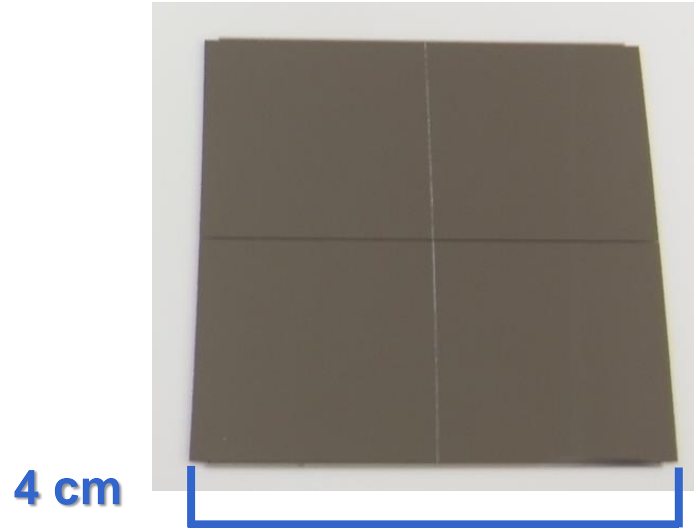
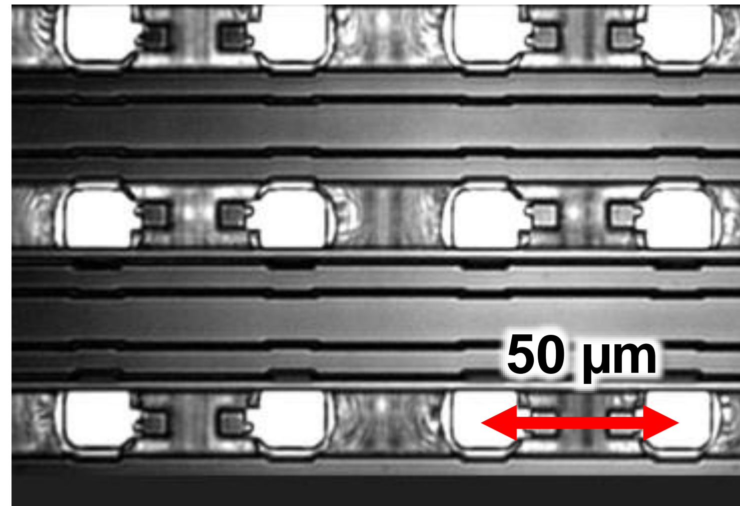
Pixel sensor & ASIC hybridization (ATLAS)
Flip Chip Bond

ATLAS pixel



	Sensor	ASIC
chip size (mm)	39.5 x 41.1	21.1 x 20.1
Number of bump	614’400	
Tile	1	4 (2x2)
Bump pitch (µm)	50	

IR plan



Cross section

A huge number of channels, 614K, can be connected with an NG rate of 1% or less.

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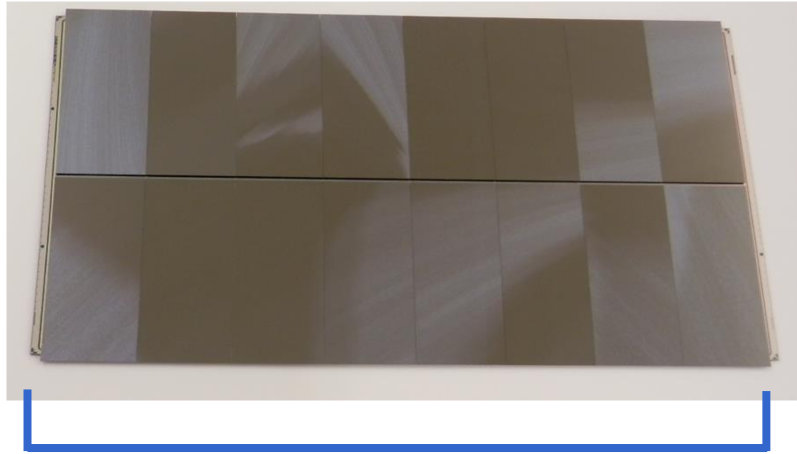
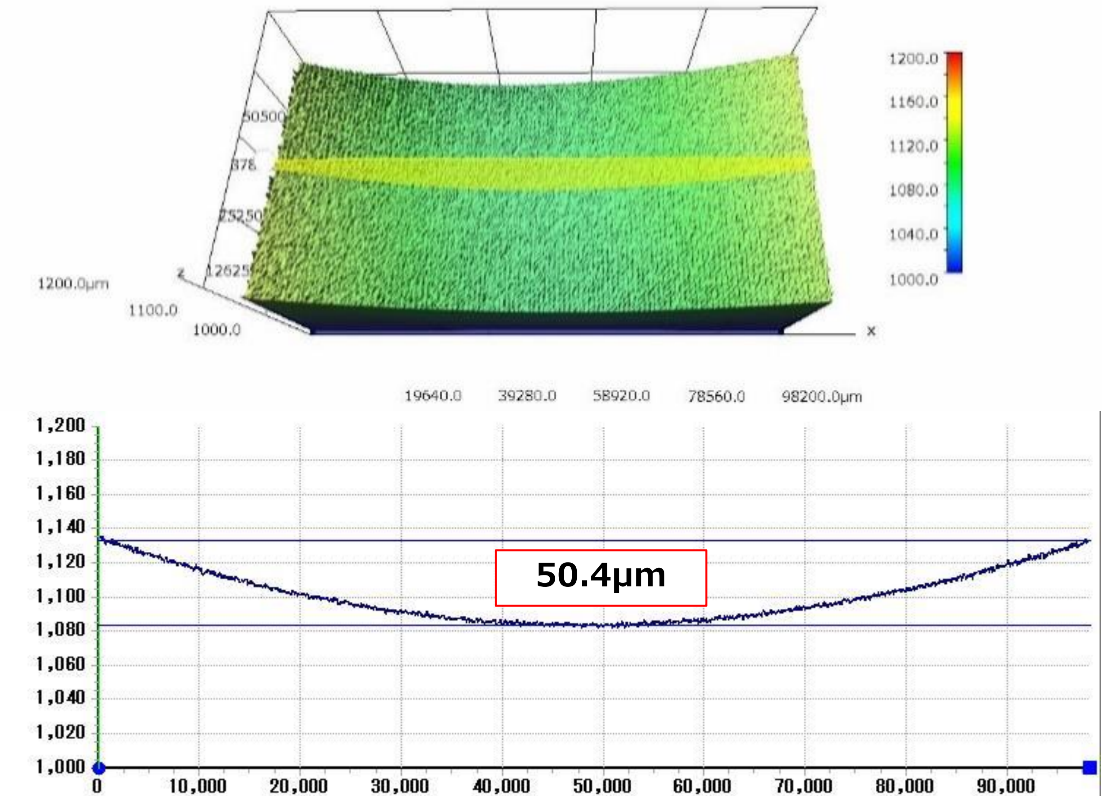
Pixel sensor & ASIC hybridization (CMS)
Flip Chip Bond

CMS MaPSA



	Sensor	ASIC
chip size (mm)	**98.7 x 49.2**	**12.0 x 25.3**
Number of bump	30’688	
Tile	1	16 (8x2)
Bump pitch (μm)	200	

Flatness measurement



Even with 10 x 5 cm sensor, ASIC can be mounted with about 50 μm bow.

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Developing technology

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Direct Bond Interconnect (DBI)

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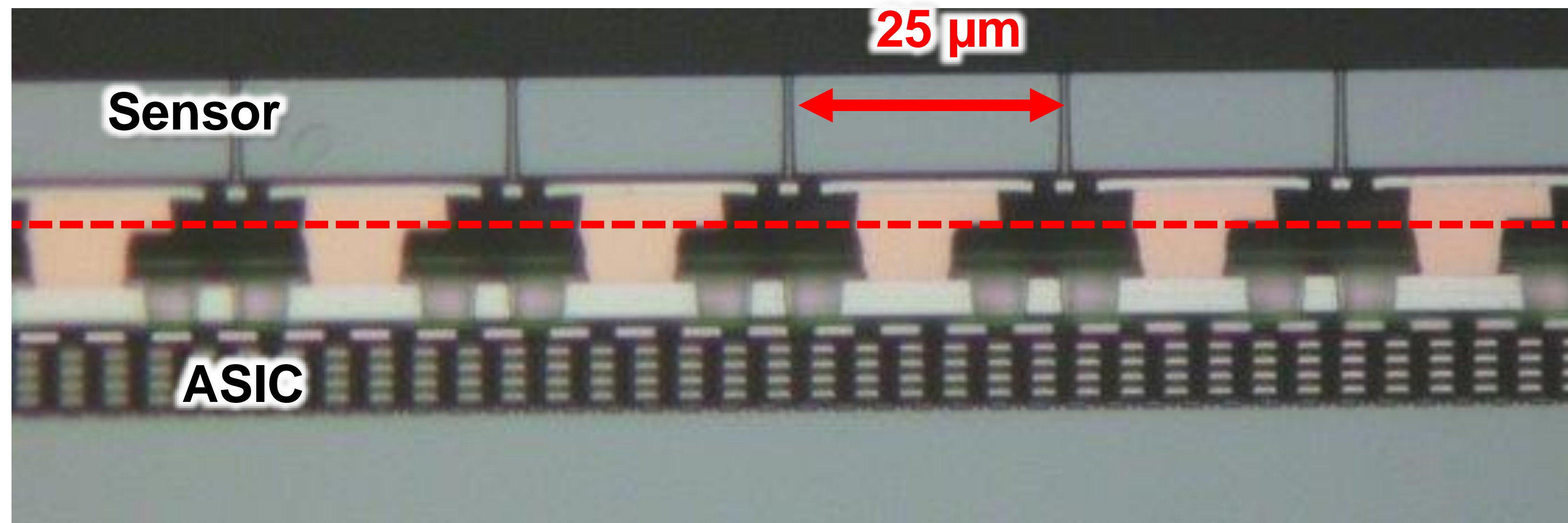
We are currently developing narrower pitch assembly in future.



Direct wafer-to-wafer bonding of sensor and ASIC.
(Cu-Cu connection)

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Summary ---Development items---

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- High radiation hardness
  → Change wafer material from n-substrate to p-substrate.
- Better chip size accuracy and clean edge
  →Stealth dicing
- Reduction of dead area
  →Establishment of 8-inch process line
- Request for Pixel sensor and ASIC modules
  →Flip Chip Bonding

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Closing

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- **At this Hiroshima symposium, I will participate fully 12/4～12/8.**
- **We also exhibit Hamamatsu booth during the symposium.**
- **If you have any interests, please feel free to speak to us!**

Thank you for your attention.

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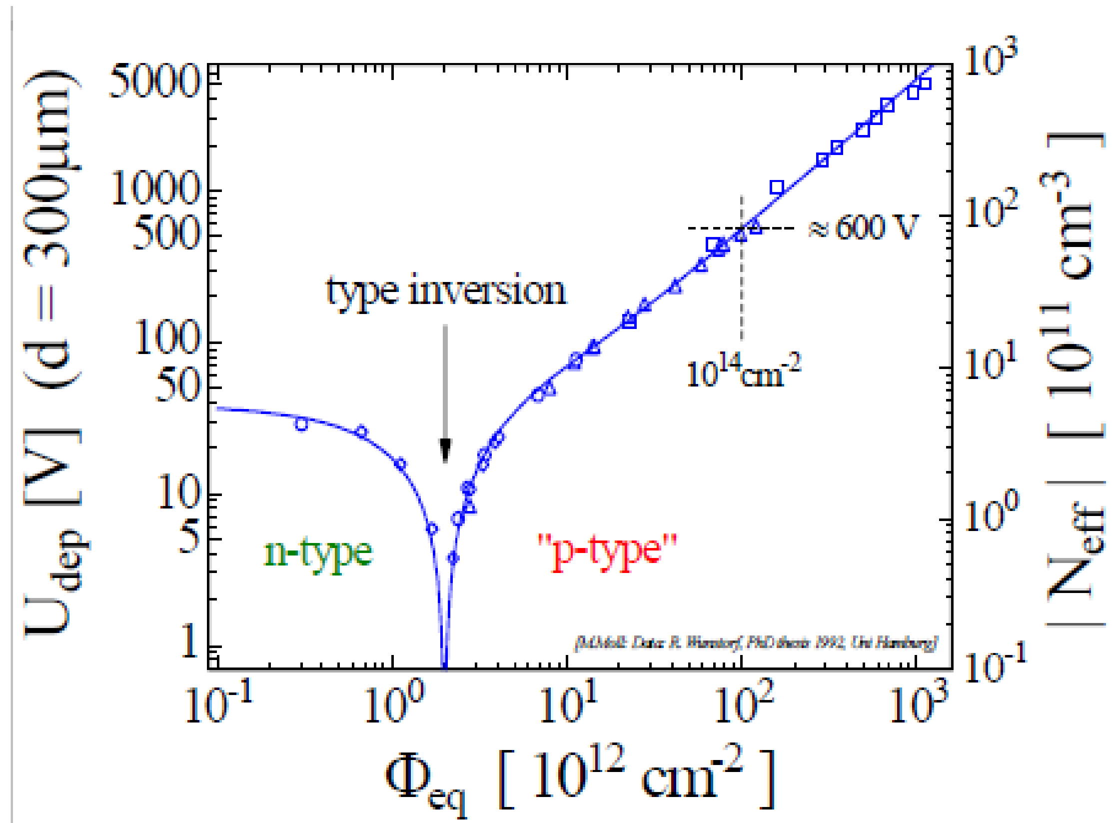
Bulk inversion



※Thanks to Tsukuba Univ.

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