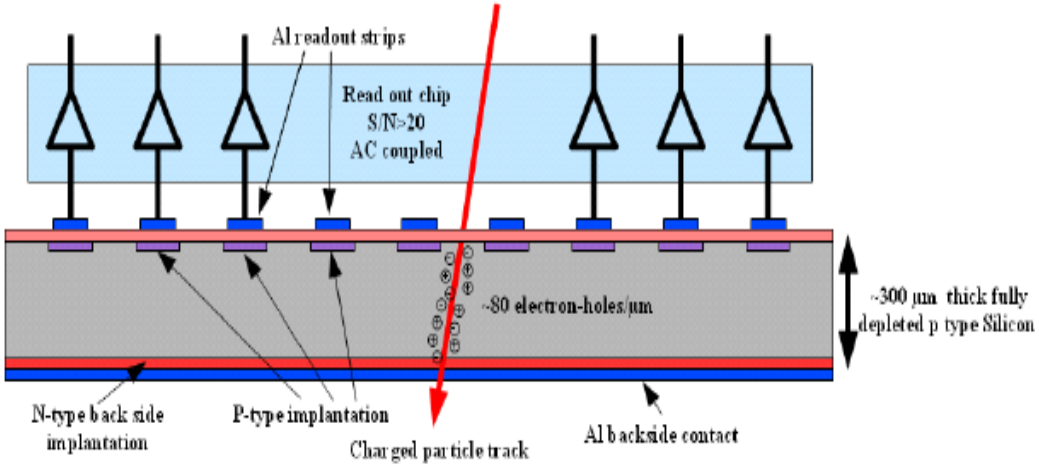
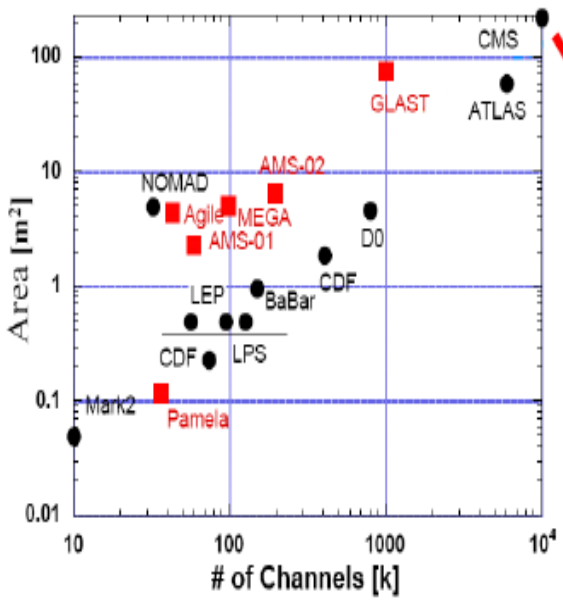
Prospects for Si sensors in Korea

Ming Liu (LANL)
for
Youngil Kwon and Ju Kang
(Yonsei Univ., Korea)

Microstrip silicon sensors in particle physics: a success story!





CMS Silicon Inner Tracker:
223 square meters of silicon!!!

Possibility in Korea

Excellent cost effective R&D and Fabr. Environement

PHENIX MPC-EX
Silicon Sensor MOU

6 inch fabrication line

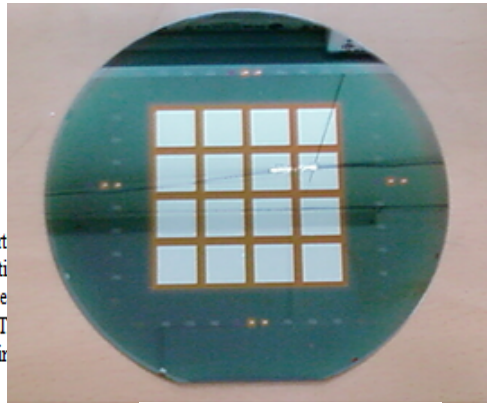
MEMORANDUM OF UNDERSTANDING(MOU)

among

(1) Youngil Kwon, Mann-Ho Cho, Gyetae Park, Department of Physics, Yonsei Univ., Korea
(2) Edward Kistenev, Andrey Sukhanov, Physics department, BNL, USA
(3) John Lajoie, Physics and Astronomy, Iowa State University, USA
(4) Yongsun Yoon, BT division, ETRI, Korea
(5) Kwun-bum Chung, Elecrophysics department, Dankook Univ., Korea
(6) Zheng Li, SDDPL, Instrumentation, BNL, USA
and
(7) Jinsoo Kim, National Nano Fabrication Center, Korea

I. Purpose & Scope
The purpose of this MOU is to state common academic interests of participating part
the '**Radiation damage and radiation defects in Si sensors/devices**'. Participati
planning to contribute their own experiences and equipment necessary in the course
studies. This MOU clarifies the areas of particular interests of participating parties. T
collaborate by sharing their expertise and seek common funding among agencies fundi
parties for the stated academic goal.

II. Responsibilities Under this MOU
A. Dr. E. Kistenev, and Prof. J. Lajoie, and Prof. Y. Kwon will propose silicon semiconductor detectors/devices to achieve academic goals in their field of interest in the experimental nuclear and high energy physics.
B. Dr. Z. Li will design the proposed silicon semiconductor detectors/devices using standards approved by industry for large area radiation hard Si devices and will advice on the radiation induced defects in Si devices.
C. Dr. A. Sukhanov will advice on the electronic design and implementation of the readout electronics for silicon semiconductor device testing.
D. Dr. Yoon will inspect designs of the proposed detectors/devices and advise on matching design ideas to fabrication technologies. He will also perform his own radiation hardness testing of the devices he develops.
E. Prof. M.-H. Cho, Prof. G. T. Park, and Prof. K. B. Chung will advise on possible defects in silicon sensors/devices and will study radiation defects in the produced sensors/devices exposed to different kinds of radiation.
F. Mr. Kim, leader of nano patterning process team in National Nanofab Center, will assist in fabrication of the silicon sensors/devices with university discount program and consult on details of silicon detector device fabrication process.

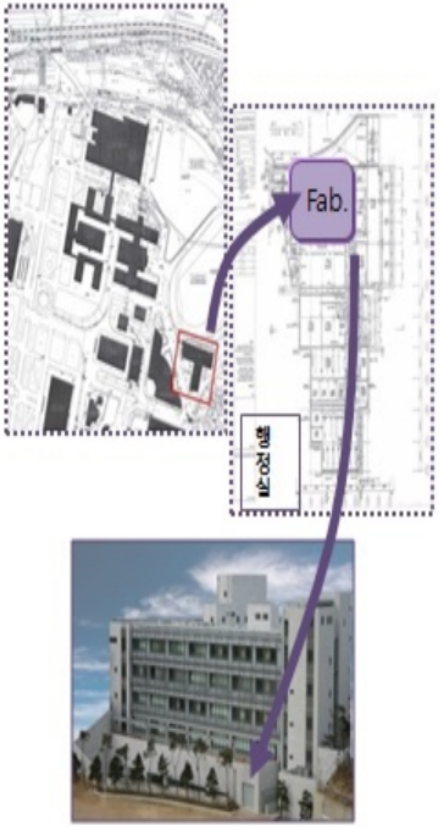


1 cm^2 ~ $ 2

8 inch fabrication line

Yonsei Uinv. BIO-IT Micro Fab.

-. 시설개요



위치	연세대학교 첨단과학
면적	분양면적 150평 / 전용
행정실	첨단과학관 510호
공간배분	• Access Floor 상단 : • Access Floor 하단 : • Fab 외부 공간 : 유틸
공간구성	• 공정실 : 68.9 • Photo Room : 11.4 • 측정실 : 6평 / • Smock Room : 6평 • 반입구, 가스저장소

구성원 소개

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· 담당분야 : 장비유지 관리

Samsung S5K8AA

Ultra thin HD image sensor for compact mobile application

HD 1/8" 1.4um BSI Pixel Image Sensor provides;

- HD sensor integrated Image Signal Processor suitable for slim mobile phone, tablet and notebook
- High speed HD 30fps and VGA 60fps
- BSI sensors providing clear and sharp still images in low light, YSNR10 86 Lux

SK hynix

SAMSUNG

SK하이닉스 M8라인, 시스템반도체 전환 완료

애플을 최대 고객사로 확보

서울시민신문

▲ SK하이닉스 M8라인. © 서울시민신문

SK하이닉스가 청주 M8 라인을 거점으로 시스템반도체 생산을 본격화했다.

10월 25일 유경동 SK하이닉스 상무는 `국제반도체컨퍼런스 2012`에서 청주 소재의 자사 M8 공장을 메모리에서 시스템반도체로의 전환 작업을 성공적으로 끝냈다고 밝혔다.

M8 공장은 CMOS 이미지 센서(CIS)와 DDI, 전력반도체(PMIC), 고주파(RF), 베이스밴드 반도체를 생산한다. CIS의 경우 90나노미터(㎚) 공정 기반으로 터치스크린과 드라이버칩

Dongbu HiTek

CIS (CMOS Image Sensor) | SPECIALIZED FOUNDRY

Design Toolkits, 웨이퍼 가공, 패키지, 테스트 등 턴키 서비스 제공

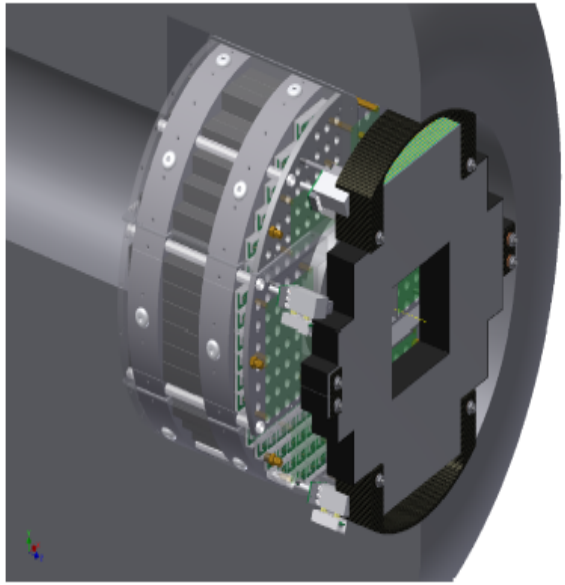
CMOS 이미지 센서는 렌즈를 통해 들어오는 빛을 전기적 신호로 전환하는 디지털 제품의 핵심 부품으로, 저전력·초소형·저비용이라는 제품의 특성 때문에 캠코더, 디지털 카메라, PC용 카메라, 이동전화, PDA, 스캐너, 팩스 등에 널리 쓰이는 등 제품의 수요가 급증하고 있는 첨단 기술 분야입니다.

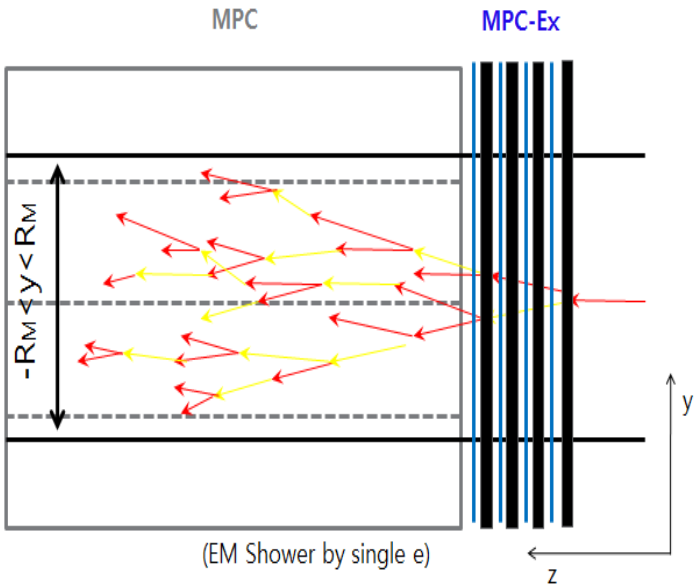
동부하이텍은 국내외 Fabless 등 고객사들에게 보다 저렴한 비용과 편리한 서비스를 제공하기 위해 CIS 제품 개발에 필요한 디자인 툴킷(Design Toolkits)을 제공하고 있으며, 웨이퍼 제조공정, 패키지, 테스트 등 이미지 센서 양산에 필요한 모든 공정들을 일괄적으로 서비스하고 있습니다.

동부하이텍이 제공하는 CIS(CMOS Image Sensor)기술은 0.18㎛ 와 0.13㎛급 기술을 기반으로 하고 있으며, CIS 공정기술의 경우 N+/PW Photo Diode와 Color Filter, Microlens 등을 제공하여 CIF, VGA, Mega-Pixel 등 다양한 형태의 CIS 칩을 양산하고 있습니다.

Minipad Sensor for PHENIX MPC-EX

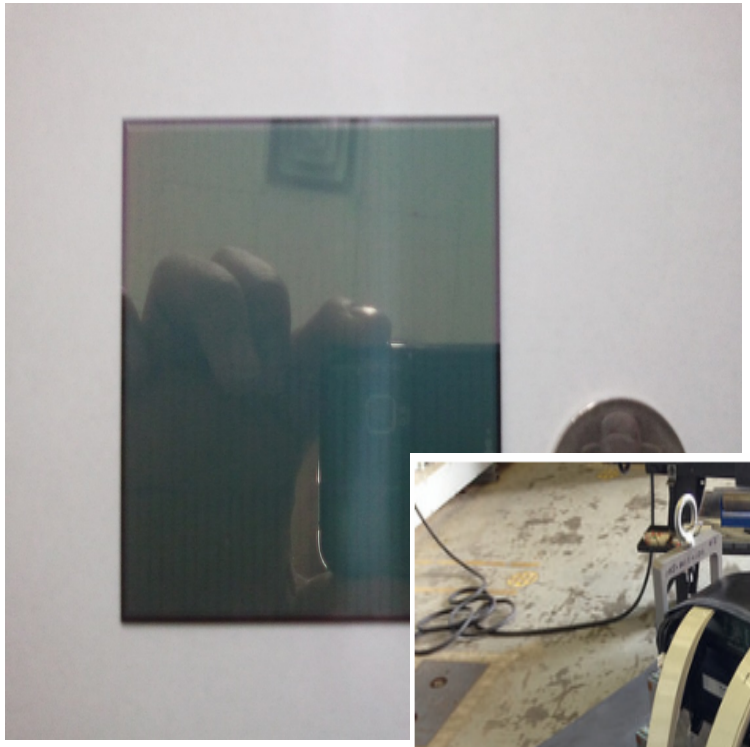
Installed in PHENIX in 2014, successfully participated in data taking in Run15





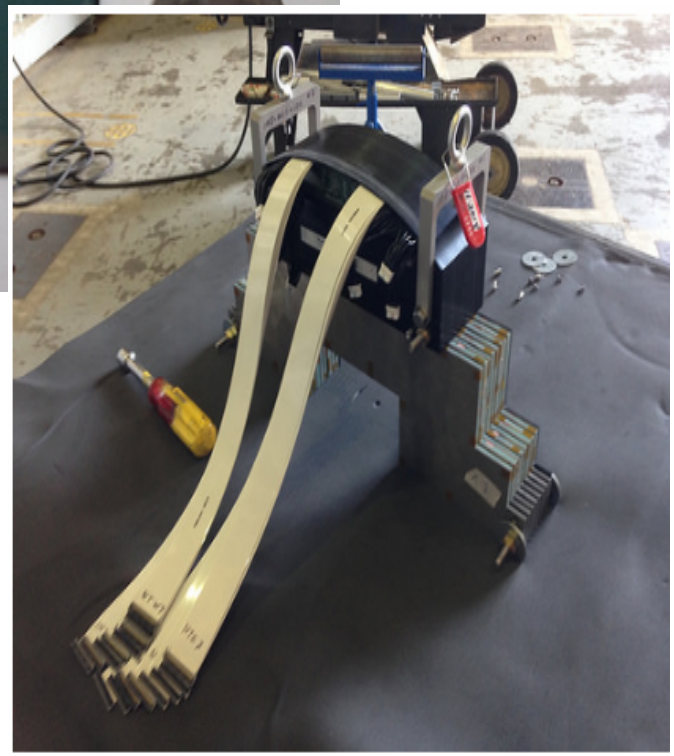
MPC-EX (**M**uon **P**iston **C**alorimeter **Ex**tension) is a pre-shower detector for the electromagnetic calorimeter called **MPC**(**M**uon **P**iston **C**alorimeter) of the experiment **PHENIX**. Minipads are used as the active sensors in MPC-EX to detect charged particles appearing in pre-shower, initial part of an electromagnetic shower. **MPC-EX** will reconstruct π^0 particles within its acceptance up to the momentum of 50 (GeV/c).

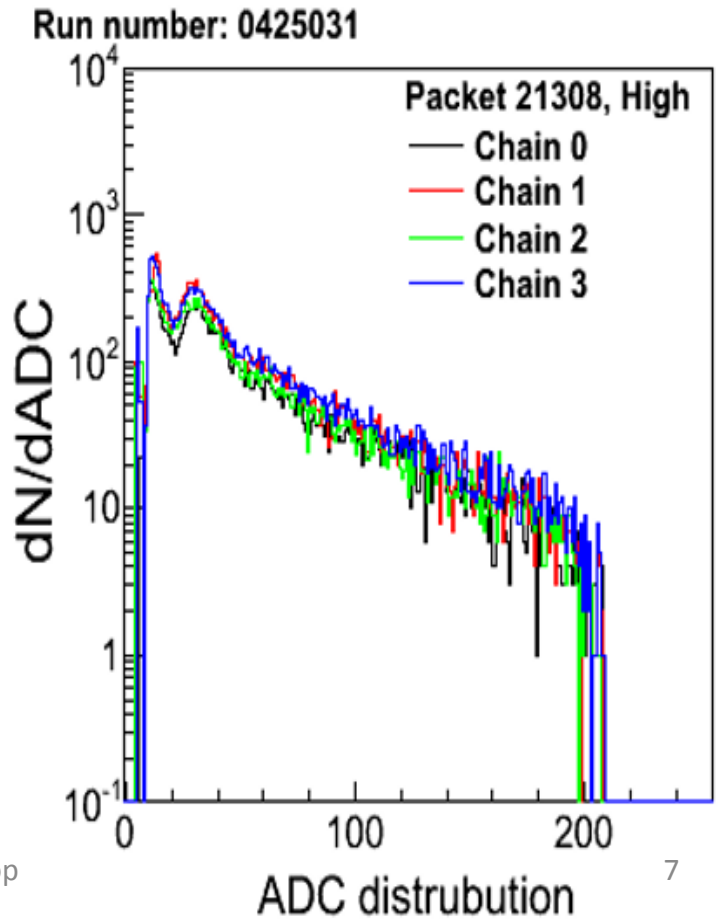
Korean PHENIX MPC-EX Sensors



Minipad: 6.2cm x 6.2cm

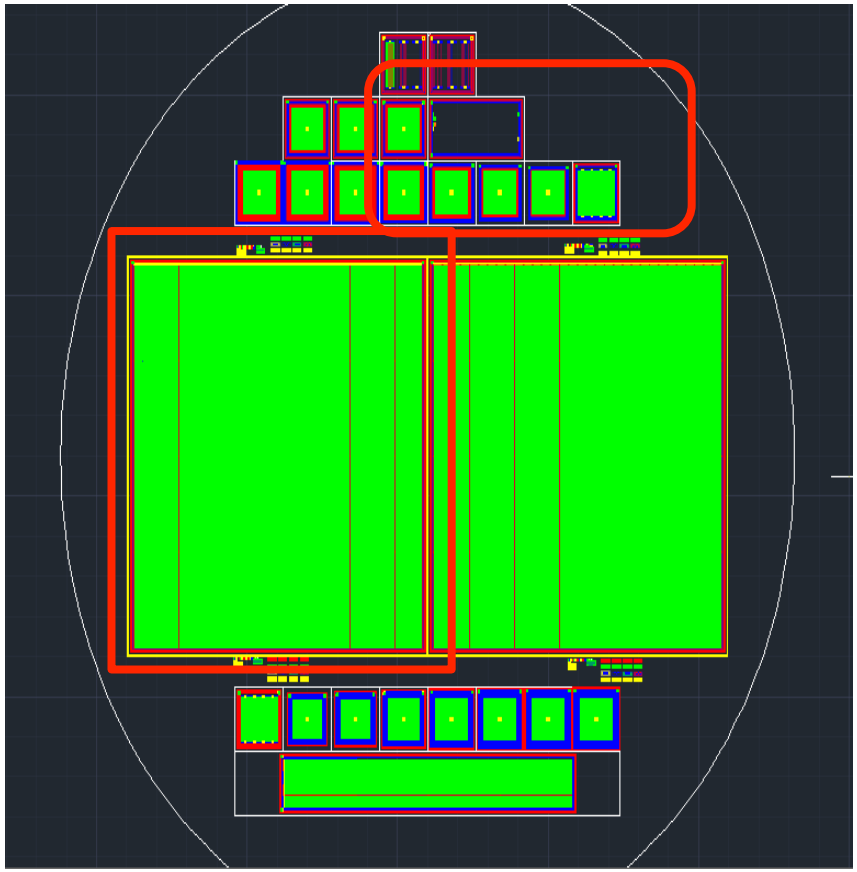
Strip size: 1.5 mm x 15mm x 500um



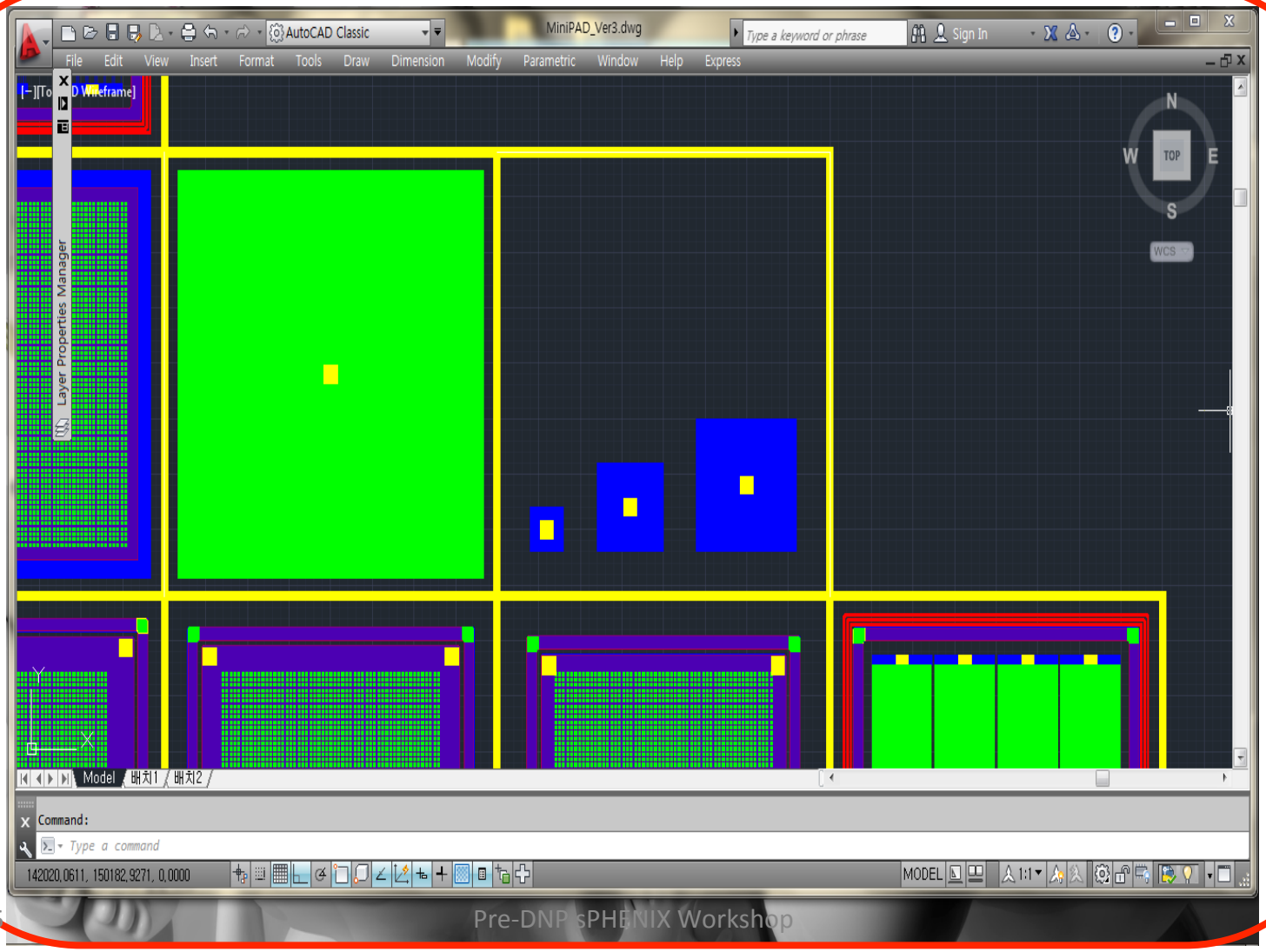


What was done in Korea on MPX-EX Sensors…

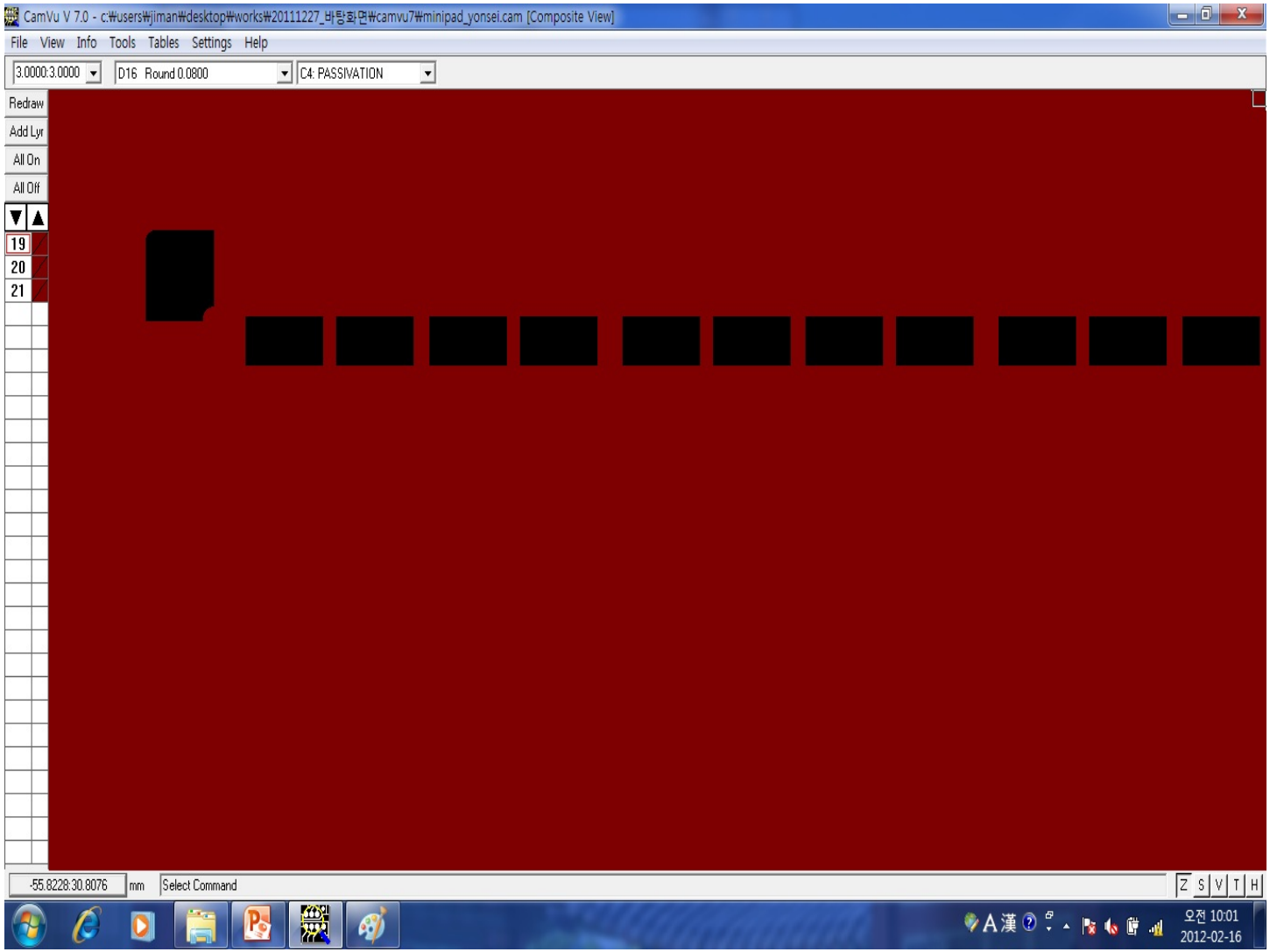
Sensor Design



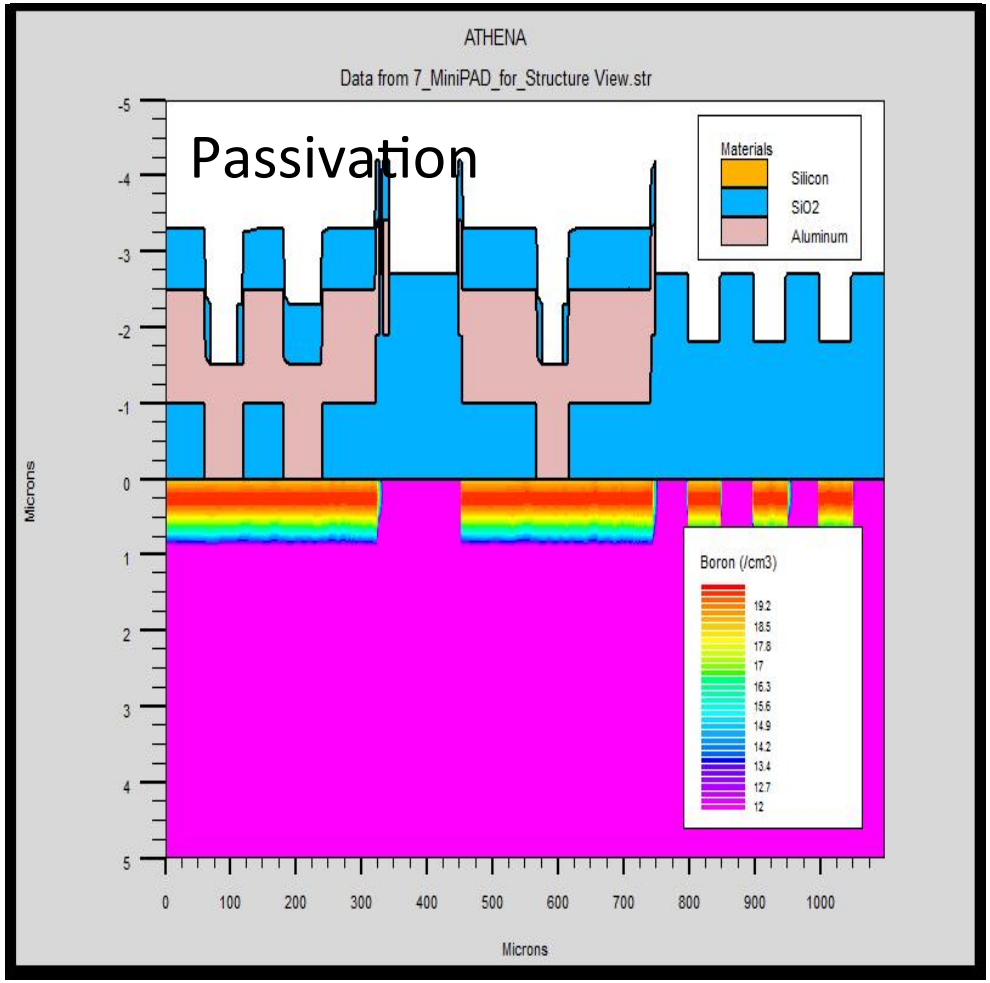
Test structure



Actual masks

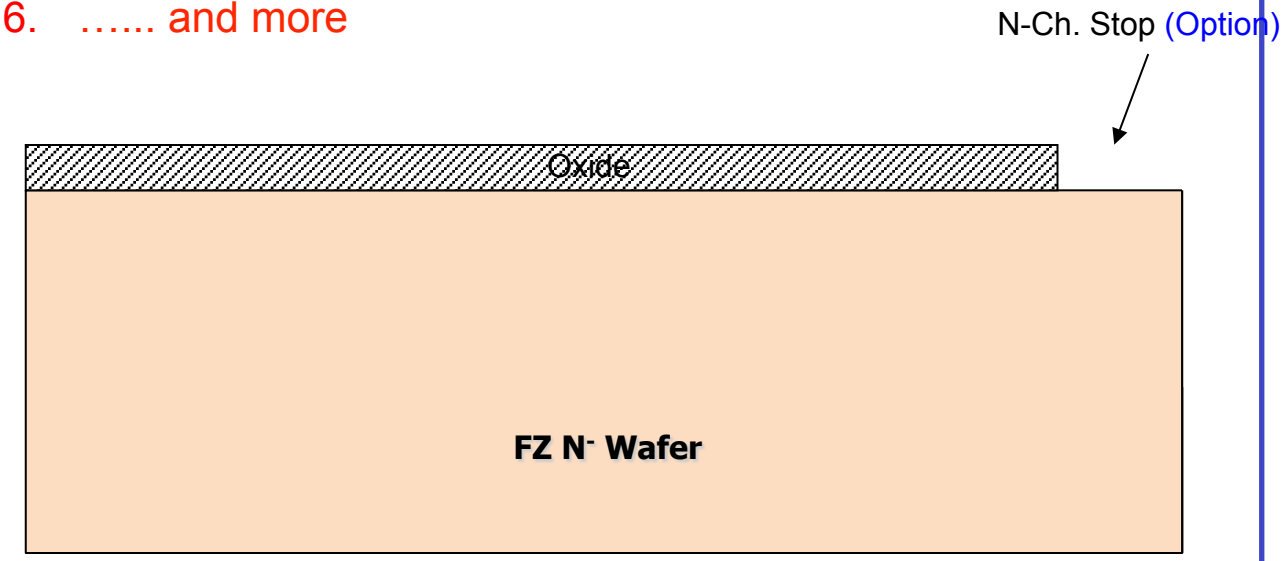


Fabrication

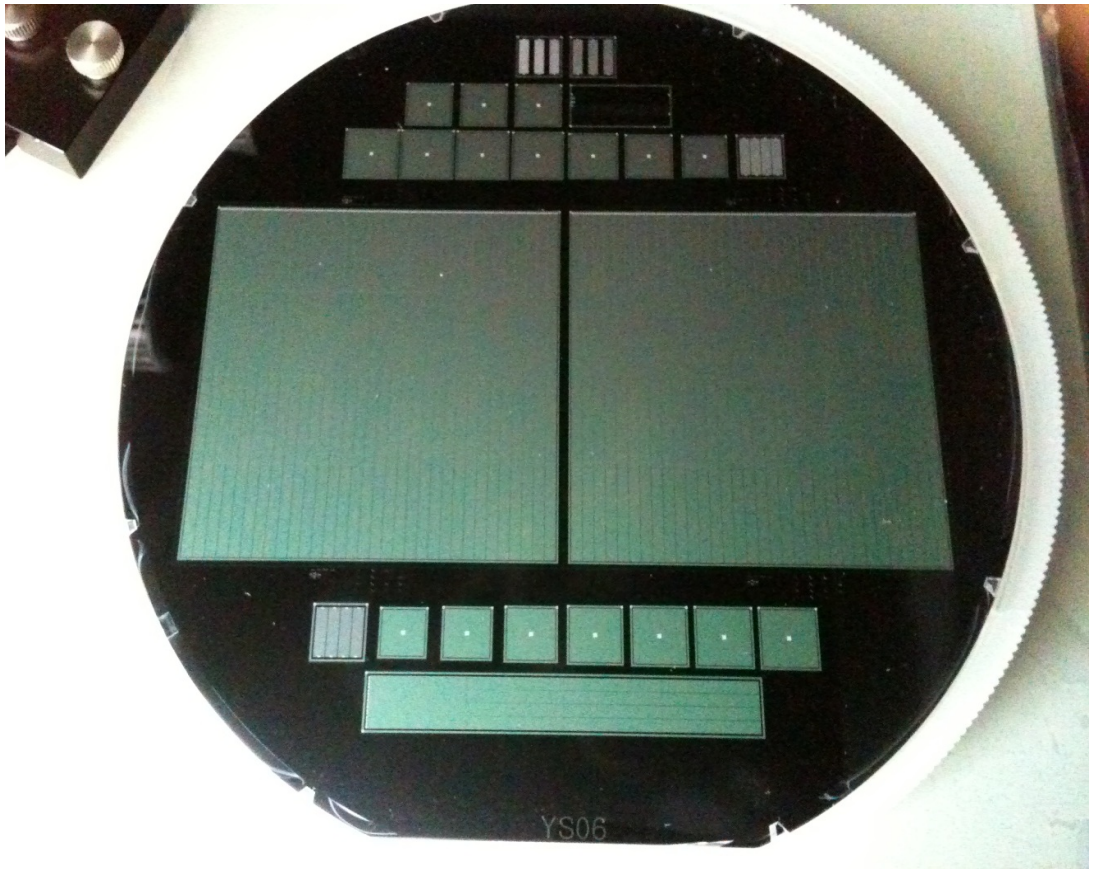


Fabrication…

1. Starting Material (FZ N^- Wafer, > 5 kΩ.cm)
2. Thermal Oxidation: 900 nm
3. Front-Side PR Coating
4. **Photo Mask(1);** N-Channel Stop (Option)
5. Back-Side Oxide Wet-Etch
6. …… and more



Minipad Sensors on Si Wafer



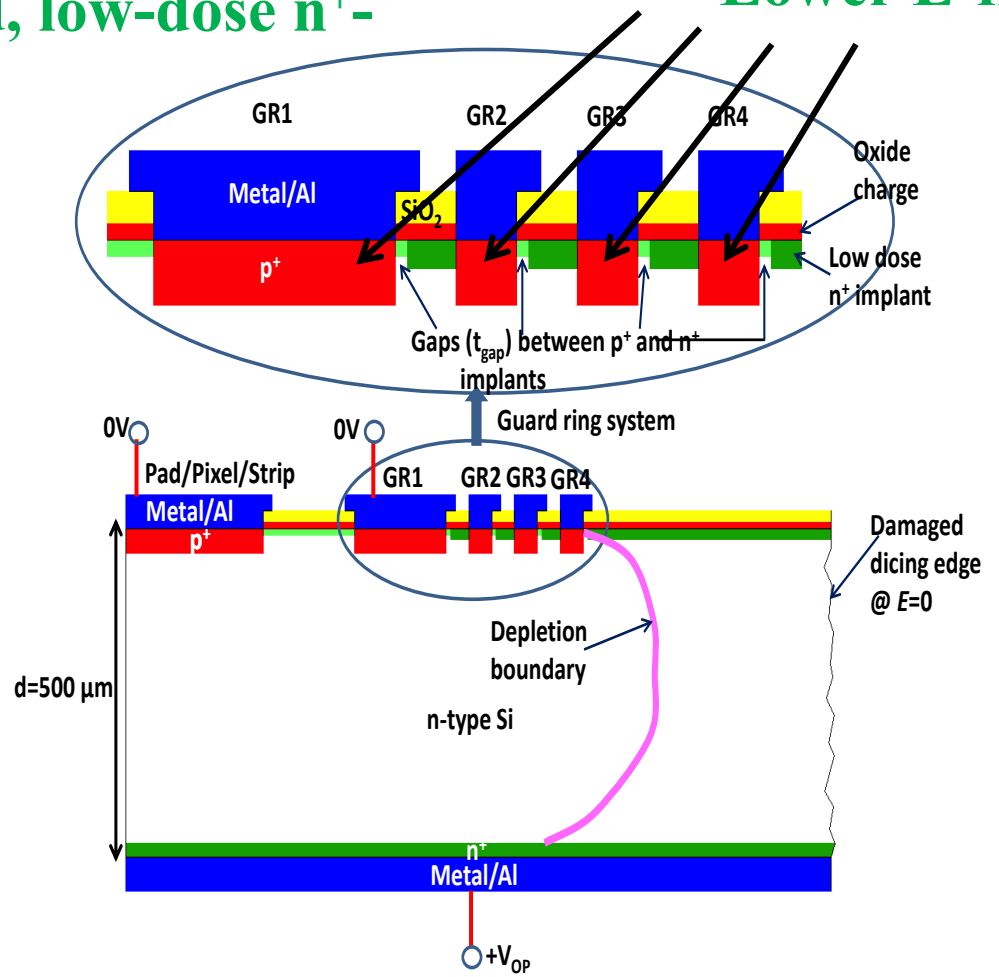
R & D

Yes, there was R&D with BNL Instrumentation Division

Concept of Novel Sensor Guardrings

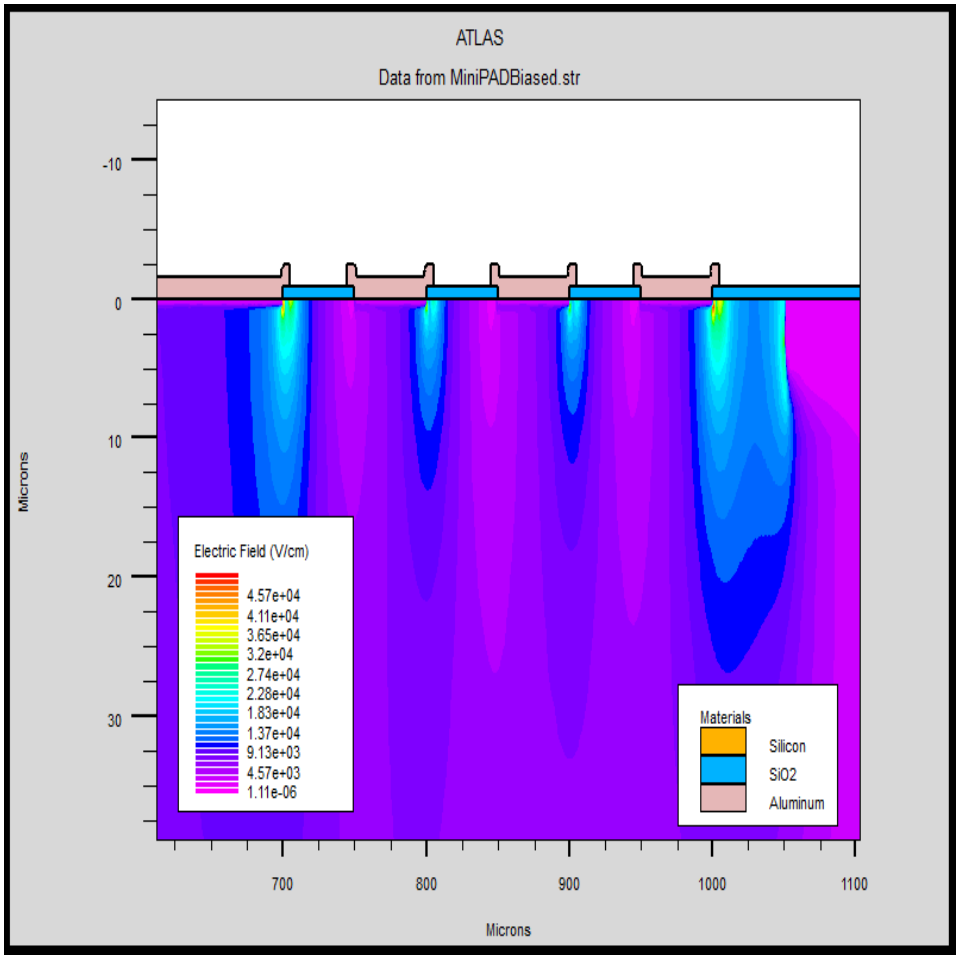
Segmented, low-dose n^+-implant

Lower E-fields

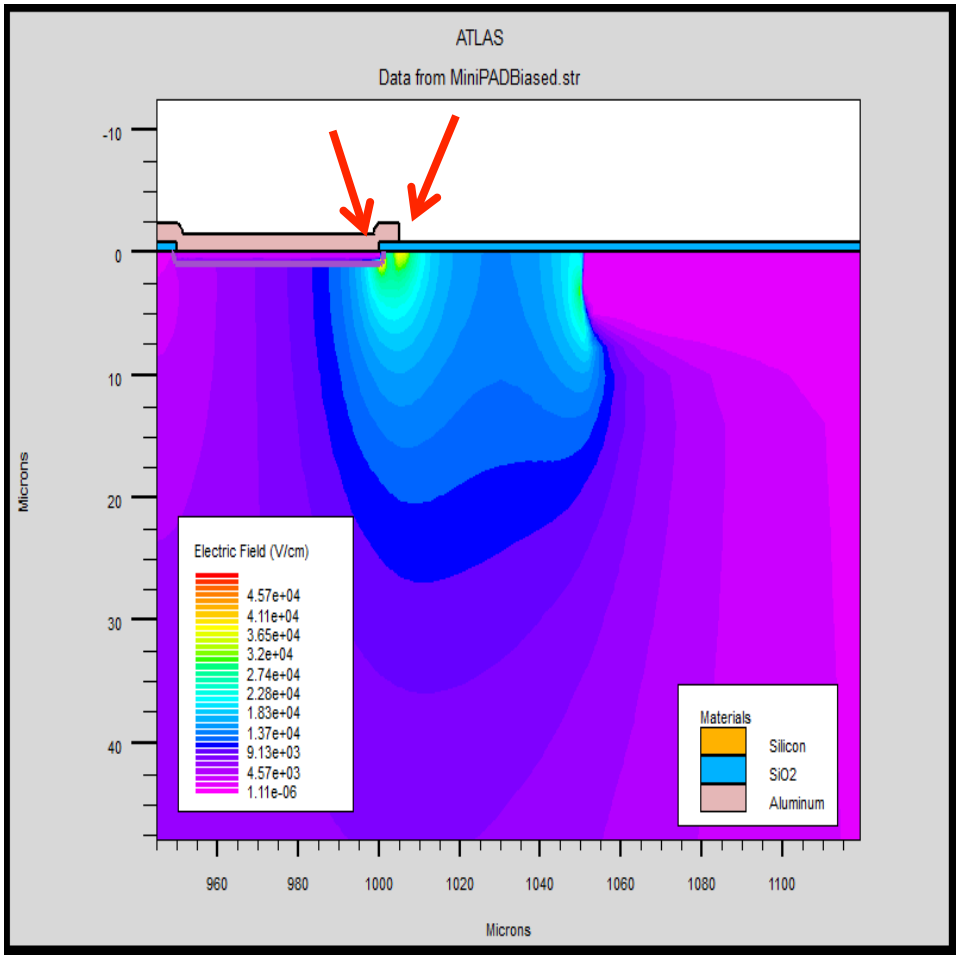


A segmented, low-dose (a few times of $10^{12}/cm^2$) n^+-implant on near GRS can remove the detector oxide-property dependence with lower E-field

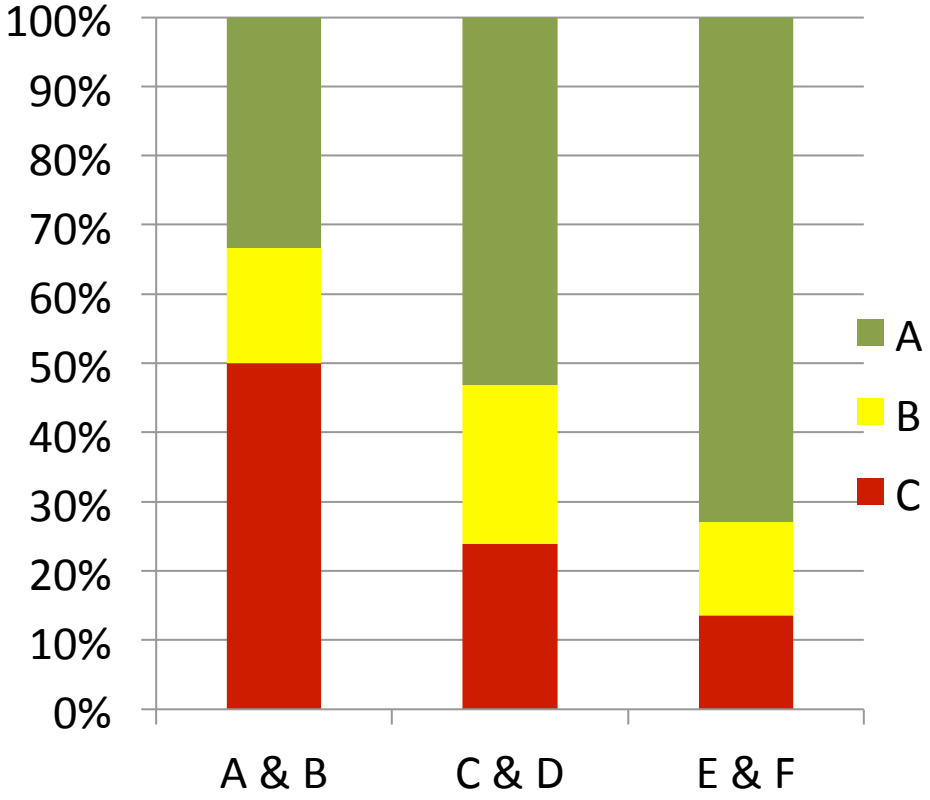
Main guardring, 3 tertiary guardrings, & channel stop



Simulation of 3rd Tertiary Guardring Region



Successful Fabrication & Delivery



Grey: excellent quality, Yellow: good quality, Red: failure

Final sensor yield ~ 75%

Summary of PHENIX MPC-EX Work

- Have provided 381 good Si Mini-Pad sensors for the PHENIX MPC-EX detector.

Simple math:

Stability of all sensors was tested for 2 hours at the bias of 60(V), twice full depletion voltage. 2 hours/sensor * 481 sensors = 40 days

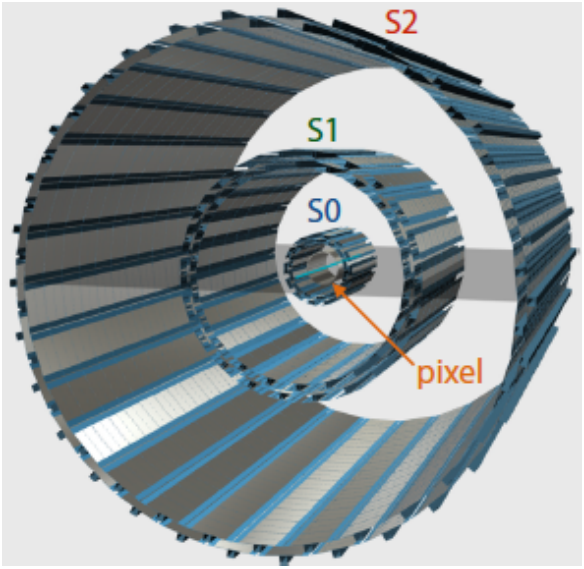
Trained many students and postdocs in Korea!

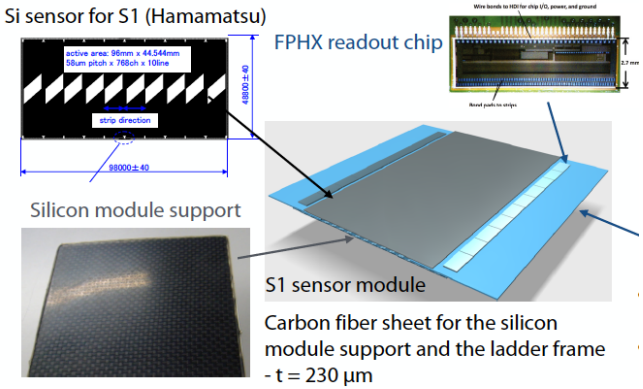
Possible Future Work?

FPHX Based Silicon-Strip Tracker: S2 Sensors?

- 5 strip layers + 2 pixel layers
  S2: 1 strip layer at R~60 cm ~1% X0 (2% in ref. design), 500um is OK/better
  S1ab: 2 strip layer at R~34 cm ~1% X0 total (2% in ref. design)
  S0ab: 2 strip layer at R~ 8 cm ~1% X0 total (2.7% in ref. design)
  P1: pixel at R~5 cm (reconfigured VTXP) 1.3% X0
  P0: pixel at R~2.5cm (reconfigured VTXP) 1.3% X0

  - All strips are 75 μm x 9.6mm. S0b has a small stereo angle.
  - Air cooling to achieve small radiation length
  - Small rad. length enables smaller over-all size and to keep the required momentum resolution to separate 3 Upsilon states
  - S0+S1+S2: ~8m^2 of silicon and 3.2M ch
- FPHX chip for read-out.
  - FPHX is the read-out chip of FVTX
  - 128ch/chip. 3bit ADC /ch.
  - Low power (64mw per chip)





Possible future contribution?

S2 layer area ~ 6.0 m^2,

500um thick sensors, large signal!

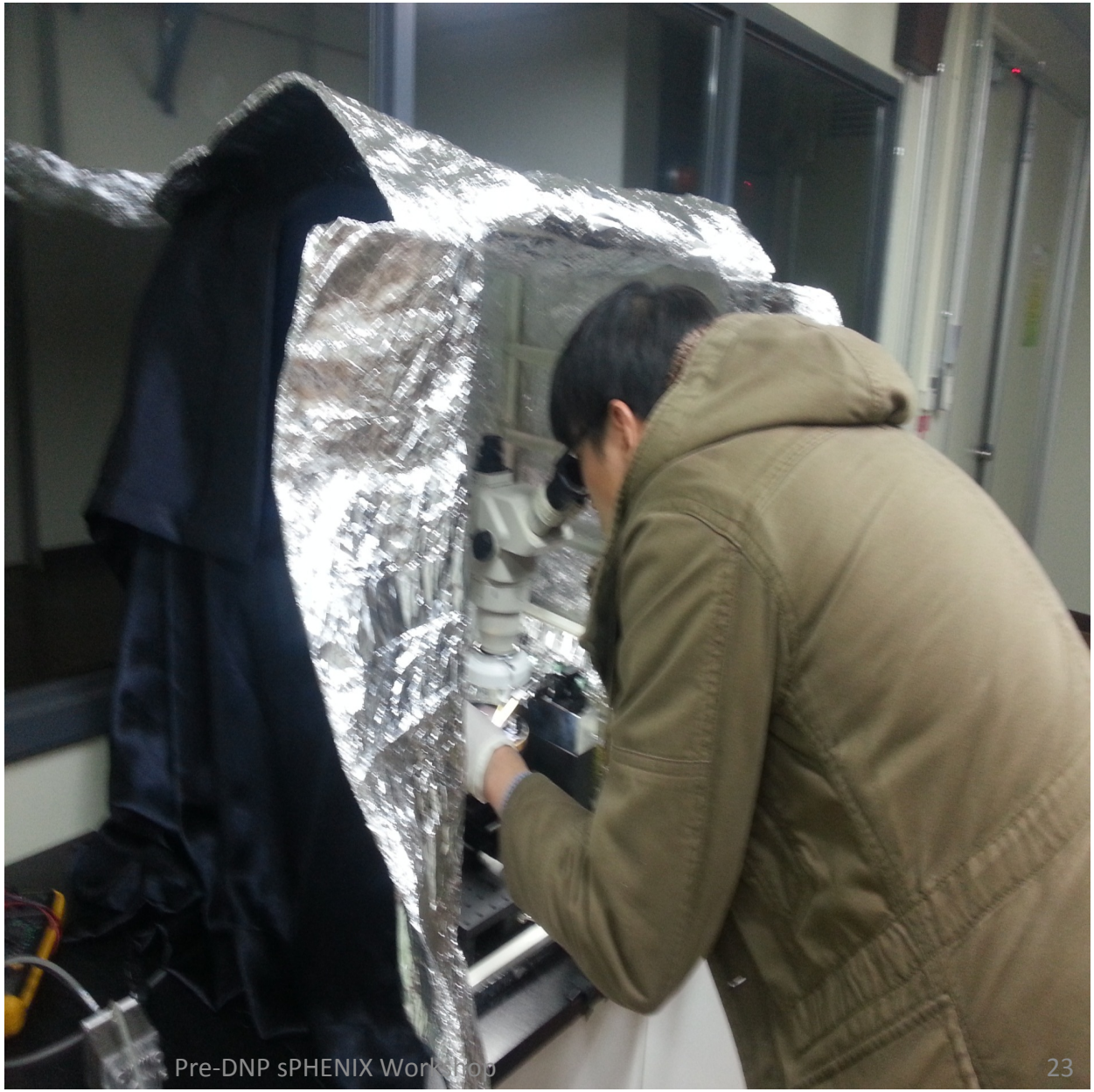
sensor cost + test ~ $5/cm^2,

Total cost ~ $5 x 6 x10^4 = $300 K

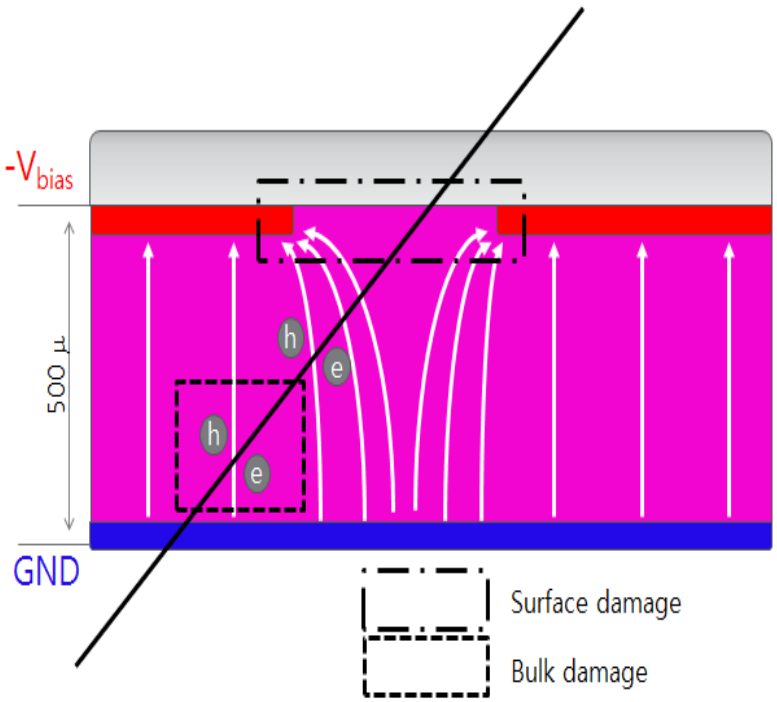
Proven technology !

R&D : Two publications

Sensor Damage Measurement at ARTI, Jungeup



Radiation Damage Study



Bulk damage

Non**I**oinzing **E**nergy **L**oss

→ Point defect

→ Defect cluster

: Leakage current

: Charge collection efficiency

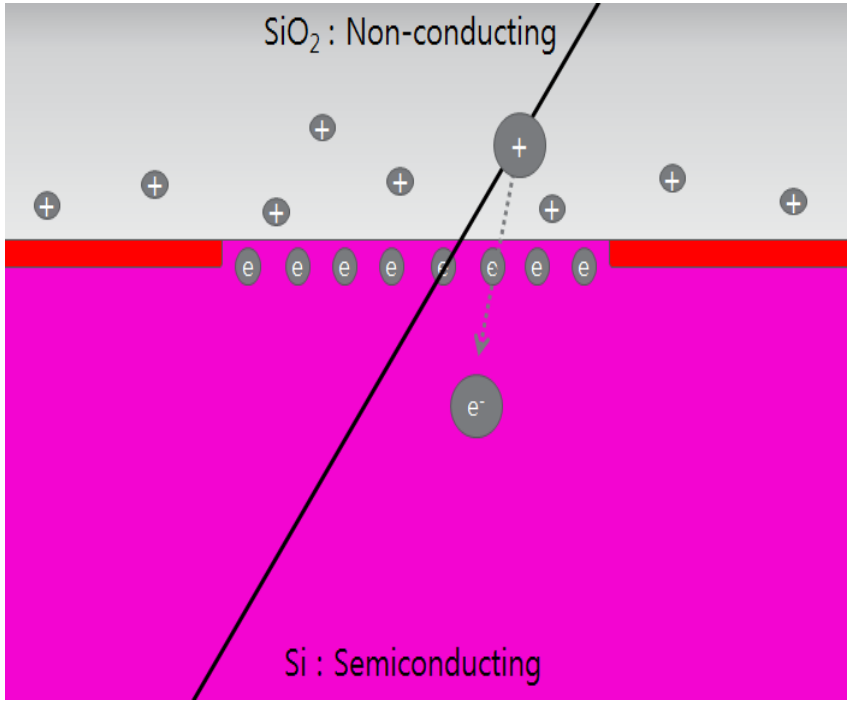
Surface damage

Total **I**onization **D**ose

→ Charged surface

: Surface leakage current

Surface Damage



A given fraction of ionizing energy loss produces hard electrons from the SiO_2 layer at the surface of sensor. These hard electrons penetrate the same layer and reaches semiconducting Si bulk. Therefore, <u>the SiO_2 layer gains positive charge with **T**otal **I**onization **D**ose.</u> Subsequently, electrons gather underneath the charged SiO_2 layer and reduce resistivity of the intrinsic Si channel between p+ patterns. Hence, <u>leakage current between p+ patterns increase.</u>

Surface Pattern of a Si Mini-pad Sensor for the PHENIX MPC-EX and Damage Caused by Ionizing Radiation

J. -S. Chai[8], M. Ghergherehchi[8], K. I. Hahn[4], S. Y. Han[4], I. W. Jeong[10], K. S. Joo[7], E. J. Kim[2], Y. K. Kim[5], E. Kistenev[1], Y. Kwon[10],* J. G. Lajoie[6], Z. Li[1,9], J. H. Lee[3], K. S. Lim[7], J. M. Park[3], K. S. Park[3], H. S. Song[8], D. G. Sue[10] and A. Sukhanov[1]

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The Si Mini-Pad sensor is an essential component of the MPC-EX preshower detector. This detector will be integrated into the PHENIX experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider. We describe the development of the surface pattern and the fabrication process of the Si Mini-Pad sensor and present a test by the low energy γ irradiation that is sensitive to the surface design.

Effects of Damage Caused by Non-ionizing Energy Loss in Si Mini-Pad Sensors for the PHENIX MPC-EX

J. -S. Chai[8], M. Ghergherehchi[8], K. I. Hahn[4], S. Y. Han[4], I. W. Jeong[10], K. S. Joo[7], E. J. Kim[2], S. G. Kim[3], Y. K. Kim[5], E. Kistenev[1], Y. Kwon[10],* J. G. Lajoie[6], Z. Li[1,9], J. H. Lee[3], K. S. Lim[7], S. H. Lim[10], J. M. Park[3], K. S. Park[3], S. Y. Park[4], H. S. Song[8], D. G. Sue[10] and A. Sukhanov[1]

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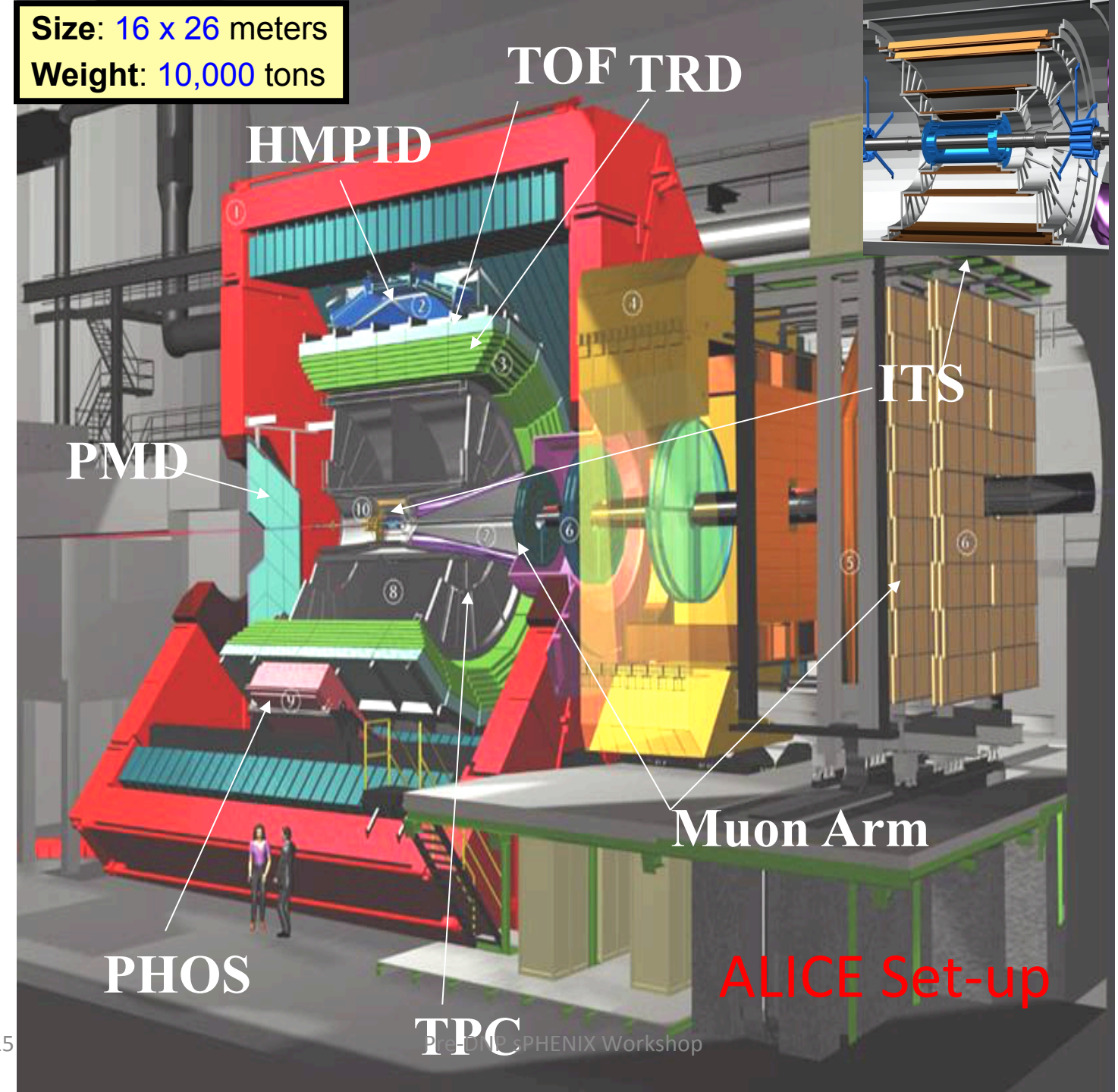
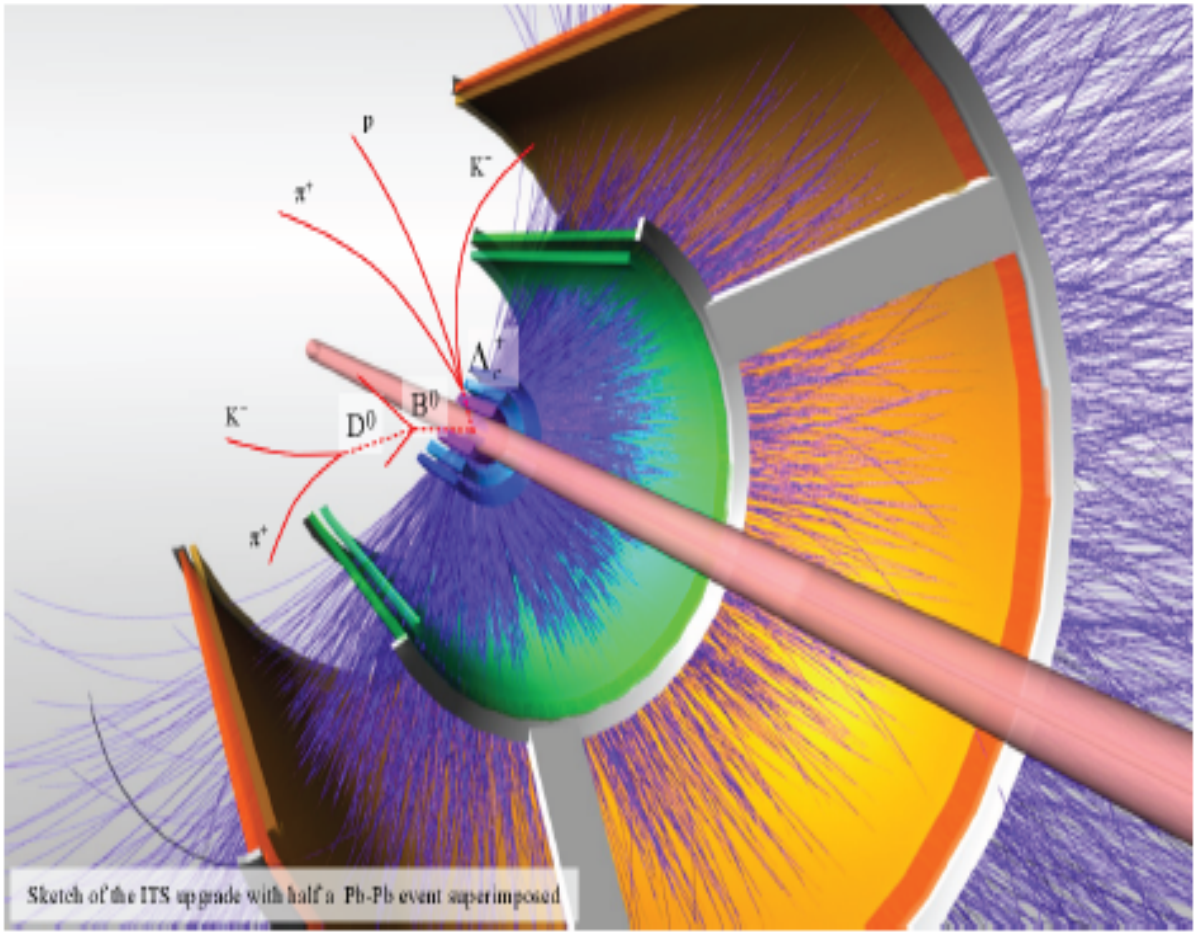
The PHENIX MPC-EX is an W/Si pre-shower detector operating at small angles with respect to the beam in the Relativistic Heavy Ion Collider (RHIC). The Si Mini-Pad sensors are the active element of the detector. The expected hadron flux to the Si Mini-Pad sensors will generate significant non-ionizing energy loss in the sensors, which may damage the crystalline structure of the sensor's bulk material. We investigated the nature of the hadron flux to the Si Mini-Pad sensors through a full simulation and determined its effect on the sensor's characteristics based on a beam test. The investigation showed key issues in designing a preshower detector using silicon sensors and operating under a large neutron fluence and offered valuable information on the operation of the MPC-EX detector.

Latest Work on Pixel Sensors


Size: 16 x 26 meters
Weight: 10,000 tons
TOF TRD
HMPID
ITS
PMD
Muon Arm
PHOS
TPC
ALICE Set-up

ALICE ITS Upgrade



Work in Progress in Korea ...

State of the Art Facilities exist in Korea …

Samsung S5K8AA

Ultra thin HD image sensor for compact mobile application

HD 1/8" 1.4um BSI Pixel Image Sensor provides;

- HD sensor integrated Image Signal Processor suitable for slim mobile phone, tablet and notebook
- High speed HD 30fps and VGA 60fps
- BSI sensors providing clear and sharp still images in low light, YSNR10 86 Lux

SAMSUNG

SK hynix

SK하이닉스 M8라인, 시스템반도체 전환 완료

애플을 최대 고객사로 확보

To produce production MAPS chips:
Companies are too busy to serve us. One needs careful approach.
If we prepare well and be careful, we might be successful next time.

▲ SK하이닉스 M8라인. © 서울시민신문

SK하이닉스가 청주 M8 라인을 거점으로 시스템반도체 생산을 본격화했다.

10월 25일 유경동 SK하이닉스 상무는 `국제반도체컨퍼런스 2012`에서 청주 소재의 자사 M8 공장을 메모리에서 시스템반도체로의 전환 작업을 성공적으로 끝냈다고 밝혔다.

M8 공장은 CMOS 이미지 센서(CIS)와 DDI, 전력반도체(PMIC), 고주파(RF), 마이크로컨트롤러 등 시스템반도체를 생산한다. CIS의 경우 90나노미터(㎚) 공정 기반으로 터치스크린과 드라이버칩

CIS (CMOS Image Sensor) | SPECIALIZED FOUNDRY

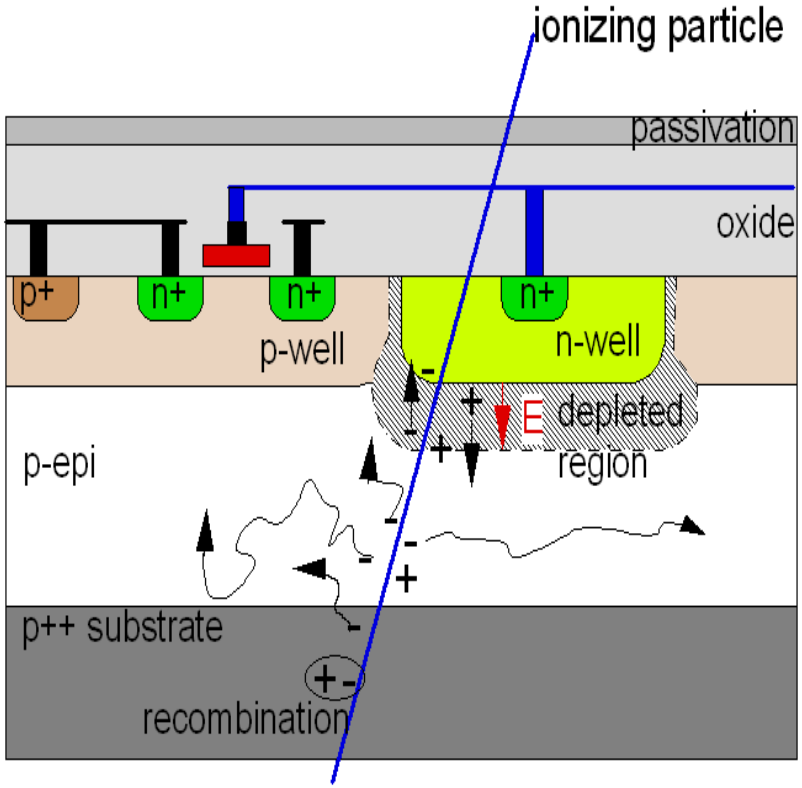
Design Toolkits, 웨이퍼 가공, 패키지, 테스트 등 턴키 서비스 제공

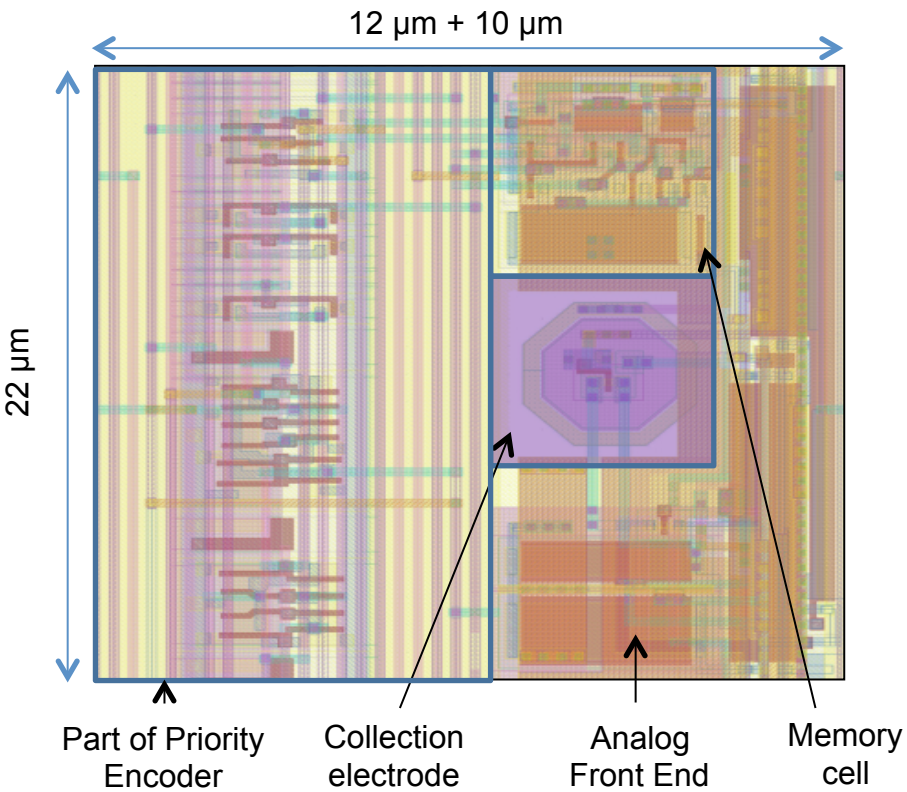
CMOS 이미지 센서는 렌즈를 통해 들어오는 빛을 전기적 신호로 전환하는 디지털 제품의 핵심 부품으로, 저전력·초소형·저비용이라는 제품의 특성 때문에 캠코더, 디지털 카메라, PC용 카메라, 이동전화, PDA, 스캐너, 팩스 등에 널리 쓰이는 등 제품의 수요가 급증하고 있는 첨단 기술 분야입니다.

동부하이텍은 국내외 Fabless 등 고객사들에게 보다 저렴한 비용과 편리한 서비스를 제공하기 위해 CIS 제품 개발에 필요한 디자인 툴킷(Design Toolkits)을 제공하고 있으며, 웨이퍼 제조공정, 패키지, 테스트 등 이미지 센서 양산에 필요한 모든 공정들을 일괄적으로 서비스하고 있습니다.

동부하이텍이 제공하는 CIS(CMOS Image Sensor)기술은 0.18㎛ 와 0.13㎛급 기술을 기반으로 하고 있으며, CIS 공정기술의 경우 N+/PW Photo Diode와 Color Filter, Microlens 등을 제공하여 CIF, VGA, Mega-Pixel 등 다양한 형태의 CIS 칩을 양산하고 있습니다.

ALICE ITS Pixel Sensors



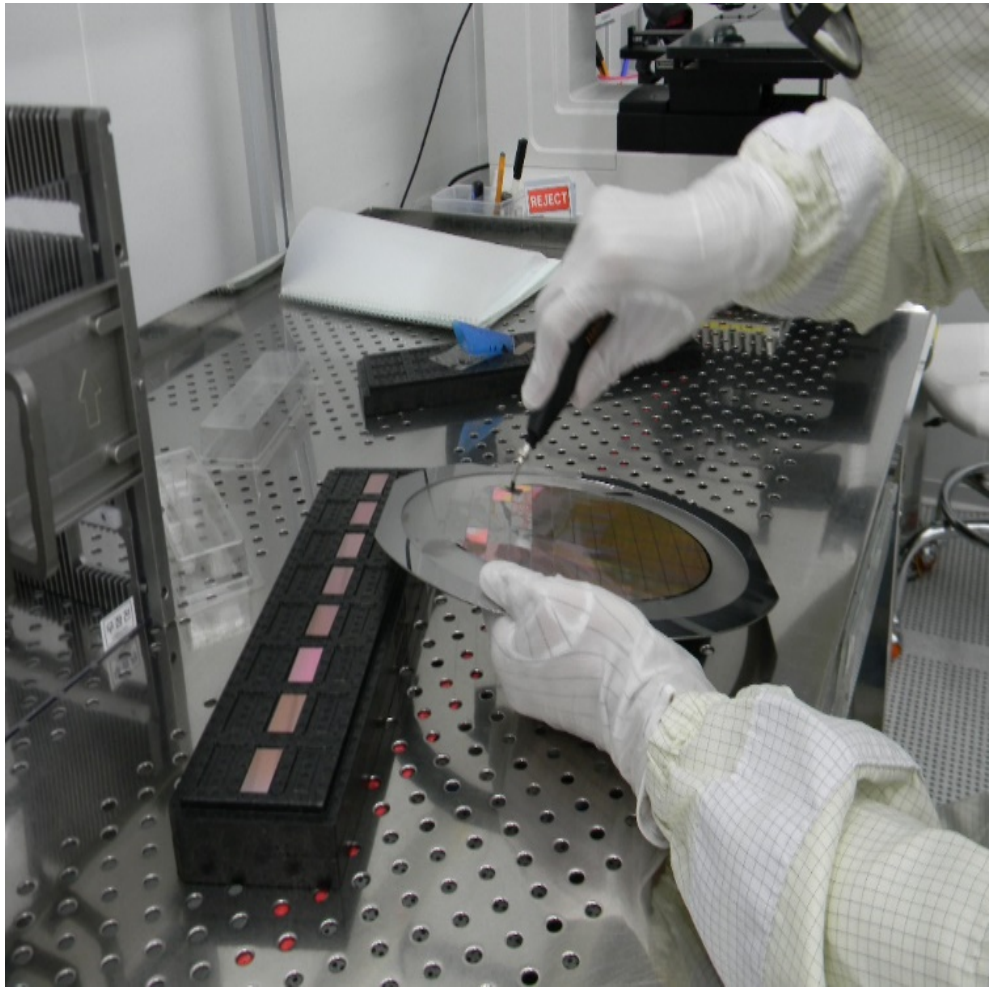


Infra-structure under Development (for ALICE ITS upgrade)

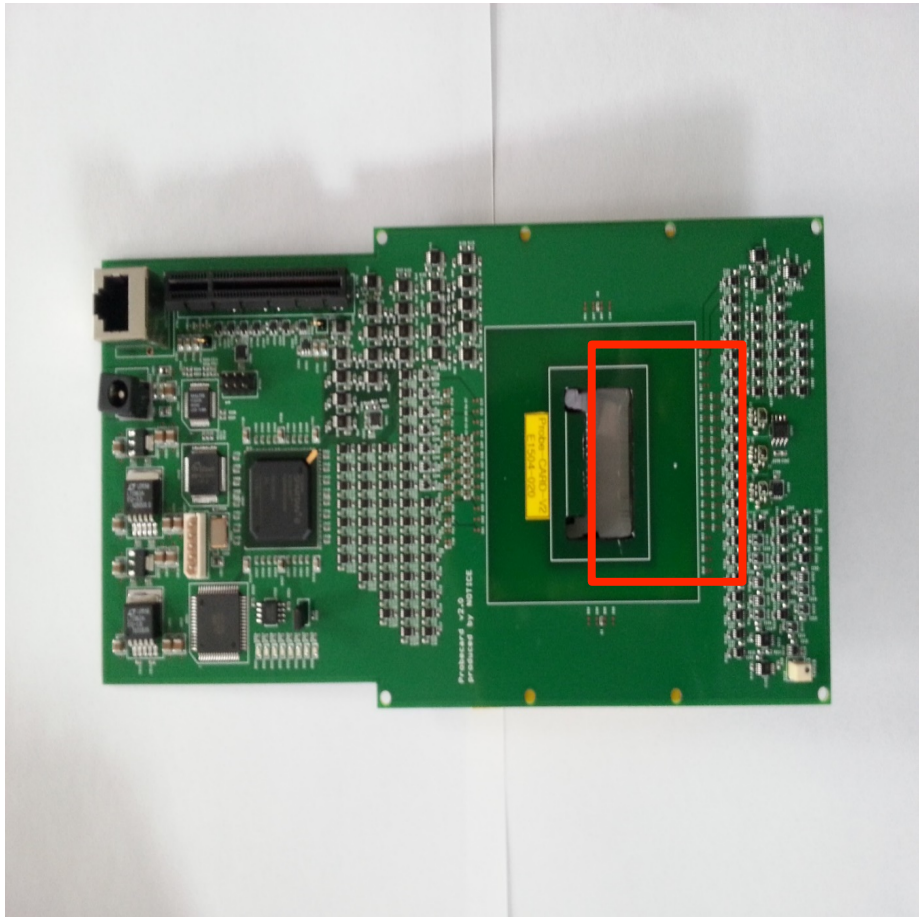
- Thinning & Dicing
  - Innofab(consultant)/ Purex(service provider)
- Probecard for ALICE ITS-Upgrade
  - Probe needles : EQENG
  - Electronics and readout : NOTICE
- Automatic test station : C-ON

Thinning & Dicing at Purex

To reach
~ 50um



Probecard Development



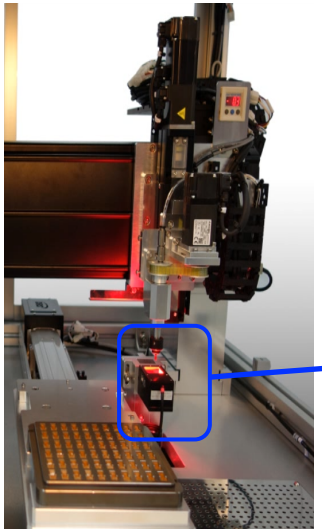
Probecard ver. 2

1. Automatic **contact detection**

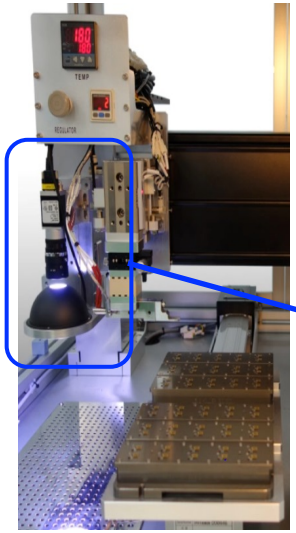
2. Operation **at 1 GHz**
   By-pass mode
   : simple signal routing

Stand-alone mode ~ DAQ

Automatic Test Equipment (Pick & Place)



PICK up ARE
A



PLACE AREA

Qualified companies are willing to serve…

Summary

There are good potentials for Si-sensors, Electronics & Automation work in Korea.

- PIN-structured Si sensors: Strip sensors for outer tracking system

  Yes, we can design, fabricate, dice, and test.

- CMOS image sensors : MAPS based pixel detectors

  High barrier to access premier fab. We experienced design of, thinning & dicing of, and developing test system for the ALICE ITS pixel sensors.

- Test electronics :

  We developed probe needle & board, and developing DAQ-like operation of the board.

  We are developing automated test station with an enthusiastic local company.