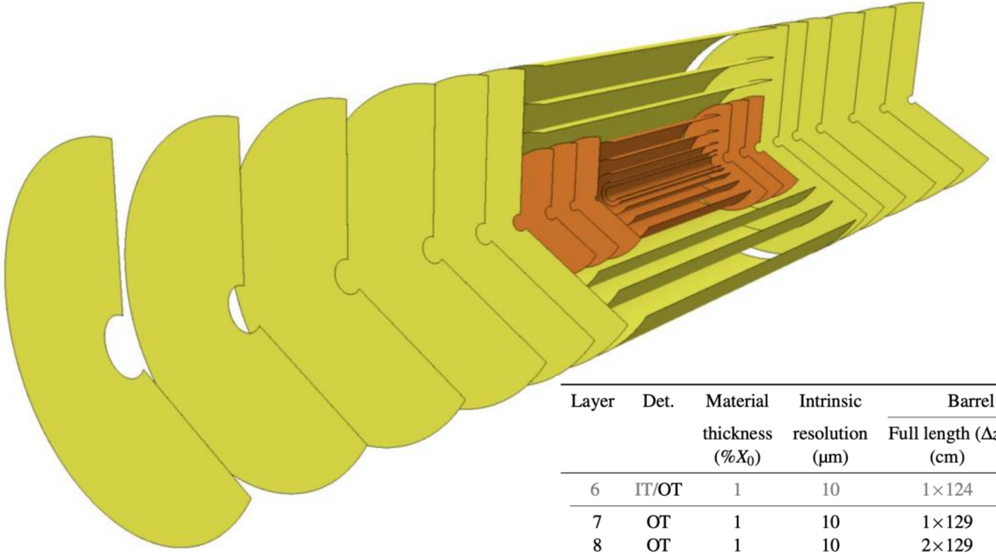
OT module design and assembly

Sanghoon Lim
Pusan National University
Korean ALICE team

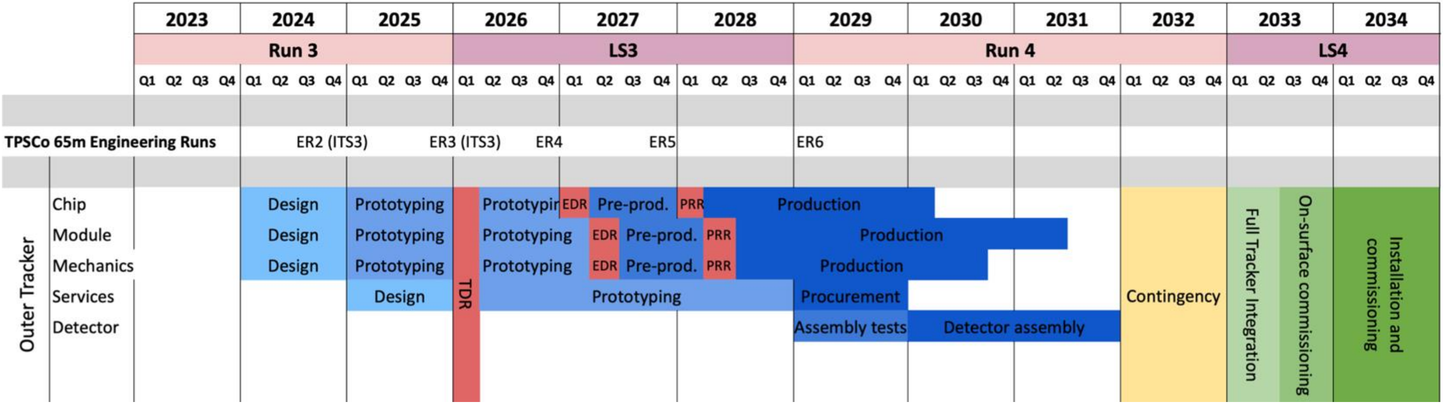
5th ALICE Upgrade Week in Krakow

ALICE 3 Outer Tracker

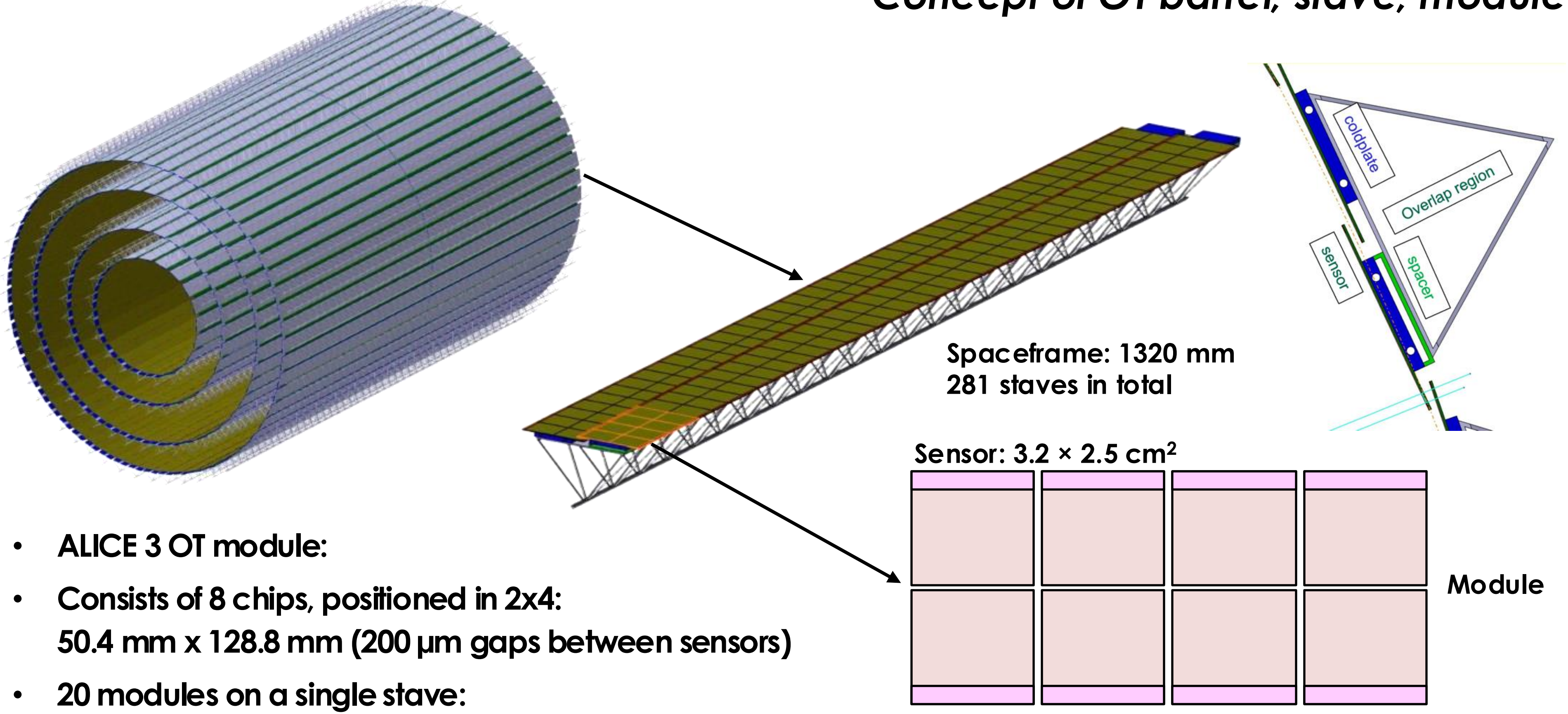


- **~50 m^2 of active area:** **~33 m^2 for barrel**
- **Low material budget (1% X_0)**
- **~50 µm effective pixel pitch for 10 µm position resolution**
- **Low power consumption: 30-50 mW/cm^2**

Layer	Det.	Material thickness (%X_0)	Intrinsic resolution (µm)	Barrel layers		Forward disks	
				Full length (Δz) (cm)	Radius (r) (cm)	Position (|z|) (cm)	R_{in}–R_{out} (cm)
6	IT/OT	1	10	1×124	20	150	5–68
7	OT	1	10	1×129	30	180	5–68
8	OT	1	10	2×129	45	220	5–68
9	OT	1	10	2×129	60	260	5–68
10	OT	1	10	2×129	80	300	5–68
11	OT	1	10			350	5–68



Concept of OT barrel, stave, module



Spaceframe: 1320 mm
281 staves in total

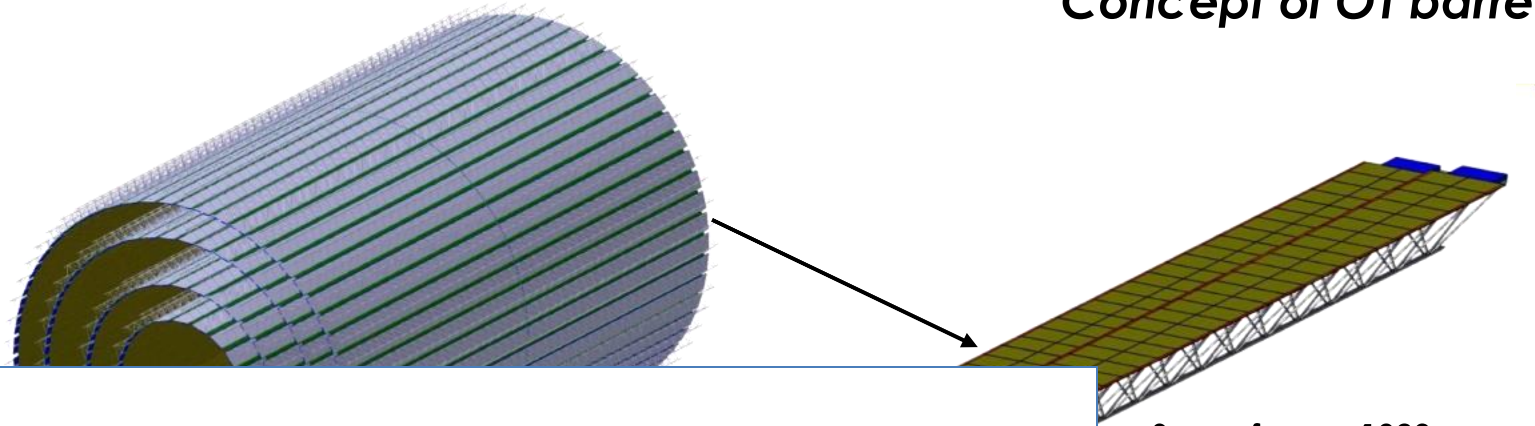
Sensor: 3.2 × 2.5 cm²

Module

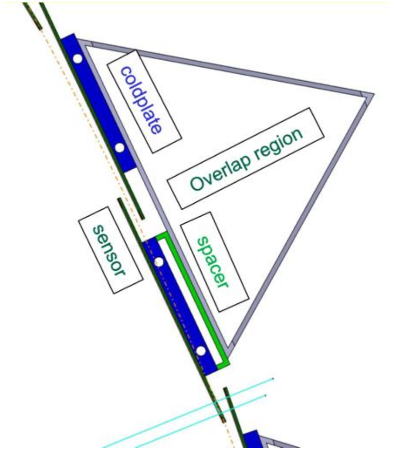
- **ALICE 3 OT module:**
- **Consists of 8 chips, positioned in 2x4:**
  50.4 mm x 128.8 mm (200 µm gaps between sensors)
- **20 modules on a single stave:**
  5620 modules in total for barrel
- **2688 modules for disks**

More technical details in Roman's talk [Link]
(IT+OT+FCT - Parallel session)

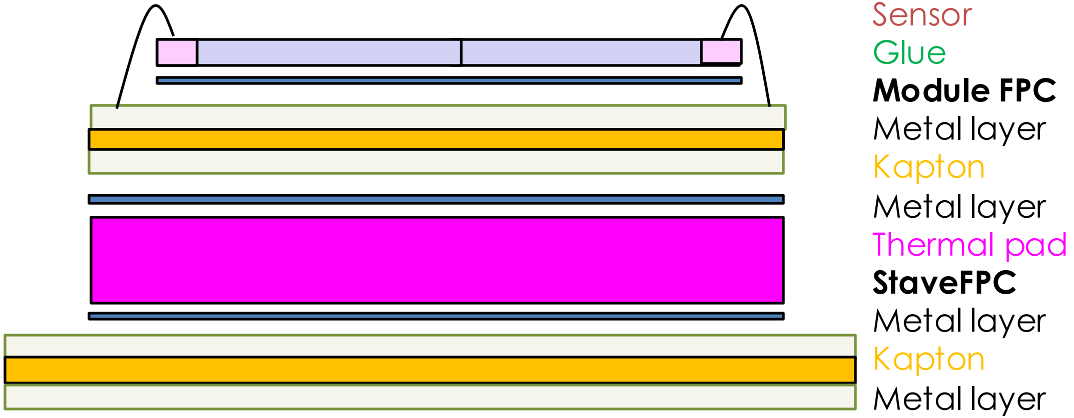
Concept of OT barrel, stave, module



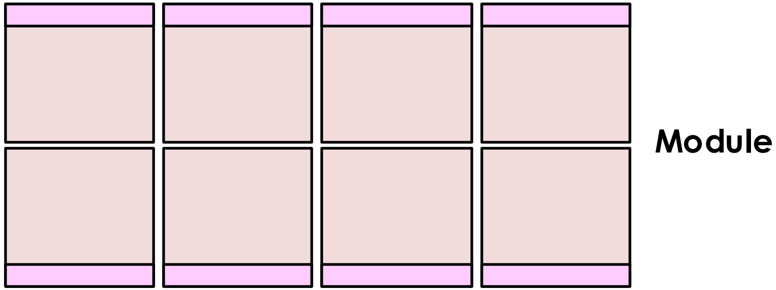
Spaceframe: 1320 mm
281 staves in total



Bonding std 15 μm Al wire



Sensor: 3.2 × 2.5 cm^2



More technical details in Roman's talk [Link]
(IT+OT+FCT - Parallel session)

Path to the module after sensor fabrication

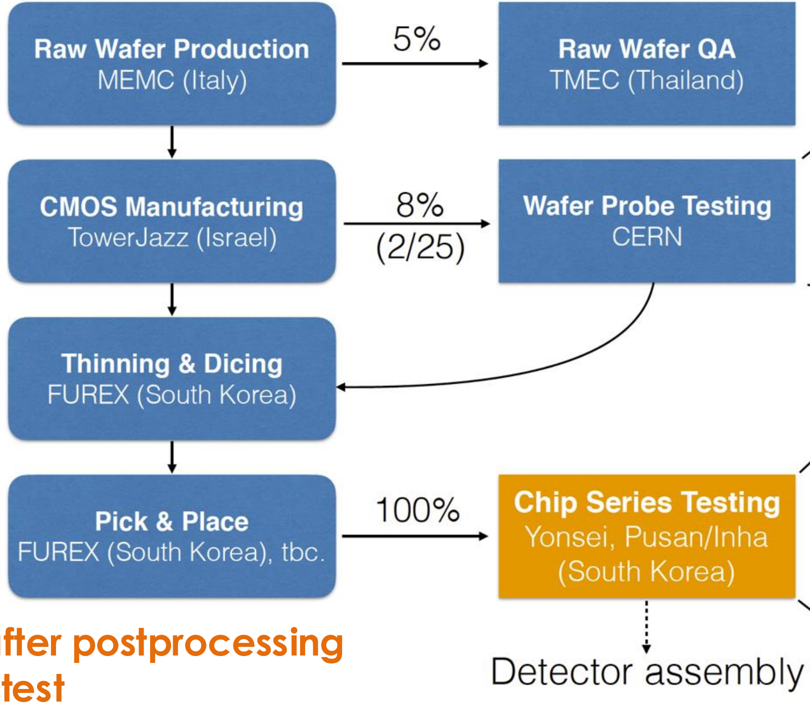
Sensor test procedure for ITS2

for ALICE 3 OT

1,500 raw wafers

1,200 CMOS wafers
1,920 CMOS wafers

55,000 sensors
109,200 sensors



Raw Wafer Production
MEMC (Italy)

5%

Raw Wafer QA
TMEC (Thailand)

CMOS Manufacturing
TowerJazz (Israel)

8%
(2/25)

Wafer Probe Testing
CERN

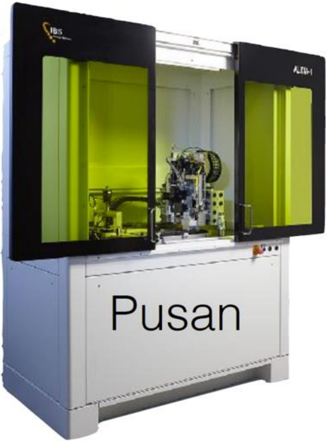
Thinning & Dicing
FUREX (South Korea)

Pick & Place
FUREX (South Korea), tbc.

100%

Chip Series Testing
Yonsei, Pusan/Inha
(South Korea)

Detector assembly



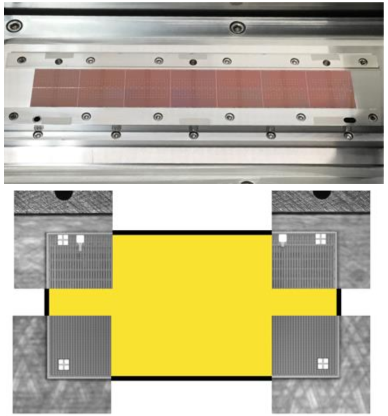
Chip-level test after postprocessing
~1 year for chip test

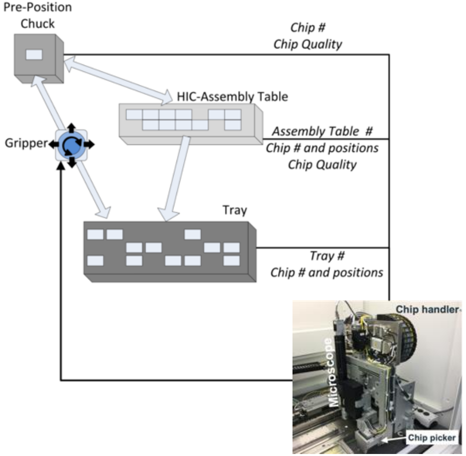
Chip-level or wafer-level test for ALICE 3 OT?
Under discussion with a wafer probing company in Korea for a test run

Path to the module after sensor fabrication

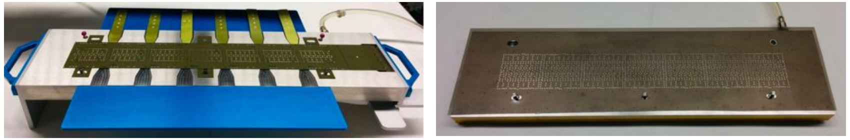
Module assembly procedure for ITS2 OB
2600 modules for ~2 years in 5 sites

1) Chips positioned on the HIC table

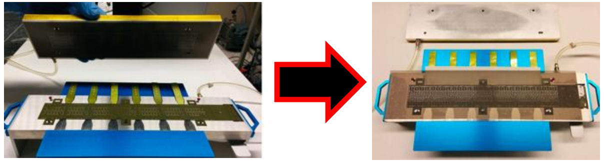




2) Glue mask on FPC



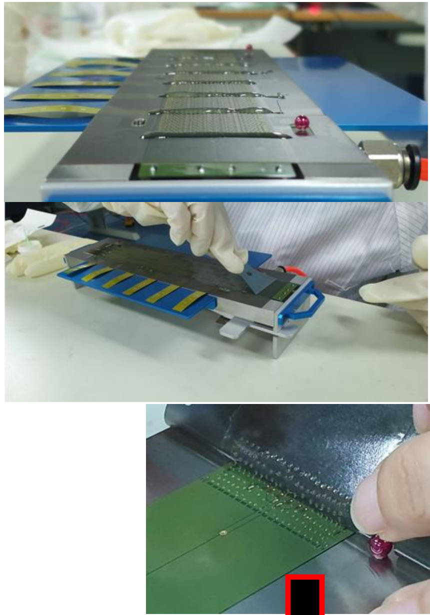
FPC and glue mask on the gripper



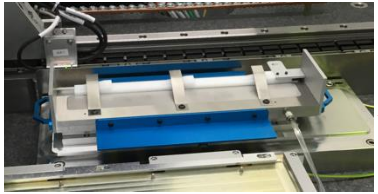
ALICE 3 OT:
5620 for barrel and 2688 for disks
~10000 modules considering yield and spares

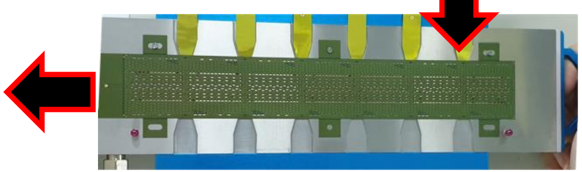
3) Gluing and curing

Glue (Araldite 2011) mixing



<u>~5 hours curing time</u>





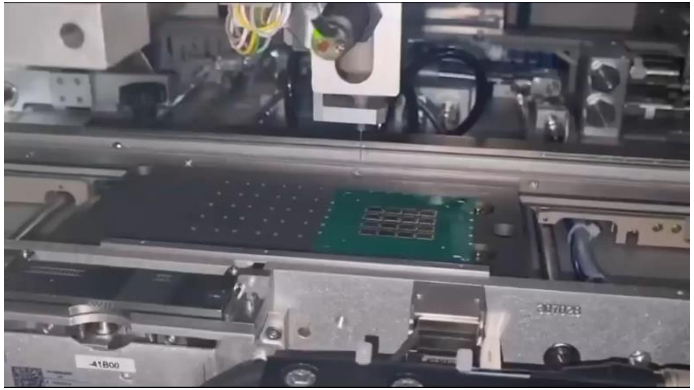
Module assembly for ALICE 3 OT

- **Automatization and industrialization of module assembly**
  - Collaboration with MEMSPACK
    using a multi-purpose machine die bonder

Datacon 2200 evo+

MRSI 705

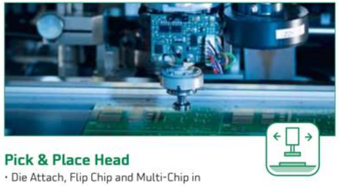
Henner and Ralf's visit (May)



Integrated Dispenser
- Pressure/time (Musashi®), Auger, Jetter types available
- Epoxy stamping option
- Filled and unfilled epoxy, wide viscosity range
- Small footprint, low cost-of-ownership

Vision Alignment
- New high-speed image processing unit
- Full alignment & Bad mark search
- Pre-defined fiducial geometry & customized teaching

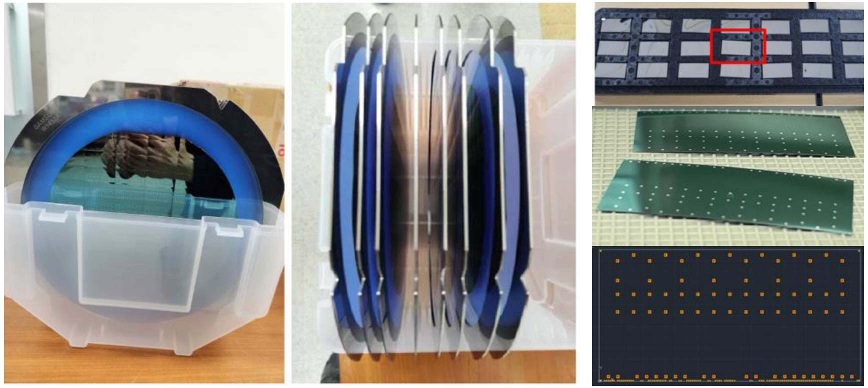
Automatic Wafer and Tool Changer
- Fully Automatic cycle for Multi-Chip production
- Up to 7 Pick & Place tools (optionally 14), 5 eject tools
- Stamping tools and calibration tools possible

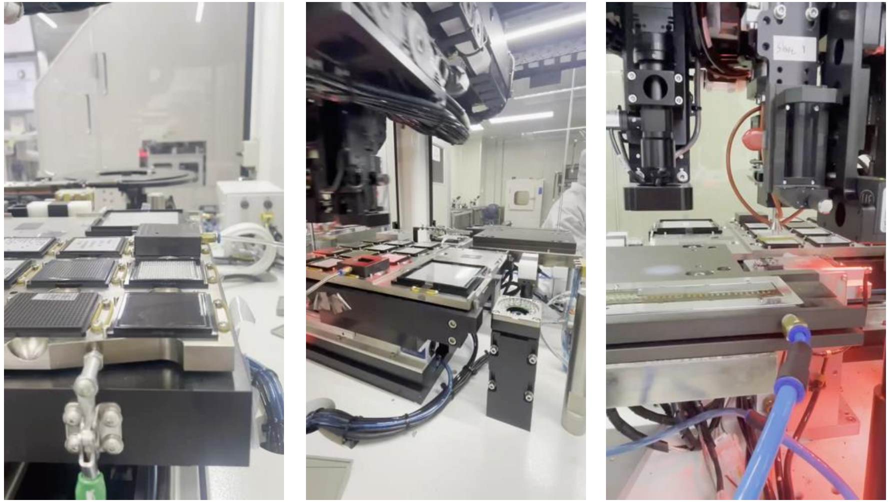


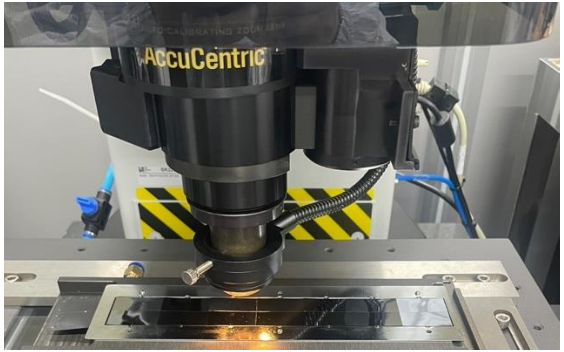
Pick & Place Head
- Die Attach, Flip Chip and Multi-Chip in one machine
- Die pick from: wafer, waffle pack, Gel-Pak®, feeder
- Die place to: substrate, boat, carrier, PCB, leadframe, wafer
- Hot and cold processes supported: epoxy, soldering, thermo-compression, eutectic

Dummy module assembly (2023 Dec.)

- Dummy HIC production (ITS2 OB design) for machine validation (using double-sided tape):

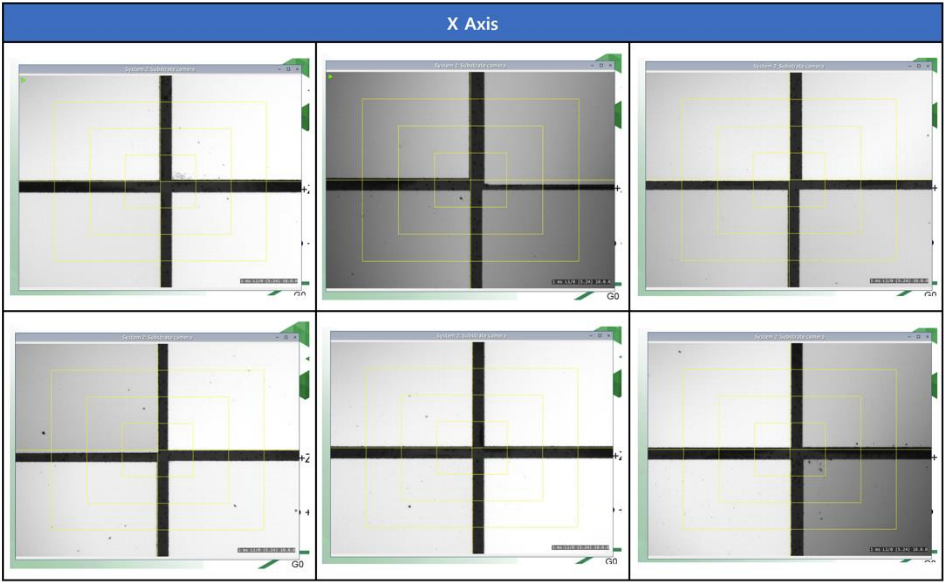


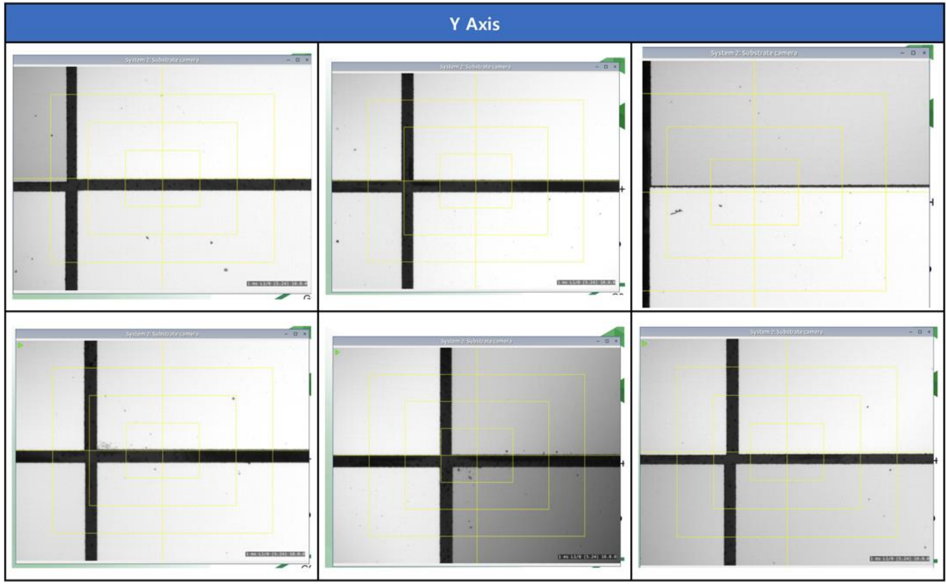




Dummy module assembly (2024 Mar.)

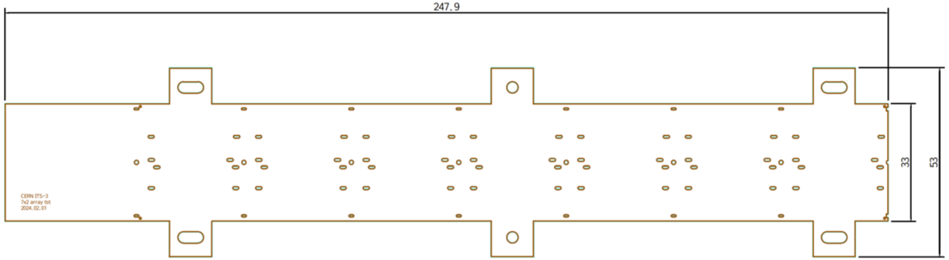
- Chips are aligned with respect to the marker on the FPC
  Chip-to-chip alignment may vary due to the precision of FPC production
- Difficult to achieve stable results of position precision due to the warpage of dummy FPC
  - Different brightness is because of the tilt of chips

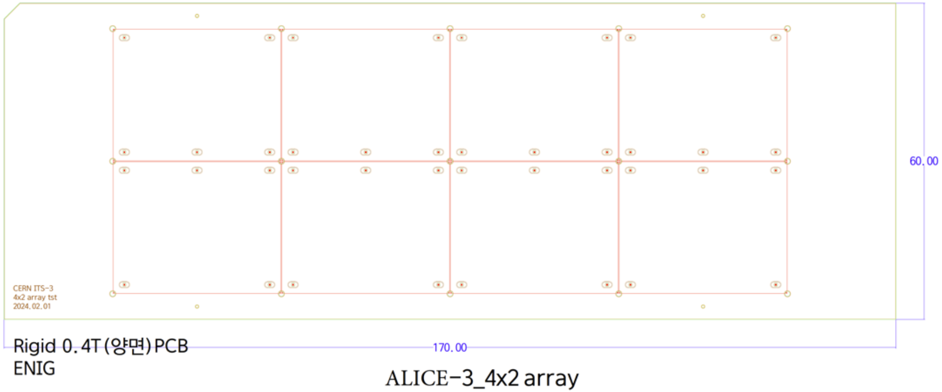




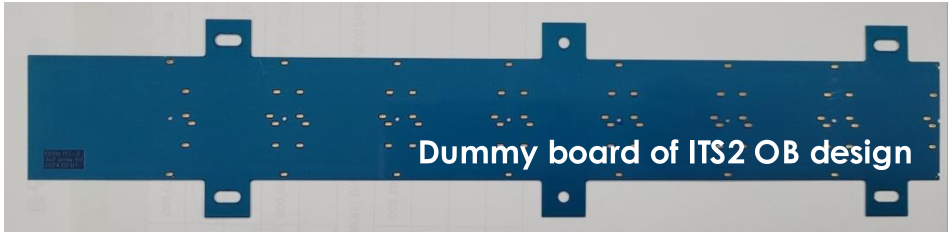
Dummy module assembly (2024 Mar.)

- 2nd production of dummy chip and dummy board
  - Both for ITS2 OB HIC design and ALICE 3 OT design
  - Using thicker chips (50-100 μm) and boards (0.3 mm) to validate the repeatability of position precision





ALICE−3_4x2 array

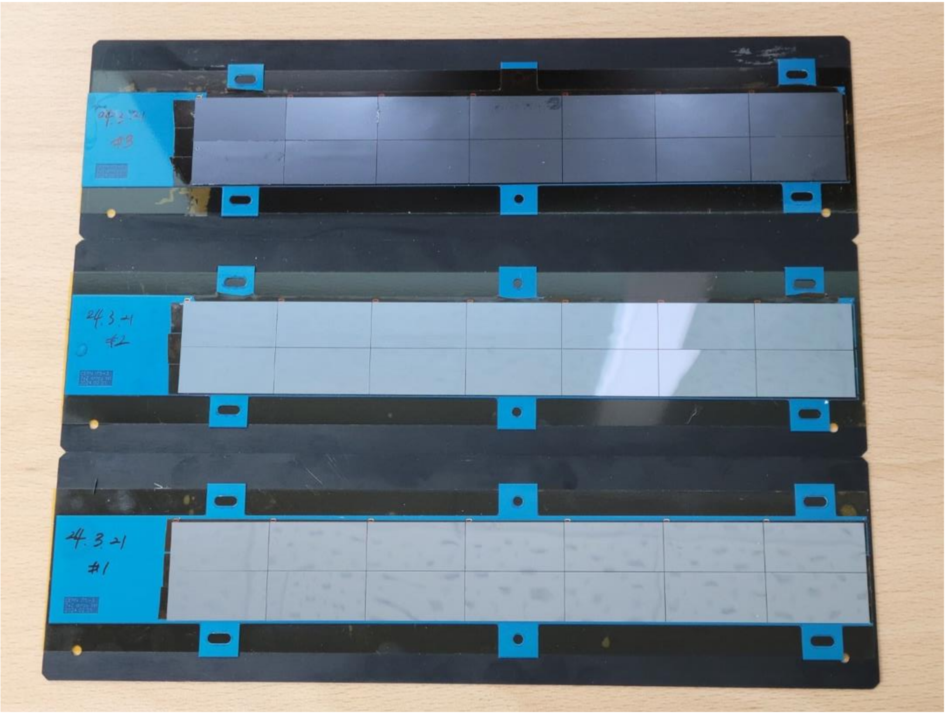

Dummy board of ITS2 OB design

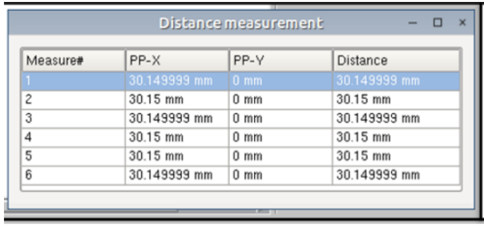

Dummy board of ALICE 3 OT design


First version PCB

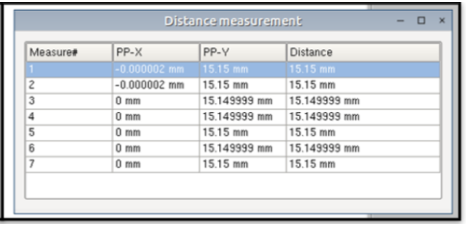
Dummy module assembly (2024 Mar.)

- 2nd production of dummy chip and dummy board
  - Both for ITS2 OB HIC design and ALICE 3 OT design
  - Using thicker chips (50-100 μm) and boards (0.3 mm) to validate the repeatability of position precision
  - Successfully produced five modules with a good position precision (using double-sided tape)

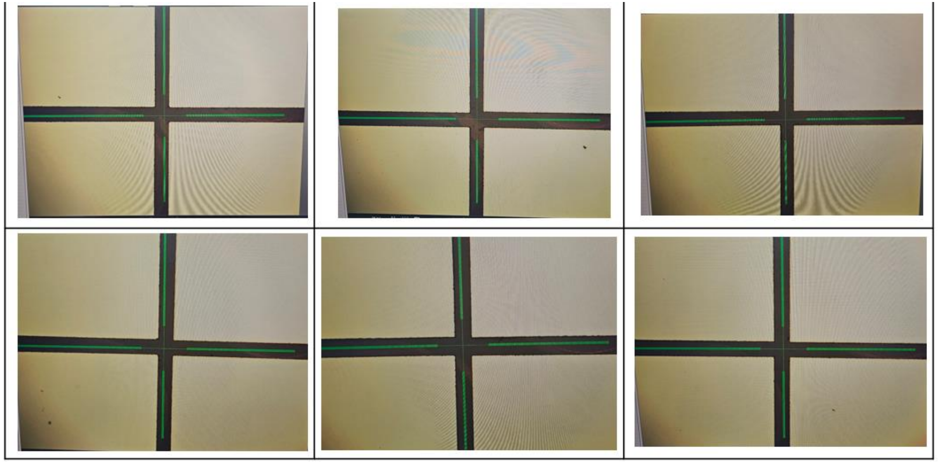




Measure#	PP-X	PP-Y	Distance
1	30.149999 mm	0 mm	30.149999 mm
2	30.15 mm	0 mm	30.15 mm
3	30.149999 mm	0 mm	30.149999 mm
4	30.15 mm	0 mm	30.15 mm
5	30.15 mm	0 mm	30.15 mm
6	30.149999 mm	0 mm	30.149999 mm

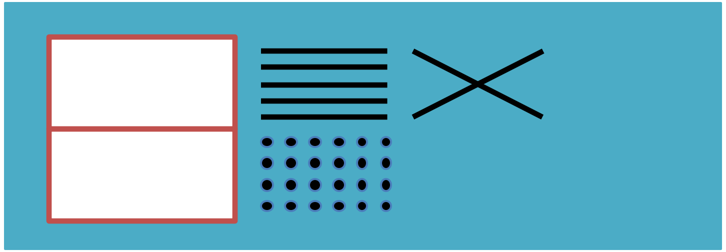


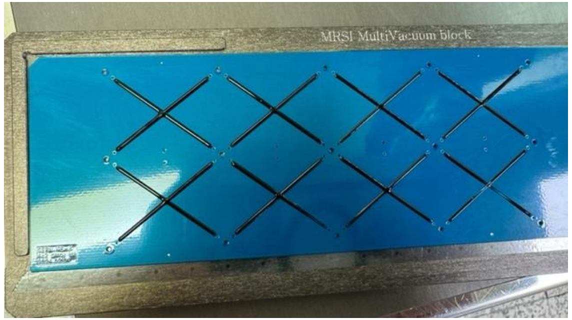
Measure#	PP-X	PP-Y	Distance
1	-0.000002 mm	15.15 mm	15.15 mm
2	-0.000002 mm	15.15 mm	15.15 mm
3	0 mm	15.149999 mm	15.149999 mm
4	0 mm	15.149999 mm	15.149999 mm
5	0 mm	15.15 mm	15.15 mm
6	0 mm	15.149999 mm	15.149999 mm
7	0 mm	15.15 mm	15.15 mm



Dummy module assembly (2024 Jun.)

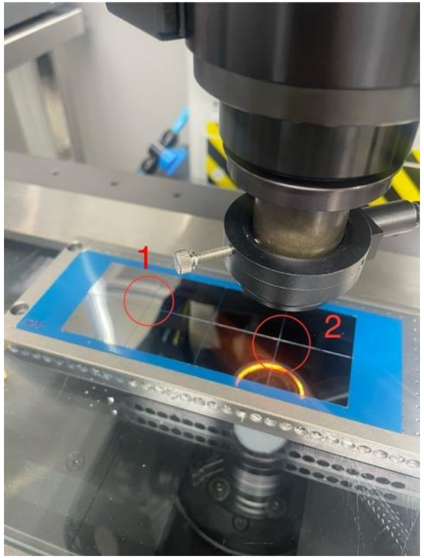
- Die bond with heat cure epoxy
  - Epoxy generally used by MEMSPACK
  - Heat cure condition: 100 ℃, 30 minutes (outside from the die bonder machine)
  - Dispense epoxy on the PCB (a few lines) and place chips
  - 0.3 mm thick chip (will reduce gradually)
  - Various dispensing patterns to minimize the position variation

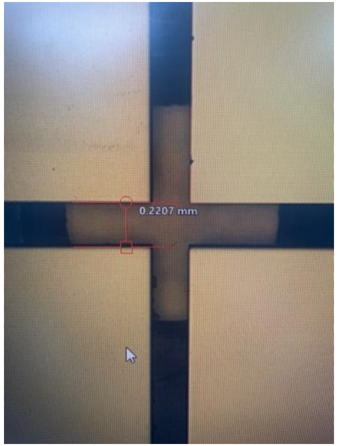


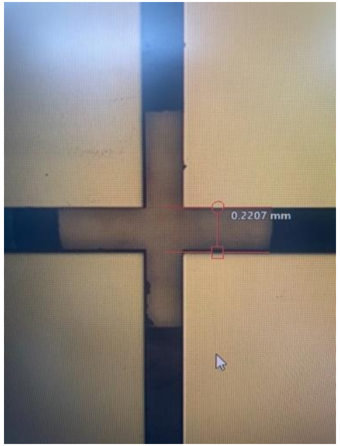


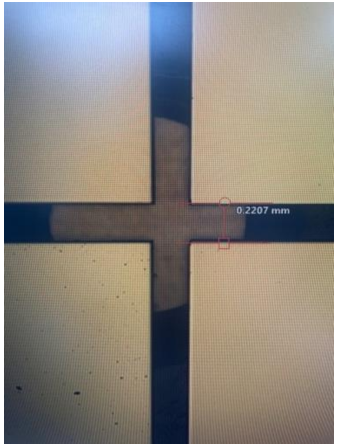
Dummy module assembly (2024 Jun.)

- Die bond with heat cure epoxy
  - Epoxy generally used by MEMSPACK
  - Heat cure condition: 100 ℃, 30 minutes (outside from the die bonder machine)
  - Dispense epoxy on the PCB (a few lines) and place chips
  - 0.3 mm thick chip (will reduce gradually)
  - Various dispensing patterns to minimize the position variation
  - Reasonable position precision but needs to be optimized





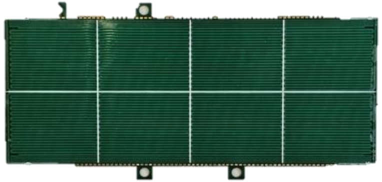


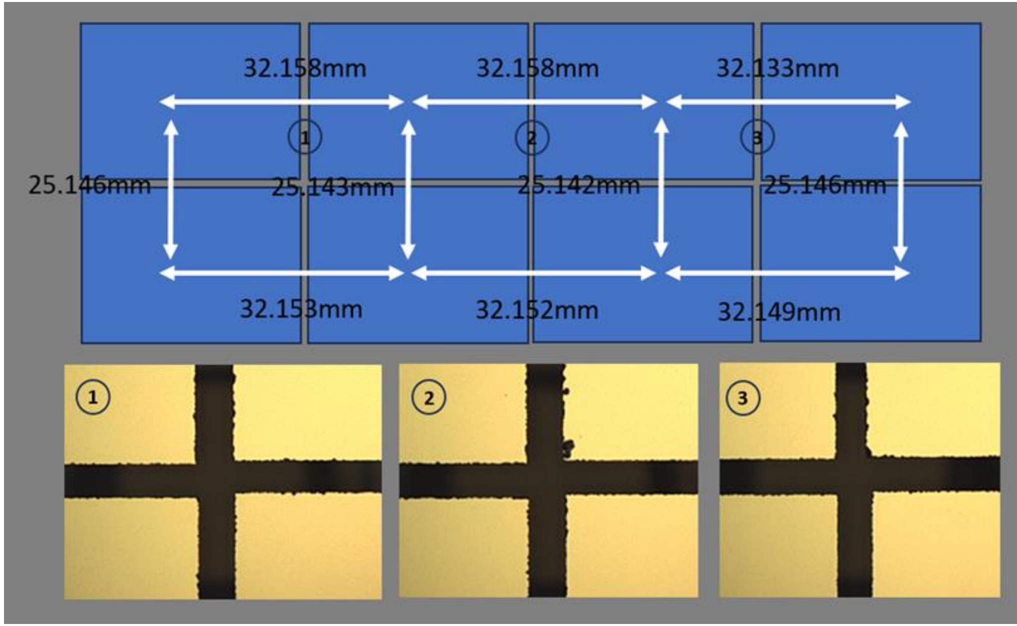


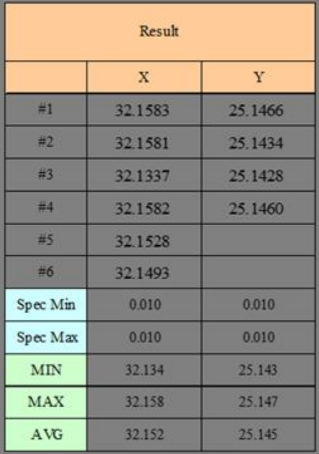
Dummy module assembly (2024 Oct.)

- Die bond with heat cure epoxy
  - Epoxy generally used by MEMSPACK
  - Heat cure condition: 100 ℃, 30 minutes (outside from the die bonder machine)
  - Dispense epoxy on the PCB (a few lines) and place chips
  - 0.3 mm thick chip (will reduce gradually)
  - **Confirmed a good position precision**

- To do
  - Thinner chip
  - Flexible PCB
  - Wire bonding
  - Epoxy (Araldite 2011)



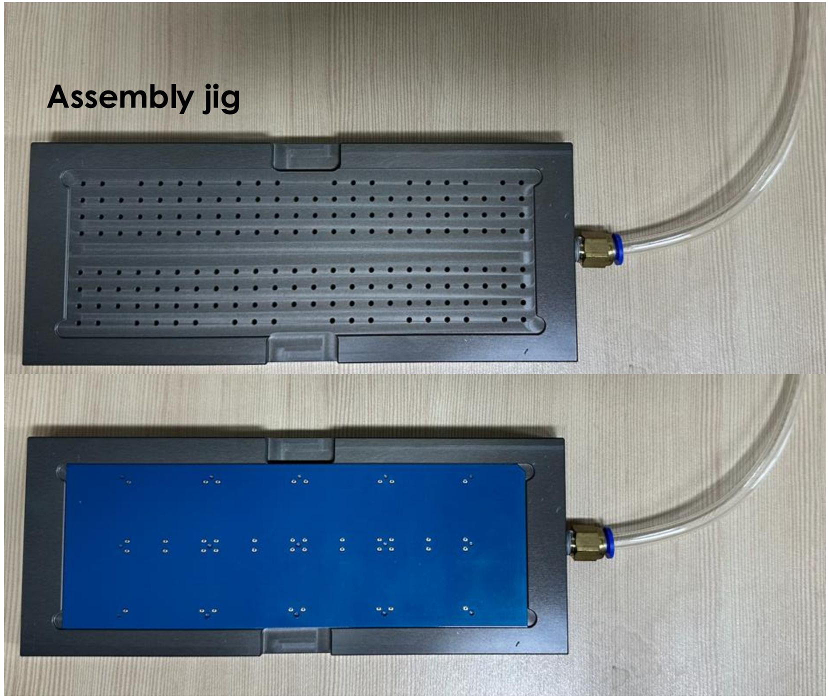


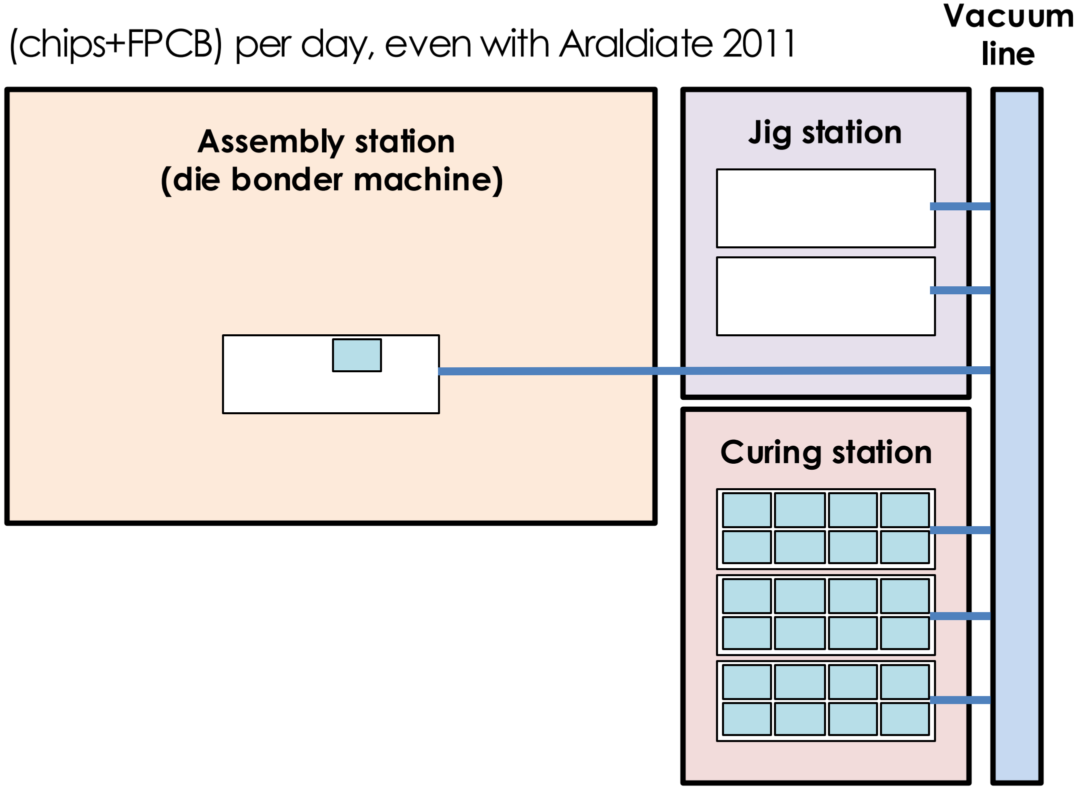


Result		
	X	Y
#1	32.1583	25.1466
#2	32.1581	25.1434
#3	32.1337	25.1428
#4	32.1582	25.1460
#5	32.1528	
#6	32.1493	
Spec Min	0.010	0.010
Spec Max	0.010	0.010
MIN	32.134	25.143
MAX	32.158	25.147
AVG	32.152	25.145

Concept of mass production procedure

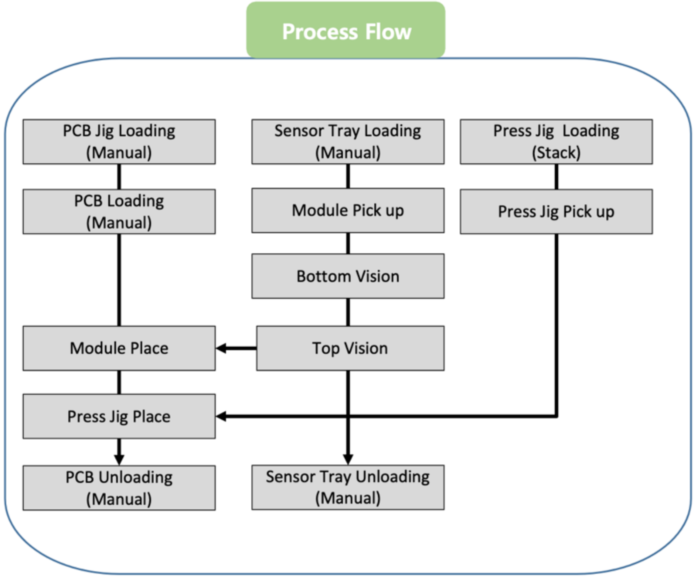
- Uses several assembly jigs to run the assembly station continuously
  - FPCB is held with a vacuum during curing
  - Plan to build the system and verify the procedure
  - Expected production rate: 20-30 modules (chips+FPCB) per day, even with Araldiate 2011





Customized module assembly machine (C-ON tech)

- Initial design for the customized machine
  - Chip handling system will provide an accurate position precision
  - Plan to produce a prototype machine in 2025



Process Flow

PCB Jig Loading (Manual)

PCB Loading (Manual)

Module Place

Press Jig Place

PCB Unloading (Manual)

Sensor Tray Loading (Manual)

Module Pick up

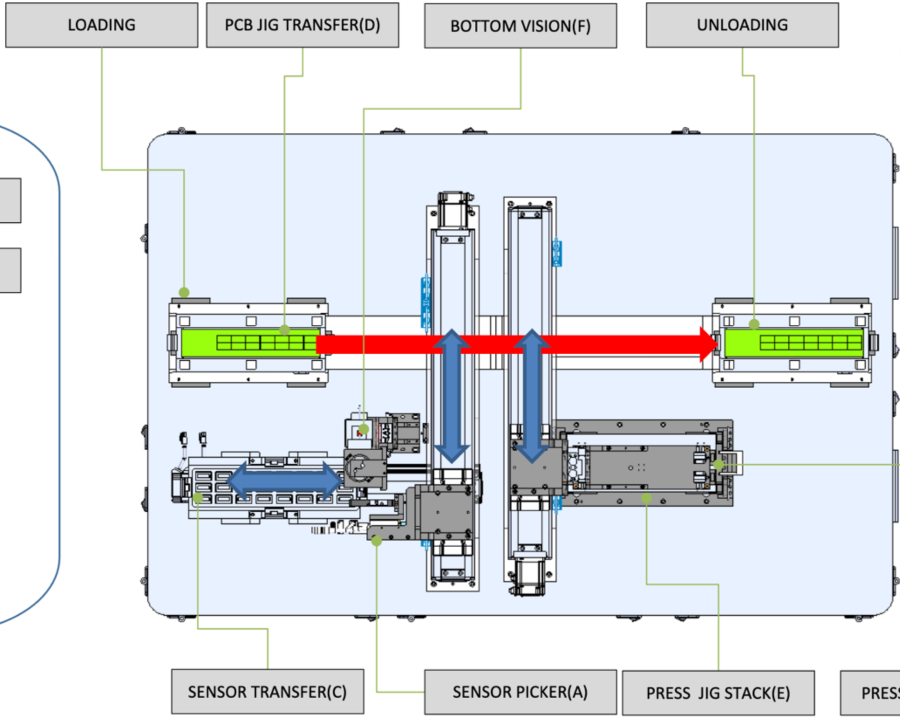
Bottom Vision

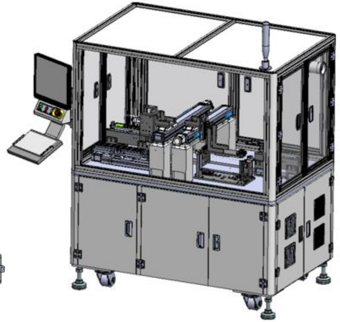
Top Vision

Sensor Tray Unloading (Manual)

Press Jig Loading (Stack)

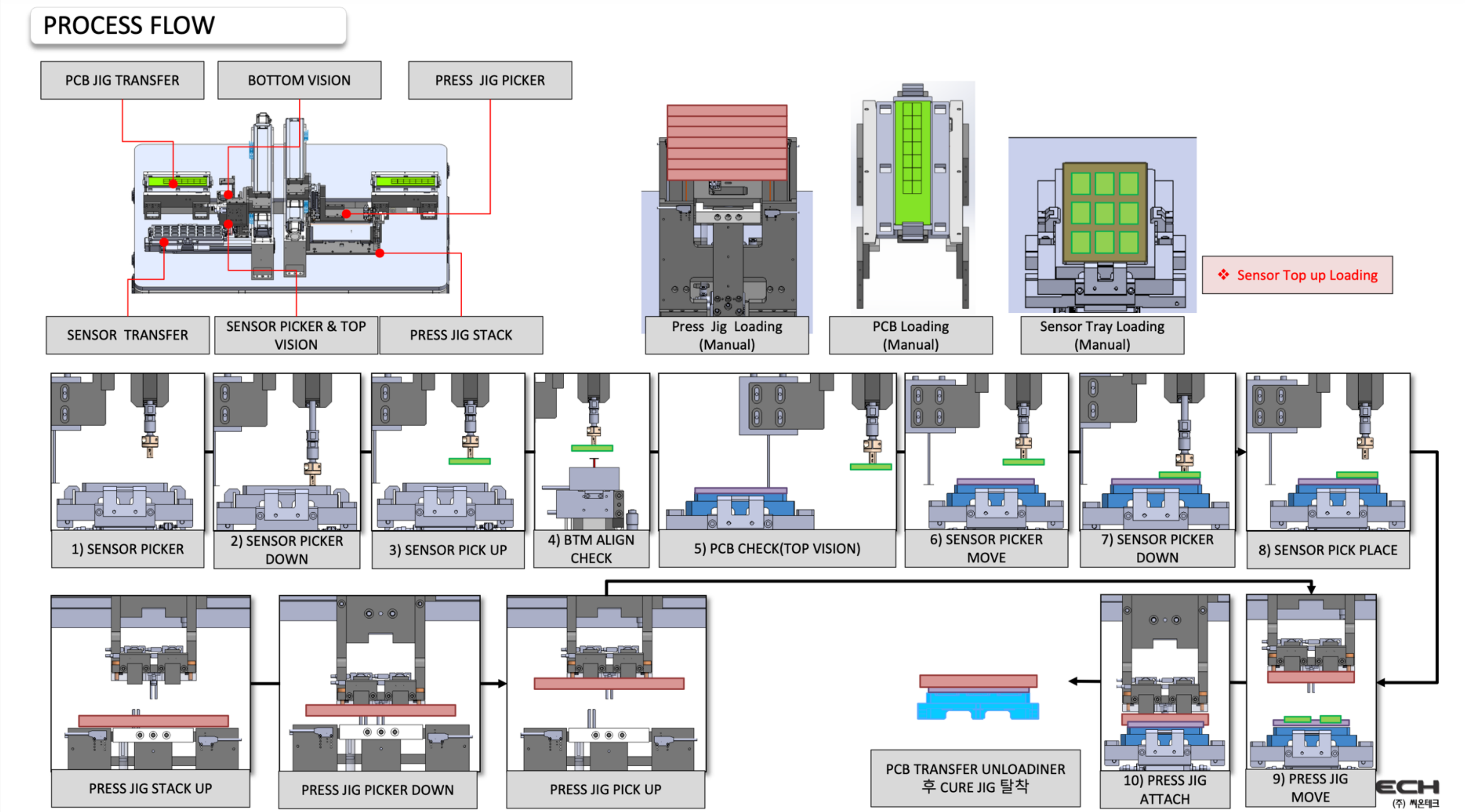
Press Jig Pick up





Customized module assembly machine (C-ON tech)

- Option 1: Chips are placed/attached directly onto the PCB (same as the procedure from MEMSPACK)



PROCESS FLOW

PCB JIG TRANSFER

BOTTOM VISION

PRESS JIG PICKER

SENSOR TRANSFER

SENSOR PICKER & TOP VISION

PRESS JIG STACK

Press Jig Loading (Manual)

PCB Loading (Manual)

Sensor Tray Loading (Manual)

❖ Sensor Top up Loading

1) SENSOR PICKER

2) SENSOR PICKER DOWN

3) SENSOR PICK UP

4) BTM ALIGN CHECK

5) PCB CHECK(TOP VISION)

6) SENSOR PICKER MOVE

7) SENSOR PICKER DOWN

8) SENSOR PICK PLACE

9) PRESS JIG MOVE

10) PRESS JIG ATTACH

PCB TRANSFER UNLOADINER 후 CURE JIG 탈착

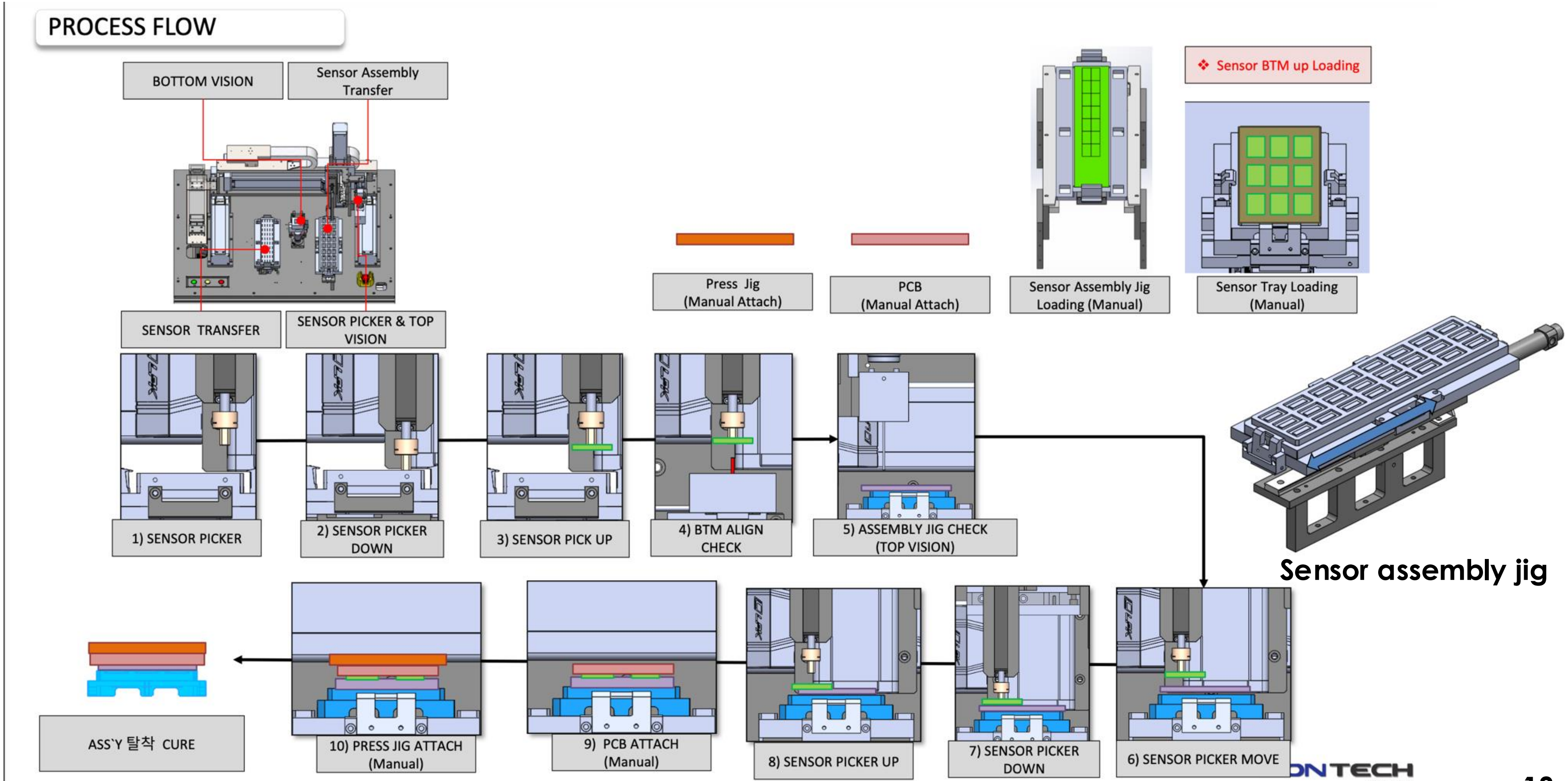
PRESS JIG STACK UP

PRESS JIG PICKER DOWN

PRESS JIG PICK UP

Customized module assembly machine (C-ON tech)

- Option 2: Chips are placed onto the jig, and the PCB is attached later (same as ALICIA)



PROCESS FLOW

BOTTOM VISION

Sensor Assembly Transfer

SENSOR TRANSFER

SENSOR PICKER & TOP VISION

Press Jig (Manual Attach)

PCB (Manual Attach)

Sensor Assembly Jig Loading (Manual)

❖ Sensor BTM up Loading

Sensor Tray Loading (Manual)

1) SENSOR PICKER

2) SENSOR PICKER DOWN

3) SENSOR PICK UP

4) BTM ALIGN CHECK

5) ASSEMBLY JIG CHECK (TOP VISION)

6) SENSOR PICKER MOVE

7) SENSOR PICKER DOWN

8) SENSOR PICKER UP

9) PCB ATTACH (Manual)

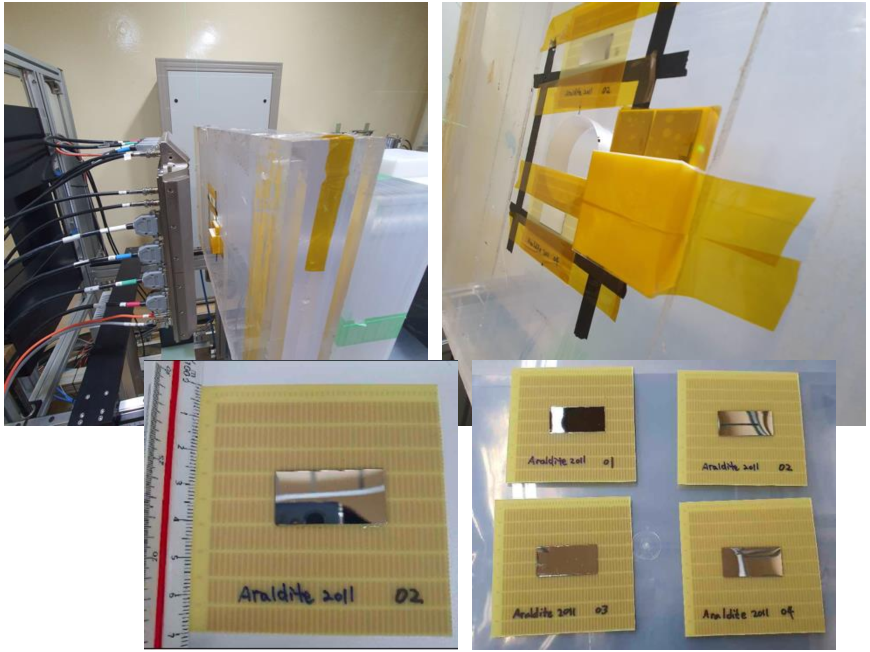
10) PRESS JIG ATTACH (Manual)

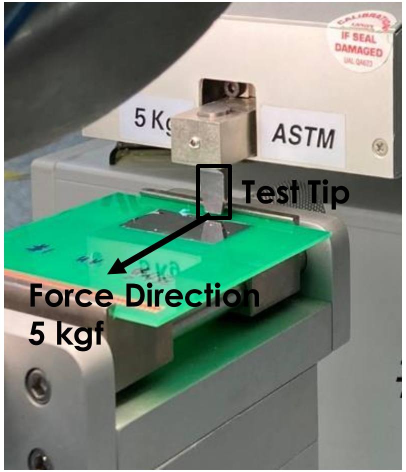
ASS`Y 탈착 CURE

Sensor assembly jig

Radiation hardness test for epoxy

- Proton beams (15~20 MeV) at KOMAC can be utilized for radiation hardness test of epoxies
  - High-intensity beams ($10^{10\text{-}11}$ #/cm^2 s)
  - Comparison between different epoxies, including Araldite 2011
  - First run in Oct/16-17 and second run in Dec/23-24

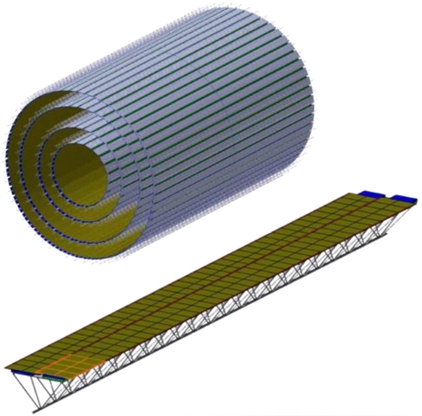


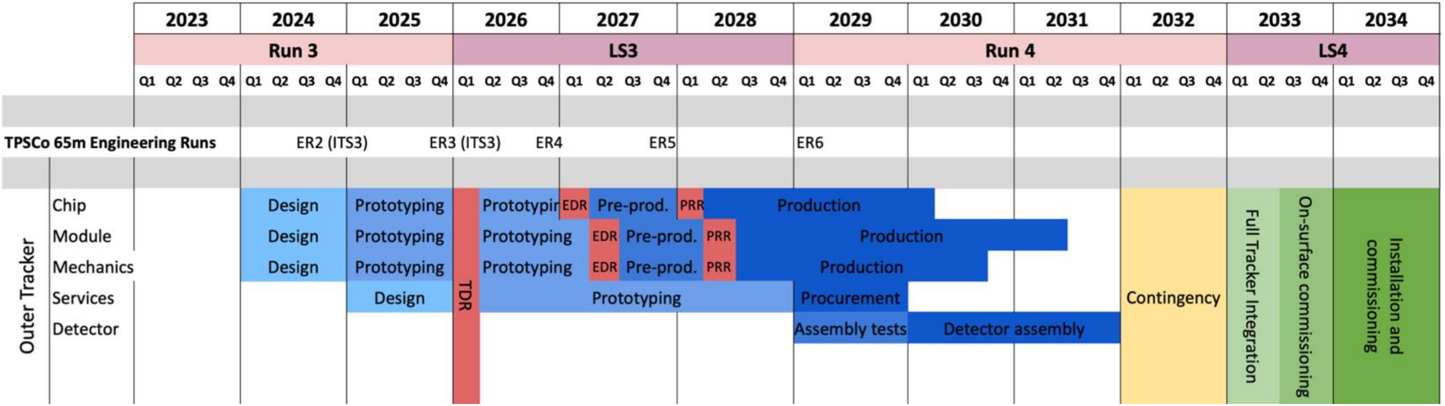


Automatic dispenser
E4V
PerformusX100

Summary and outlook

- Module design and assembly for ALICE 3 OT
  - Conceptual design of stave and module
  - R&D of module assembly with a general-purpose die-attach machine
    Obtained a good precision of chip positioning with epoxy (heat cure epoxy)
  - Further testing with more realistic conditions and developing mass production in 2025
  - R&D of a prototype of the customized assembly machine for a backup plan





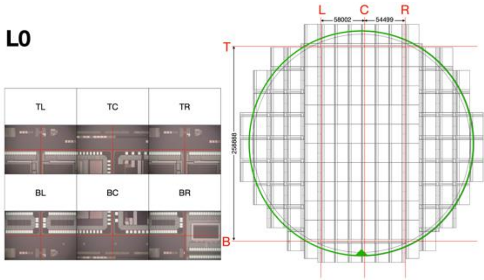
		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
		Run 3			LS3			Run 4				LS4	
		Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4	Q1 Q2 Q3 Q4
TPSCo 65m Engineering Runs			ER2 (ITS3)		ER3 (ITS3) ER4	ER5		ER6					
Outer Tracker	Chip		Design	Prototyping	TDR Prototypin	EDR Pre-prod.	PRR Production	Production	Production		Contingency	Full Tracker Integration On-surface commissioning	Installation and commissioning
	Module		Design	Prototyping	TDR Prototyping	EDR Pre-prod.	PRR Production	Production	Production	Production			
	Mechanics		Design	Prototyping	TDR Prototyping	EDR Pre-prod.	PRR Production	Production	Production				
	Services			Design	TDR Prototyping	Prototyping	Prototyping	Procurement					
	Detector				TDR			Assembly tests	Detector assembly	Detector assembly			

BACKUP

Post-processing (EngiOn)

- First meeting (Aug/28) to discuss a sample run with pad wafer
- Recently received three pad wafers

- Plan to request 50 um (for ITS3)
  can be done down to 30 um



두산테스나/엔지온 사업 영역

테스트와 연결되는 연마/절삭/리컨 역량 확보를 위해 2024년 엔지온 인수

🟧 두산테스나 영역
🟨 엔지온 영역

전공정 · 후공정

설계 (Design) → 제조/생산 (Fab) → 범핑 (Bumping) → 웨이퍼 테스트 (Probe Test) → 연마/절삭 (BG/Saw) → 리컨 (Recon.) [CIS only] → 패키징 (Packaging) → 패키징 테스트 (Final Test) → Module PKG/Test → Final Product

DOOSAN Tesna

웨이퍼 테스트 (EDS)

- 전공정을 거친 웨이퍼에 위치한 **반도체 칩의 양품/불량품 선별 과정**
- 불량칩이 패키징되는 것을 방지해 원가 절감
- 테스트 결과를 기반으로 공정/제품 설계의 문제점을 파악하여 개선 조치 실행 가능

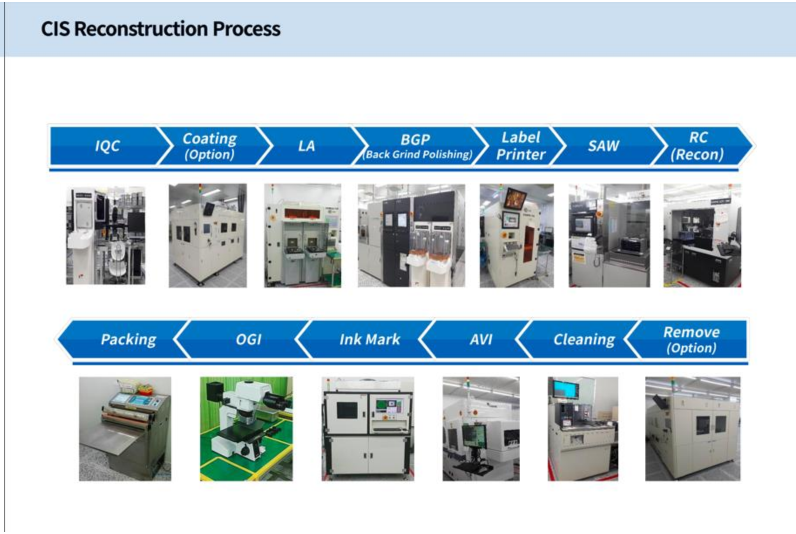
웨이퍼 내 개별 칩 (Die)의 불량여부 판별

EngiOn엔지온

리컨 공정 (Reconstruction)

- EDS 완료된 웨이퍼 후면에 연삭 및 연마 진행 후, 개별 chip 분리하여 **양품 chip만 재배열 하는 공정**
- 저화소부터 고화소용 CIS 불량 제품을 선별해 출하 방지하여 품질 비용 절감
- 후공정 yield loss를 최소화하여 효율적인 모듈 PKG 구현 가능

CIS 웨이퍼에서 양품 칩을 선별해 재배열



CIS Reconstruction Process

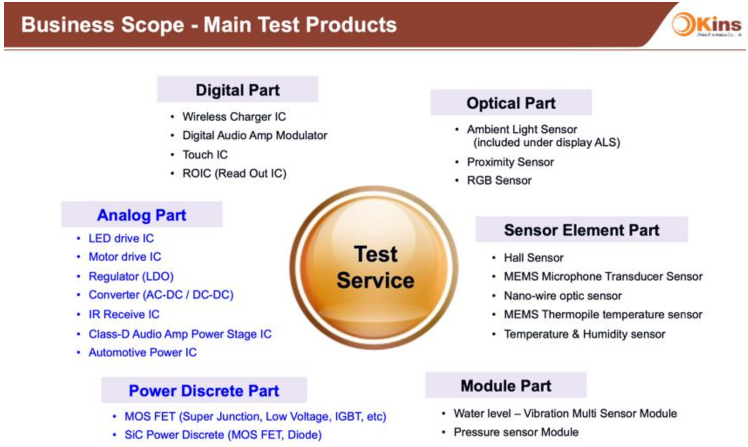
IQC → Coating (Option) → LA → BGP (Back Grind Polishing) → Label Printer → SAW → RC (Recon)

Remove (Option) → Cleaning → AVI → Ink Mark → OGI → Packing

Wafer probing (OKins)

- Wafer probing:
  "OKins" is a company working wafer probing
  Engineering support from probe card design

- Plan to start a test run with the ER1 wafer



Business Scope - Main Test Products

Test Service

Digital Part
- Wireless Charger IC
- Digital Audio Amp Modulator
- Touch IC
- ROIC (Read Out IC)

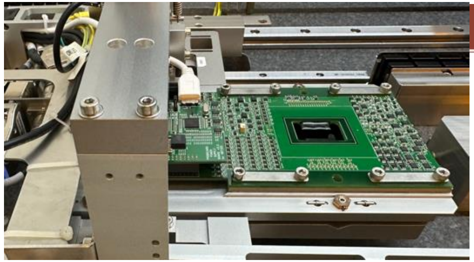
Optical Part
- Ambient Light Sensor
  (included under display ALS)
- Proximity Sensor
- RGB Sensor

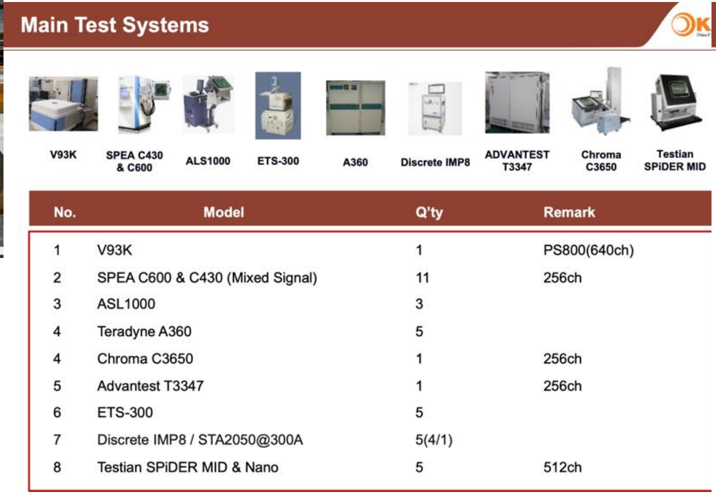
Analog Part
- LED drive IC
- Motor drive IC
- Regulator (LDO)
- Converter (AC-DC / DC-DC)
- IR Receive IC
- Class-D Audio Amp Power Stage IC
- Automotive Power IC

Sensor Element Part
- Hall Sensor
- MEMS Microphone Transducer Sensor
- Nano-wire optic sensor
- MEMS Thermopile temperature sensor
- Temperature & Humidity sensor

Power Discrete Part
- MOS FET (Super Junction, Low Voltage, IGBT, etc)
- SiC Power Discrete (MOS FET, Diode)

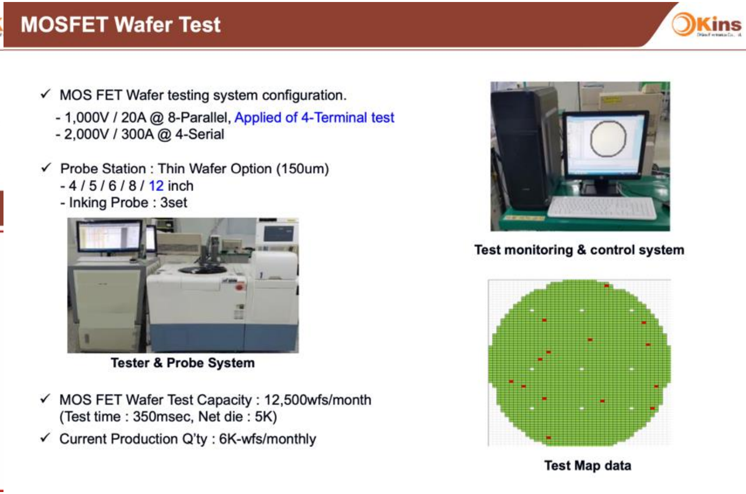
Module Part
- Water level – Vibration Multi Sensor Module
- Pressure sensor Module





Main Test Systems

No.	Model	Q'ty	Remark
1	V93K	1	PS800(640ch)
2	SPEA C600 & C430 (Mixed Signal)	11	256ch
3	ASL1000	3	
4	Teradyne A360	5	
4	Chroma C3650	1	256ch
5	Advantest T3347	1	256ch
6	ETS-300	5	
7	Discrete IMP8 / STA2050@300A	5(4/1)	
8	Testian SPiDER MID & Nano	5	512ch



MOSFET Wafer Test

✓ MOS FET Wafer testing system configuration.
- 1,000V / 20A @ 8-Parallel, Applied of 4-Terminal test
- 2,000V / 300A @ 4-Serial

✓ Probe Station : Thin Wafer Option (150um)
- 4 / 5 / 6 / 8 / 12 inch
- Inking Probe : 3set

Tester & Probe System

Test monitoring & control system

Test Map data

✓ MOS FET Wafer Test Capacity : 12,500wfs/month
(Test time : 350msec, Net die : 5K)

✓ Current Production Q'ty : 6K-wfs/monthly