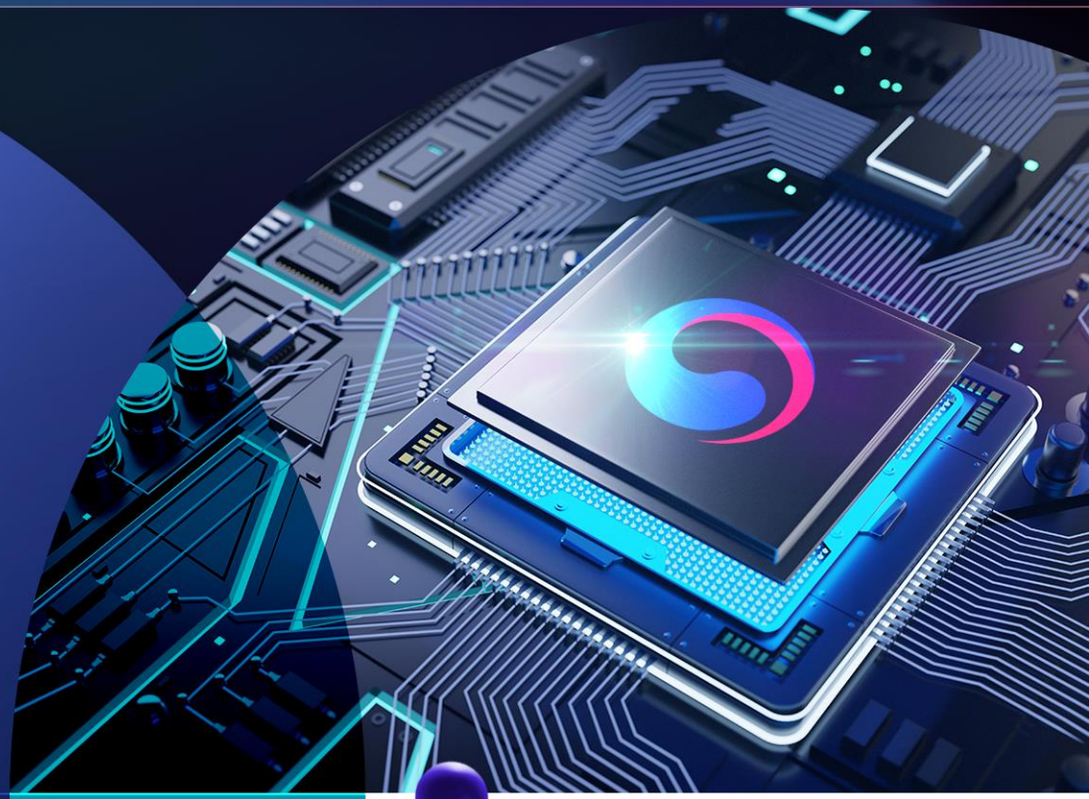
The 17th Korea-U.S.
Forum on Nanotechnology

Ministry of Science and ICT



Nano & Semiconductor Technology Initiative and R&D in Korea

April 3, 2023

Deok-kee Kim

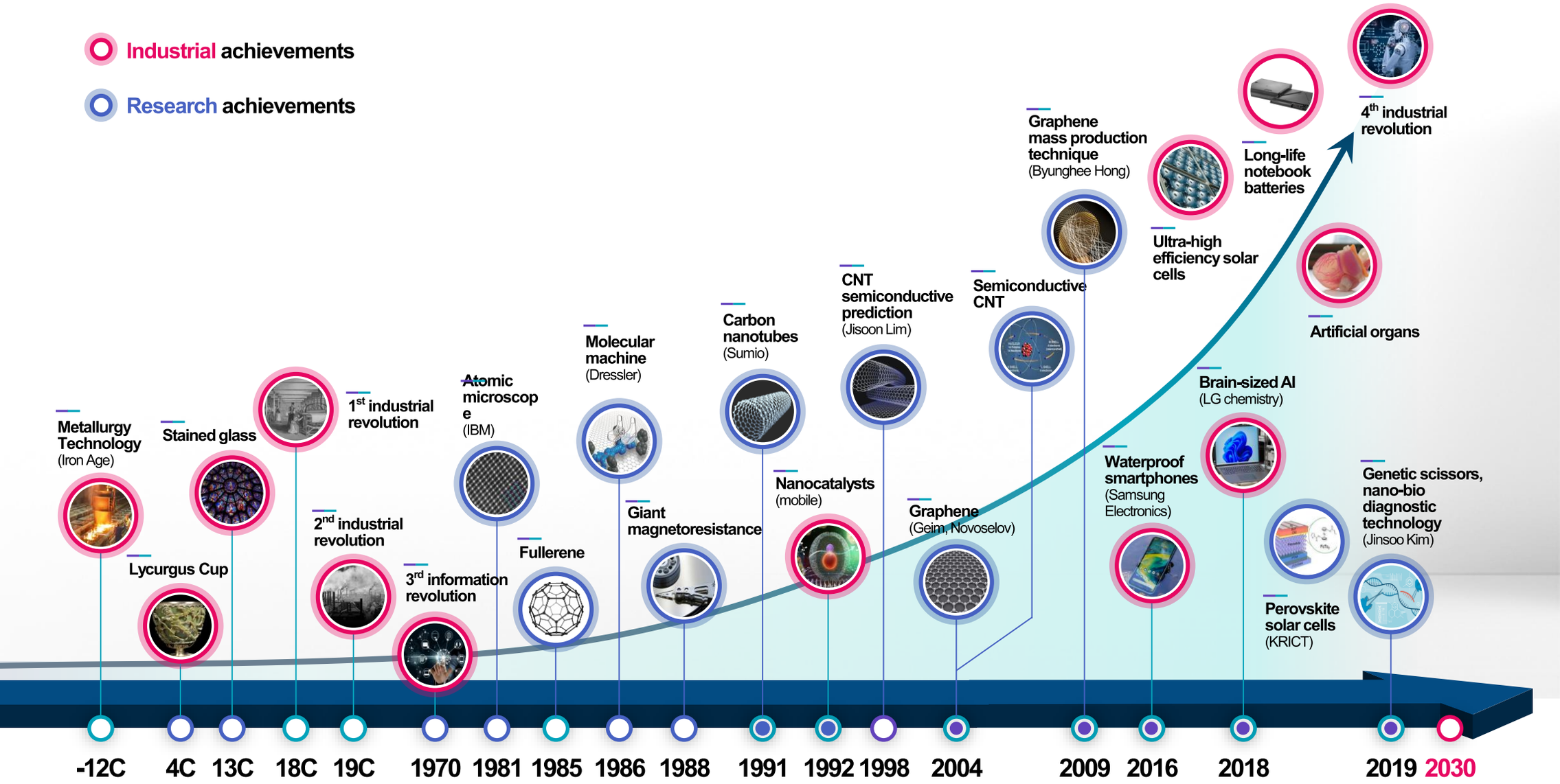
National Research Foundation of Korea

NRF National Research Foundation of Korea

Outline

01 History of Nano & Materials Technology

Nano & Materials Research & Industry Achievements



04 20 Years Korea Nanotechnology Initiative

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

Nanotechnology Initiative

- 1st Nanotechnology Initiative — Established in 2001.07 (2001~2010)
- 2nd Nanotechnology Initiative — Established in 2005.12 (2006~2015)
- 3rd Nanotechnology Initiative — Established in 2011.04 (2011~2020)
- 4th Nanotechnology Initiative — Established in 2016.04 (2016~2025)
- 5th Nanotechnology Initiative — Established in 2021.04 (2021~2030)

Nanotechnology Roadmap

- 1st National Nanotechnology Roadmap — Established in 2008.04 (2008~2017)
- 2nd National Nanotechnology Roadmap — Established in 2014.02 (2014~2025)
- 3rd National Nanotechnology Roadmap — Established in 2018.06 (2018~2027)
- 4th National Nanotechnology Roadmap — Planned in 2023.05 (2023-2032)

05 20Years Korea Nanotechnology Initiative

Total R&D investment of 1.25 trillion won for nanotechnology, accounting for 4.2% of the government's total investment (29.8trillion won) in 2022.

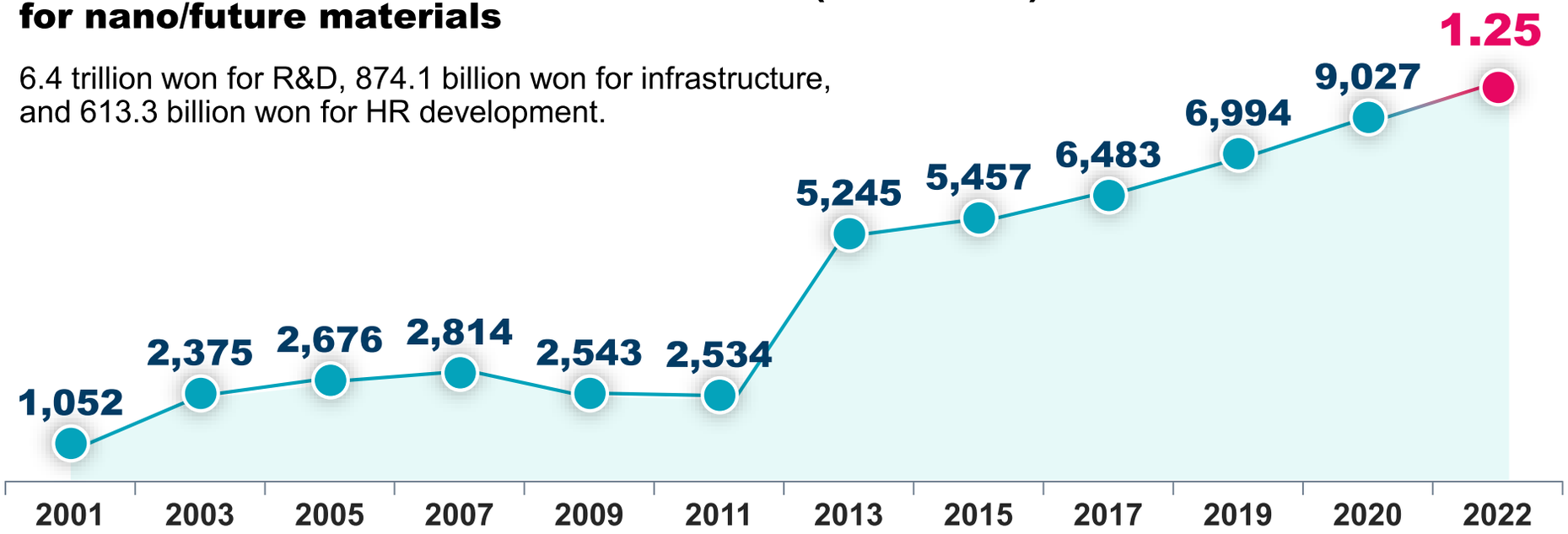
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

(Unit: 100 million won)

Current status

Total R&D investment of 7.9 trillion won (2001-2020) for nano/future materials

6.4 trillion won for R&D, 874.1 billion won for infrastructure, and 613.3 billion won for HR development.



Current status

Technology level
Ranked 4th in the world

Employment
15.4 million workers

Revenues
165.6 trillion won

Number of firms
880

07 5th Korea National Nanotechnology Initiative (2021.04)

Vision: Lead global future society with nanotechnology innovation

Reinforce creative/ challenging and globally-leading nano-research

1. Increase investment in nano fundamental and original research
2. Promote nano-based future-resolving R&D
3. Enhance nanotechnology investment strategies
4. Establish and expand the nano/material data platform

Reinforce compete -tiveness of innovative growth-led nano-convergence industry

1. Develop nano convergence industrialization technology in advance
2. Enhance support for technology commercialization of NT companies
3. Promote foundation of an innovation ecosystem for nano-convergence industry

Enhance the function of nanofab infrastructure

1. Enhance the supporting system for nanofab infrastructure
2. Enhance the supporting function for nanofab infrastructure
3. Create a nanofab infrastructure innovation and mid-to long-term development strategies

Expand the infra-structure for nano-technology innovation

1. Reinforce nurturing of nanotechnology professionals
2. Strengthen international collaboration through open innovation
3. Lead international nano safety and standardization
4. Enhance awareness of the nation on nanotechnology

※ (Original technology) Technology with original, innovative and unique feature that meets criteria for science and technology innovation(journals within top 5% in JCR) and industrial innovation(AA class patent registration in SMART INDEX and technology transformation over 500 million won advance payment).

08 3rd National Nanotechnology Roadmap (2018~2027, 2018.04)

Challenges of NT toward Future Technologies that Human Beings Dream of

3 major categories → 30 future technology fields → 70 core NTs

Core NT derivation process

Deriving future technology candidates	→	Selecting future technology 30	→	Deriving NT applications	→	Performance indicators and final goals	→	Selecting core NT
Demand base		Order of contribution		Shape		Verification of possibility		70 NTs

Convenient and Pleasant Life

Development of AI semiconductor, IoT, future display and clear performances using ultra-fine nano process technology

1. Portable human-level AI
2. Big data in my hand
3. Unlimited speed communication
4. Display that can freely change shape
5. Food tasting with smartphone
6. Cyborg feels like human
7. Drones that can fly without charge
8. Generating Electricity by walking
9. Wearable battery like clothes
10. Technology to keep young skin
11. Mask pack for automatic makeup

Eco-Friendly Life

Achievement of high efficiency and unlimited clean energy, fine dust removal, economic water resource production technology, utilizing innovative peculiar phenomena in nano-sized materials

12. Ultra high efficiency solar power generation superior to thermal power generation
13. Fuel cell ready for blackout
14. Hydrogen vehicle
15. Electric vehicles that can be operated from Seoul to Busan in 5 minutes charge
16. Artificial leaf photosynthesis
17. Energy-independent housing without electricity supply
18. Reuse of abandoned water
19. Self-sufficient urban agriculture

Healthy and Safe Life

Secure simple, accurate and effective prevention/diagnosis/treatment, safe food and disaster safety technology, utilizing fast transfer properties at the nanomaterial interface

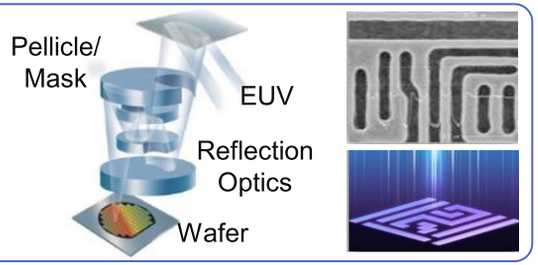
20. Batteries without risk of explosion
21. Preventive medicine for 100-year-olds
22. Drugs that diagnose and treat
23. Artificial organ without rejection
24. See and treat myself in my body
25. Self health monitoring at anytime
26. AI system that notifies harmful viruses
27. Germicidal clothing
28. Air purifiers that clear the air of the house
29. Meals solved in one capsule in space
30. Microbot to quickly find disaster victims

09 Nanotechnology Success Stories

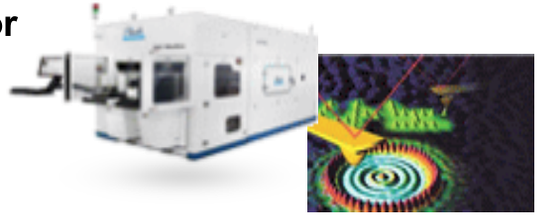
Leading technological innovation in government policy directions (carbon neutrality, pandemic response, etc.) through the convergence of IT, BT, and ET.

Semi-conductor

✓ **5nm ultra-fine patterning applied with EUV**

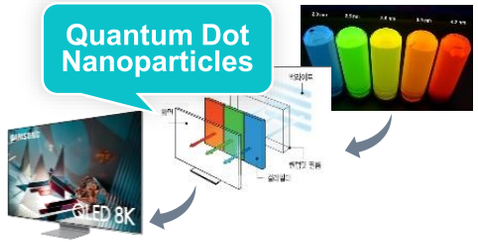


✓ **Semiconductor chip defect inspection by AFM**



Display

✓ **Nano QD applied ultra-high-definition QLED TV**

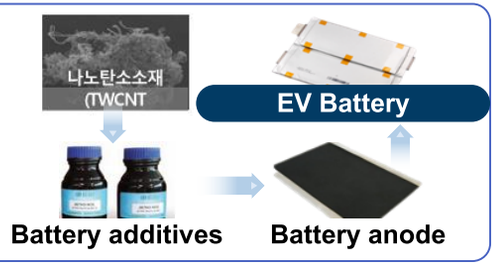


✓ **Foldable smartphone with silver nanowire**

Carbon Neutral Era

✓ **Superconducting Wire** (100 times more than copper)

✓ **Large-Capacity Battery**



Pandemic Keepers

✓ **High sensitivity in-vitro diagnostic device**

✓ **Real-time portable molecular diagnostic kit for COVID-19**

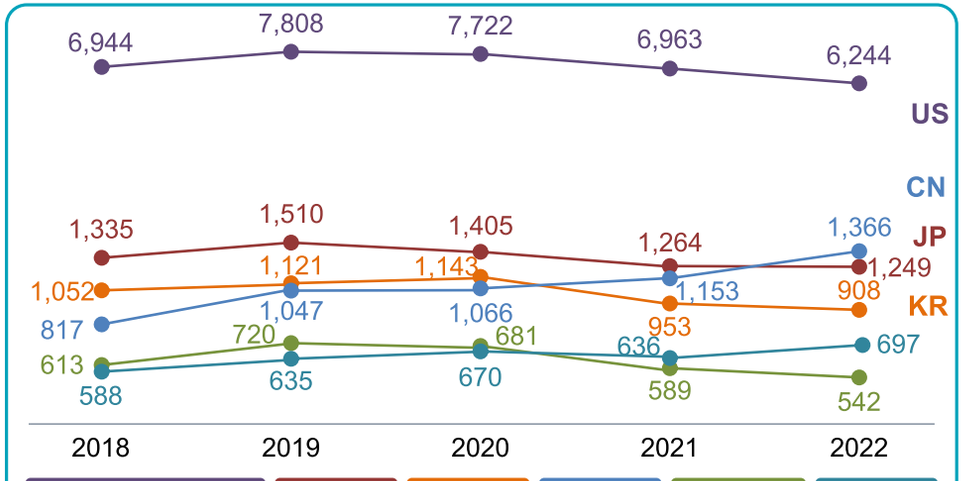
10 Key Achievements

01 R&D Performance

Patents

In 2022, US patents for nanotechnology by South Korea was 6.5% of all patents (ranked 4th)

Nanotechnology patents of major countries



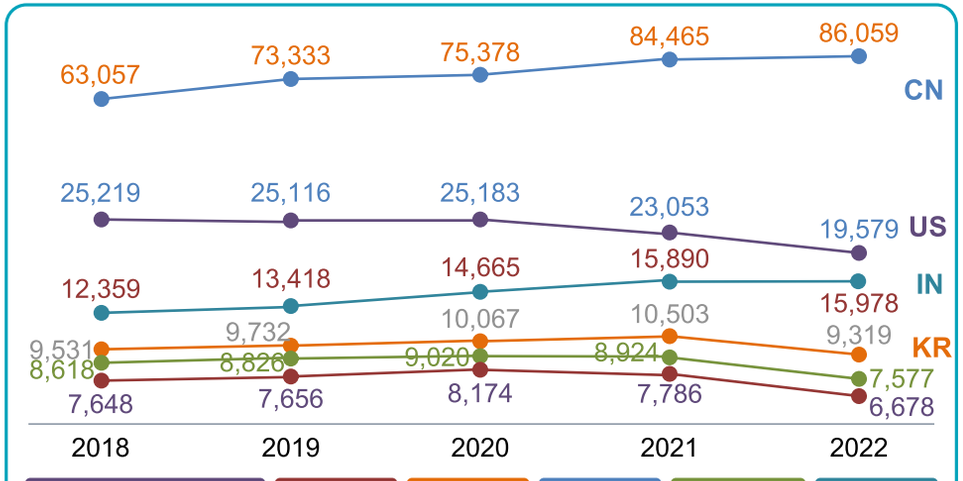
	US	Japan	Korea	China	Germany	Taiwan
Accumulative ('18~'22)	35,681	6,763	5,177	5,449	3,145	3,226
Accumulative ('13~22)	70,295	14,347	9,712	8,132	6,279	6,092

※ Based on the patents registered in U.S. Patent and Trademark Office

Articles

In 2022, SCI articles from South Korea on nanotechnology was 6.0% of the global total (ranked 4th)

Nanotechnology articles of major countries



	US	Japan	Korea	China	Germany	India
Accumulative ('18~'22)	118,150	37,942	49,152	382,292	42,965	72,310
Accumulative ('13~22)	231,917	73,898	91,417	593,302	83,166	118,248

※ Based on a Web of Science

11 Key Achievements

02 Commercialization Performance within Korea (2017-2021)

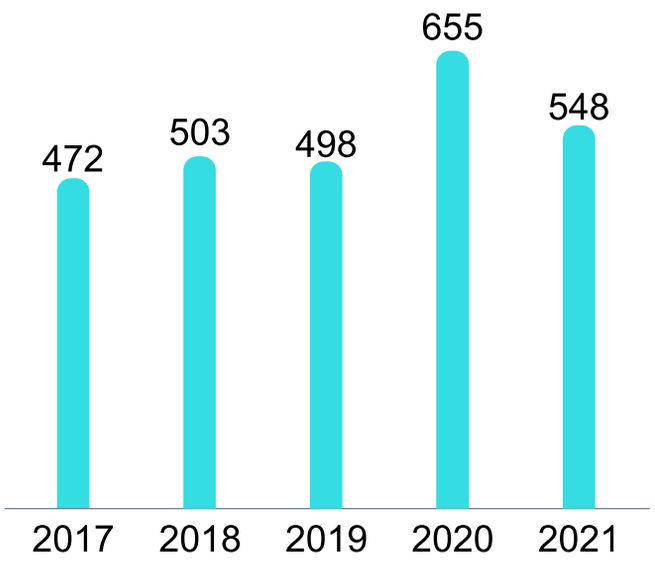
NT transfer cases
2,676

Royalty collection
93.76 billion won

Commercialization cases
8,290

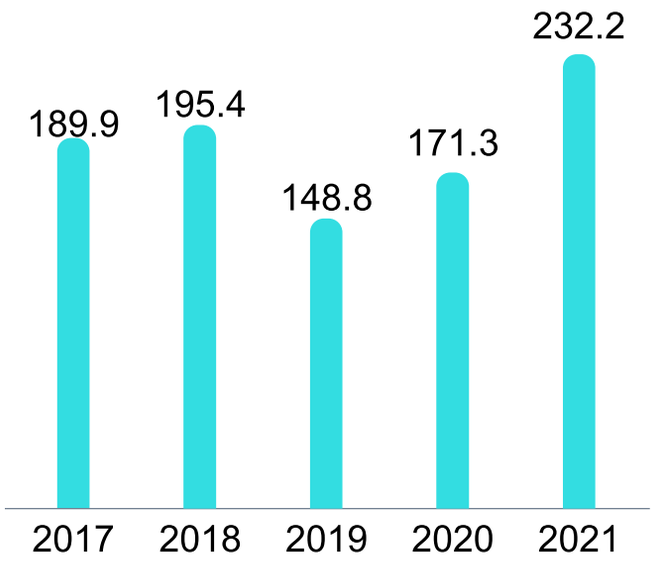
Royalty and Commercialization Performance of National NT R&D Project

NT Transfer cases



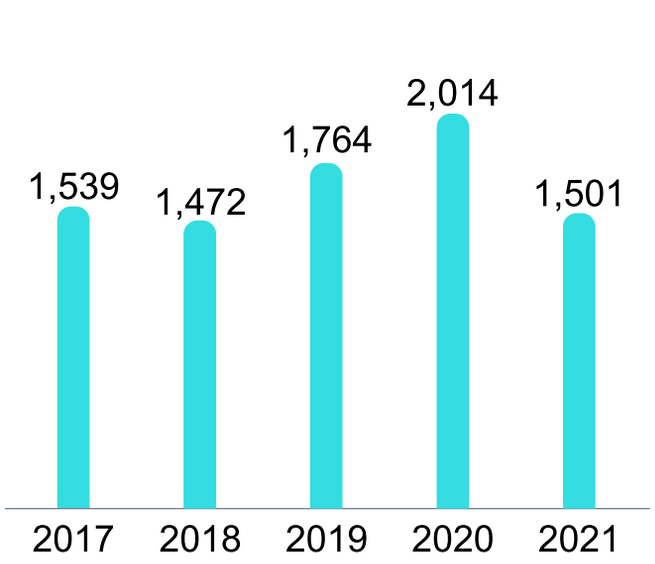
Total 2,676

Royalty collection (100 million won)



Total 937.6

Commercialization cases



Total 8,290

source : National Technical Information Service(NTIS), 2023 Nanotechnology Development Implementation Plan

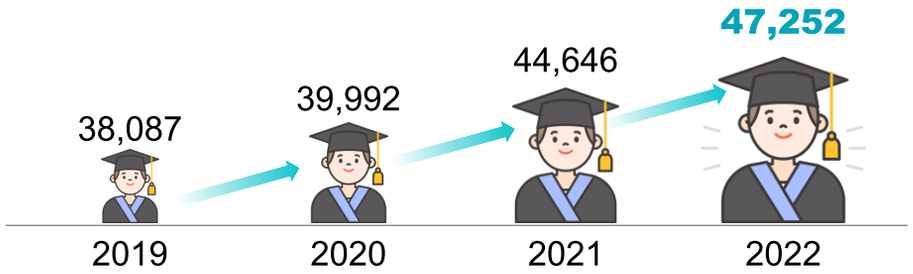
12 Key Achievements

03 Human Resources within Korea

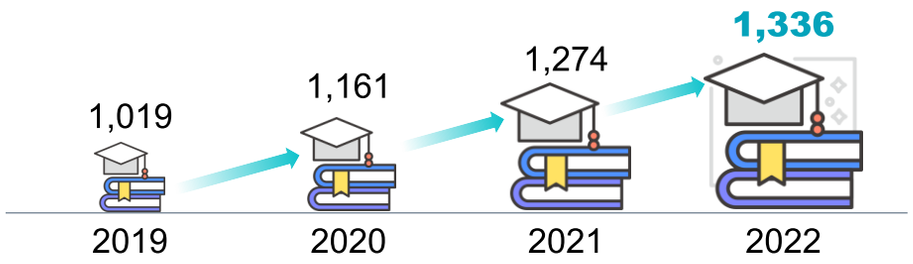
The number of researchers in NT is 16,169, college students enrolled in NT related departments is 47,252, and workers in NT industry is 153,652.

Developing Human Resources in NT

Number of college students enrolled in NT related departments

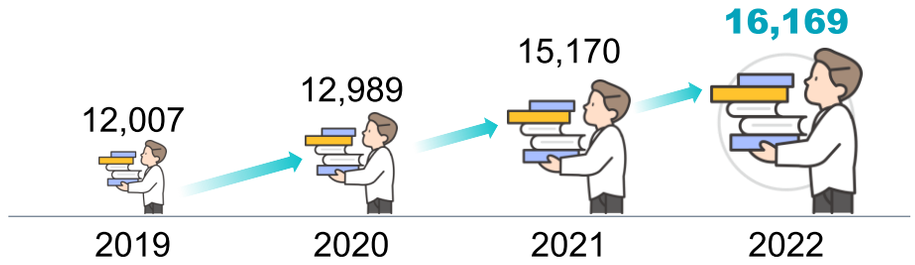


Number of NT related departments at Korean Universities

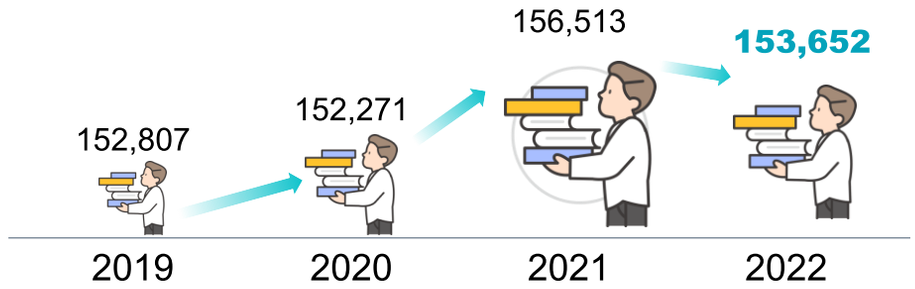


Researchers / Industrial Manpower

Researchers in NT



Manpower in NT convergence industries



Source: 2018 Nanotechnology Development Implementation Plan

Outline

01 Nano & Materials R&D Program

Overcoming external dependence in the field of nanomaterials and enhancing global competitiveness

- Establishment of R&D investment strategy to secure core technology

- R&D process innovation that increases the value of investment

Program Details (325 billion won for 2023)

1 Source Tech.

- **Creation of a technology-based market by turning basic research results into source technology.**
  - (Leading)
  - (Competitive)
  - (Challenging)

2 Future Preparation

- **Creation of new markets and new industries in line with future trends.**
  - (Strategic)
  - (Nano-connect)

3 Technical Independence

- **Core items: Independent material technology**
  Main industries: supply chain independence
  - (Specialized)
  - (Platform Type)

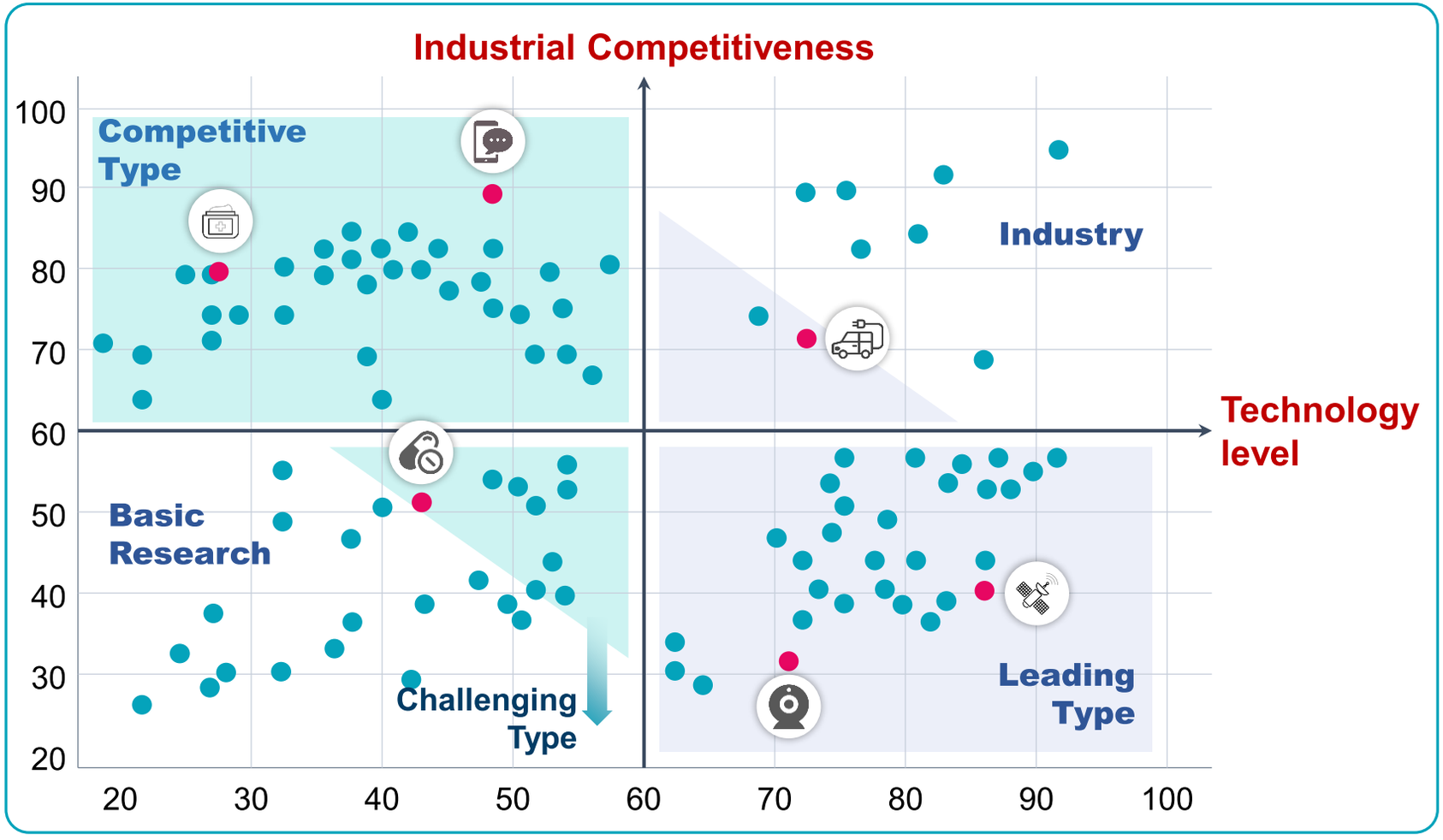
4 Infrastructure

- **Enhancing the efficiency of the entire cycle of nanomaterials.**
  - Nano & Material research data platform.
  - Nano fabrication facility improvements.

02 Investment method optimization

Differentiation of investment method considering
industrial competitiveness and domestic technology level

Technology level analysis | **Investment area selection** | **Investment type by TRL**



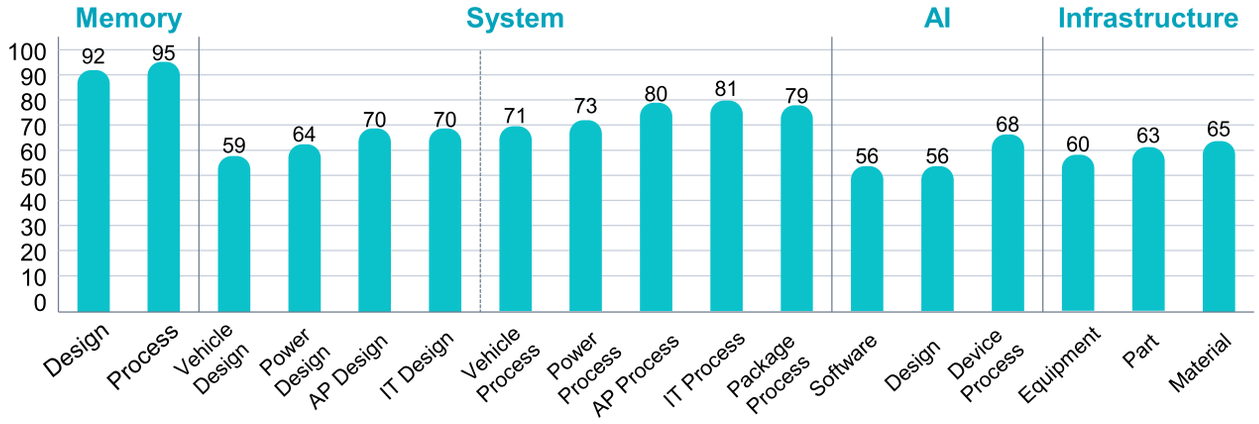
- Solar Mobile
- Smart Nano Lens
- Electric Vehicle
- Electronic pill
- Space Sensor
- Reverse aging cream

Outline

01 Domestic Semiconductor trend

Tech — Responding to global technological change by expanding semiconductor government R&D investment

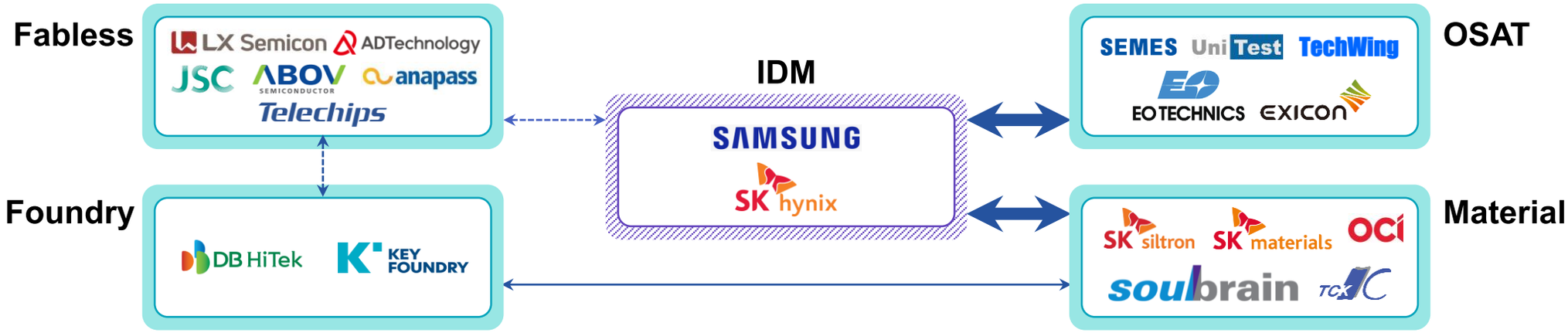
Korea's Semiconductor Technology Competitiveness



Division	Tech level	
	'18	'20
Process and equipment/material technology	94	90
Device and SoC design and manufacturing	85	85
Big data analysis and utilization	70	79
AI Common Platform	80	80

('21, FKI (Left), Science Advisory Committee (Right))

Industry — IDM-centered large corporations, ultra-centralized ecosystem structure



※ From the dotted line (⇢) to the solid line (→), the thicker the line, the higher the linkage by the sector

02 Next-generation Intelligent Semiconductor Program

Purpose

Development of core source technology and integration technology for ultra-low power and high-performance future semiconductor devices that overcome the limitations of existing semiconductor technology

- **(Basic direction) Avoid simple paper-oriented research, early commercialization and secure source IP**

1. Adoption of competitive R&D method, step-by-step evaluation, determination of target for continuous support
2. Wafer level integration and verification support (in parallel with related technology development)

Budget

- **Total 1.0096 trillion won**
  - Ministry of Science and ICT (New device): 240.5 billion won
  - Ministry of Science and ICT (Design): 247.5 billion won
  - Ministry of Industry (Manufacturing): 521.6 billion won

Period 2020. 07. 01 ~ 2029. 12.31

Institution NRF/IITP/KEIT

02 Next-generation Intelligent Semiconductor Program (Device)

Program Highlights

01 New concept Basic technology

02 New device Source technology

03 New Device Integration and verification technology

Creative ideas on a small funding scale

- Support for disruptive innovation ideas that will change the semiconductor paradigm although the possibility of commercialization is low, such as integrated verification within the development period (Decision on follow-up support after 3 years)

Medium funding scale source technology that supports new devices based on various principles with CMOS compatibility

- Support for the development of new device technologies with various principles* with CMOS process compatibility for the realization of ultra-low power consumptions and high-performance goals

* Ultra-low voltage, 3D integration, logic-memory convergence, new element-based architecture (a task in which fine control current and other five categories are fused), wiring fusion, neuromorphic, etc.

Large funding scale integration program that requires wafer-level integration and verification

- Wafer-level integration and performance verification support for commercial linkage of unit devices developed in the laboratory (Development of integrated process and design-based technology, etc.)

02 Next-generation Intelligent Semiconductor Program (Device)

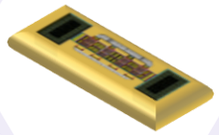
Project status

- Devices with operating voltage of 0.7V or less
- Subthreshold Swing 60mV/dec or less

Ultra low voltage
- Brain signal measurement and stimulation tech
- New device-based security chip

High memory density
- Memristor Device
- Ferroelectric-based Devices
- Multilevel Device

Fusion*



Interconnect/ NEMS
- Next-generation wiring tech
- NEMS based tech
- Spintronics based Device

Neuromorphic
- Neuron/ Synapse Device
- Neuromorphic HW and algorithm
- Calculation efficiency improvement tech

M3D
- M3D based tech
- Si/Ge based tech

Project status

TRL 1 → TRL 2 → TRL 3 → TRL 4 → **TRL 5** → TRL 6 → TRL 7 → TRL 8 → TRL 9

Laboratory testing of integrated system

Technology	Percentage
Ultra low voltage	17.4%
High memory density	13.0%
Interconnect/NEMS	8.7%
Monolithic 3D	13.0%
Neuromorphic	34.9%
Fusion*	13.0%

03 PIM Semiconductor Program

Purpose

Securing core technologies such as a new concept semiconductor (PIM) that integrates memory and processor, a new paradigm for the future semiconductor market

- In the upcoming artificial intelligence (AI) era, securing hardware (HW)-based artificial intelligence semiconductor technology is the key to preoccupying global market leadership
- It is necessary to secure global technology leadership by preemptively developing a new concept PIM semiconductor based on the world's No. 1 memory semiconductor capability

Budget

Total 402.7 billion won

- Ministry of Science and ICT (New device): 60.3 billion won
- Ministry of Science and ICT (Design): 226.7 billion won
- Ministry of Industry (Manufacturing): 113.0 billion won

Period

2022. 04. 01 ~ 2028. 12.31

Institution

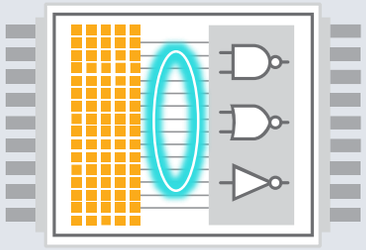
NRF/IITP/KEIT

03 PIM Semiconductor Program (Motivation)

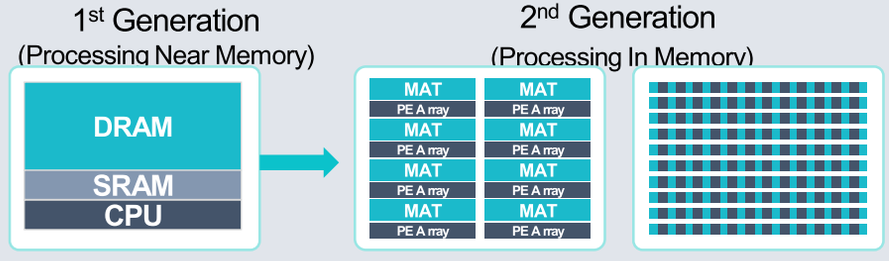
Technical Necessity of New Computing Paradigm → PIM Semi.

As an alternative to overcome the limitations of the von Neumann architecture, PIM semiconductors are newly illuminated.

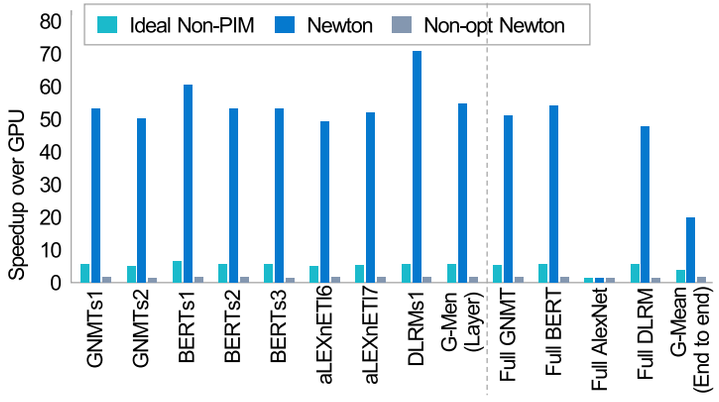
Memory and processor integrated structure



2 Types of structure



Theoretically, unlimited data movement between memory and processor is possible →
Performance improvements, power consumption reduction and cost effectiveness



Bandwidth	Performance	Power consumption
100 times ↑	100 times ↑	1/100 times ↑

*** Reference**

1. A. Boroumand, et al. and Onue Mutlu, “Google workloads for consumer devices: mitigating data movement bottlenecks,” ASPLOS 2018.
2. M. He, Il Park, and et al., “Newton: A DRAM-maker’s Accelerator-in-Memory(AiM) Architecture for Machine Learning,” MICRO 2020.

04 Next generation compound semiconductor R&D

Purpose

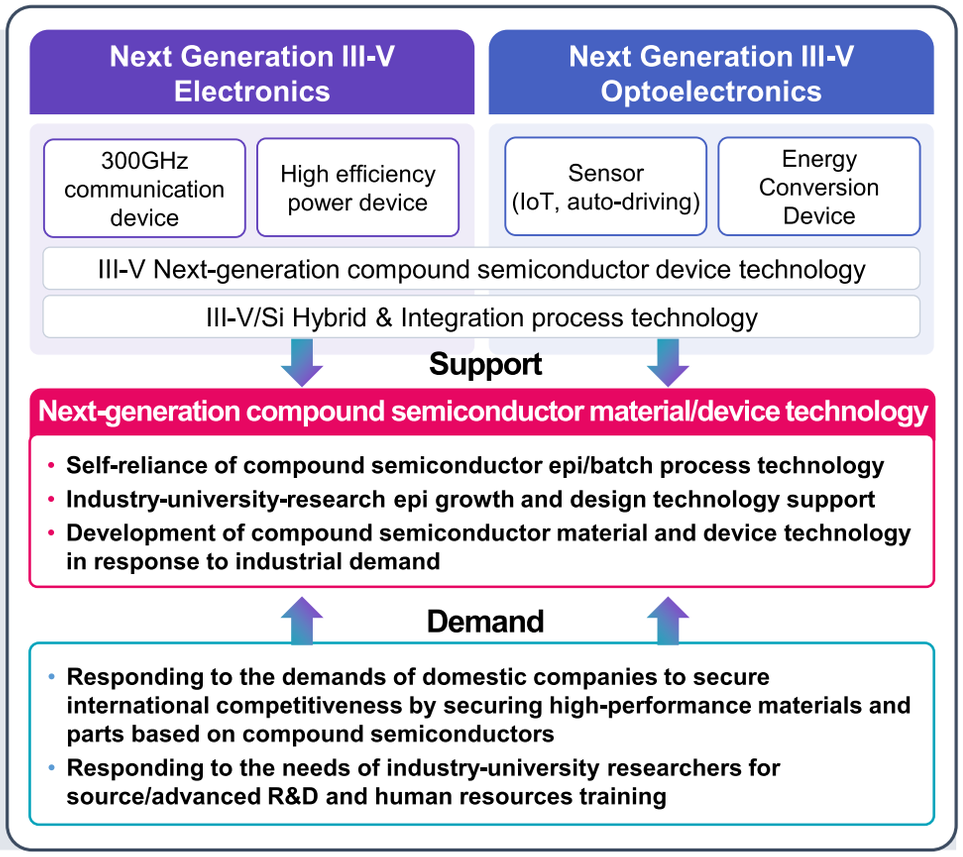
- Securing compound semiconductor source technology and early commercialization of core technology
- Preemptive support for R&D in various fields such as III-V compound semiconductors to enhance domestic system semiconductor competitiveness
- Early commercialization of core technologies by supporting the platform process such as securing compound semiconductor Epi material and device source technology and manufacturing prototypes for fabless companies

Projects

Communication Device	Secured data transmission speed of 100Gbps or higher in ultra-wideband (THz)
Power Device	Establishment of 8-inch CMOS compatible process platform and early commercialization of GaN-based
Sensor Device	High optical gain (>10) compared to Si, wide wavelength band (400nm-1650nm) light detection
Energy conversion device	Acquire photoelectric conversion efficiency of 35% or more and secure space environment elements

Funding

2022 ~ 2026 / 47.5 billion won



Outline

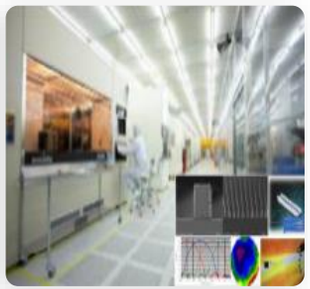
01 Korea Major Nanotechnology R&D Infrastructure

Encourage technology commercialization in specialized fields for each nano infrastructure

- Support commercialization technologies optimized for major sectors, available equipment, and development capabilities
- Achieve practical industrialization results by converging “corporate commercialization needs + specialty of researchers + process technology of nano infrastructure”

NNFC (Daejeon)

Si-CMOS



- Photoelectric transformation device for object recognition
- Flexible hybrid device
- Modular nano biosensors

KANC (Suwon)

Compound devices

- GaN nano LED device for Q-NED displays
- Micro LED devices
- 5G/6G GaAs BiFet (MEMT + HBT)

NINT (Pohang)

Power semiconductors

- Core standard process for SiC power
- International certification of semiconductor neutron test
- Commercialization of 5G wide bandgap semiconductors

Jeonbuk NCNT

Display

- Transparent display device backplane batch process
- Micro OLED display
- Form-fitting flexible/ stretchable electronic parts

Gwangju NCNT

Optical device / OLED lighting

- Optical semiconductors for ultra-high-speed, large-capacity optical communication
- Flexible, large-area OLED panel platform
- MEMS/NEMS technology-applied convergence sensors

NPAC (Daegu)

Nano convergence composite materials

- Comprehensive performance evaluation platform for light-emitting devices for next-generation displays
- Integrated-device heat dissipating material evaluation platform
- Ceramic-based carbonized/oxidized/nitrified product precision machining technology

02 NNFC (National Nano Fabrication Center, Daejeon, Korea)

National NanoFab Center

- A nanotechnology R&DB institution contributing to the domestication of semiconductor materials, parts, equipment and system IC.

Fab Service / Mostly 8-inch based 12-inch Test-bed

IoT Sensor

Nano Bio

Analysis Service

03 KANC (Korea Advanced Nano Fabrication Center, Suwon, Korea)

Nano-lithography/Patterning

Nano-patterning & general. Photolithography (pieces-8” wafer)

- E-beam lithography KrF stepper, Aligner, Nano-Imprinter, etc.

Si & MEMS Line

8” wafer = based Si & MEMS process equipment

- i-line Stepper, Track, CD-SEM, Etcher, Sputter, Implanter, Wet Station, etc.

Front End – R&D Support

Equipment to support the epi process and pieces-8” wafer to meet requirement

- MOCVD, MBE, Evaporator, Si Deep Etcher, PR Asher, Wet Station, etc.

Back End

Packaging and electrical property measurement for LED & other devices

- Wire bonder, Dicing machine, Prober, Sorter, Reliability-measuring Instrument, etc.

Front End Line-Nano-device Process Integration

Exclusive 6” wafer process line to support industrialization

- Implanter, Cluster-type Sputter, LPCVD, ICP Etcher, etc.

Measurement & Analysis Lab

Structure analysis, optical and electrical property measurements for nano devices

- Aberration corrected STEM, Dual beam FIB, FE SEM, CL, TR-PL, fs-laser system

04 Korea Nanotechnology Coordinated Infrastructure (KNCI)

Korea Advanced Nano Fab Center (KANC)

System semiconductors
(compound semiconductors)

National Nano fab Center (NNFC)

Testbed System semiconductors
(Si-CMOS)

Korea Printed Electronics Center (KPEC)

Flexible display
printed electronics

Add1	Add2	Add3
University	GFRI	GFRI
Add4	Add9	Add10
University	University	University

Approximately 10

Nano Convergence Practical Application Center (NPAC)

Nano convergence
composite materials

National Institute for Nanomaterials Technology (NINT)

Power
semiconductors

National Nanotechnology for Nano-process and Equipment (NCNE)

Optical semiconductor
OLED lighting

04 Korea Nanotechnology Coordinated Infrastructure (KNCI)

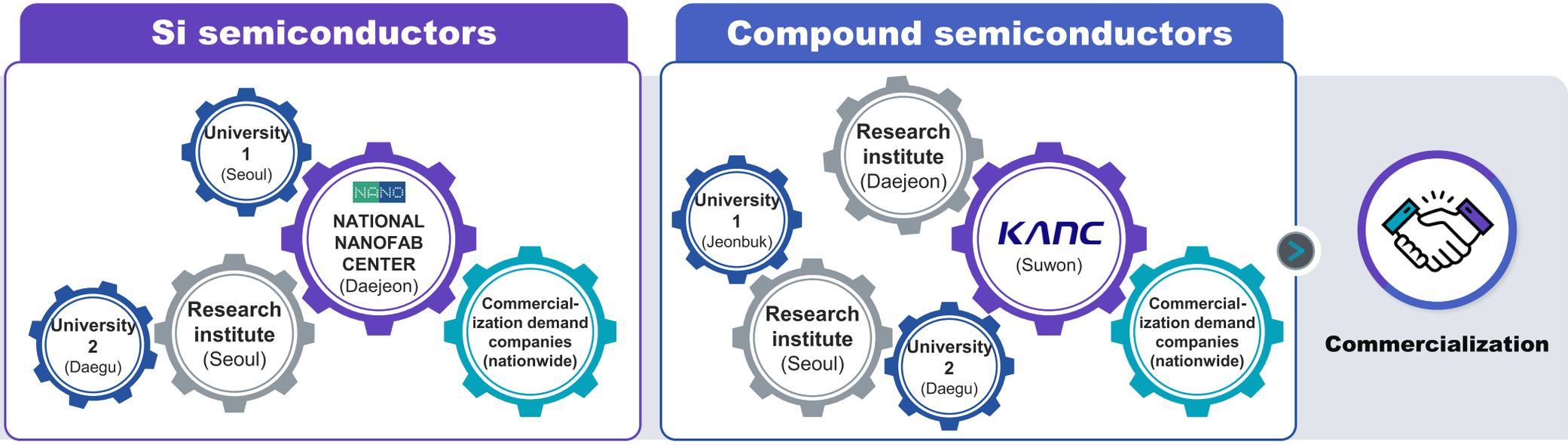
Linkage and cooperation system between institutions in different regions

Necessity

- When the specialize field or facility level of the infrastructure within a region does not meet the demand for research and industry, it is necessary to provide linkage and cooperation support with institutions in other regions capable of meeting such demand

Linkage system

- Combine universities, research labs, and nanofabs with strengths in specialized fields (e.g., Si semiconductor, compound semiconductor, etc.) to establish an integrated support system with “R&D + Process technology + Equipment”
  - (Cooperation by development stage) Basic research by universities → Applied research by research labs → Scale-up for nanofabs

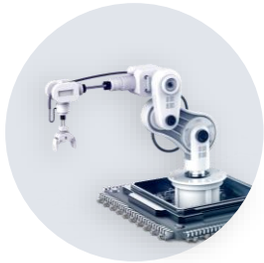


05 Summary

Summary 01

The Korean government has continued to invest in Nano & Semiconductor R&D.

- Focusing on basic research areas, and the outcomes will contribute to industrialization.



Summary 02

The Korean government's four investment strategies in the nano field:

strengthening creative and challenging global leading research
strengthening competitiveness of convergence industry leading innovative growth
upgrading infrastructure system and function
expanding technology innovation base

Summary 03

The Korean government recognizes the global environmental change as a 'semiconductor crisis' and is making intensive efforts to prepare a foothold for the 'second semiconductor leap'.

The 17th Korea-U.S.
Forum on Nanotechnology

Ministry of Science and ICT

THANK YOU

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Nano & Semiconductor Technology Initiative
and R&D in Korea

NRF National Research Foundation of Korea