

Future emerging technologies and early recommendations for international cooperation on advanced functionalities

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Content and motivation

- This presentation summarises the findings ICOS deliverables D3.4 (Update on Technology Scanning and Foresight) and D4.3 (Cooperation Cases on Advanced Functionality)
- Both deliverables contain results from earlier ICOS work on analysis of European strengths and weaknesses in the semiconductor area and potential topics for international collaboration.
- This presentation concentrates on the "Advanced functionalities": Si photonics, sensors, power devices, energy harvesting, and wireless communication

Innovation in sensors

- **Heterogeneous integration** at package level
 - Different technologies possible inside package for
 - Optimised performance of all functionalities
 - Improved reliability
 - Lower noise
 - AI inside package
 - Less data traffic
 - Real time operation with reduced latency
 - In chemical and biochemical sensing
 - Materials and process compatibility
 - Interface stability
 - Packaging

Energy Harvesting

- Different ambient energy sources can be exploited and converted into electricity: sun or artificial light, heat, RF power mechanical movements and vibrations ...
- Replacement of batteries or wiring
- Energy autonomy will also allow the development of maintenance-free and easily reconfigurable sensors networks
- Challenges:
 - Limited available power
 - Power management (conversion, storing)
 - Reduction of fabrication costs
 - Materials selection: preference on abundant, non-toxic, recyclable materials

Power Devices

- **Electrification of society** (increasing fraction of world electricity flows is governed by power devices)
- **Wide band gap** materials like SiC and GaN are replacing Si in some applications
 - Improvements on critical electric fields, thermal conductivity, ... => lower R_{ds} , higher V_{BRDS}
 - Substrate availability (price decreasing, wafer diameters increasing)
 - Other WBG materials emerging
- **Heterogeneous Integration** (modules and embedding)
 - Power chips, thermal management, drive circuits
 - OSAT & EDA-tools are gaps

Integrated Photonics

- A very broad and diversified field (imaging, sensing, displays, lightning, laser, communication, ...)
- The key driver is the **optical interconnects in data centers**
 - High bandwidth
 - Lower power consumption
 - Miniaturization
- Challenges of photonics
 - Heterogenous integration
 - Integration of light sources
 - Use of new wavelenghts require new materials
 - Very fragmented field

Wireless Communications

- remains a large market segment with moderate growth.
- Spectrum evolution is cautious, focusing on incremental improvements in coverage and efficiency rather than radical frequency shifts.
- Advanced packaging techniques support antenna-in-package (AiP) and system-in-package (SiP) for 5G and future 6G.
- GaN-Si gains traction in infrastructure power amplifiers, while GaAs HBT and RF-SOI dominate handset power amplifiers.
- Defense and aerospace sectors increasingly leverage 5G/6G for secure connectivity and integrated sensing.
- Non-Terrestrial Networks (NTN) complement terrestrial networks to provide global coverage, especially for IoT and emergency communications, with seamless integration planned in future standards. Despite innovation, structural constraints like spectrum scarcity and costs slow dramatic changes

Future research topics

- Common research topics for all advanced functionalities (based on findings of ICOS D3.3 and D3.4)
 - **Integration and Miniaturization:** Across all fields, there is a strong emphasis on integrating multiple components into cohesive systems and reducing the size of devices while maintaining or improving performance.
 - **Sustainability and Materials:** The use of non-toxic, sustainable materials and the development of processes to enhance material properties for increased efficiency
 - **Advanced Packaging and Structural Solutions** to ensure power and signal integrity
 - **AI and Machine Learning** for optimizing designs, adaptive manufacturing, and predictive failure analysis
 - **Strategies to improve** energy efficiency, performance, and reliability of systems

Specific future research topics

- **Sensors**
 - Optimized sensor designs using AI-enhanced EDA-tools
 - Creating IP blocks/modules leveraging machine learning for adaptive manufacturing
 - Design of high-speed and high-sensitivity sensor chips
- **Photonics**
 - Wafer-scale heterogeneous integration of different PIC material systems to offset the missing functionality of a certain PIC platform.
 - PIC manufacturing (especially for silicon photonics) on wafers with larger diameters
 - Enhanced intimacy between electronic ICs and photonic IC either through monolithic approaches or through advanced packaging techniques.
 - Improvement in the functional performance of key photonic IC building blocks
- **Power devices**
 - Efficient power management architectures, miniaturization of systems embedding micro-magnetic components, and integration of complex load management functions into silicon
- **Energy harvesting**
 - developing circuits for power management, enhancing materials properties for increased energy conversion efficiency, and integrating solutions into flexible substrates

Key strengths of some non-EU countries and cooperation recommendations

- These recommendations are based on ICOS stakeholders country survey and mapping of cooperation cases
- 1) The survey was conducted in early 2024. (103 respondents)
- Some questions:
 - Which countries would you be interested in developing R&D Cooperation with
 - Select Topics (More than Moore, Heterogeneous Integration)
 - In which country would you like to have access to research infrastructure
 - In which country(s) would you seek partners for R&D cooperation
- 2) Results from gaps and strength analysis

Key information of semiconductor ecosystems of **China, South Korea, Japan, India, Singapore, Taiwan**, and the **USA** is available here: [Factsheets - ICOS Semiconductors](#)



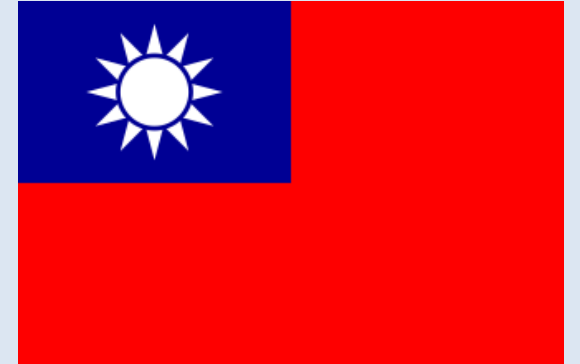
United States

- 83 of 103 respondents were interested in cooperation with US. Half of them were from industry. The most popular R&D cooperation topic was More than Moore functionalities (31% of respondents). Heterogeneous integration and packaging, which is extremely relevant for advanced functionalities, was the second popular topic (22%). 65 respondents would like to have access to US research infrastructures, mainly for technology development in all parts of the value chain. The most popular type of partners were large companies (29%), academia (28%), and SMEs (23%).
- The United States is a major player in several semiconductor domains. The US dominates in semiconductor manufacturing equipment and EDA tools. US academic institutions such as MIT, Stanford, etc. are producing world class science. As packaging is critical for many sensors, IoT and edge-AI devices, the EU could benefit from joint development of packaging standards, collaboration in advanced thermal, mechanical co-design and simulation/EDA-tools as well as reliability solutions. Development of tools and libraries for photonics and heterogeneous integration are potential collaboration topics.



Japan

- More than Moore functionalities were the most popular topic (29%). The most popular part of value chain was the Semiconductor/Chip production (23%).
The most wanted partners in Japan were academics (44%) and large companies
- Japan has several Memorandum of Cooperation on semiconductors and related topics with EU countries and digital partnership with EU. Japan is very strong in research with several top universities, especially in sensing and power devices and photonics. Japan is a major manufacturer of specialty chemicals and raw materials for electronics.
Research for **using non-toxic and sustainable materials in** power devices and in their packaging is recommended as a research topic as well as **cost and size reduction of power devices**. For energy harvesting there is need to **enhance materials properties for increased energy conversion efficiency**. Across all fields, there is a strong emphasis on integrating multiple components into cohesive systems and reducing the size of devices while maintaining or improving performance.
- Recommended areas for cooperation: sensing, components, and materials



Republic of China (Taiwan)

- the “Heterogeneous Integration and Packaging” were the most popular topic (29%) for international cooperation. The clearly most popular part of value chain was the Semiconductor/Chip production (28%). The preferred partners in Taiwan were large companies (43%)
- With TSMC as the global leader in advanced logic scaling, Taiwan is a strategic partner for co-development of leading-edge technologies. Research institutions like ITRI and NCTU enable collaborative innovation spanning from materials to system integration. The Taiwanese manufacturing excellence would be something that could benefit Europe, especially for silicon photonics manufacturing on wafers with larger diameters

South Korea

- The “More-than-Moore Technologies” were preferred topics. The most popular part of value chain was the Semiconductor/Chip production (30%). The preferred partners in South Korea were large companies (38%)
- South Korea has a digital partnership with EU. While South Korea is leading country in memory production with global industrial leaders such as Samsung and SK Hynix and world class institutes, South Korea is also strong in advanced back-end integration, where cooperation could improve Europe's packaging supply chain resilience. South Korea has same kind of goal as has been set for Europe with European Chips Act. Korean goal is to achieve 50% self-sufficiency in key materials and equipment by 2030.
- Recommended areas for cooperation: materials and back-end equipment





Singapore

- “More-than-Moore Technologies” were preferred topics with Singapore (27%), the second popular field was “Heterogeneous Integration and Packaging” (24%).
The most popular part of value chain was the Semiconductor/Chip production (25%). The preferred partners in Singapore were academia (32%).
- Singapore has a digital partnership with EU. Singapore’s A*STAR and IME are highly active in backend integration, and 2D materials processing. Their ability to rapidly move from materials R&D to device prototyping makes them lucrative partners for European RTOs and SMEs. Collaboration could focus on heterogeneous integration platforms, AI-driven packaging, and advanced materials, areas where Singapore’s applied R&D focus can complement EU strengths in science and infrastructure. Developing **advanced packaging solutions and structural solutions for microsystems** is one of the recommended research topics.

Canada

- The “More-than-Moore Technologies” were preferred topics with Canada (28%) the second popular field was “Heterogeneous Integration and Packaging” (22%). The most popular part of value chain was the Semiconductor/Chip production (20%). The preferred partners in Canada were academia (36%).
- Canada is very strong in photonics and GaN power devices. Canada offers technological diversity and strong government-academic ecosystems, making them valuable collaborators for Europe.



India

- India got the smallest number of respondents.
The More than Moore functionalities were the most popular topic (30%).
Chip design was the most popular field for cooperation (25%), another popular topic was “Semiconductors/Chip production” (21%).
The most preferred partners in India were academics (44%)





China

- (China was not addressed in stakeholder survey)
- Despite current geopolitical complexities, China remains a major player in semiconductor technologies with growing capabilities in several domains. Chinese academia and startups are highly active in materials, packaging, and AI. Joint EU-China academic research or Horizon Europe-style exchanges could help advance the science. China is home to leading OSAT providers, making it a potential partner in packaging co-development or in advanced integration techniques. While some semiconductor technologies are highly strategic, basic research in new sustainable materials remains a possible area of scientific exchange with leading Chinese universities.

Summary

- Europe is strong in R&D of Advanced Functionalities
- Gaps and future needs:
 - Heterogeneous Integration (chipselets, advanced packaging)
 - Sustainability, cost, and availability of materials
 - AI should be integrated into devices/systems and AI should be exploited in design
 - Power efficiency
- International cooperation would accelerate development
- Recommendations for Research Topics in Advanced Functionalities
 - There are cooperation possibilities everywhere, in all topics
 - Most obvious cases:
 - USA: microsystems, heterogeneous integration, EDA
 - Japan: sensing, components, materials
 - South Korea: back-end equipment
 - Taiwan: 3D integration, foundry access
 - India: design of circuits and systems

Thank you for your attention

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