ESSERC 2024

SiNANO-ICOS-INPACE Workshop

"Emerging technologies in Advanced Computation, Advanced Functionalities, Ground-breaking Technologies: Impact on International Cooperation"

Emerging Material Integration for Advanced Functionality of Semiconductor Devices and Systems

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Bruges, September 9, 2024

Outline

- Introduction
  - Pivotal role of international research cooperation

- Emerging Materials Integration
  - Beyond CMOS, IRDS
  - Energy Harvesting, MtM IRDS
  - Environmental, Social, Health and Safety (ESHS)

- International Electrotechnical Commission, IEC
  - The role of international standards
  - Nanotechnology for electrotechnical products and systems (TC113)

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ICOS International Cooperation On Semiconductors

Home | About ICOS | Strategy | Project

Pivotal role of international research cooperation

International research cooperation has already proved its value in the development of the Semiconductor industry.

The clearest example of this type of cooperation has probably been the International Technology Roadmap for Semiconductors (ITRS), which has supported the continuous growth of semiconductor industry, following the Moore's Law for 20 years, or the IPSR-I Roadmap

Started in 1991 in the US, it was later extended to other technology leading countries like EU, Japan, Korea and Taiwan. With the increasing complexity of the semiconductor value chain, the initiative became the International Roadmap for Devices and Systems (IEEE-IRDS) in 2016, covering also the evolution and needs of Electronic Systems that are critical dependent on the semiconductor industry.

European partners have been involved since the beginning in ITRS and IRDS, even promoting its extension outside the pure logic and memory-oriented technologies to cover application-specific technologies, like power and sensor, of more interest for the European application industry.

Introduction

A long-term expert-driven mechanism for international research cooperation

Road mapping creates new value from collective knowledge

International standards
serve to advance mutual understanding between different cultures and spread knowledge and innovation

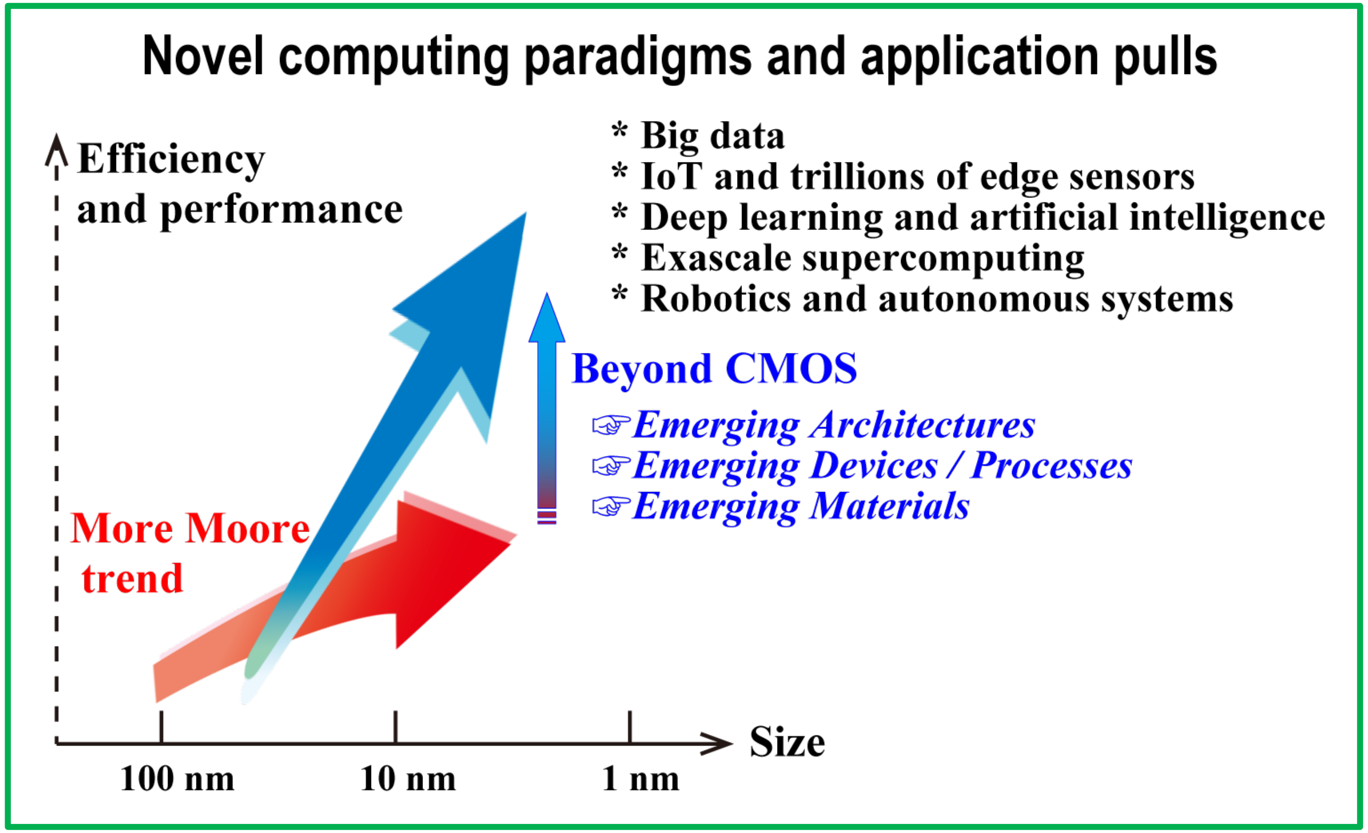
hummingbird

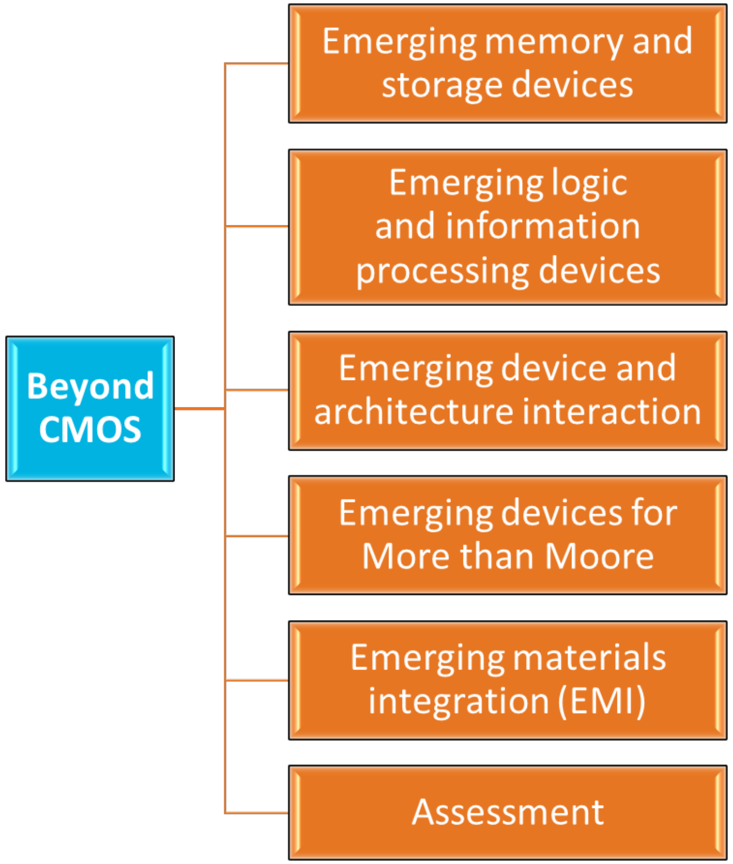
These cooperations act as both wings of a bird to promote research and development

IRDS Beyond CMOS

IRDS: International Roadmap for Devices and Systems

- Most beyond-CMOS devices have been proposed to address the scaling challenges
- Many of them are also explored for novel computing paradigms beyond Boolean logic





IRDS Beyond CMOS

Challenge 1 Manufacturing Fabs

Chip manufacturing infrastructure in the EU is missing or is outdated

The first challenge relates to those semiconductor technologies or technology nodes where the EU lacks manufacturing infrastructure or where the available infrastructure is no longer at the state-of-the-art level. The ideal scenario would enable Europe to host comprehensive manufacturing capacities for all key semiconductor technologies[3], ensuring that European customers and i… critical components through either foundry or IDM[4] models. Such aut… over technical and commercial strategies, primarily in European ha… contrasts with this ideal, highlighting a pressing need for infrastructure… Obvious examples of lacking infrastructure include the most advanced CMOS[5] no… …ecently completed Intel Leixlip (Ireland) fab runs an Intel 4 node[6] and the planned Intel M… will likely run an Intel 16A or 14A node[7]. Other companies, including TSMC, In… Global Foundries, are also planning investments in Europe for CMOS node… Most of these investments rely heavily on public funding, as is typically the… elsewhere in the world[8]. Public contributions originate from the European… or regional funding bodies. Nevertheless, most of these new developme… in… and the number of fabs for sub 28 nm nodes is still very limited in Europe…

While onshoring is the most direct and sovereign way to create chip… …acturing… there may be factors that put forward near-shoring and friend-shori… …iable altern… for European chipmakers to establish a manufacturing supply cha… …d on the other… customers to secure access to chip manufacturing. These approa… not only help mit…

Key semiconductor technologies; Resistive Random Access Memory

For example,
ESSERC 2024
Advanced Memory Devices Session, Paper Id 1405,
How Significant Is Set Programming Strategy in Enhancing RRAM Technology?
T. Bauvent et al.

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[3] Key semiconductor technologies include amongst others:
1. Advanced computing technologies such as: advanced logic technologies (multi-gate devices, nanowires, nanosheets, 3D integration, etc.), advanced memory technologies (charge-based and non-charge-based memories, including PCRAM (Phase-Change Random Access Memory), RRAM (Resistive Random Access Memory), MRAM (Magneto-resistive Random Access Memory), FeFET (Ferroelectric Field-Effect Transistor memory), neuromorphic computing, quantum computing, very low power technologies such as FD-SOI (Fully Depleted Silicon-on-Insulator), etc.

IRDS Beyond CMOS

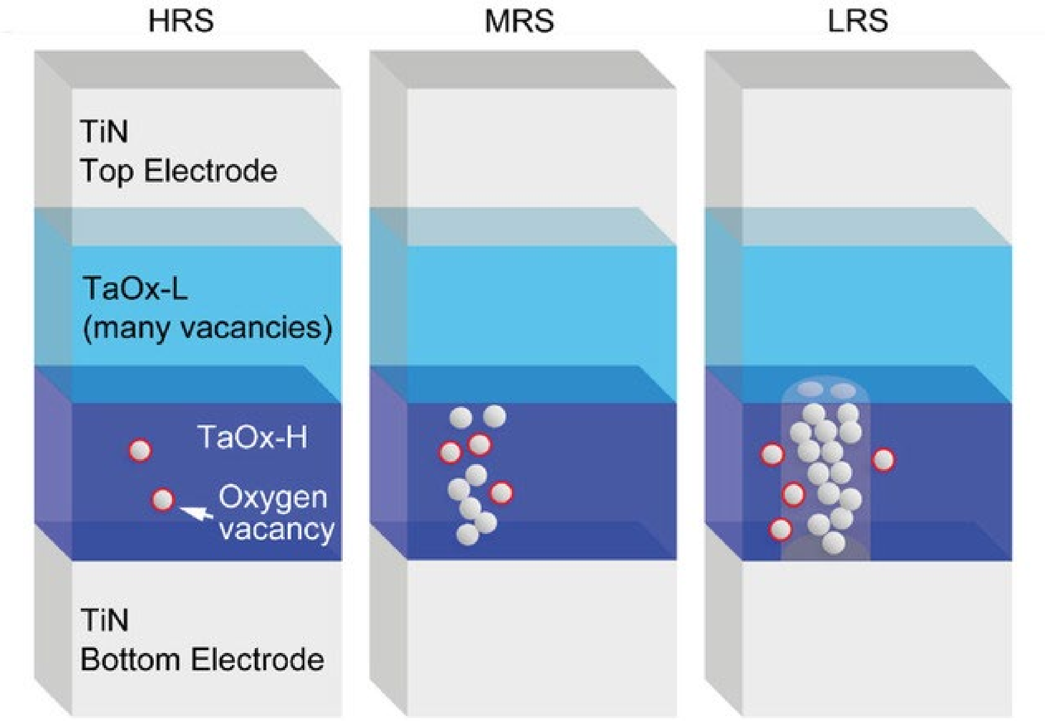


Fig. 5 Schematics of filament conduction in the resistive switching device. The red circle indicates the isolated trap, which is considered the noise source.

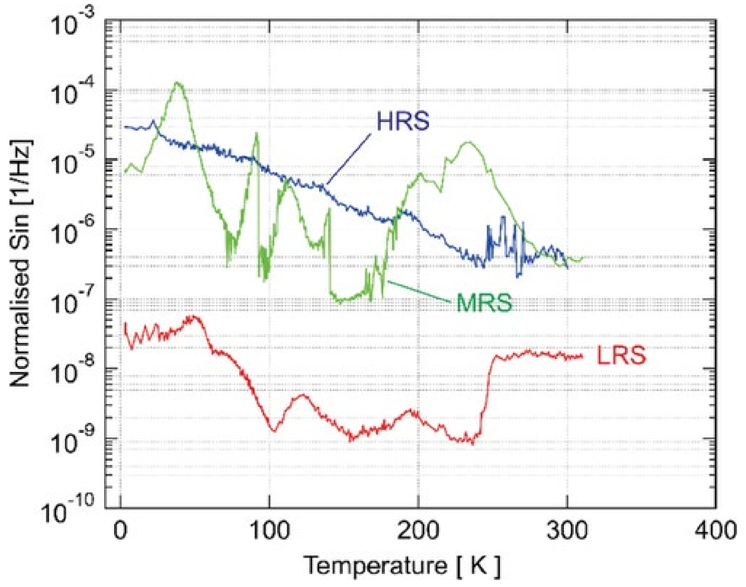


Fig.2 Changes in noise spectra normalized using the current, Sin, at a given frequency of 10 Hz as a function of temperature for HRS, MRS, and LRS.

K. Sugawara, H. Shima, M. Takahashi, Y. Naitoh, H. Suga, and H. Akinaga, "Low-Frequency-Noise Spectroscopy of TaOx-based Resistive Switching Memory", Adv. Electron. Mater. 2022, 8, 2100758, https://doi.org/10.1002/aelm.202100758

Emerging Materials Integration (EMI)

Actively adopted the perspective of emerging material development and integration using informatics, machine learning, and data-driven technologies, etc.

2022 ~

Updated

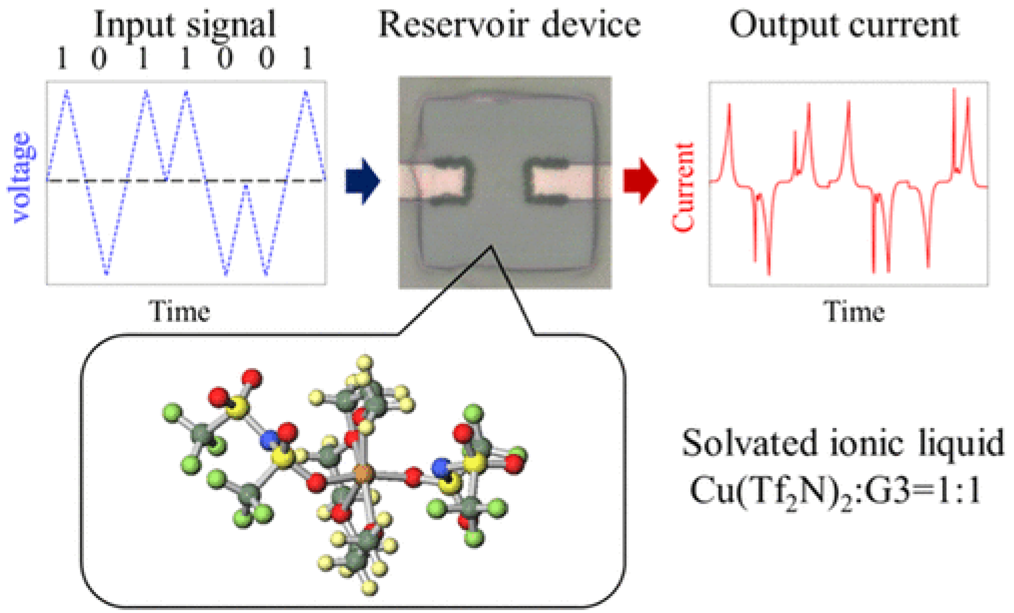
~ 2021

Typical example of EMI

6.3.3.3. EMERGING MATERIALS FOR NOVEL COMPUTING

Emerging materials spur developments of novel computing, such as neuromorphic computing, reinforcement learning, topological quantum computing, and reversible computing, and probabilistic computing. Since the performance of the computing is considered to be dependent on the intrinsic properties of the emerging material, the material research will further boost the performance, such as the energy efficiency [1202,1203,1204,1205,1206,1207]. Two-dimensional materials are also expected to play an important role in memristors for neuromorphic computing.[1208, 1209]

@ IRDS BC 2023



Dynamic Nonlinear Behavior of Ionic Liquid-Based Reservoir Computing Devices
T. Matsuo et al., ACS Appl. Mater. Interfaces 2022, 14, 32, 36890–36901
https://doi.org/10.1021/acsami.2c04167

Reference: Reservoir Computing by Memristors (Open Access)
Midya, R., Wang, Z., Asapu, S., Zhang, X., Rao, M., Song, W., Zhuo, Y., Upadhyay, N., Xia, Q. and Yang, J.J. (2019), Reservoir Computing Using Diffusive Memristors. Adv. Intell. Syst., 1: 1900084. https://doi.org/10.1002/aisy.201900084

Emerging Materials Integration

Emerging Materials for More-than-Moore Diversification

*Revisions are underway for the 2024 edition.

Emerging Materials Integration

LISBON
11-14 SEPTEMBER 2023
ESSDERC
ESSCIRC

ESSCIRC/ESSDERC 2023
SiNANO-ICOS Workshop
"European Strengths and Gaps in Emerging Semiconductor Technologies"

Energy Harvesting: review of the main EU and international activities and technologies

Gustavo Ardila
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Lisbon, September 11, 2023

ESSDERC/ESSCIRC 2023 Workshop
European Strengths and Gaps in Emerging Semiconductor Technologies

https://www.sinano.eu/wp-content/uploads/2023/09/ICOSworkshop_ESSDERC_Energy-Harvesting.pdf

Emerging Materials Integration

Energy Harvesting for Green Transition (Transformation)

PROPOSAL FOR A NEW FIELD OF TECHNICAL ACTIVITY
ISO TS/P 317 (2023.10), Human-centered transition pathway
Benefits to SDG 7

https://www.jisc.go.jp/international/nwip/TSP317_Human-centered%20transition%20pathways.pdf

Near-Zero Energy (NZE) devices that are capable of connecting and communicating over the cellular network
Next G Alliance

https://nextgalliance.org/

Proposal for a
REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, See Article 9

Emerging Materials Integration

Energy Harvesting for AI

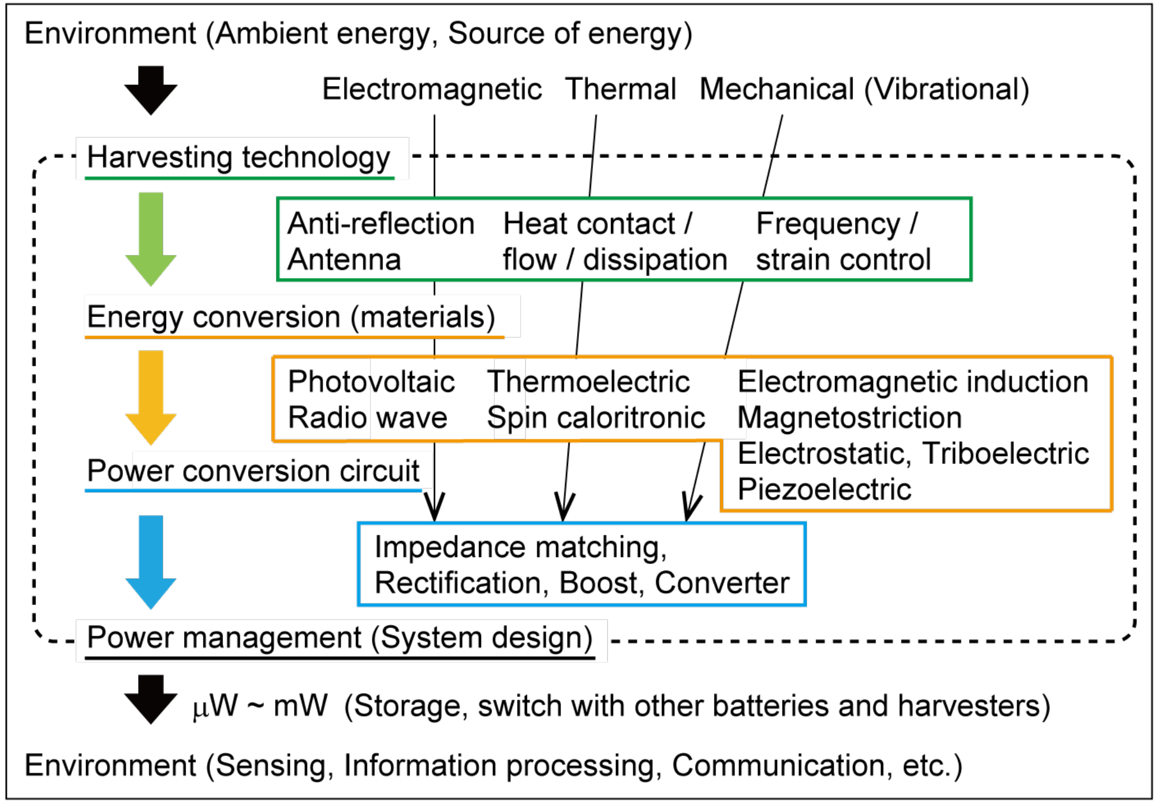


Fig. 1. Survey of energy harvesting technologies.

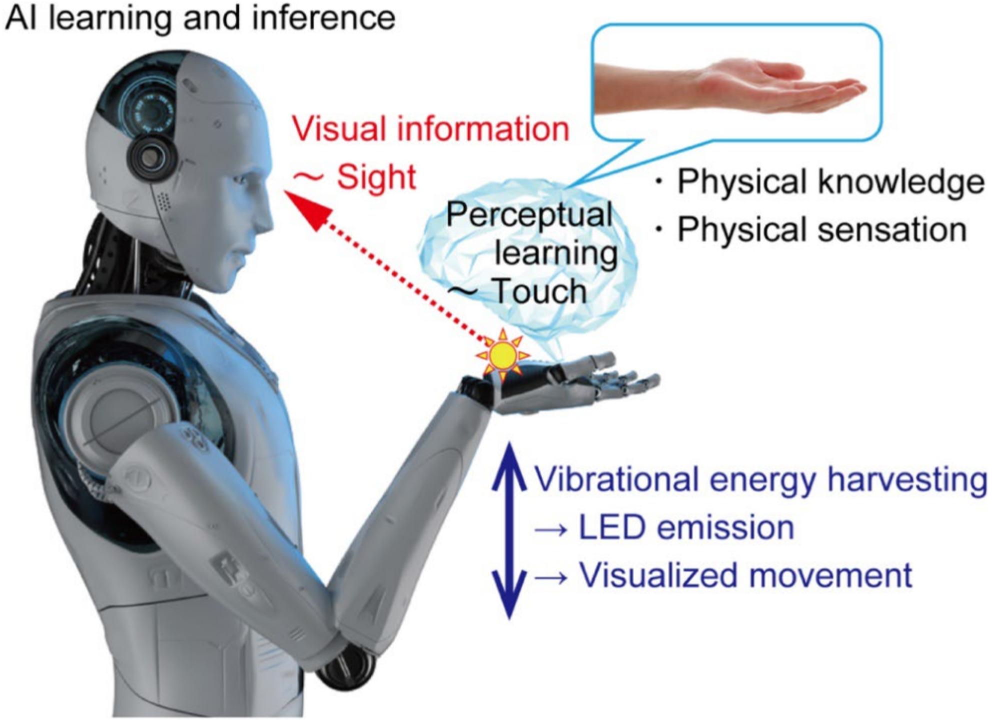


Fig. 6. Possible future of energy harvesting technology.

H. Akinaga, *Jpn. J. Appl. Phys.* 59, 110201 (2020)
https://iopscience.iop.org/article/10.35848/1347-4065/abbfa0/pdf

Bitly QR-JAM

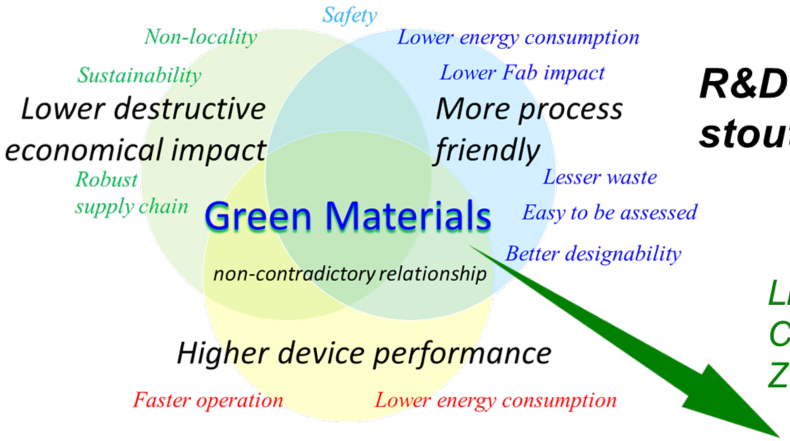
EMI for
Environmental, Social, Health and Safety (ESHS)

Table EMI2 Long term difficult challenges for emerging research materials

Green and sustainable fabrication	To realize an integration process that is environmentally friendly and economically viable. Utilizing AI, ML, and informatics to develop production processes that can introduce green new materials.

Liaison concept of Materials Sub-team & EMI of BC

NEEDS AND CHALLENGES OF EMERGING RESEARCH MATERIALS FOR ESHS



R&D of Beyond CMOS devices will be stout under limitation of Green Materials.

Life cycle assessment
Circular economy
Zero emission

Evaluation index

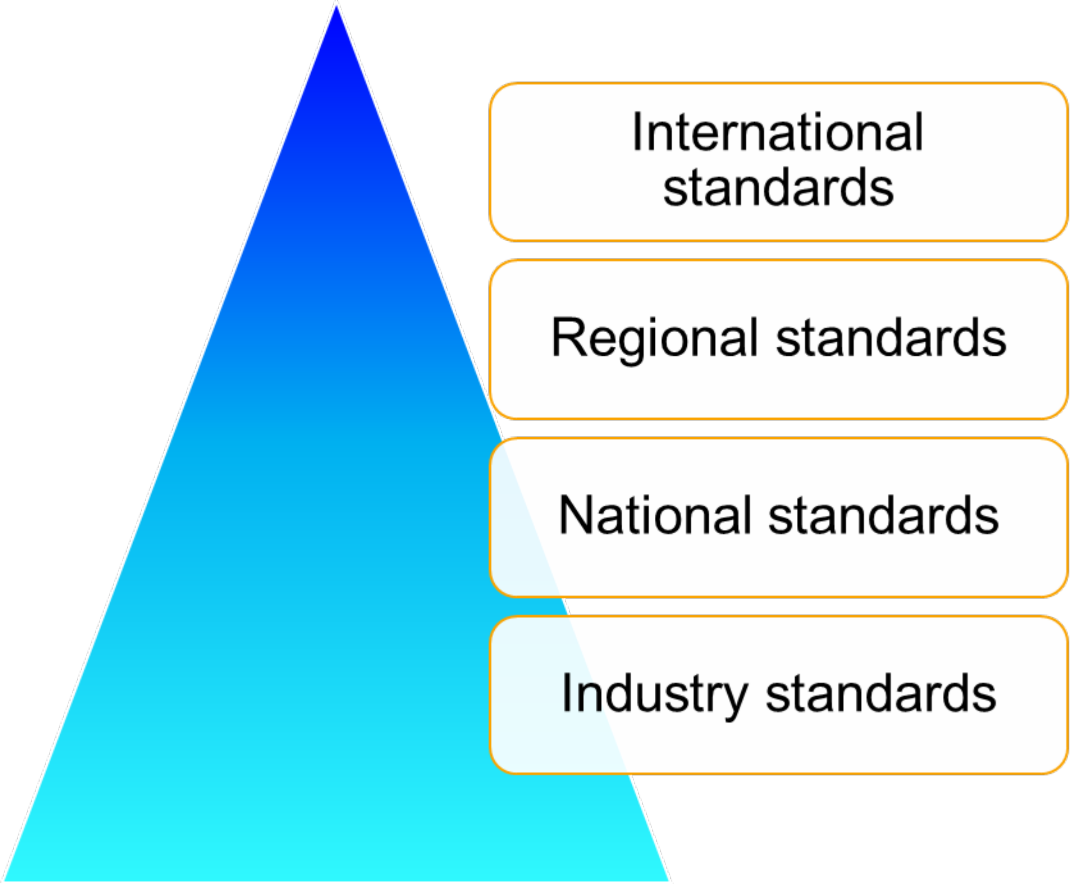
Material		Process		Device operation
Low energy consumption *Sustainability* *Easy to manufacture* *Safety* *Cost*	→	*Lower energy consumption* *Lower Fab impact* *PFAS, substance of concern* *Better designability* *Safety* *Cost*	→	*Lower energy consumption* *Faster operation* *New functionality*

Updated toward 2024!

Sustainability,
Environmental impact
Part I: Materials for Device
Part II: Materials for Process

International Electrotechnical Commission

- Hierarchy of standards



Representative Standards Bodies

	Representative Standards Bodies
International standards	**ISO, IEC, ITU**
Regional standards	Comité Européen de Normalisation (**CEN**)
National standards	British Standards Institution (**BSI**) German Institute for Standardization (**DIN**) Japanese Industrial Standards Committee (**JISC**)
Industry standards	**IEEE**

- Classification by Developer / De jure, Forum, and De facto standards

The role of international standards

- **Early Development Stage:**
  Terminology and units
- **Peak Development Stage:**
  - Characterization
  - Reliability, durability
  - Others

Standards for Technology Development

Benefit R&D as common platform

Spur R&D as part of inseparable wheels in combination with road mapping (such as IRDS)

- **Early Stage of Business Development:**
  Interface/Safety

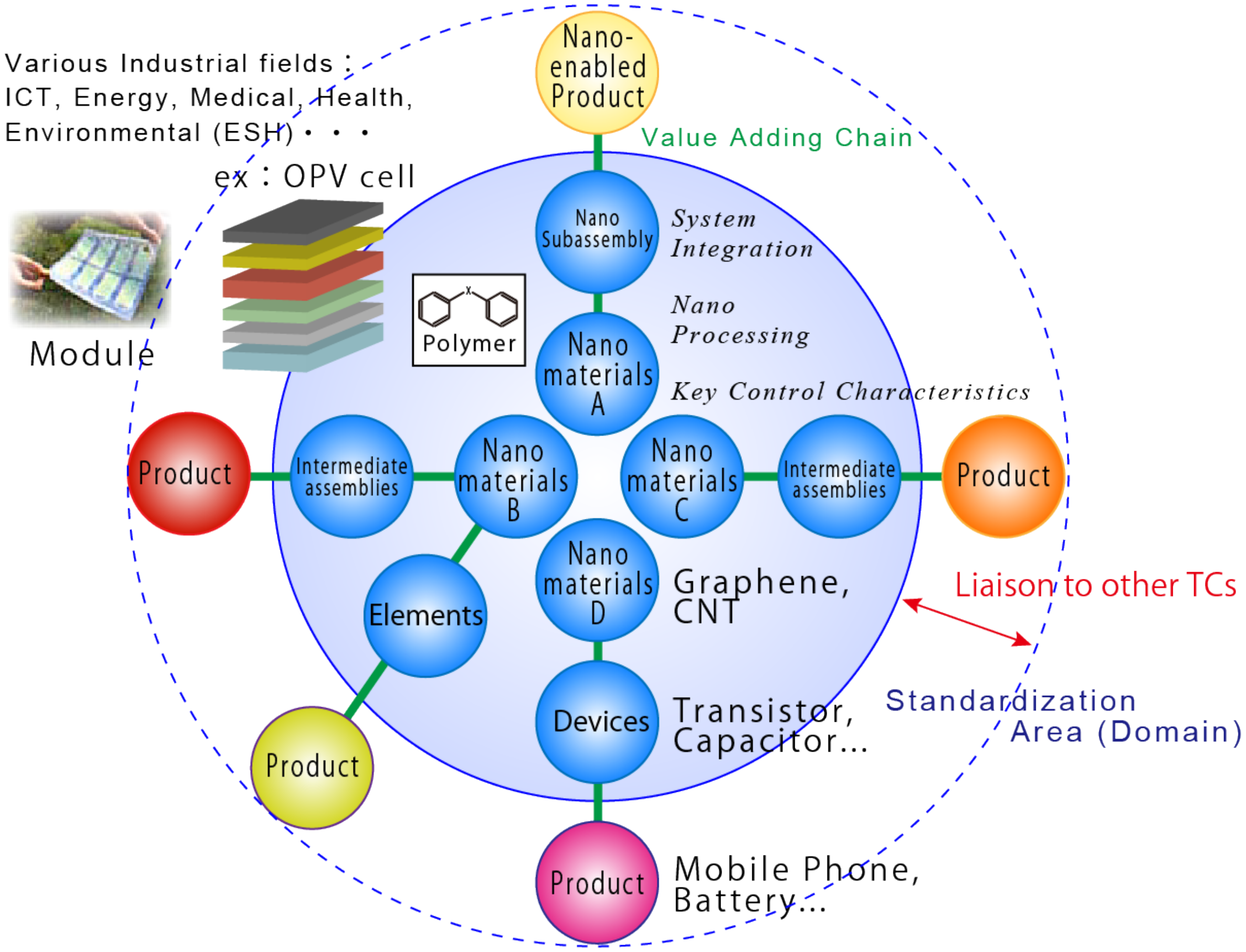
Standards for Business Promotion

- **Peak Stage of Business Development:**
  Product standards

Standards for Users

*Approaches vary by industry type.

IEC TC113
Nanotechnology for electrotechnical products and systems



TC 113 Scope

Standardization of the technologies relevant to electrotechnical products and systems in the field of nanotechnology in close cooperation with other committees of IEC and ISO

Examples of WG targets

WG3 (Performance assessment)
- 2D material-based FET, oxide device

WG7 (Reliability)
- 2D material-based FET, graphene-capped copper

WG8 (Graphene related materials/Carbon nanotube materials)
- Carbon nanotube & Graphene devices

WG9 (Nano-Enabled Photovoltaics Thin Film Organic/Nano Electronics, Nanoscale)
- Photovoltaic cell, energy harvester

WG13 (Wafer-Scale System Integration)

WG14 (Electromagnetic compatibility)

IEC TC113
Nanotechnology for electrotechnical products and systems

TC 113 Nanotechnology for electrotechnical products and systems

Scope | Structure | Projects / Publications | Documents | Votes | Meetings | Collaboration Platform

Subcommittee(s) and/or Working Group(s) > WG 7

WG 7 Convenor & Members

WG7: Reliability

Convenor	National Committee
Mr Hiroyuki Akinaga	
Mr Won-Kyu Park	
Member	

WG 13 Task: To develop standards for measurement, characterization, test methods and the assessment of performance related to the nanotechnology-enabled wafer-scale system integration for support of continuous improvement at all stages of the functional diversification. The activity is expected to promote More-than-Moore activities, especially in which nano materials plays a crucial role, in the close relationship to IEEE and other IEC, ISO committees

Subcommittee(s) and/or Working Group

WG 13 Convenor & Members

WG13: Wafer-Scale System Integration

Convenor	National Committee
Mr Hiroyuki Akinaga	JP
Ms Minghong Wu	CN
Member	National Committee

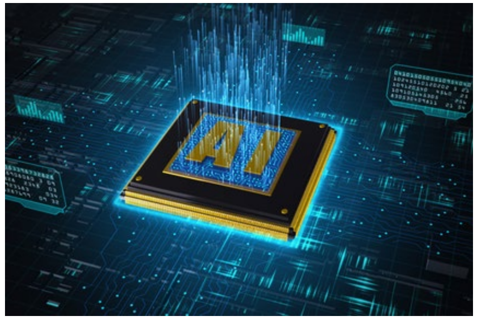
https://www.iec.ch/dyn/www/f?p=103:7:406843861295553::::FSP_ORG_ID,FSP_LANG_ID:1315,25

International standards related to BC/EMI

Test method to determine physical properties (KCC) of nano-enabled electronic devices

IEC TS 62607-8-3
Nano-enabled metal-oxide interfacial devices - Analogue resistance change and resistance fluctuation: Electrical resistance measurement

H. Shima, M. Takahashi, Y. Naitoh and H. Akinaga, "Electrode Material Dependence of Resistance Change Behavior in Ta_2O_5 Resistive Analog Neuromorphic Device," in *IEEE Journal of the Electron Devices Society*, vol. 6, pp. 1220-1226, 2018, https://doi.org/10.1109/JEDS.2018.2875942



IEC TS 62607-8-2
Polarization states at metal / oxide interface by TSDC

IEC TS 62607-8-1
Defect states at metal / oxide interface by TSC

Ref. H. Akinaga and H. Shima, "Resistive Random Access Memory (ReRAM) Based on Metal Oxides," in *Proceedings of the IEEE*, vol. 98, pp. 2237-2251, Dec. 2010, https://doi.org/10.1109/JPROC.2010.2070830

IEC 62876-3-2(tentative)
Passivation (Graphene): Reliability assessment by Ellipsometry

Ref. S. Nakajima *et al* 2023 *Jpn. J. Appl. Phys.* **62** SC1092. https://doi.org/10.35848/1347-4065/acb77a

IEC TS 62607-2-4
Interconnect (Carbon nanotube materials)

IEC/TR 63258
Dielectric layer by ellipsometry

Prospect

Road mapping

International standards

Create a healthy development competition and market environment through roadmapping and international standardization

New materials integration technologies bring advanced and diverse functionality to semiconductor devices and systems

Appendix:
External presentations and publications

- “Beyond CMOS” article in the EDS Newsletter (Jul. 2021, vol. 28, no. 3)
  https://eds.ieee.org/images/files/newsletters/Newsletter_July21.pdf

- “Beyond-CMOS roadmap” paper in Jpn. J. Appl. Phys. (Jun. 14, 2022)
  https://iopscience.iop.org/article/10.35848/1347-4065/ac5d86
  https://iopscience.iop.org/article/10.35848/1347-4065/ac5d86/pdf

- Global Innovation Platform
  H. Akinaga, “Open foundry to spur open-innovation
  - Establishment of a foundry to realize an innovative cooperation platform and development of its sustainable management strategy –”, Synthesiology 7 (2014) pp.1-11
  https://doi.org/10.5571/syntheng.7.1

Emerging Materials Integration

Recent topics: Emerging Materials for Thermal Energy Harvesting

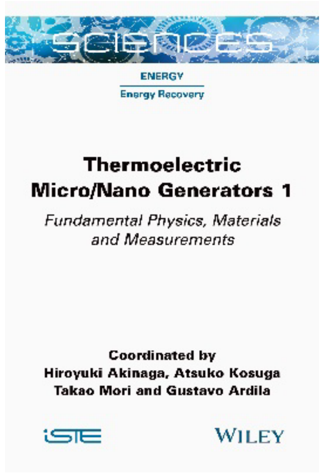
S. Bano, R. Chetty, J. Babu, and T. Mori, "$Mg_3(Sb,Bi)_2$-based materials and devices rivaling bismuth telluride for thermoelectric power generation and cooling", Device 2 (2024) 100408, https://doi.org/10.1016/j.device.2024.100408

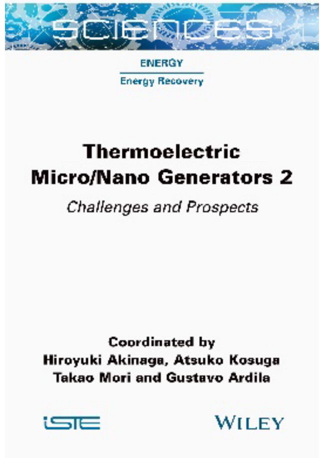
Recent topics: Test methods for Thermal Energy Harvesting

R. Chetty, J. Babu, and T. Mori, "Best practices for evaluating the performance of thermoelectric devices", Joule 8 (2024) 556, https://doi.org/10.1016/j.joule.2024.02.009

IRDS MtM Related Activities for Thermal Energy Harvesting

SCIENCES - Energy Recovery
Thermoelectric Micro/Nano Generators 1: Fundamental Physics, Materials and Measurements
https://iste.co.uk/book.php?id=2071
Thermoelectric Micro/Nano Generators 2: Challenges and Prospects
https://iste.co.uk/book.php?id=2072





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Especially, Akiko Ueda

IRDS MtM Energy Harvesting team members

Especially, Gustavo Ardila

IRDS ESHS members

IEC TC113 members

IRDS
INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™

SDRJ
The System Device Roadmap Committee of Japan

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Historisch Stadhuis van Leuven @ 1997