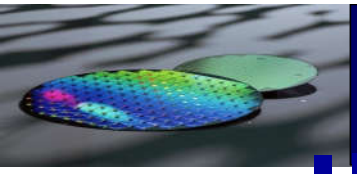
3-14-2023

# Invited; ULSI and TFT technologies joint forces to meet the future challenges of a pervasive digital society

Olivier Bonnaud



# ULSIC vs. TFT 8

*May 15–18, 2023, Sapporo, Japan*

*Engineering Conferences International (ECI)*

**Semiconductor Technology for Ultra Large Scale Integrated Circuits and Thin Film Transistors 8**

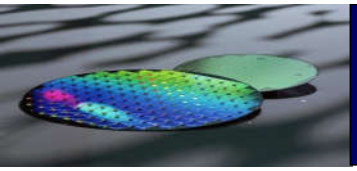
## ULSI AND TFT TECHNOLOGIES JOINT FORCES TO MEET THE FUTURE CHALLENGES OF A PERVASIVE DIGITAL SOCIETY

Otaru (Japan), May 15-18, 2023


**Olivier Bonnaud**

Executive Director of GIP-CNFM (France)

Professor Emerite Univ. of Rennes - France



# Introduction

The worldwide development of communication and data exchange systems has strongly encouraged the development of digital technology, growing exponentially since 2005.

The transparency of the operation of these tools does not highlight their energy consumption!

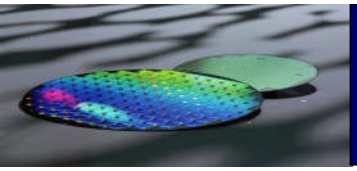
These digital hardware are physically made of electronics and microelectronics, highly integrated or of large area.

The solution is to reduce the power consumption of all electronics.

After presenting the context and the issues, my talk details the different proposals to improve electronics, by combining both technologies.

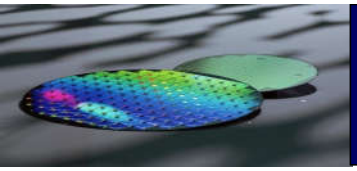
Furthermore, to face the challenges of electronics, human resources with skills and know-how covering a wide spectrum will be needed.

The corresponding strategy will close the presentation.



# Outline

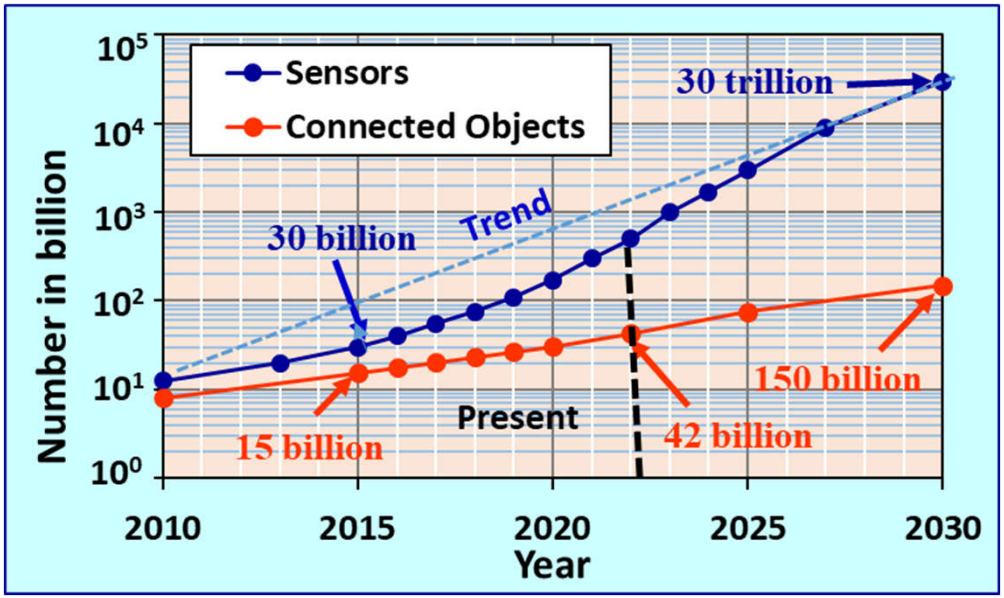
- Introduction
- **Huge evolution of digital society**
- Consequence on energy consumption and sustainable resources
- Challenges for electronics and microelectronics: ULSI & TFT roles
- Skills and jobs in shortage
- Strategy of the Microelectronics training
- Conclusion



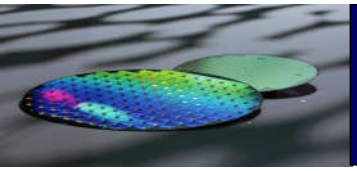
# Huge evolution of digital society

## Exponential growing of Sensors & connected objects

**The new connected objects include dozens of sensors (iPhone, iPad, PC). The global number of sensors is increasing exponentially like the number of connected objects.**




*After* O. Bonnaud, IJPEST, 10 (2), p. 115 (2016)
*After J.* Bryzek, iNEMI Spring Webinar, Berkeley, CA (2013)
*After* https://www.postscapes. com/trackers/video/the-internet-of-things-and-sensors-and-actuators/.



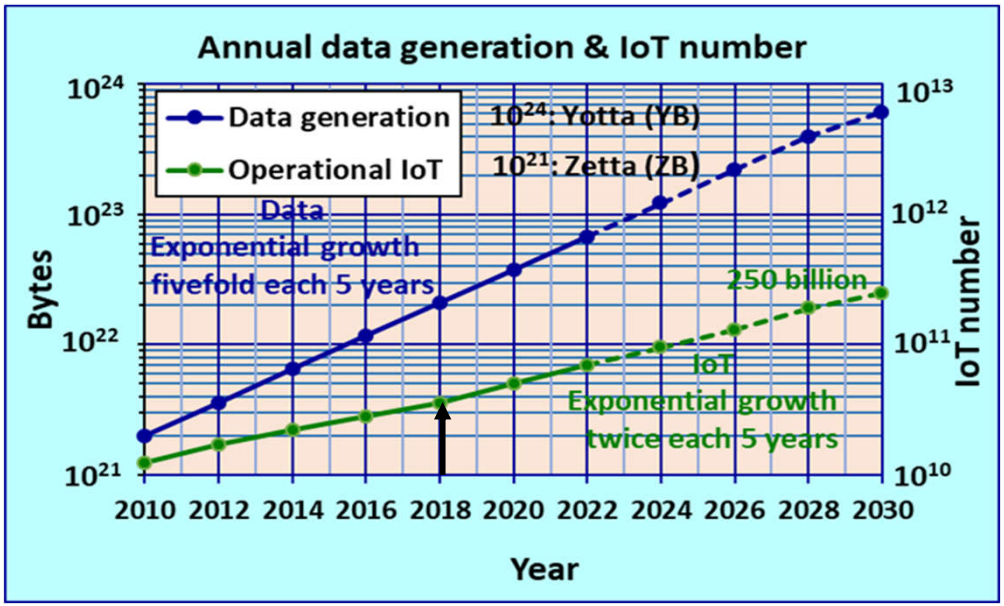
# Huge evolution of digital society

## Exponential growing of data transfer and IoT

The amount of data transferred is X 10 each 4 years. 90% of the data is stored/processed by data centers.

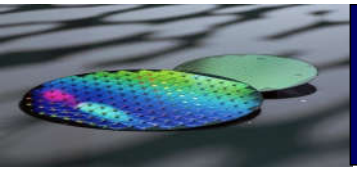
$10^{27}$: Bronto (BB)
$10^{24}$: Yotta (YB)
$10^{21}$: Zetta (ZB)
$10^{18}$: Exa (EB)
$10^{15}$: Peta (PB)
$10^{12}$: Tera (TB)

The number of IoT is x2 each 5 years and will reach 250 billion in 2030.
Since 2018, the growth is faster due to cryptocurrencies (Bitcoin, Litecoin, or Ethereum), the 5G, and artificial intelligence




*After* J. Desjardin, World Economic Forum, 17 April 2019

*After* O. Bonnaud, IJPEST, vol. 14, n° 1, pp. 1-8, , 2020



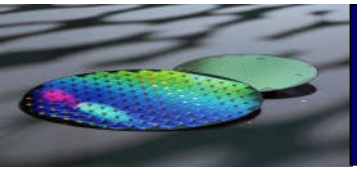
# Huge evolution of digital society

## Huge involvement of electronics devices circuit and systems

**The hardware associated to digital world, such as connected objects and IoT is mainly based on electronics and microelectronics components and devices:**

- **Integrated circuits (microprocessors, DSP, memories, digital/analog converters, ..),**
- **Embedded electronics (FPGA, Arduino,..),**
- **Large area devices and systems (flat panel displays, sensors, actuators, energy harvesters, ..),**
- **High frequency systems (antennas, amplifiers, modulators,..),**
- **Hybrid packaging (3D stacking,..),**
- **Power electronics devices and circuits (power supply, voltage converters, ..).**

**All these devices are electrical power consuming even in off-state.**



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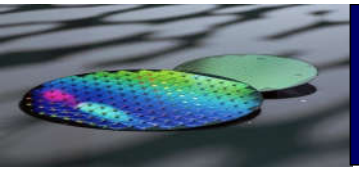
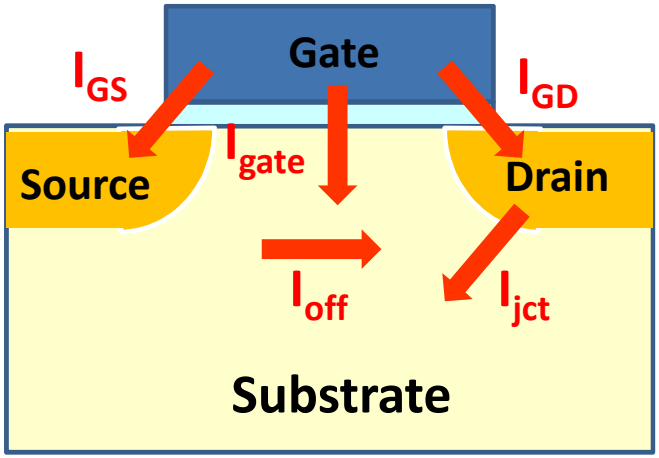
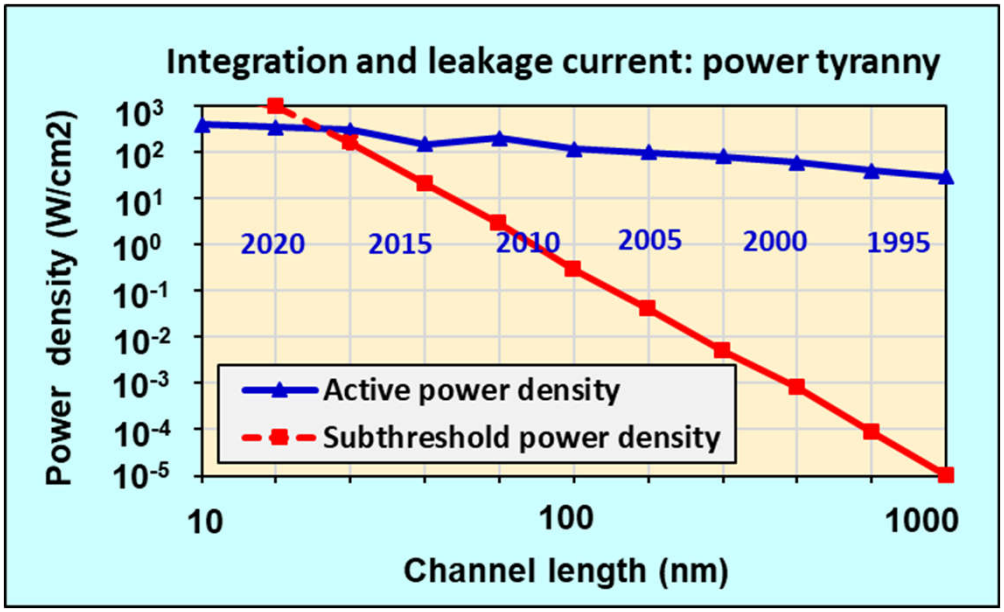


# Consequence on energy consumption and sustainable resources

## Origin of the power electrical consumption (1/3)

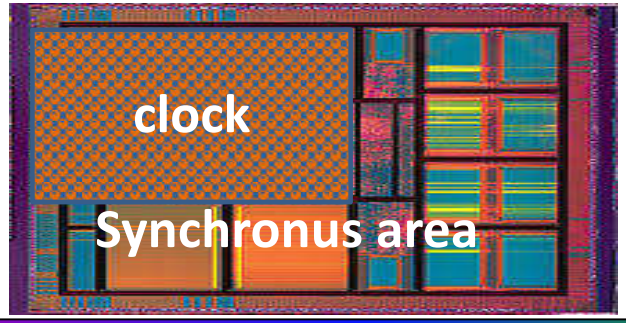
Smaller the device, higher the relative leakage currents!



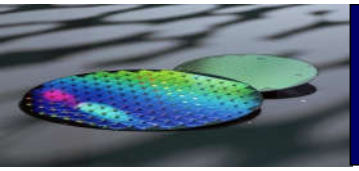




*After* W. Haensch, *IBM J. Res. Dev. 339 (2006)*

*After* O. Bonnaud *et al, PETI, 9, p. 01 (2018).*

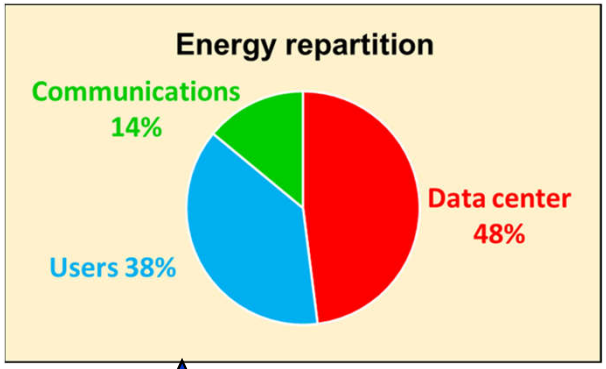



In synchronous technologies: billions of transistors are driven simultaneously by the clock that occupies up to 1/3 of the area.

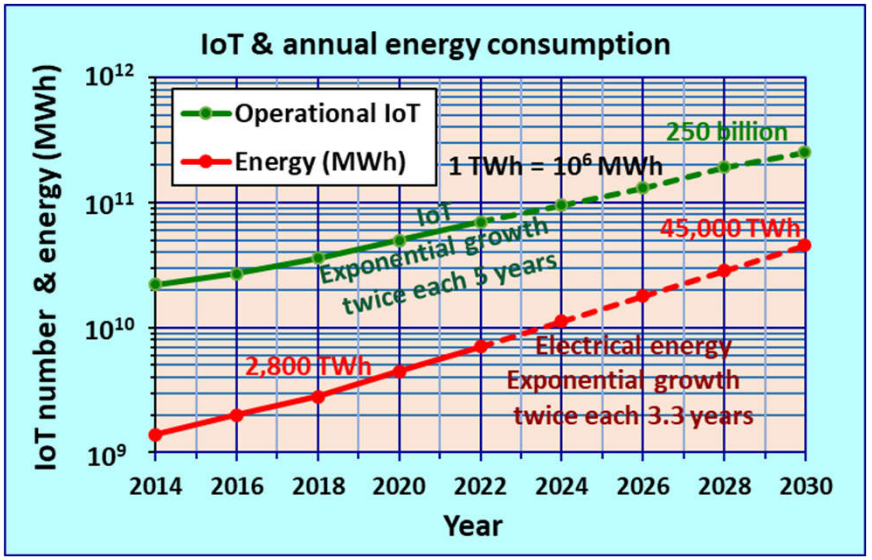


# Consequence on energy consumption and sustainable resources

## Origin of the power electrical consumption (2/3)




In 2018, each 1GB data transferred induced an electrical energy consumption of 2 kWh at least taking into account of all the digital chain




*After* https://www.src.org/about/decadal-plan/

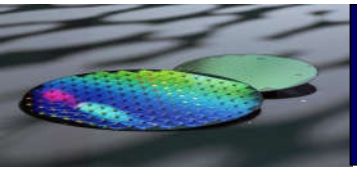
### Transoceanic optical fiber cable

- optical loss 0.5dB/km, - length 6,000 to 10,000 km,
- an amplifier/repeater every 80 km (gain $10^4$)!
- 7 cm conductor diameter for 4 fibers (15kV, 40MW).

IoT consumption growth: x2 each 3.3 years since 2005
Global IoT consumption in 2030 : 45,000 TWh

## Origin of the power electrical consumption (3/3)

6.000 TWh lost for transport/conversion, 26% of the consumption: power electronics is seriously concerned



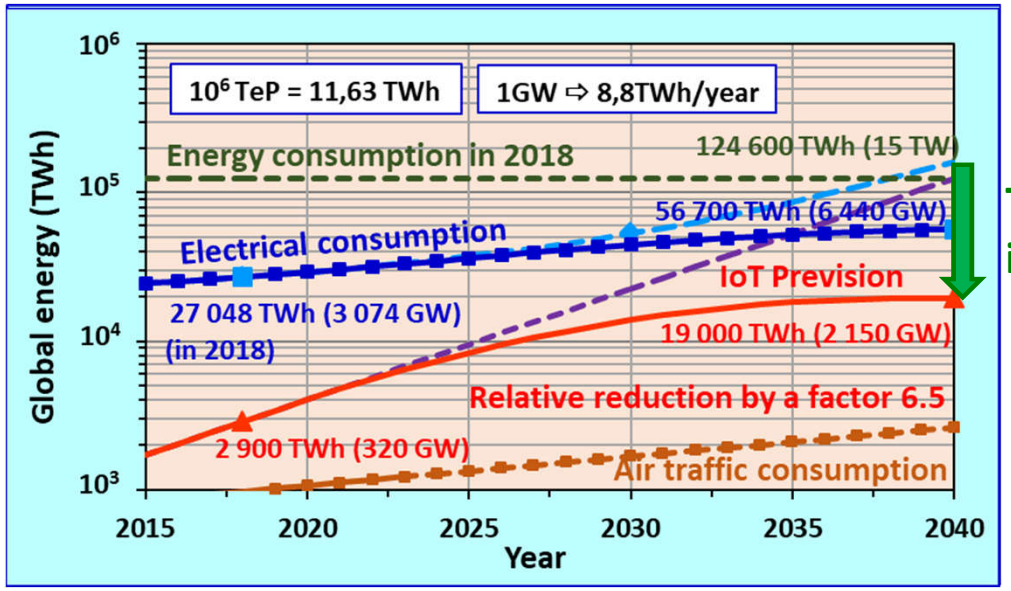
# Consequence on energy consumption and sustainable resources

## Reduction of the exponential growing of electrical energy consumption

The IoT energy consumption is exponential and will reach non-realistic level in 2040.

To avoid a dead-end, the solution is the electronics improvement.

It is possible to progressively decrease by a factor 10 the total consumption of electronics with innovation over the next fifteen ears .

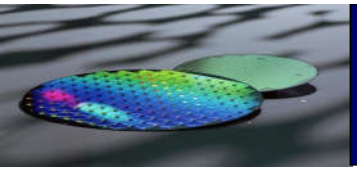



This evolution is simulated!

Global elect. Consump. in 2018 : 30,000 TWh
IoT Consump in 2030 higher without action
IoT Consump. in 2040 less than 20,000 TWh!

*After* O. Bonnaud, Int. J. Plasma Environ. Sci. Technol. vol. 14, n° 1, pp. 1-8, , 2020

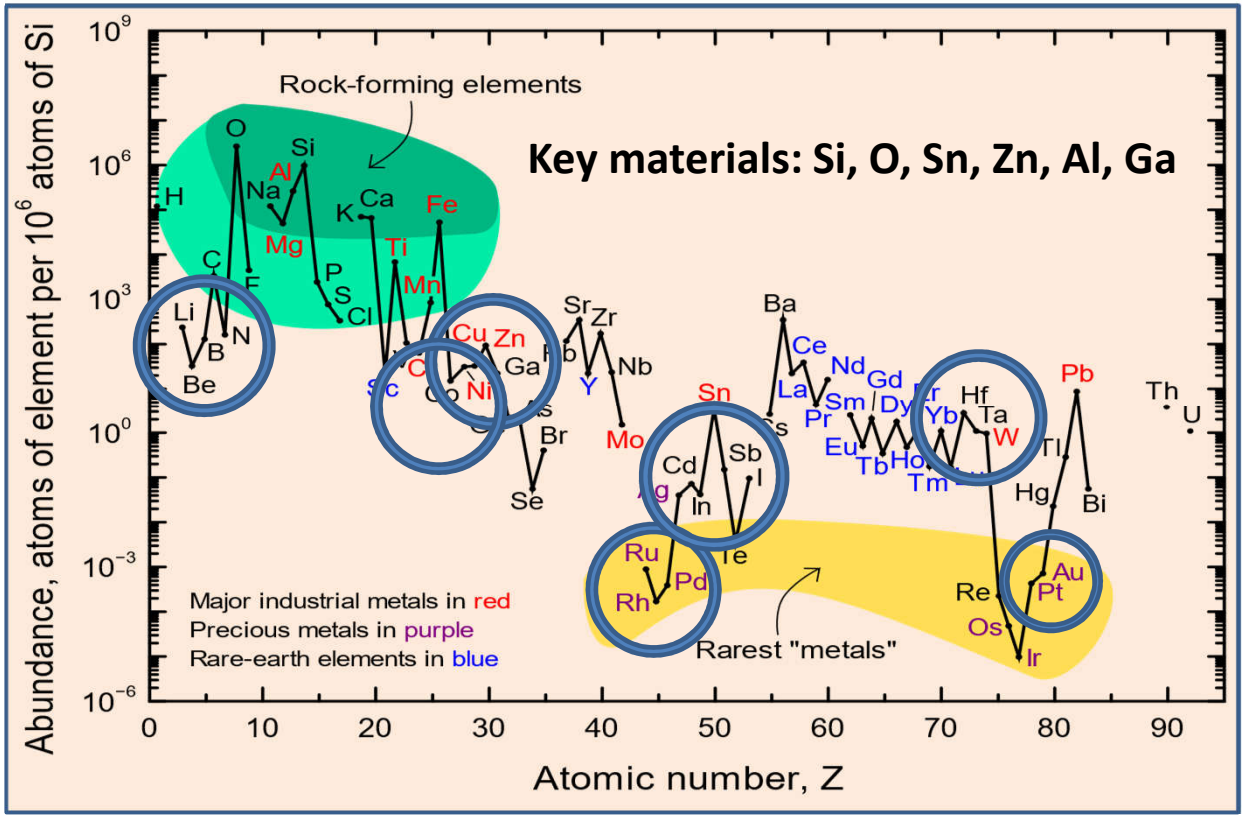
*After* J-R. Léquepeys *et al.*, *Proc. ESSCIRC 2021*, p. 7-14



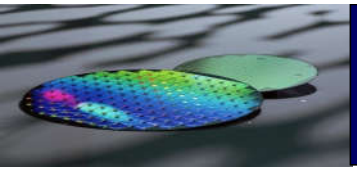
# Consequence on energy consumption and sustainable resources

## Sustainable resources: abundance of elements in the earth crust

- The lower the abundance, the higher the complexity of the extraction and purification, the higher the energy consumption.
- For the less abundant elements, the available natural sources are mostly concentrated in a few regions of the planet.
- For electronic applications Ga, In, As, Hf, Sb, and Li, Co (battery's) are concerned.




*After* CRC Handbook of Chemistry and Physics, 97th edition (2016–2017)



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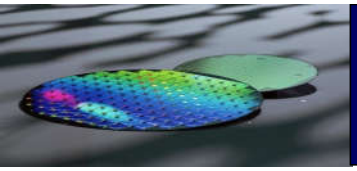


# Challenges for electronics and microelectronics: ULSI & TFT roles

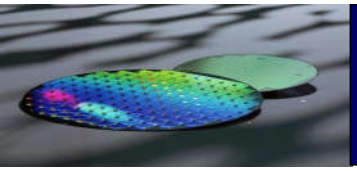
## Challenges in micro-nanoelectronics

**Process**

- Creating active and passive new nanometric components with infinitesimal electrical consumption and with new materials (wide bandgap and 2D materials),
- Increasing the electronic operating frequencies in order to increase data flow,
- Improving the efficiency of power electronics: components and circuits
- Developing energy harvesting systems, integration in 3D architectures.

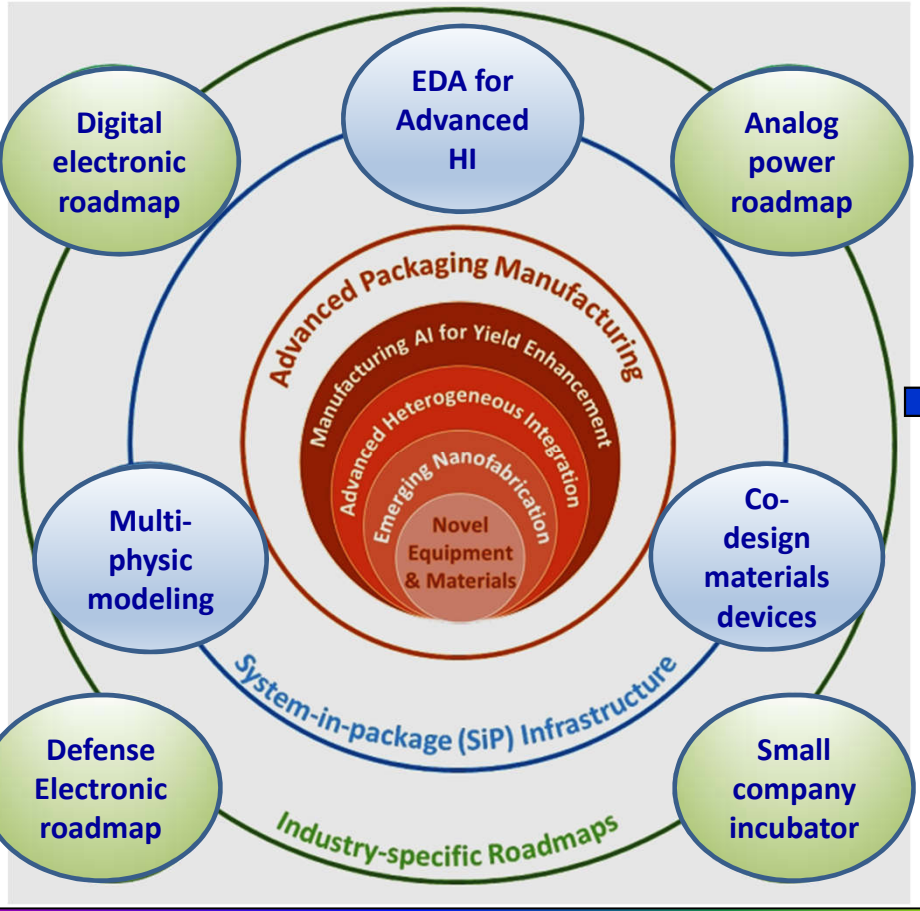
**Design**

- Adapting circuit architectures that can monitor the idle of areas,
- Combining asynchronous and synchronous electrical IP,
- Developing systems for "edge-computing" which enable locally treatment ,
- Opening up the spectrum of electronics applications by 3D integration,
- Focusing the electronic innovation on sustainability.



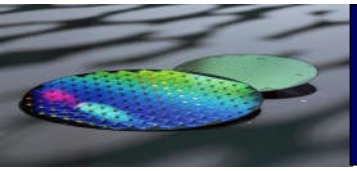
# Challenges for electronics and microelectronics: ULSI & TFT roles

## Texas Institute for Electronics Program Overview (US Chips Act): towards applications




| Application Areas |
|---|
| Cloud Computing and AI |
| Electric Vehicles and Automotive Systems |
| Consumer/Mobile Electronics and Edge Computing |
| Healthcare and Wearable Electronics |
| High Power Electronics |
| Communications |
| Aerospace Applications |
| Sensors, Actuators and Micro Electro-mechanical Systems |
| Quantum Computing |

*After* V. Sreenivasan, Un. TA, Nov.2022



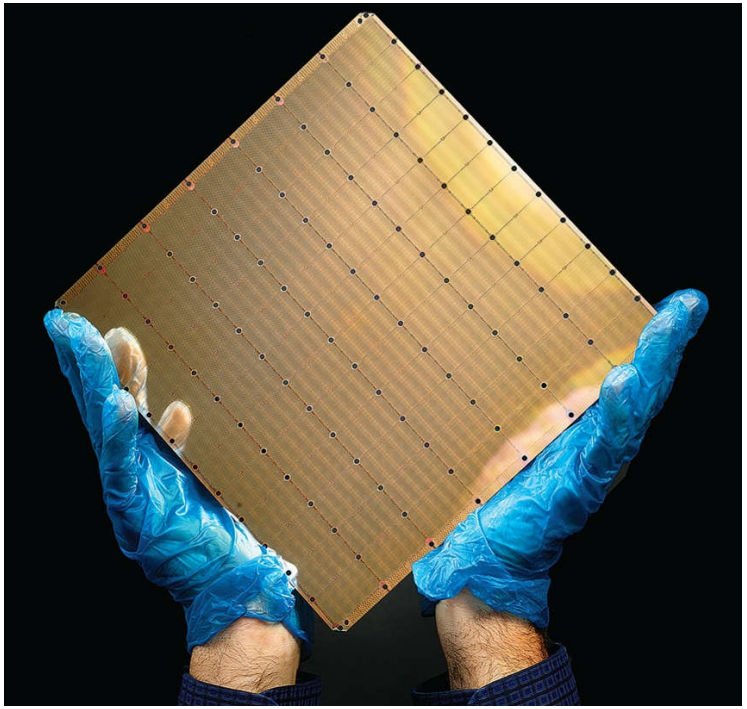
# Challenges for electronics and microelectronics: ULSI & TFT roles

## New ULSI Integrated circuit for AI application: challenge on the large area

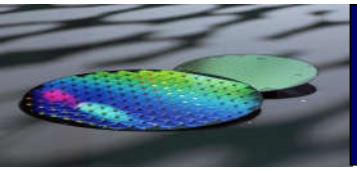
**Integrated circuit, 7nm technology, 2.6 trillion transistors, 850,000 cores, 220 Pbytes/s, 4.6 $dm^2$**

**Larger area with good production yield allows much more complex circuits and systems.**

**The large area allows power dissipation in this case!**



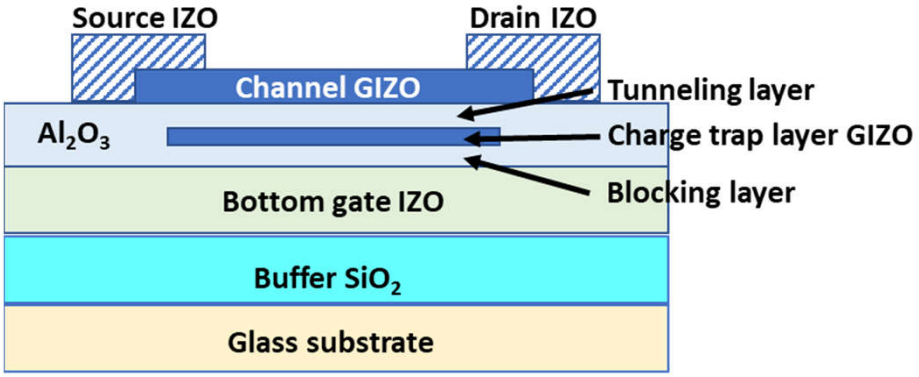
***After* S.M. Moore, Cerebras's silicon-wafer-size chip boasts 2.6 trillion transistors, IEEE spectrum, July 2021**

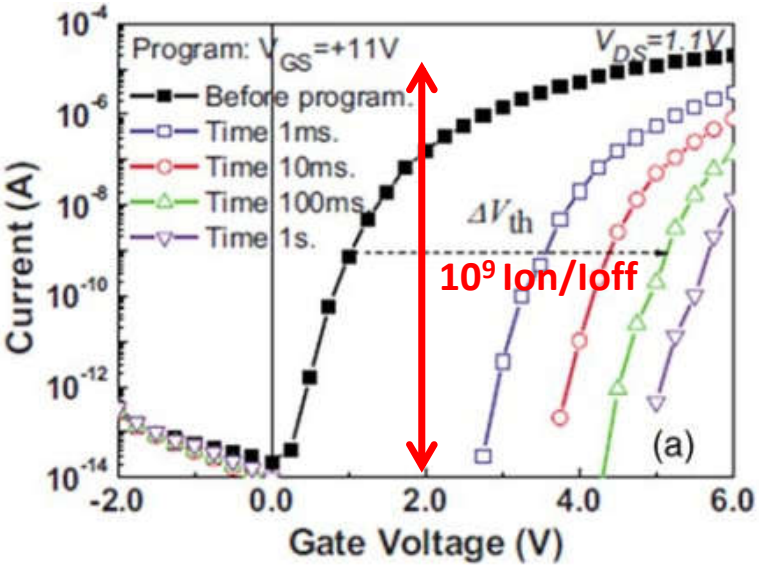


# Challenges for electronics and microelectronics: ULSI & TFT roles

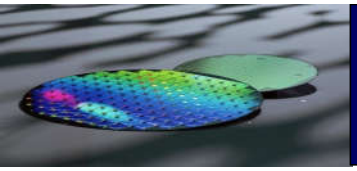
## New devices based on metal-oxide-semiconductor: role of TFT

**The main interest is to have a very high $I_{on}/I_{off}$ ratio in this elementary memory ($\approx 10^9$).**
**Charges are trapped in GIZO (GaInZnO)**



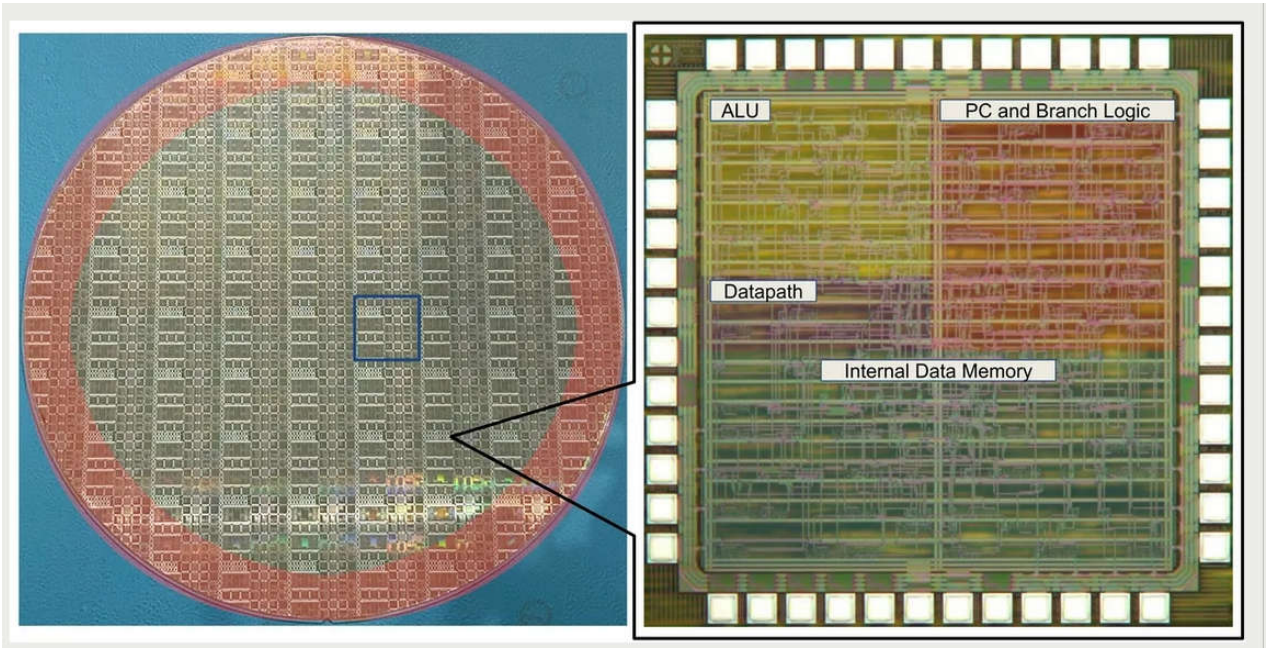

*After* **M. Kimura, Jpn. J. Appl. Phys. 2019 , 58, pp:1-10**



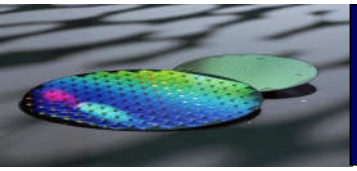
# Challenges for electronics and microelectronics: ULSI & TFT roles

## New TFT-based integrated circuit for low-power applications: IGZO-based

**4-bit microcontroller on plastic, the first yield study on plastic processors (4004 Intel based architecture).**
**Flexible thin-film semiconductor indium gallium zinc oxide (IGZO), which can be built on plastic.**
**$I_{on}/I_{off}$ ratio is much higher than usual Silicon IC devices?**



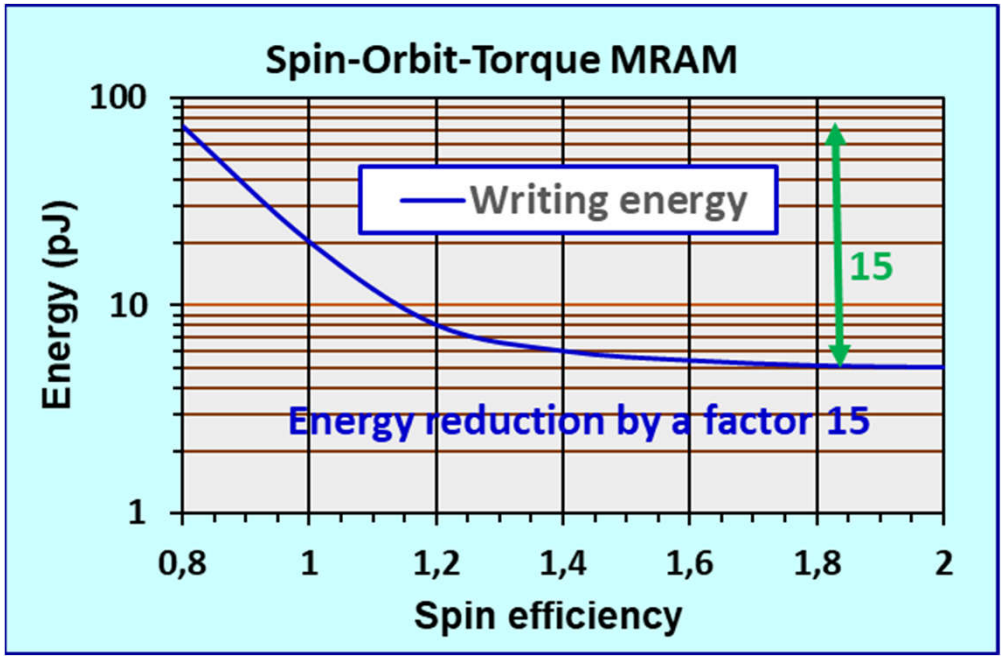

*After* S.K. Moore, The First High-Yield, Sub-Penny Plastic Processor", IEEE Spectrum Journal, August 2022

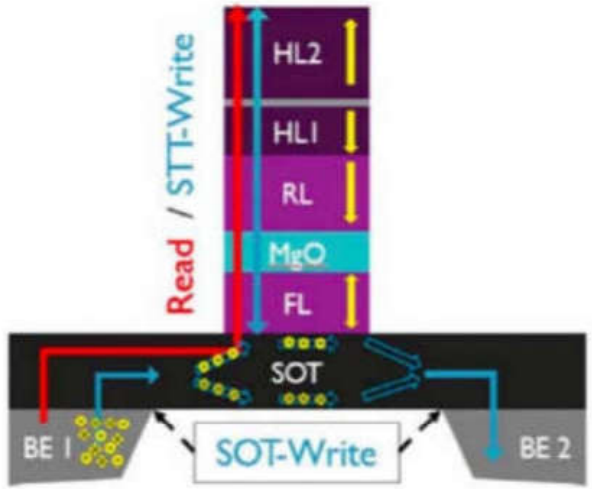


# Challenges for electronics and microelectronics: ULSI & TFT roles

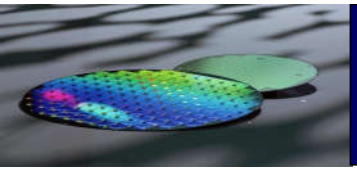
## New low-energy consumption memory: SOT-MRAM (3D mixed device)

**Combining ULSI & TFT allows a main writing energy 15 times lower (≈ 5 x $10^{-12}$J).**



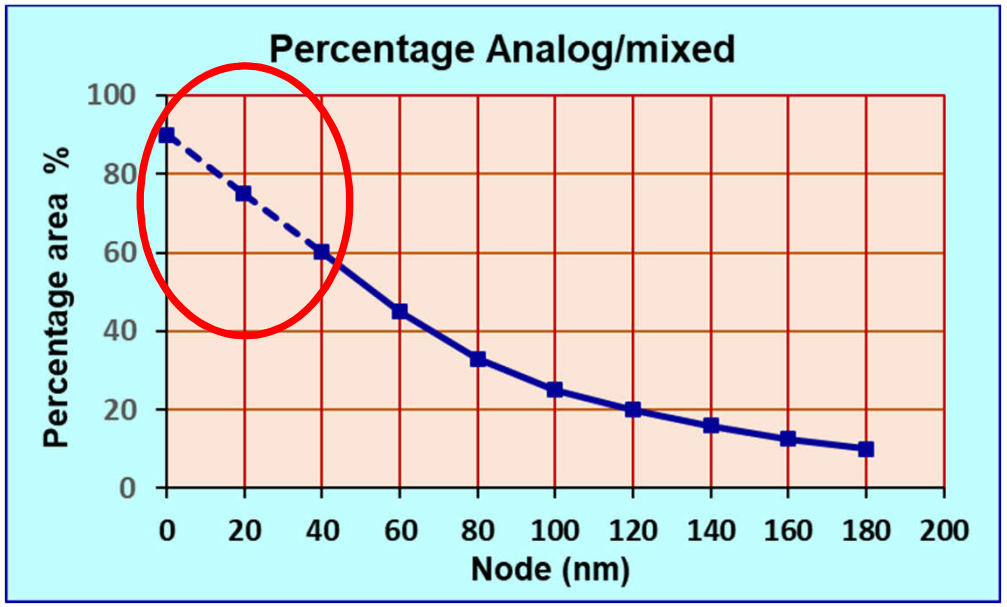

*After* M. Gupta et al., Proc. IEDM 2020, pp. 24.5.1-24.5.4, 2020
*After* M. Gupta et al., Proc. ESSDERC 2022, pp.241-244, 2022

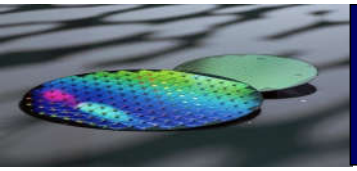


# Challenges for electronics and microelectronics: ULSI & TFT roles

## Relative increase of analog electronic involvement

**The percentage of analog functions in the new integrated circuits allows a decrease of the power consumption of the application at off-state.**
**This approach is very important for the digital data treatment.**
**This means a growing need for specialist in analog electronics both ULSI and TFT based.**





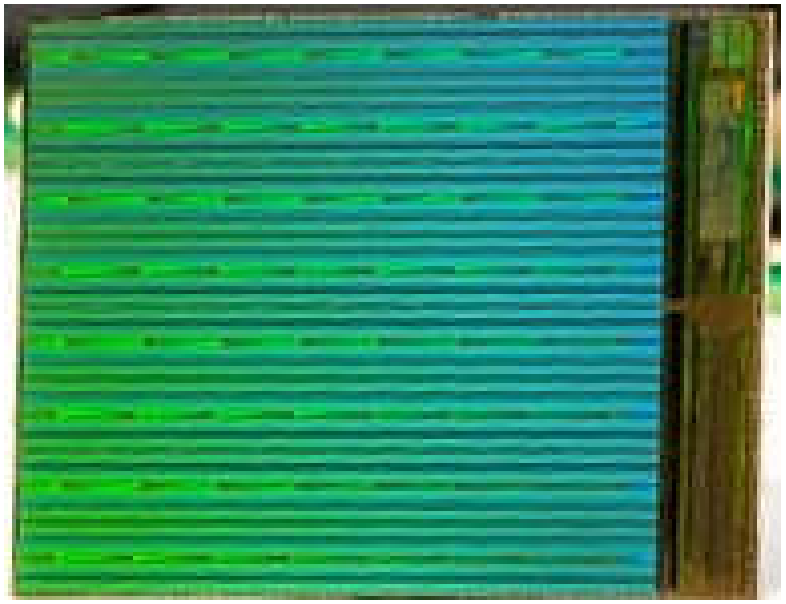
# Challenges for electronics and microelectronics: ULSI & TFT roles

## Higher integration thanks to 3D approach: role of packaging

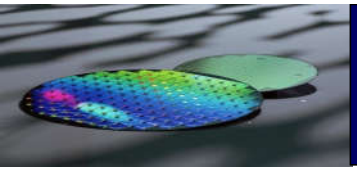
**Stacking of 48 dies for a new prototype of Flash memory: 10 Tbytes.**

**The integrated packaging allows very high complexity systems.**

**This approach imposes a very low power dissipation of each die! The challenge lies in the elementary devices and the architecture of integrated functions**



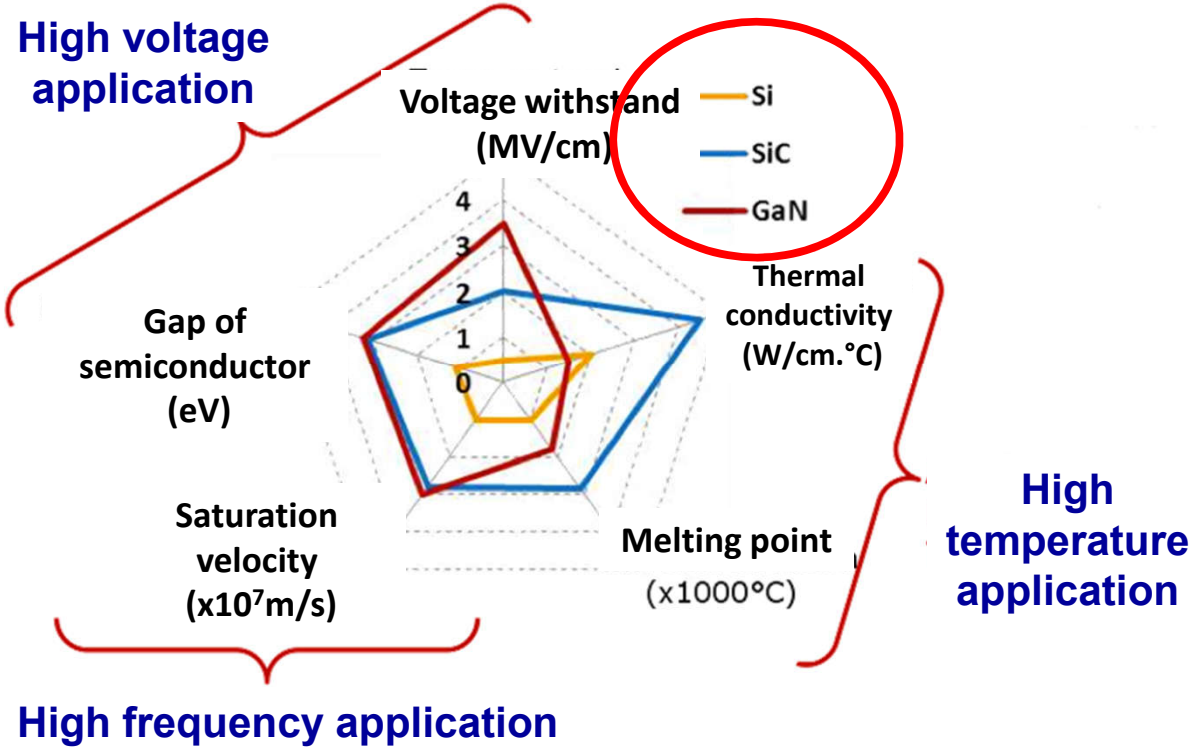
***From* Intel*, Nand Flash 10Tb, 2015***

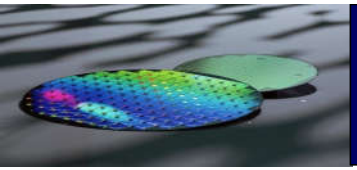


# Challenges for electronics and microelectronics: ULSI & TFT roles

## Introduction of new materials for power devices: Si, SiC, GaN

Depending on the application domain of power electronics, the semiconductor materials have specific properties.
SiC and GaN allow a decrease of leakage current at high voltage or high frequency.





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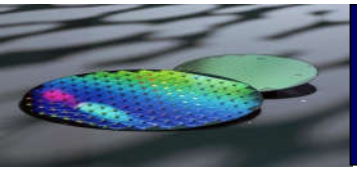


# Skills and jobs in shortage

**All these improvements will only be achieved if the human potential capable of bringing innovation is developed.**

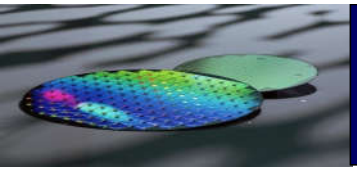
**At the global level, the profession is observing a growing deficit of skills corresponding to jobs in high shortage.**

**It is urgent to increase the pool of specialists in the field and adapt the pedagogical approach that can be focused on knowledge and know-how.**

**If a part of the knowledge can be acquired from digital tools on line (MOOC), the know-how must be acquired on physical equipment and platforms with face-to-face training.**

**In the following we will analyze:**

- **Human resource limitations**
- **Disaffection of sciences and Electrical Engineering**
- **Jobs in shortage**
- **Teacher shortage in Higher education**

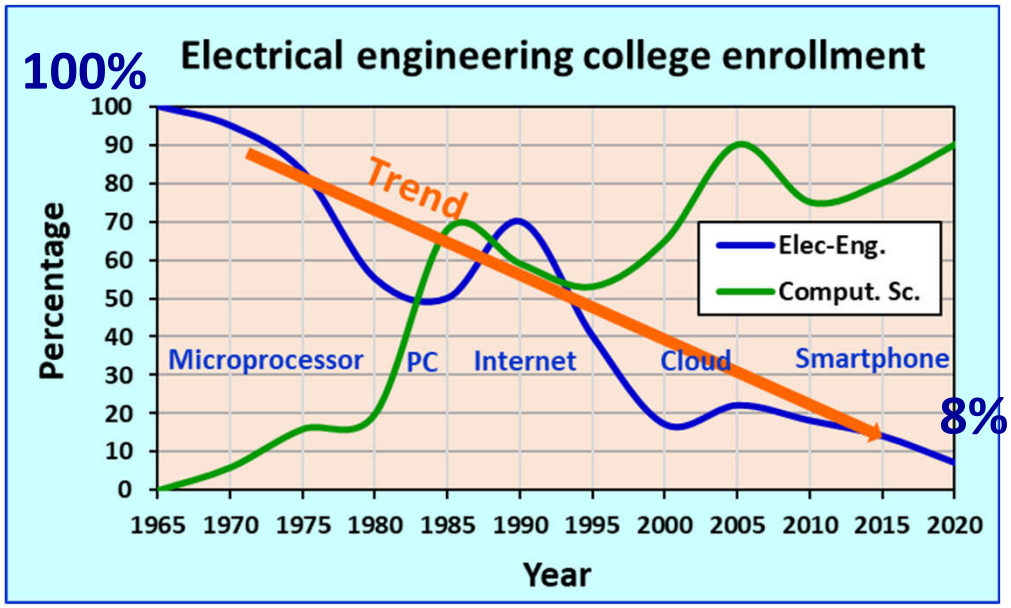


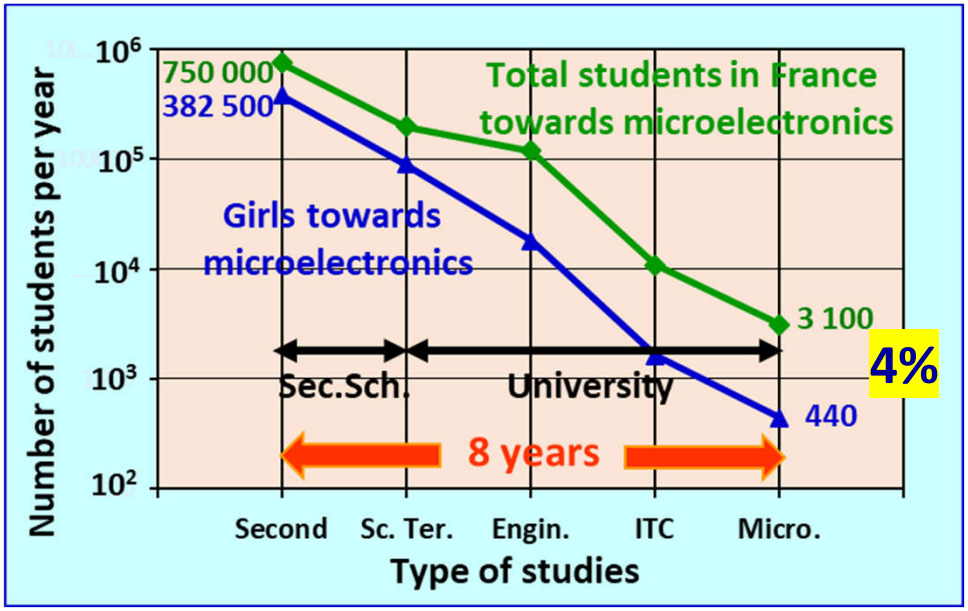
# Skills and jobs in shortage

## Human resource limitations

**No longer attractive** for young people. A large part of the Electrical engineering pool was transferred to **Computer sciences** one (USA example).

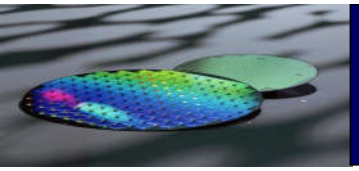
Less and less students in the EE field in France. Only **4% of students** population are graduate. Among them, only **14% of females**.




*After* R. Koduri, IEEE VLSI Symp., 2022 (Intel Vice-President)

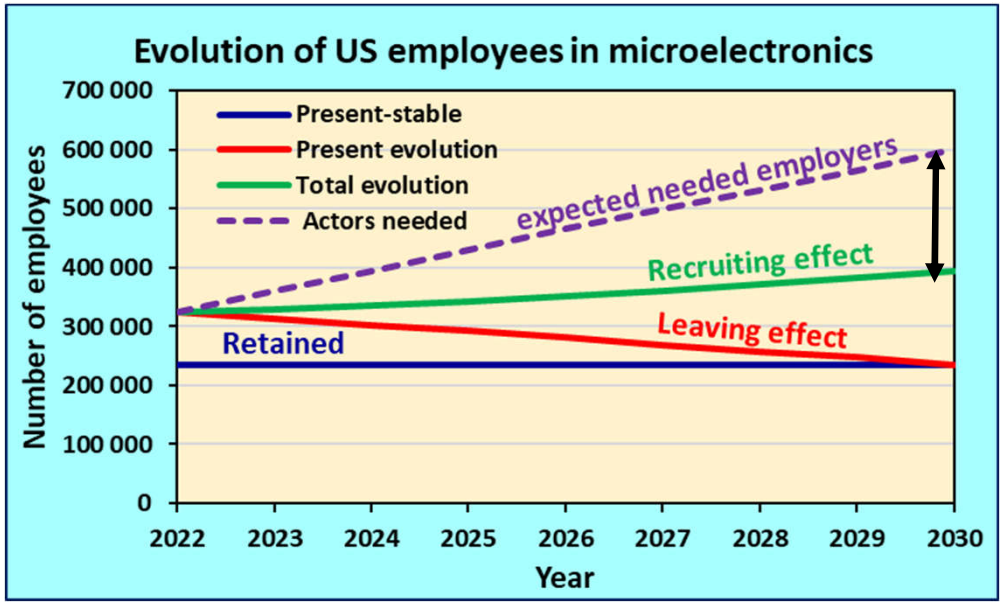
*After* O. Bonnaud, IMAPS'22, 2022



# Skills and jobs in shortage

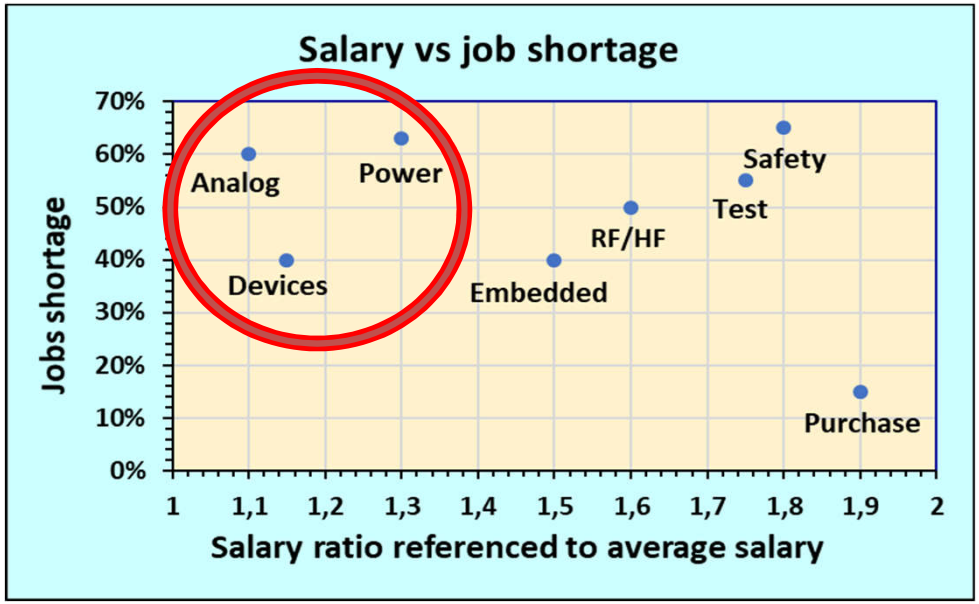
## Disaffection of sciences and Electrical Engineering

**Disaffection with science and electrical engineering. Forecasting the changing U.S. workforce.**

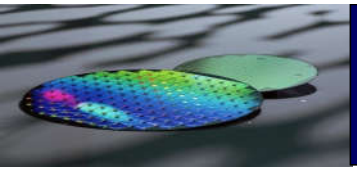



*From* Intel, *Nand Flash 10Tb, 2015*

**Effect of salary on jobs shortage. People working in marketing are favored! Technique is less considered!**




*From* Konexio analysis, 2022

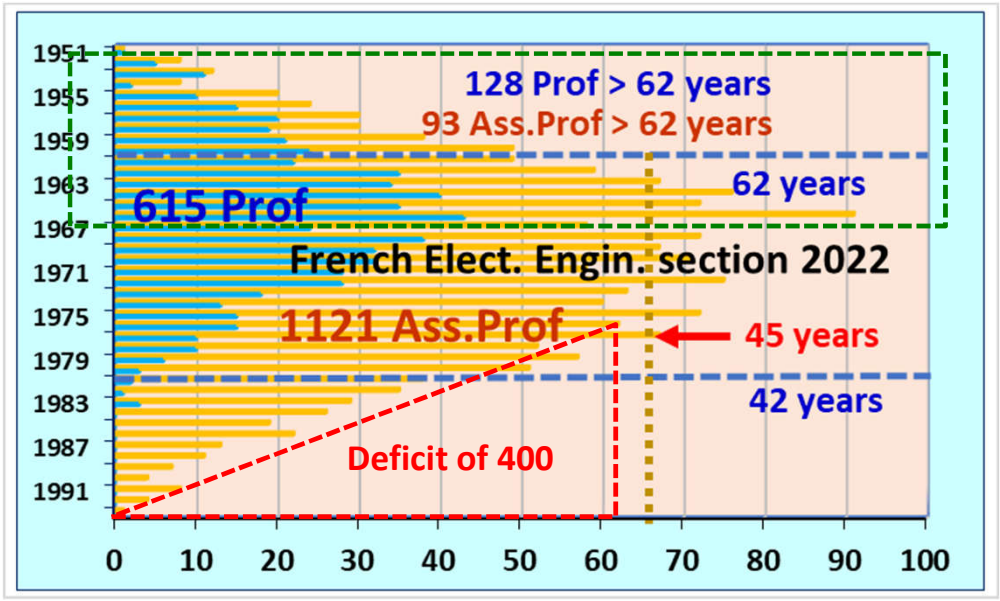


# Skills and jobs in shortage

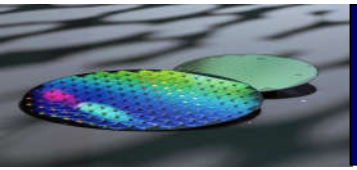
## Teacher shortage in French Higher education

**Academic teachers in shortage in electrical engineering: the age pyramid shows a strong recruitment deficit for teachers under 45 years old more than 400 in 2022.**
**Since 2007, the number of teachers in the field has continuously decreased.**

**In addition, more than 500 teachers will be retired by 2027!**




*After* O. Bonnaud, Report of CNU'63, France , 2022



# Skills and jobs in shortage

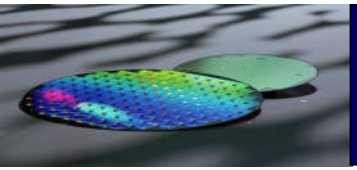
## Human resource: jobs in shortage declared by French industry

**Process**

- **In the field of technological process:**
  - **electronic and clean room operators (microelectronic processes),**
  - **production machine technicians/engineers,**
  - **process engineers in microelectronics,**
  - **technicians/engineers for the manufacturing of electronic boards (printed circuits).**

**Design**

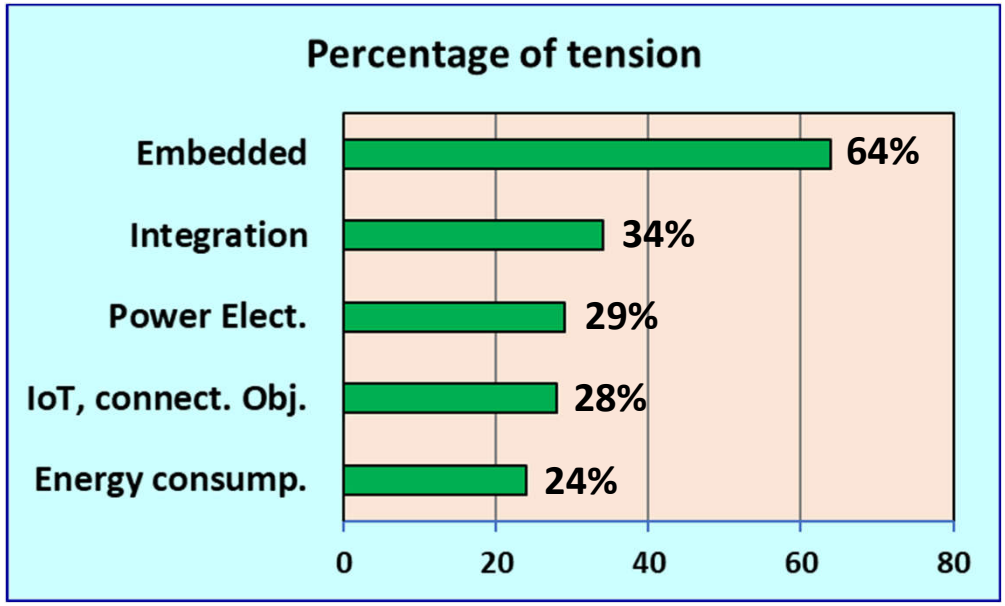
- **In the field of design:**
  - **analog design engineers,**
  - **test product engineers,**
  - **development engineers,**
  - **architectural engineers,**
  - **design engineers of electronic boards.**



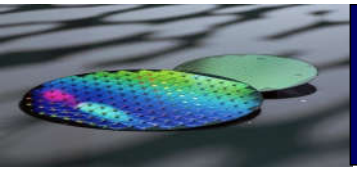
# Skills and jobs in shortage

## Jobs in shortage and tension on recruitment

**The needs identified by CSF in terms of skills are split according to the following themes: the percentage indicated corresponds to the degree of tension on recruitment position not satisfied.**




*After* **Report of CSF France , 2022**



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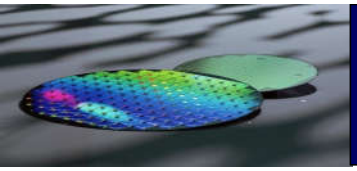


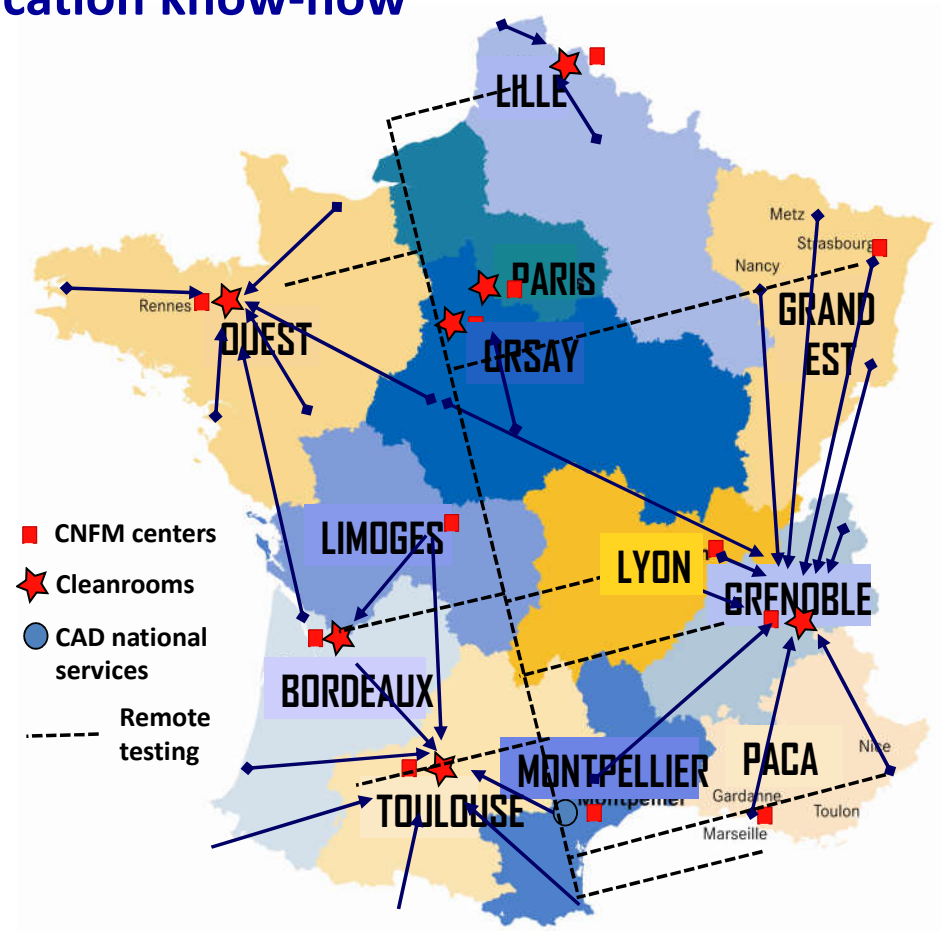
# Strategy of the Microelectronics training

## The French network for Higher Education know-how

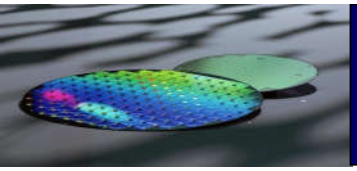
The structure of GIP-CNFM network is in the form of a Public Interest Grouping or Consortium (GIP in French) entitled National Coordination for Training in Microelectronics and Nanotechnologies (CNFM in French).

The goal: to share the functioning of advanced platforms offering a wide spectrum of innovative know-how training.

12 academic structures & ACSIEL
12 CNFM centers - 7 clean-rooms
National CAD services for testing, software's, prototyping
18,000 students /year  150 training courses



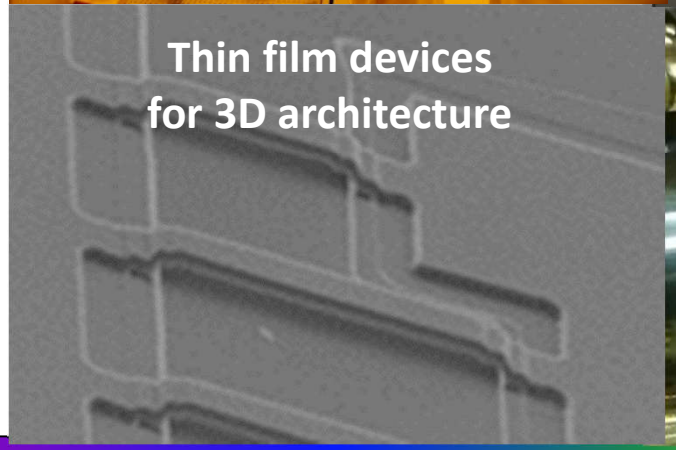

*After* O. Bonnaud *et al.*, ECS Transactions, 64 (10), 187-192 (2014)

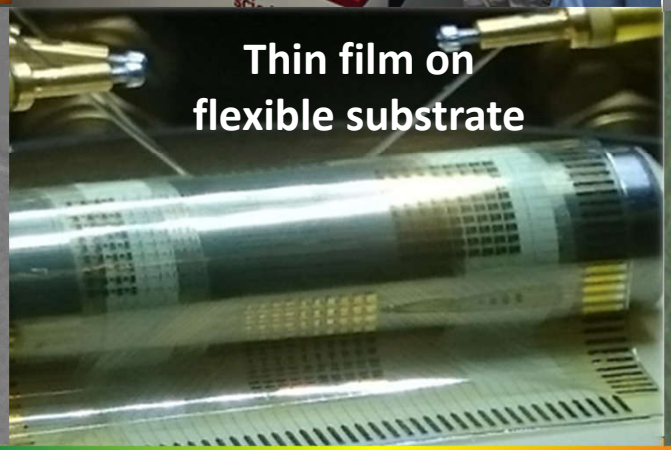


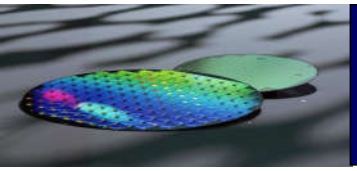
# Strategy of the Microelectronics training

## The French network for Higher Education know-how
## Varieties of technologies in the Higher education training



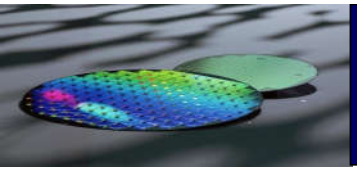
# Strategy of the Microelectronics training

## Attractivity of young schoolers and employees

**Each year, many classes are coming on platforms for a one day know-how experiment.**
**This experience makes them aware. Not enough schoolers are trained! The strategy: increase their number!**

## New digital tools involved in higher education

**The ministry strategy encourages the developing of digital tools and distance learning in order to minimize the face–to-face between professors and students.**
**Several tools were developed by the network to prepare the students to the practical training.**
**This pedagogical approach was experienced during the COVID-pandemic.**



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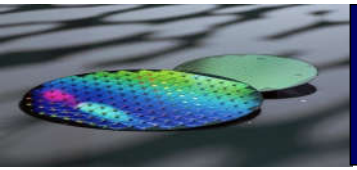

# Conclusion

The proper training of engineers and masters in microelectronics, requires the acquisition of know-how.

The key points of the current strategy to meet the challenges of microelectronics are :

- adapting content to the industrial needs,
- developing knowledge, know-how in ULSI & TFT technologies,
- preparing trainees for a more efficient acquisition of know-how on platforms,
- creating new training platforms targeting skills and know-how deficits,
- preparing the future engineers and doctors to innovation in order to face the future challenges,
- increasing the awareness of young people in secondary school to enlarge the pool of skills.

This field, which is at the center of societal evolution, requires rapid and appropriate adaptation, which is a long-term objective over several years, both in Europe and worldwide.


## Acknowledgement

Special thank to my colleagues of the CNFM national network for their contribution in many works and to my executive assistant for her technical support in the preparation of this presentation.


ご清聴ありがとうございました

Thank you for your attention