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

Proceedings

5-20-2019

ULSI and TFT technologies in industry, research and higher education in France: An evolution towards innovation resulting from close and sustainable interaction

Olivier Bonnaud

ULSI and Thin Film Semiconductor Technologies: Evolution of Industry and Research Linked to Higher Education in France

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

May 19-23, 2019 - Kyoto, Japan

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UMR 6164

The microelectronics: a long term national strategy

- **The evolution of microelectronics in France was linked to a very strong effort of the French government in 80's.**
- **More recently, a new national plan was engaged by the French government with the goal to answer to the evolution towards connecting objects, Internet of Things, and Industry 4.0.**
- **Thus, this plan wants to boost the national activities in the large area technologies and the IC's in order to meet the new needs and the related challenges.**
- **Both aspects are considered:**
  - **The technological challenges in terms of integration, flow of data, broadening of application domains, and energy consumption**
  - **The human challenges in terms of the higher education that guarantee a minimum of know-how to overpass the technological challenges: high skills in the field and multidisciplinary adaptability.**

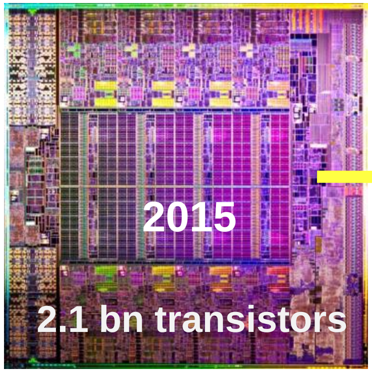
Outline

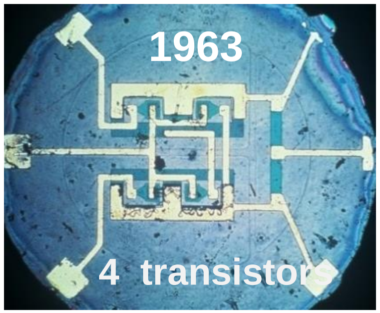
- Introduction
- ULSI &TFT technologies: common evolutions
- New challenges towards IoT and connected objects
- Needs of a National Microelectronics education network
- Challenges on the training of engineers and doctors
- Conclusion

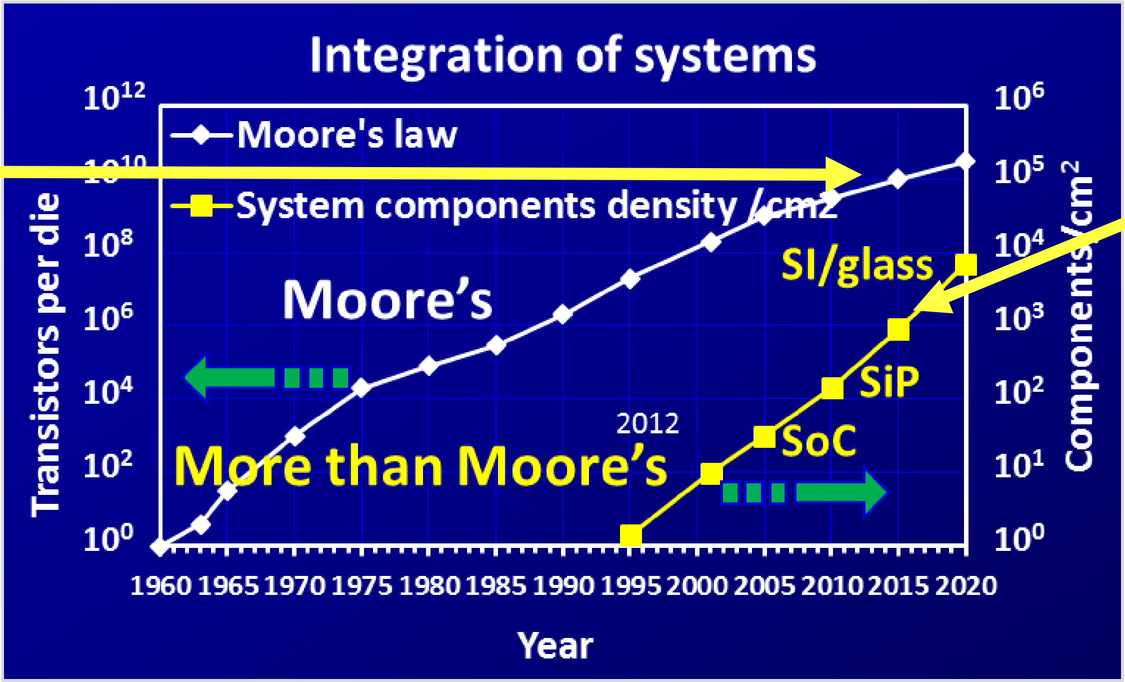
Outline

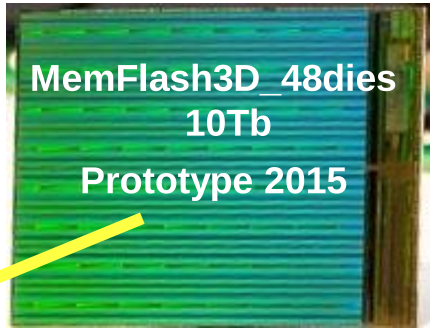
ULSI &TFT technologies: common evolutions

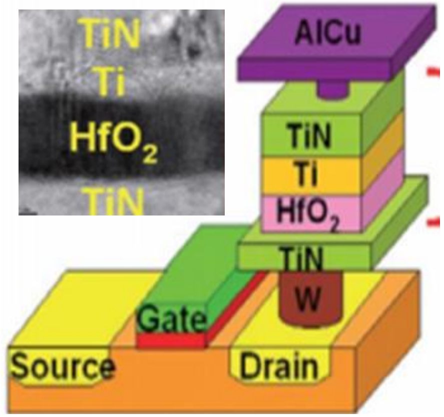
ULSI technologies: continuous integration increase











After G.E. Moore, *Electronics Magazine, 38 (8), pp.114-117 (1965)*
After M. Swaminathan, J.M. Pettit, *3rd System Integration Workshop (2011).*

The integration was governed by the decreasing of the minimum size of elementary device based on self-organization control, till at atomic scale.

Main approaches of ULSI technologies

The main goal is to reach high electrical properties of the final devices or circuits

ULSI technologies

Architecture
- MOS
- FDSOI
- FinFET

Materials
- Semi-conductor
- Insulator ; High Key
- Oxidation

Material depositions: low temperature
- LPCVD
- PECVD
- ALD

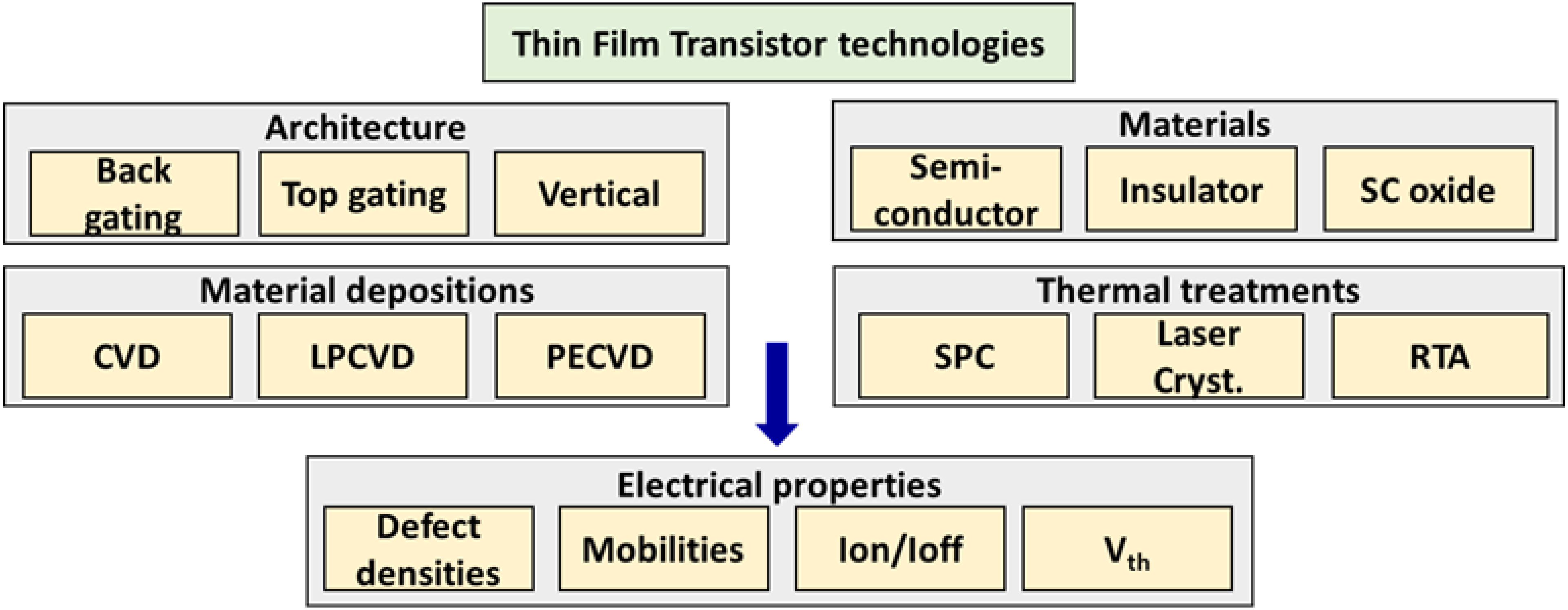
Thermal treatments
- Diffusion - annealing
- Laser
- RTA

Electrical properties
- Conduc-tance
- V_{DD}
- Ion/Ioff
- V_{th}

These approaches are very close to the TFTT ones! Many topics are common, more especially the low temperature process steps and thermal treatments.

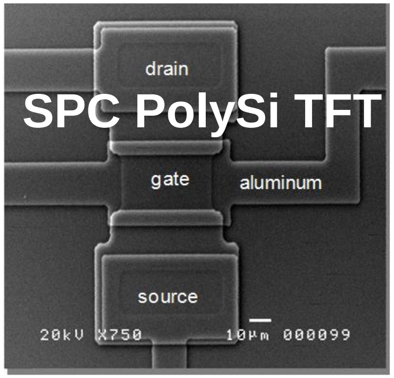
Main approaches of TFT technologies

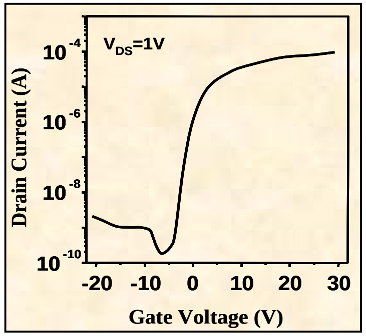
The main approaches of thin film transistors technologies are very close to ULSI ones : high electrical properties of the final devices or circuits



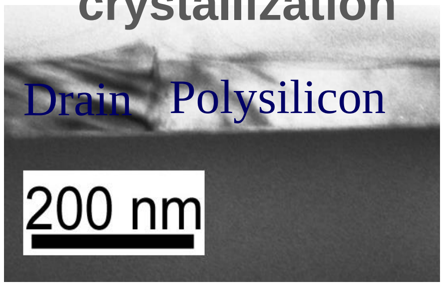
Main approaches of TFT technologies

Example of evolution of thin film transistors: from polySi transistors to sensors, 3D and new materials for flexible applications

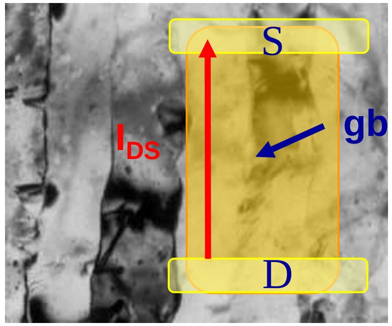


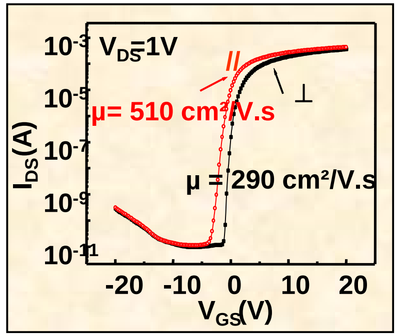


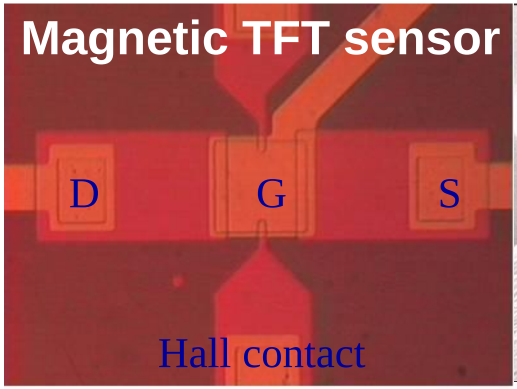
Laser crystallization

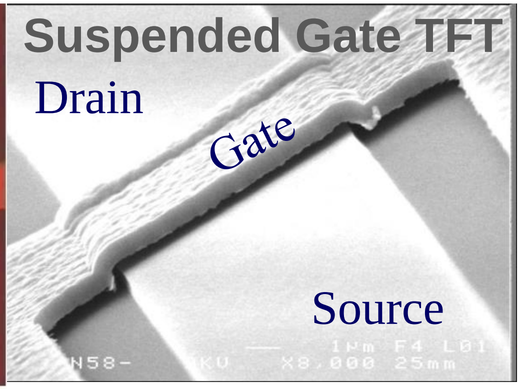


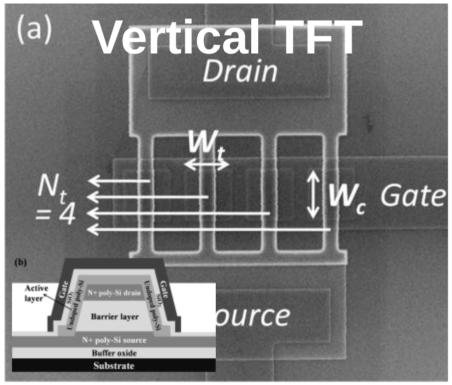
Pulsed Laser TFT

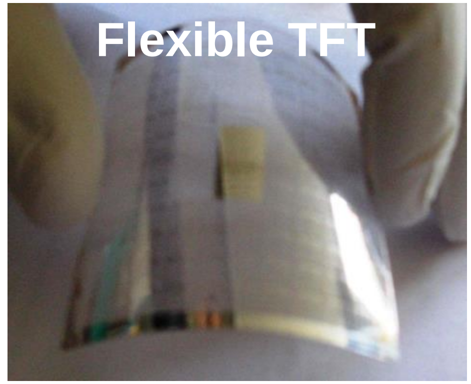










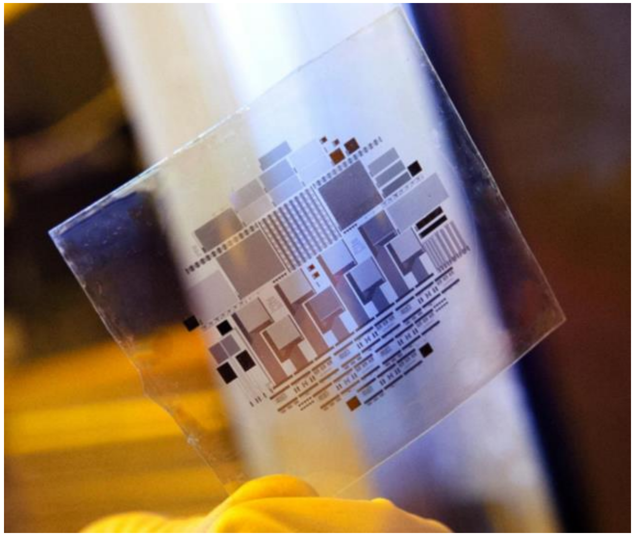


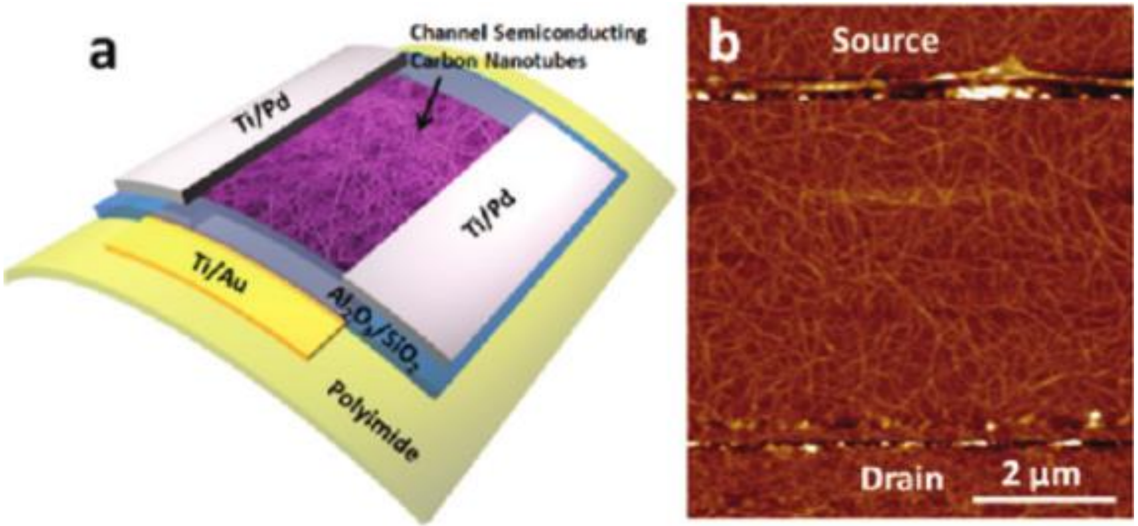
After L. Pichon *et al. Solid State Electronics, 38(8), 1515-1521 (1995)*

After F. Bendriaa, *et al., ECS Vol. 2004-15, (2005), pp.284-288*

After P. ZHANG, *et al. Solid-State Electronics, Vol. 86, 1-5, Aug. 2013*

New processes for TFT circuits





E. G. Bittle, *et al." Nature Communications 7, Article number: 10908, March 10, 2016*

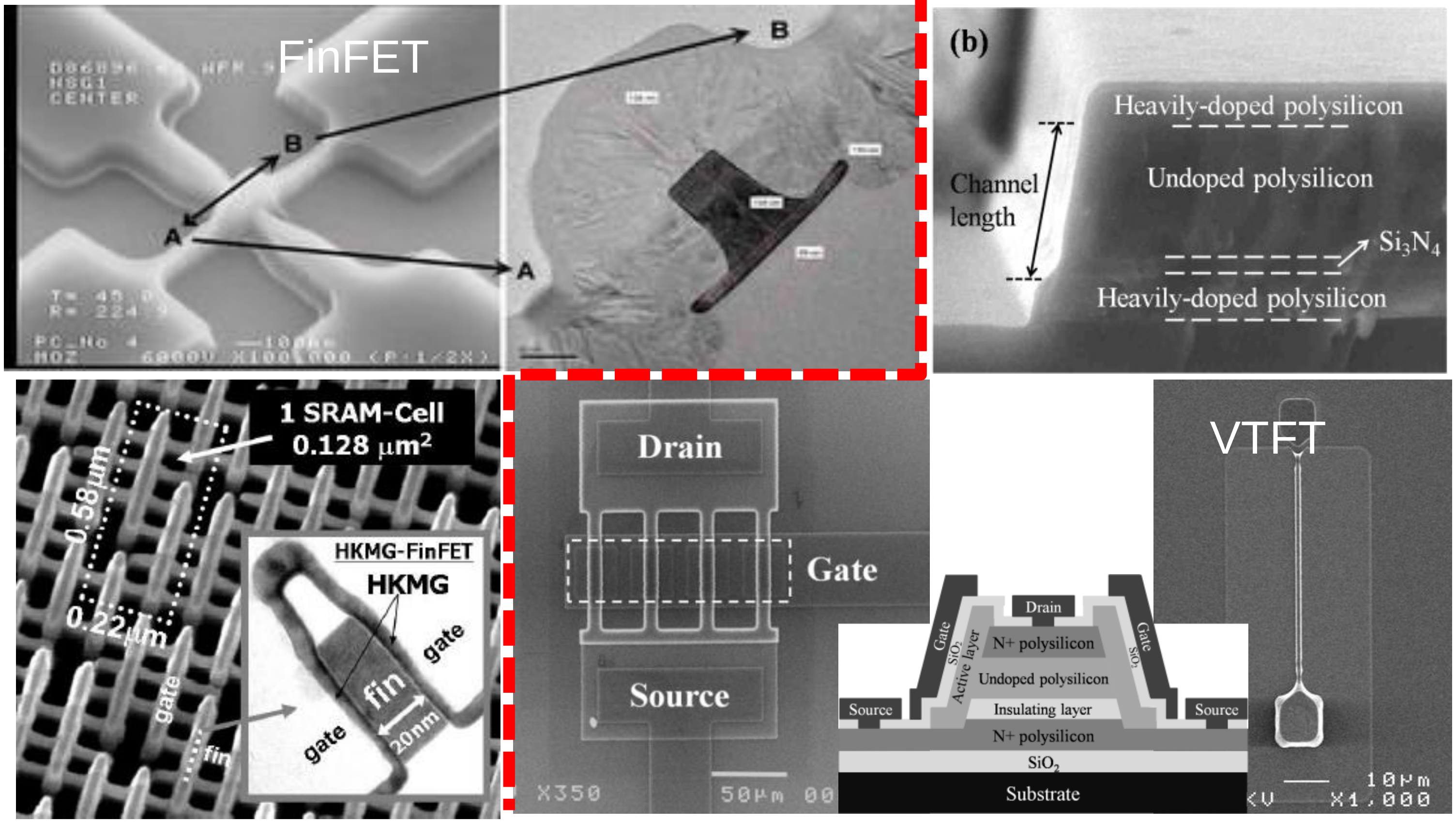
Chuan Wang *et al. Nano Letters 12(3):1527-33 · February 2012*

Flexible substrates, organic semiconductors, room temperature processes, and printed technics are the main breakthroughs in thin film technologies.

Common needs: third dimension

Examples of ULSI and TFT technologies with vertical conductions.

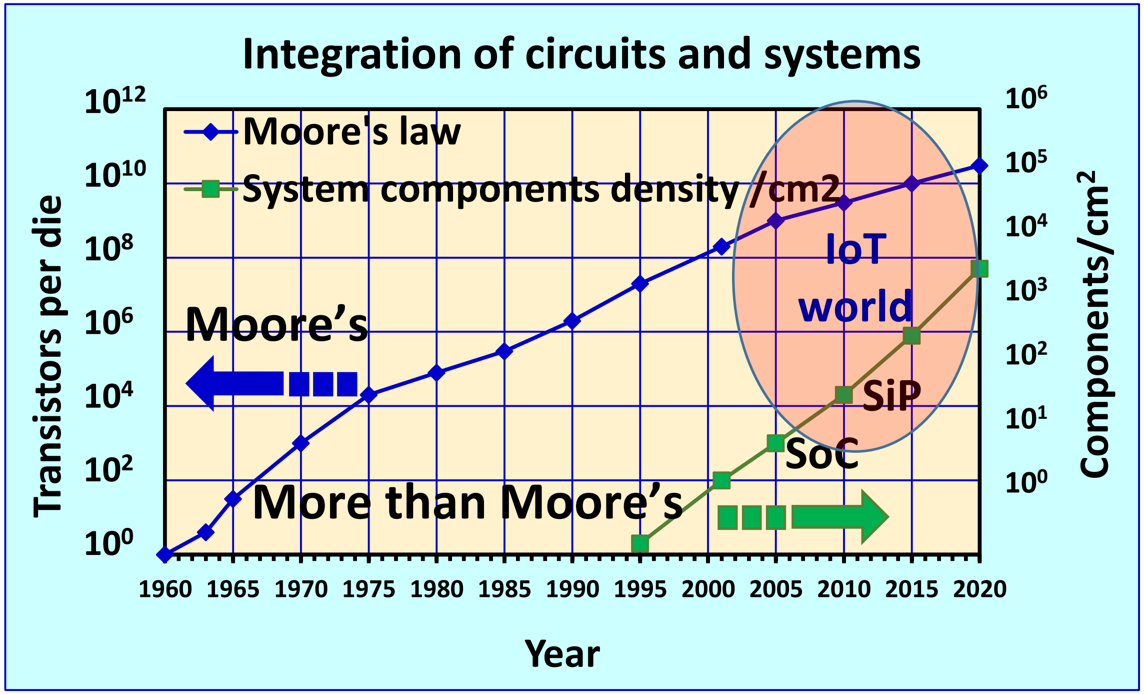
ULSI ← | → TFT



After J.P. Colinge, *Microelectronic Engineering 84, 2071-2076 (2007)*

After P. Zhang, *et al.*, *ECS Trans.* 50(8), 59-64 (2012)

Convergence of both technologies

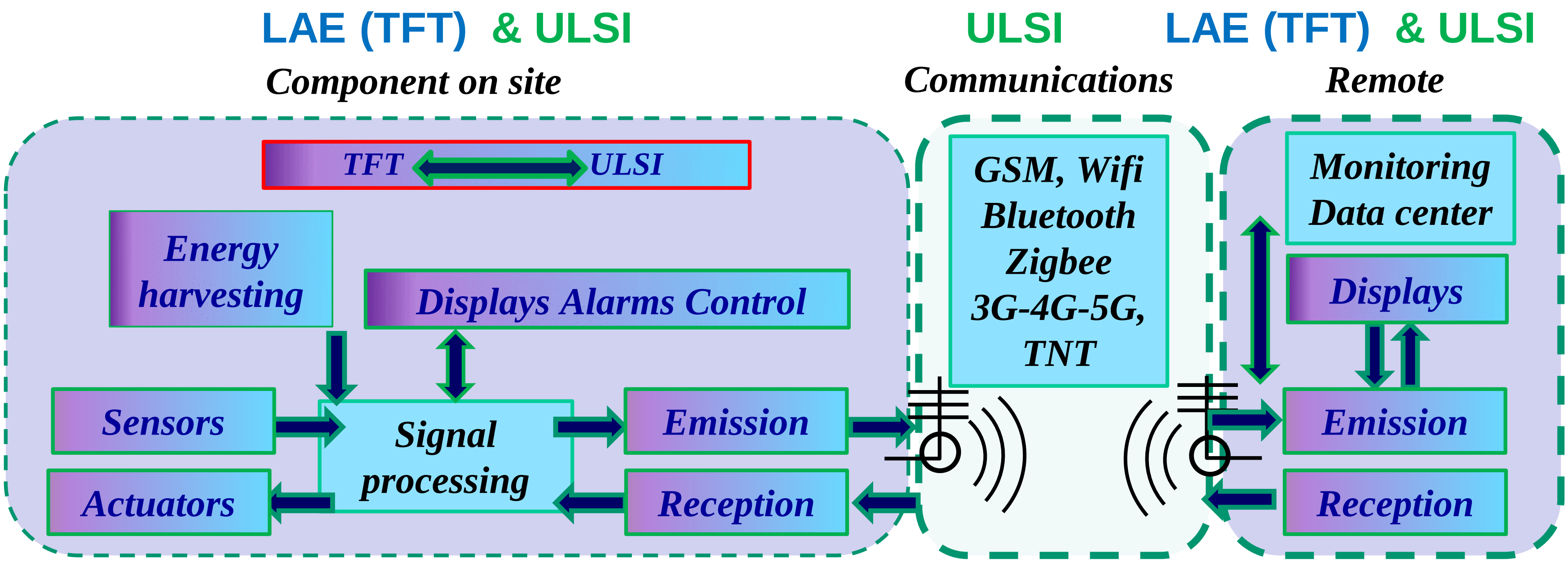


The new integration for IoT includes SIP and SOC, and thus involves ULSI and TFT techniques and technologies.

Outline

Principle of the connecting objects: new technologies

- A connected object includes sensors, actuators, signal processing, emission, reception, energy harvesting, and displays, alarms, controls ...
- Connected object combines large area electronics (LAE) and ultra-large integrated electronics (ULSI). A large spectrum of knowledge!



After O. Bonnaud et al., ICATI'2016, Bali (Indonesia), July 2016

Enlargement of the application domains

- The connected objects are covering a **wide spectrum of applications.**
- The application fields are wider than ever and are able to cover most of **new societal needs.**

Main fields of application of connecting objects

Energy

Environment

Health

Security

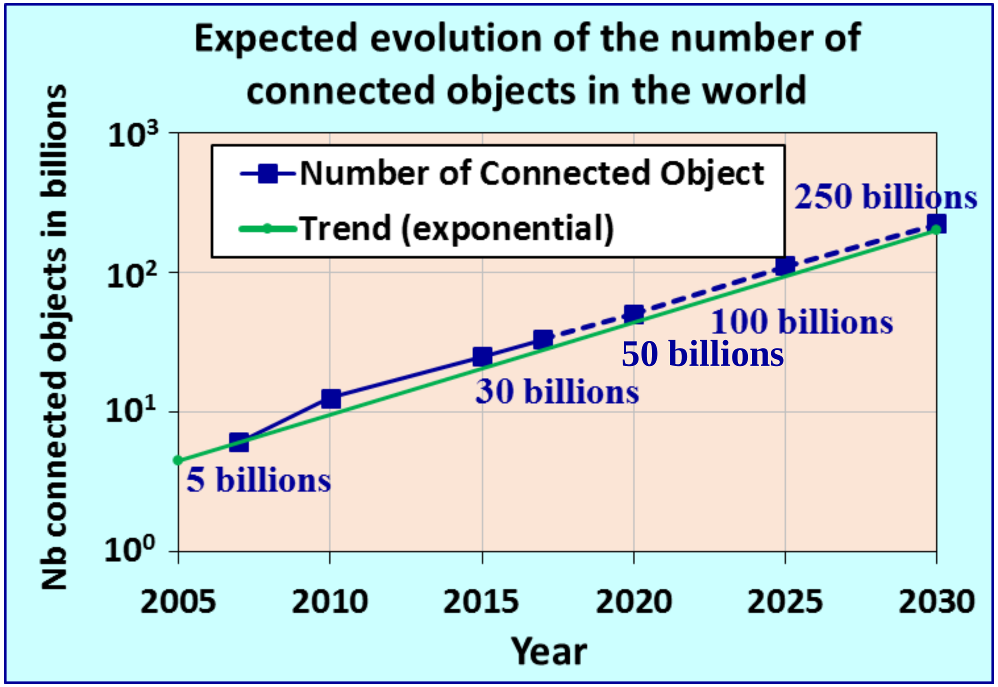
Communications

Transport

After **O. Bonnaud & L. Fesquet,** *Proc. of ITHET'15 Lisboa (Portugal), pp.1-5 (2015)*

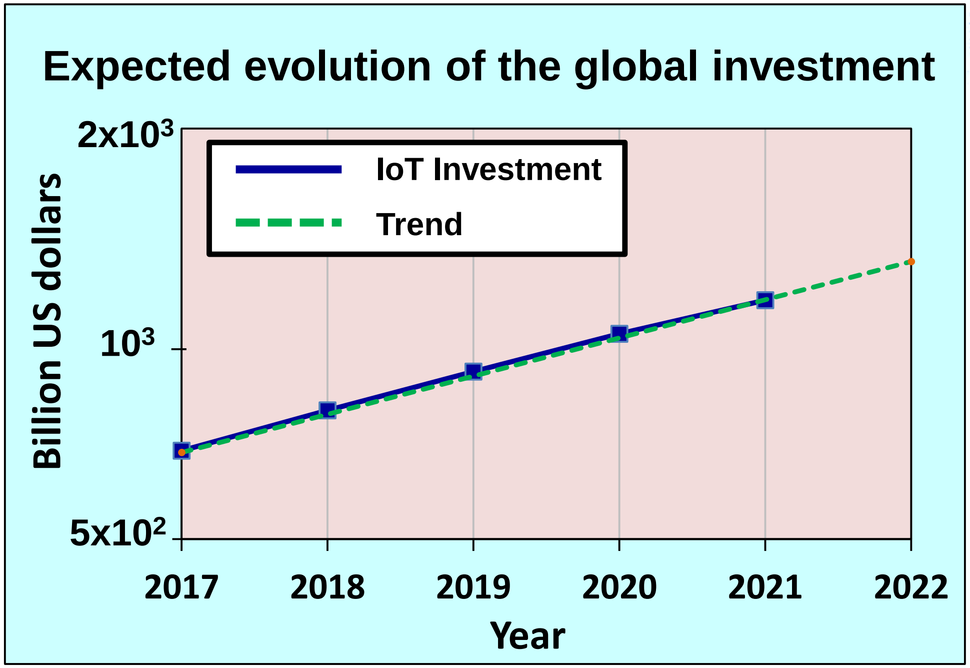
Expected development of Connected objects and IoT

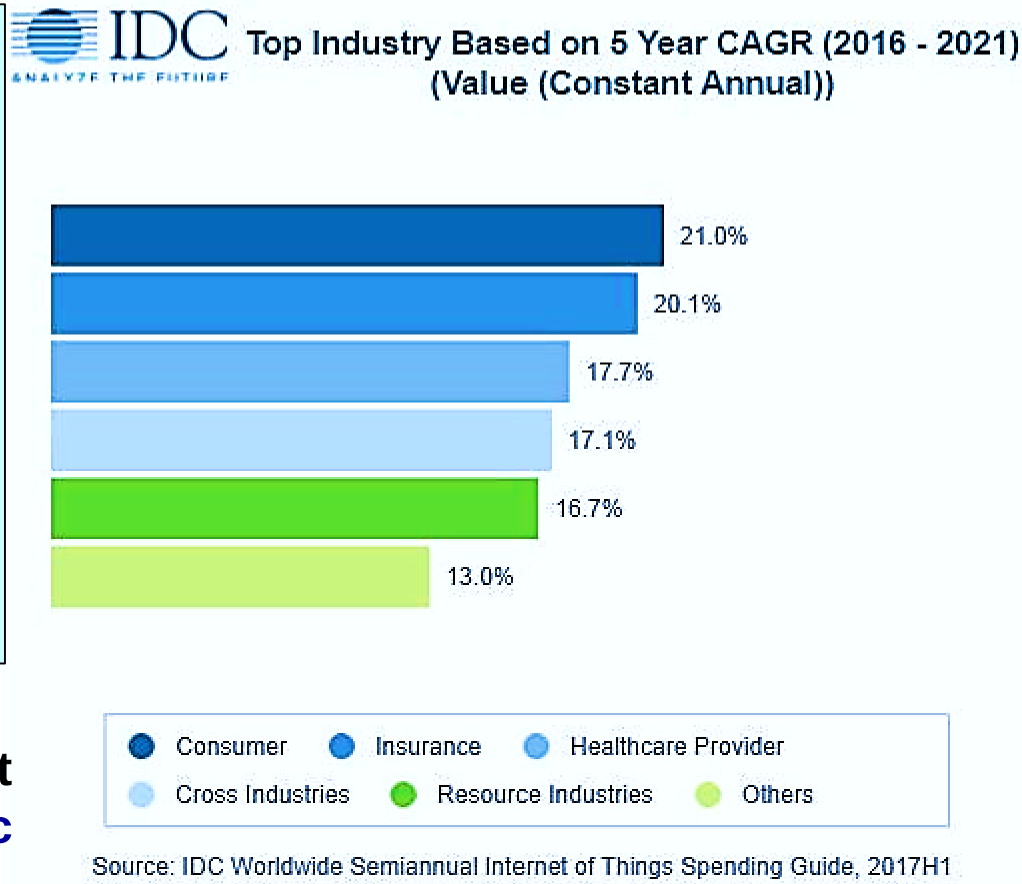
- **In 2020, it is expected that about 50 billions objects should be connected**
- **Expected evolution : an exponential variation similar to Moore's Law one!**



After **O. Bonnaud,** ***ULSI vs TFT conf., Hernstein (Austria), 2017***

Investment on IoT and connected objects

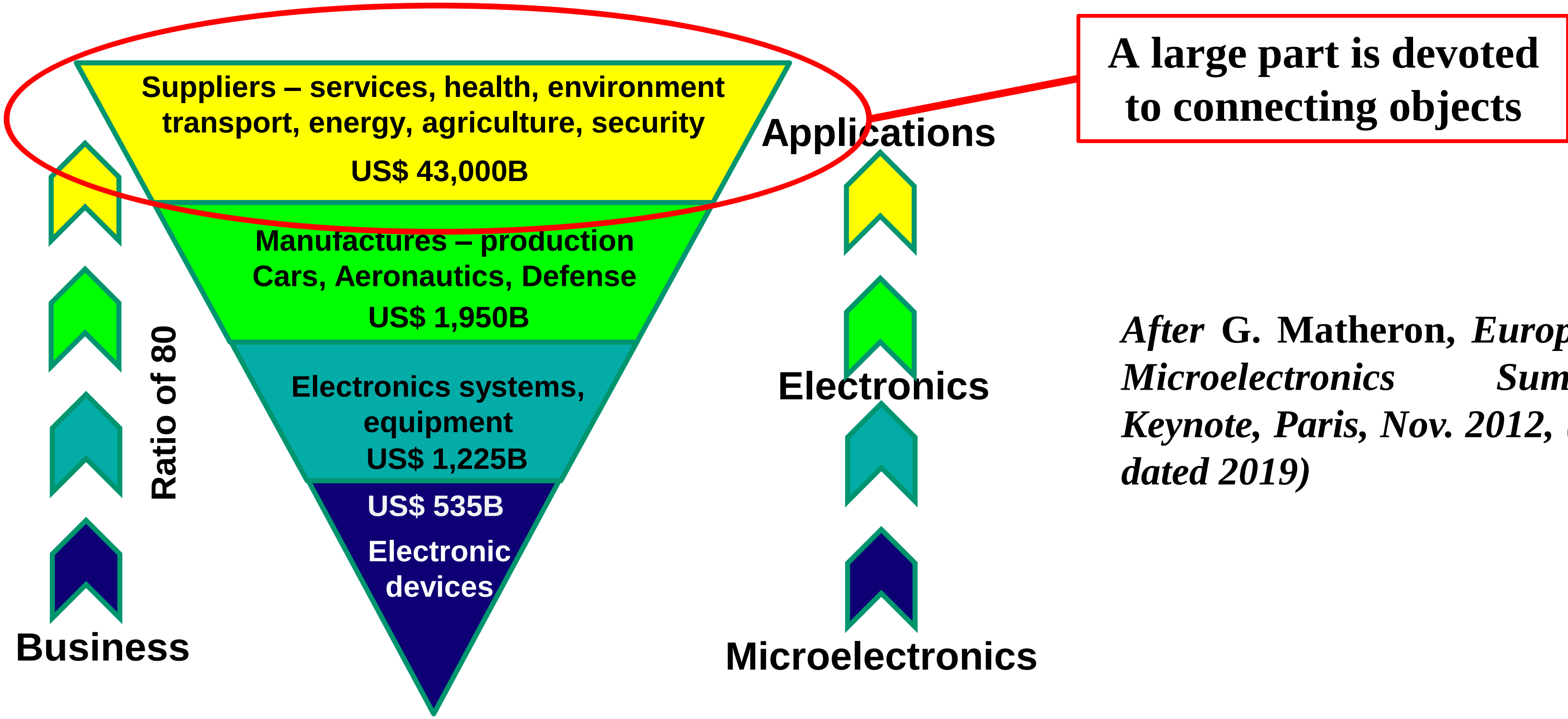




Exponential increasing activity that will need technical and scientific human resources

Consequence on the annual global activity

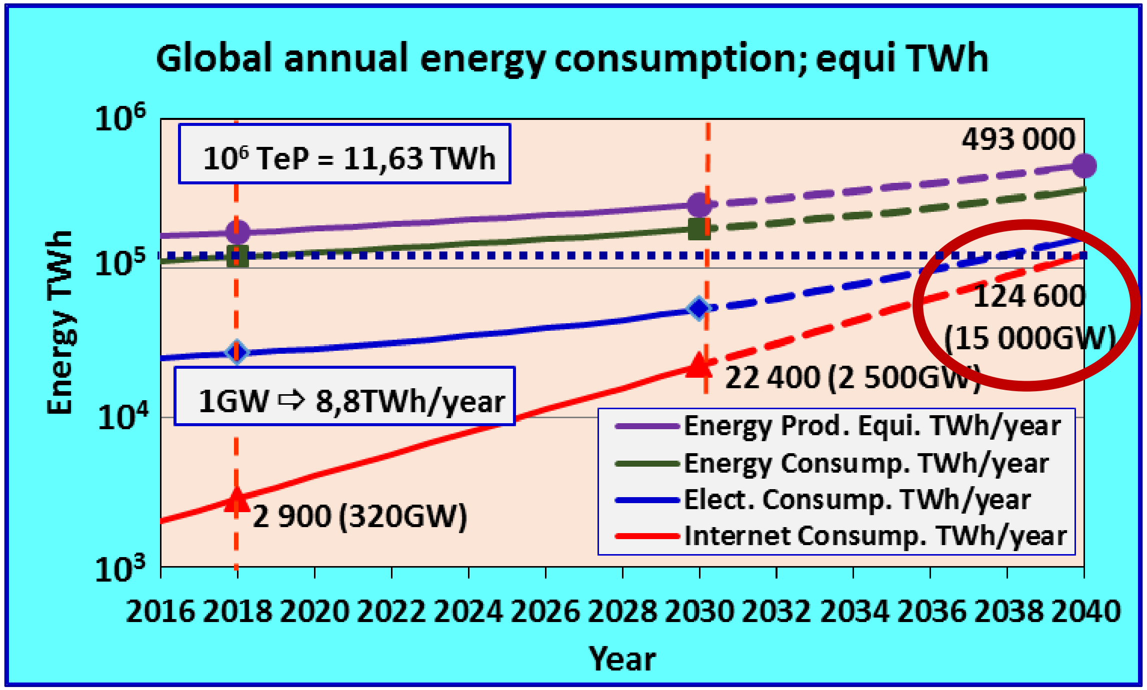
- Importance of the microelectronics activity **> US$ 470B /year**.
- Huge effect on the global economic activity **> US$ 43,000B /year**



After G. Matheron, *European Microelectronics Summit, Keynote, Paris, Nov. 2012, (up-dated 2019)*

Effect of IoT on global energy consumption

Several data:
A gigabyte of downloaded data consumes 5.12 kWh (1 DVD 25kWh!).
48% of this consumption comes from data centers (servers, routers),
38% of the end user (computer, smartphone),
14% of transport-communicatons (optic fibers, cables, switches, amplifiers).



IoT consumption equal to 2018 global ones

After O. Bonnaud, A. Bsiesy, *Proc. of ICATI'2019, Sapporo (Japan)*

Expected: exponential evolution of the IoT consumption !

Effect of IoT on global energy consumption

By 2018, IoT consumed 11% of the world's electricity (100 nuclear reactors).

By 2018, this consumption was equivalent to three times that of global air transport.

IoT consumption doubles every 4 years (Moore's law)!

By 2025, IoT will be the first source of pollution on the earth.

In 2040, IoT will represent the whole global energy consumption of 2018

This evolution arises new challenges:

- Improvement of the microelectronic technologies: division by 100 of the energy consumption of elementary devices and circuits!
- New concepts, new architectures of circuits and systems.
- New skills and know-how of the new graduate, engineers and PhD.
- Adaptation of the higher education content and of pedagogical approach.

Challenges for the next years

elementary devices

Decrease of the energy consumption at the level of elementary devices by decreasing:

- **the currents at on state at off state and their ratio,**
- **the leakage current by limitation of tunnel effects,**
- **the conduction sections (atomic scale),**
- **the supply voltage,**

Circuits Harvesting

Decrease of the energy consumption of circuits – new architecture by:

- **Controlling the standby of functions and modules (similarly to the brain),**
- **Involving increasingly the asynchronous architecture,**
- **Inserting local energy harvesting modules,**
- **the transmission, communication and storage losses,**
- **Minimizing the power electrical conversion and its transportation.**

Skills Know-how

Human resource challenges:

- **skills and know-how in microelectronics; highly-skilled specialists (know-how is mandatory for the specialists),**
- **multidisciplinary capabilities to meet societal needs**
- **an education and a practice training adapted.**

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The know-how of the engineers moves towards multidisciplinary approach

- The design of new architectures requires a lot of competences in modeling, simulation, VHDL, multi-physic simulations, and thus a **widening of the spectrum of knowledge**.
- The process steps combine many phenomena (chemical, physical, thermal, mechanical, electrical, optical, etc.), which implies an **increasing multidisciplinarity**.
- In terms of education, the difficulty comes from the **large diversity** of the knowledge and know-how. The graduate students must have a **good background** as well as some **specialized skills**.
- The **know-how training** is becoming a challenge for the higher education in the field.

Needs of a Microelectronics education network

A way to give the know-how to our students on shared platforms

- The proposed method consists of an intensive practice on dedicated platforms in initial education as well as in labworks, projects and internships. It is more and more difficult to give a proper and comprehensive education to these students.
- The software and hardware used in microelectronics and its applications are becoming so complex and expensive that the most realistic solution for practical training is to share facilities and human resources.
- This approach has been adopted by the French microelectronics education network, which includes 12 joint university centers and 2 industrial unions.

Pooling the practice in microelectronics:12 CNFM centers

12 CNFM interuniversity centers and 2 industrial bodies (ACSIEL, FIEEC)

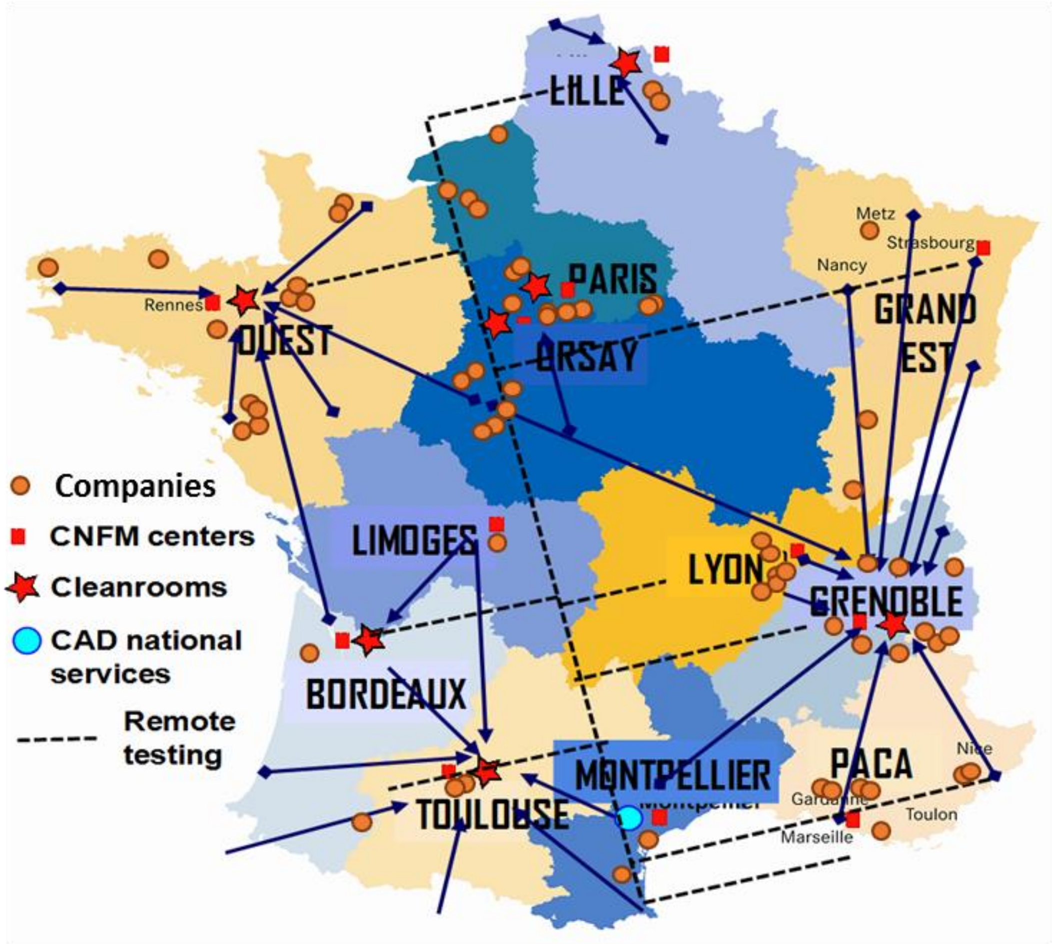
81 platforms among them 7 cleanrooms (100M€ total invest)

National CAD services for testing, software's, prototyping

16,000 students/year (950 PhD)
900,000 hours*students/year

The users:

- **93 Higher education institutions**
- **60 research laboratories**
- **many companies**



Mobility of students and partnership with industry

A way to give the know-how to our students on updated platforms

The innovative strategy consists :

- **to create new practice each year**
- **to be incentive for multidisciplinary subjects**

Each year, the network management organizes a call for innovative practices in the frame of GIP and FINMINA project that contains, obviously, the new fabrication process and design techniques.

The goal consists to create innovative practice on new platforms dedicated to the training on the new techniques and their applications.

In the following several examples of practice are given. They concern all the elements of connected objects including several technological challenges.

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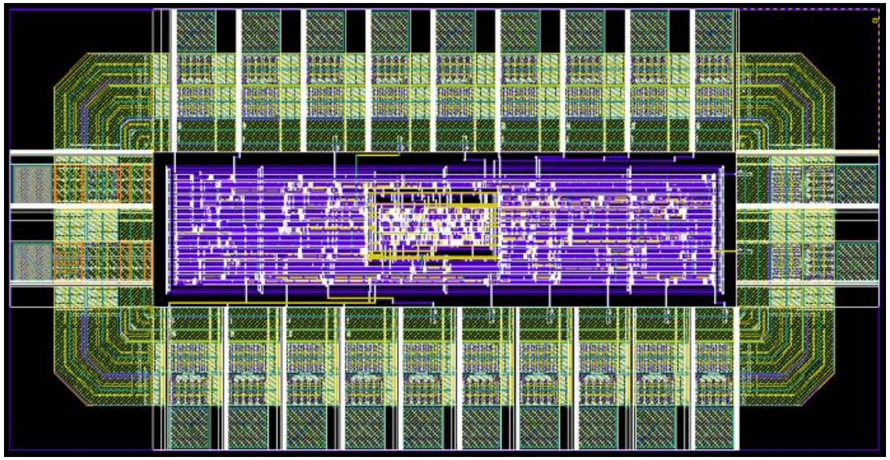
Signal processing

Computer-Aided-Design of Innovative devices

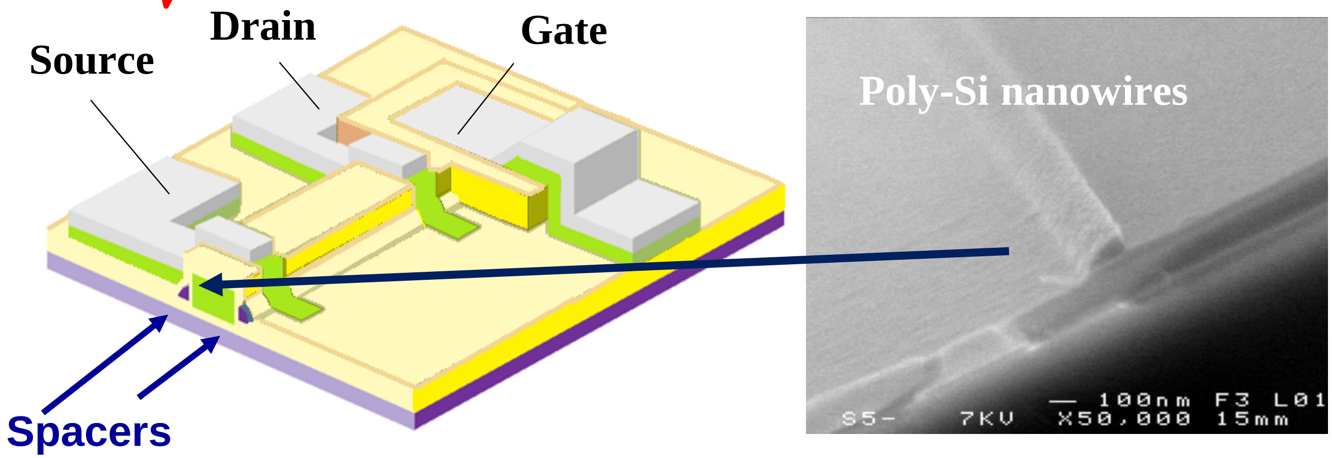


- **Cadence tools for designing digital/analog ULSI circuits (MultiChip Projects)**
- **Asynchronous circuits (lower energy consumption)**
- **Embedded electronics with FPGA (Intel-Altera/Xilinx)**

After **O. Bonnaud, L. Fesquet,** ***Proc. of IEEE Micro. Techno. Dev., 2014***

New devices

Innovative devices based on silicon nanowires



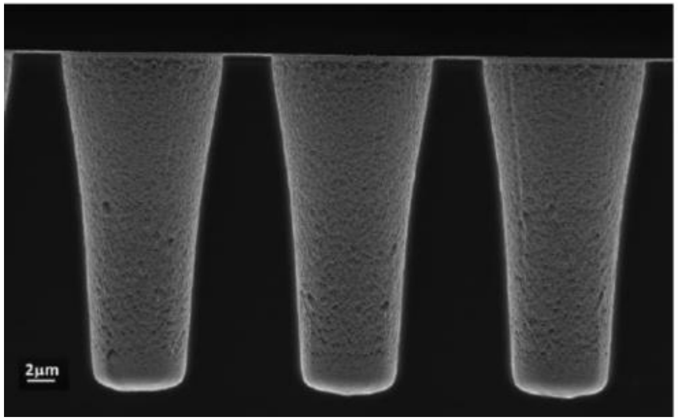
Silicon nanowire-based transistor at CNFM center of Rennes. The nanowires are fabricated through a spacer fabrication process: application to sensors.

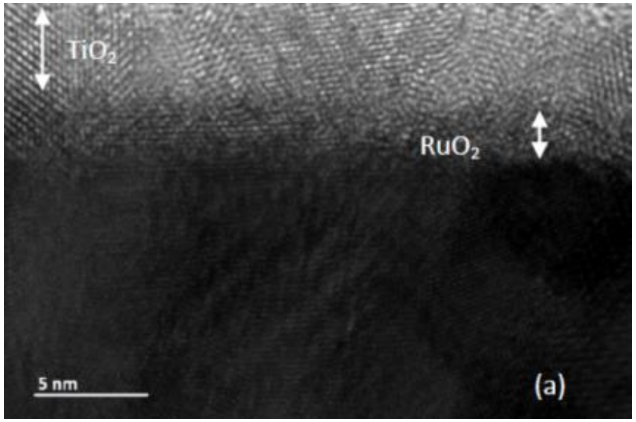
After L. Pichon *et al.,14th NAMIS Workshop, July 4-6, 2016*

New devices

Innovative memories based on thin films involving ALD

- **MIM (metal/insulator/metal) memories for very large scale integration involving very thin film technologies. Practice developed at Grenoble CNFM center.**





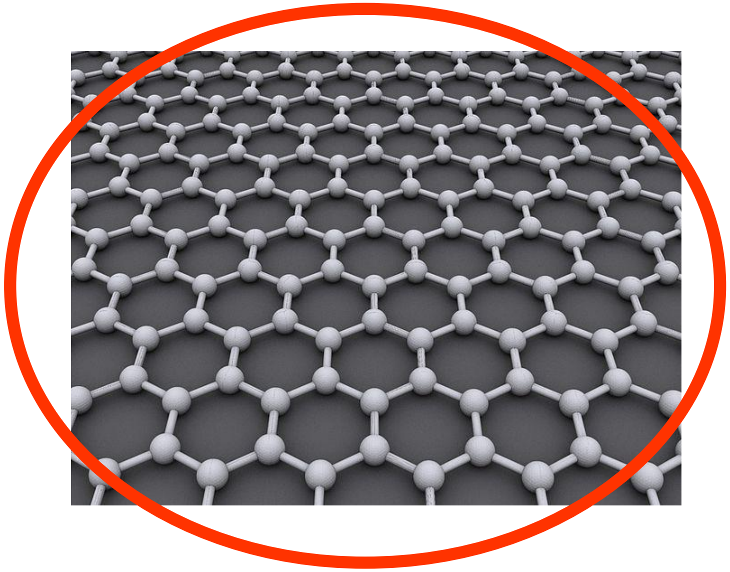
- **This training enables students to work in cleanrooms, to have ALD experience and analyze the nano-structure of films.**

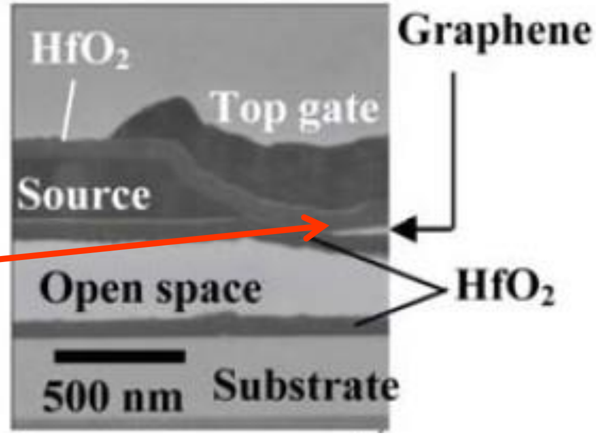
After **A. Chaker** ***et al., Appl. Phys. Lett., 110, 243501 (2017)***

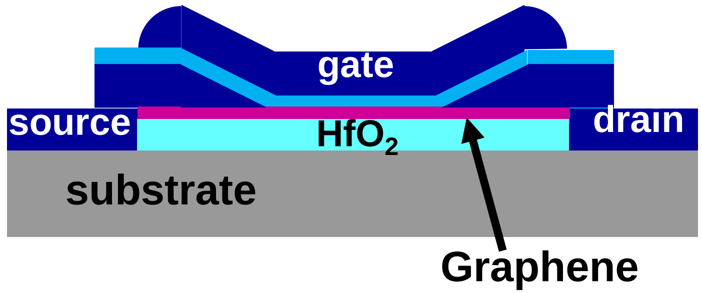
New devices

Innovative practice on graphene thin films

After University of Manchester
A. Geim, K. Novoselov 2004





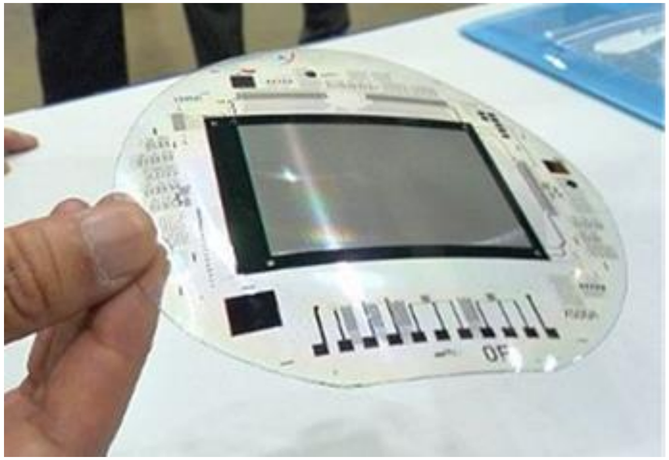


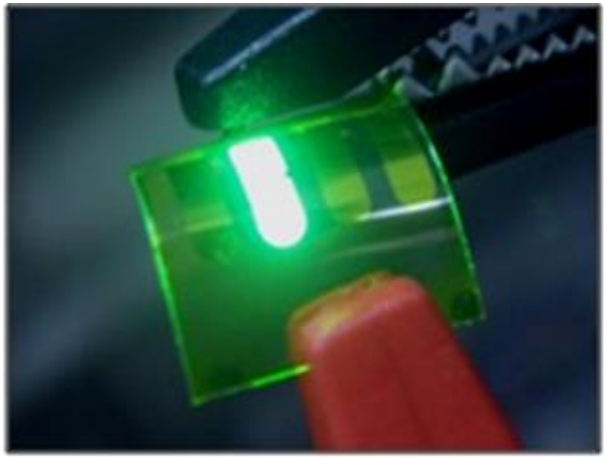
Graphene based devices, nanometric 2D material; students learn the transfer of 2D-materials - practice at CNFM center of Lille.

After H. Happy *et al., ENOVA, 2014*

New processes

Innovation in displays and flexible electronics





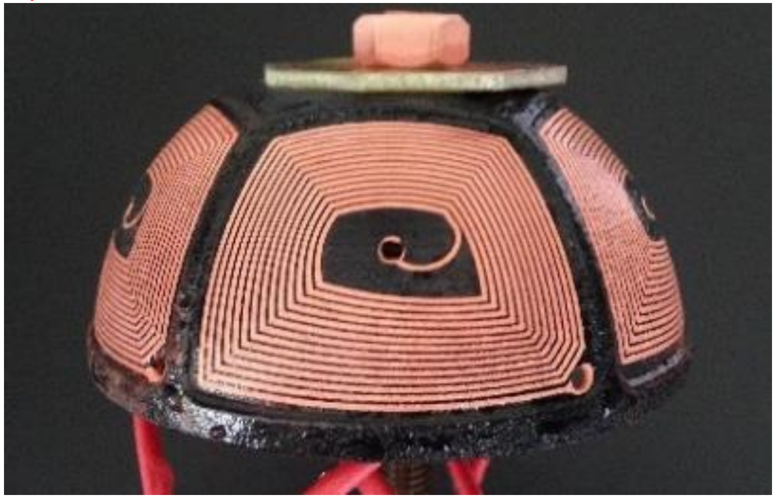
After **S. Janfaoui,** ***et al., Solid State Electronic, vol.93, n°3, pp.1-7 (2014)***

After **G. Gruntz** ***et al., IMS Bordeaux document (2012)***

Flexible electronics fabricated by students in the CNFM centers of Rennes and Bordeaux.

New processes

Innovation in plastronics electronics



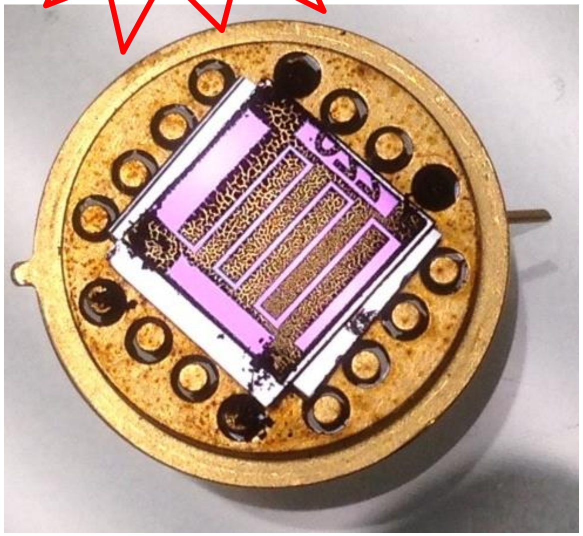
After Ph. Lombard *et al., J3eA, Vol 16, 1013, 13 pages (2017)*

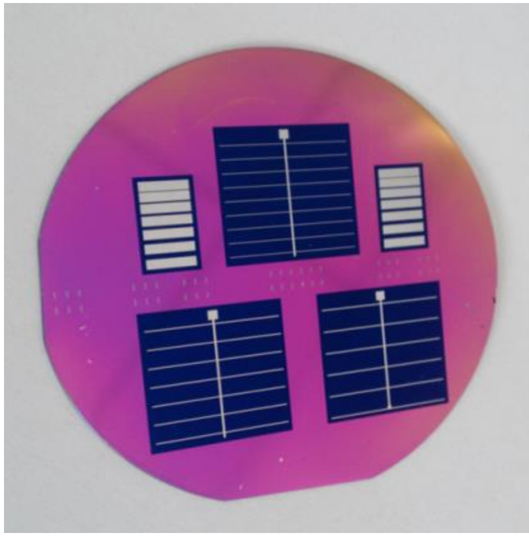
After Ph. Lombard *et al, J3eA 2019, to be published*

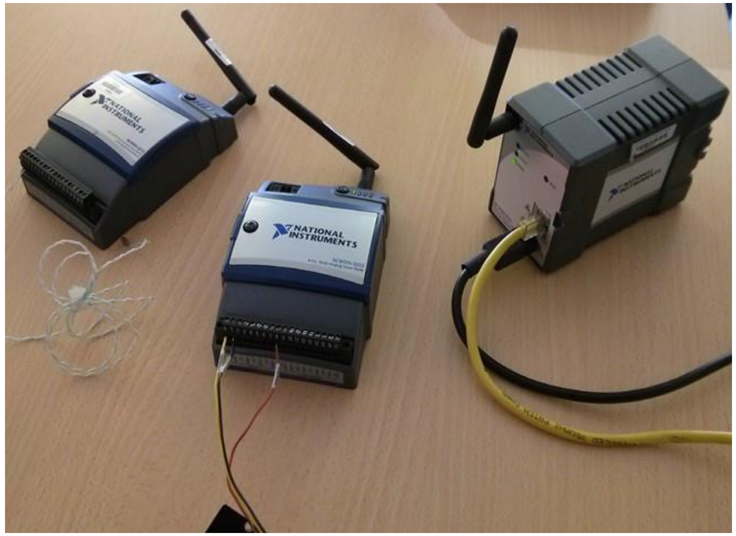
Plastronics devices fabricated by students in the CNFM center of Lyon.

Energy harvesting

Innovative projects on energy applications







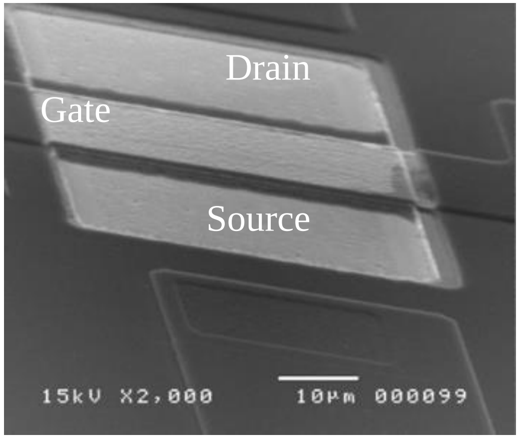
- **Micro-super-capacities** **fabricated and characterized by the "engineer" students in the clean-room of the CNFM center of Toulouse**
- **Solar cells** **fabricated and characterized by the "engineer" students in the clean-room of the CNFM center of Grenoble**
- **Building energy monitoring connected circuits, designed and fabricated by engineer students in the PACA center (Nice)**

Sensors
SoC/SiP

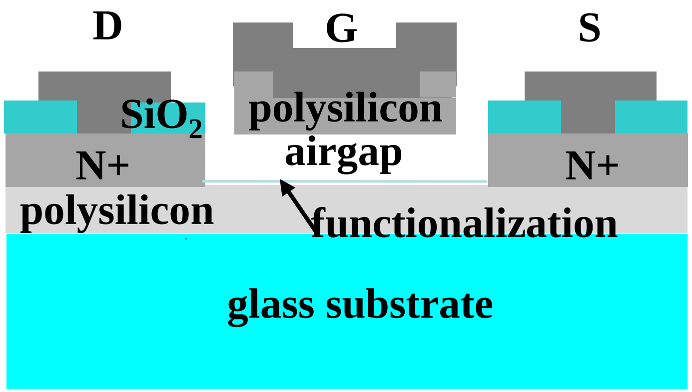
Innovative projects for chemical and biological sensors

Generic structure issued of research activities of Rennes CNFM center.

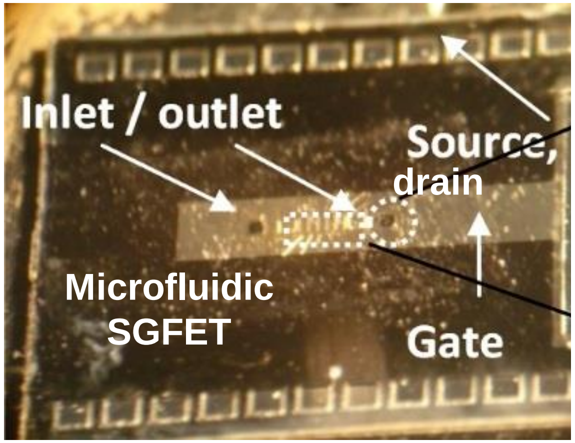
- **The structure is based on TFT technology with suspended gate (airgap design).**
- **Lab-on-Chip with microfluidics is developed.**



TFT



ULSI (SIP)



After **H. Mahfoz-Kotb, *et al., IEEE ED Let., 24(3), pp.165-167 (2003)***

After **I. Bouhadda *et al., Microsystem Technologies, Springer Verlag, 2015, 21 (1), pp.289-294.***

Connected objects

Innovative projects on connected objects

- **Drone designed and built by students at master (engineer) level**
- **A project that can be attractive and that can aware the students on connecting objects.**

After **O. Bonnaud, L. Fesquet,** *Proc. SBMicro 2013 978-1-4799-0516-4*

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Common challenges of TFT and ULSI technologies

- During 40 years, the development of French microelectronics followed the increasing of the performance of microelectronic circuits as well in integrated technologies as in thin film's ones.
- The need of specialists has transformed the Higher education landscape with the creation of academic microelectronics centers devoted to Higher education in this field that might give the knowledge and the know-how to the future actors.
- The advent of new technologies with a huge development (including IoT) creates new challenges for both scientific (performances, consumption) and education (new skills and know-how) aspects.
- This strategy needed also a permanent up-dating of the activities that are oriented today towards innovation and the future societal challenges.
- Thanks to strong links between education and industry in the frame of the national network, the strategy based on the innovation and on the multidisciplinary know-how seems to be well engaged and ready to overcome the global challenges.

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Thank you for your attention

The end