UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes

FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

ACADEMIA SCIENTIARUM EUROPAEA EUROPEAN ACADEMY OF SCIENCES

CENIMAT CENTRO DE INVESTIGAÇÃO DE MATERIAIS | i3N INSTITUTO DE NANOESTRUTURAS, NANOMODELAÇÃO E NANOFABRICAÇÃO INVESTIGAÇÃO, INOVAÇÃO E APLICAÇÕES DE ENGENHARIA

Electronic Materials for Shaping the Future with Responsibility

Rodrigo Martins, L. Pereira, P. Barquinha, E. Fortunato
Univ. NOVA de Lisboa – FCT
President of the European Academy of Sciences

SicT. Summer school on Sustainable ICT

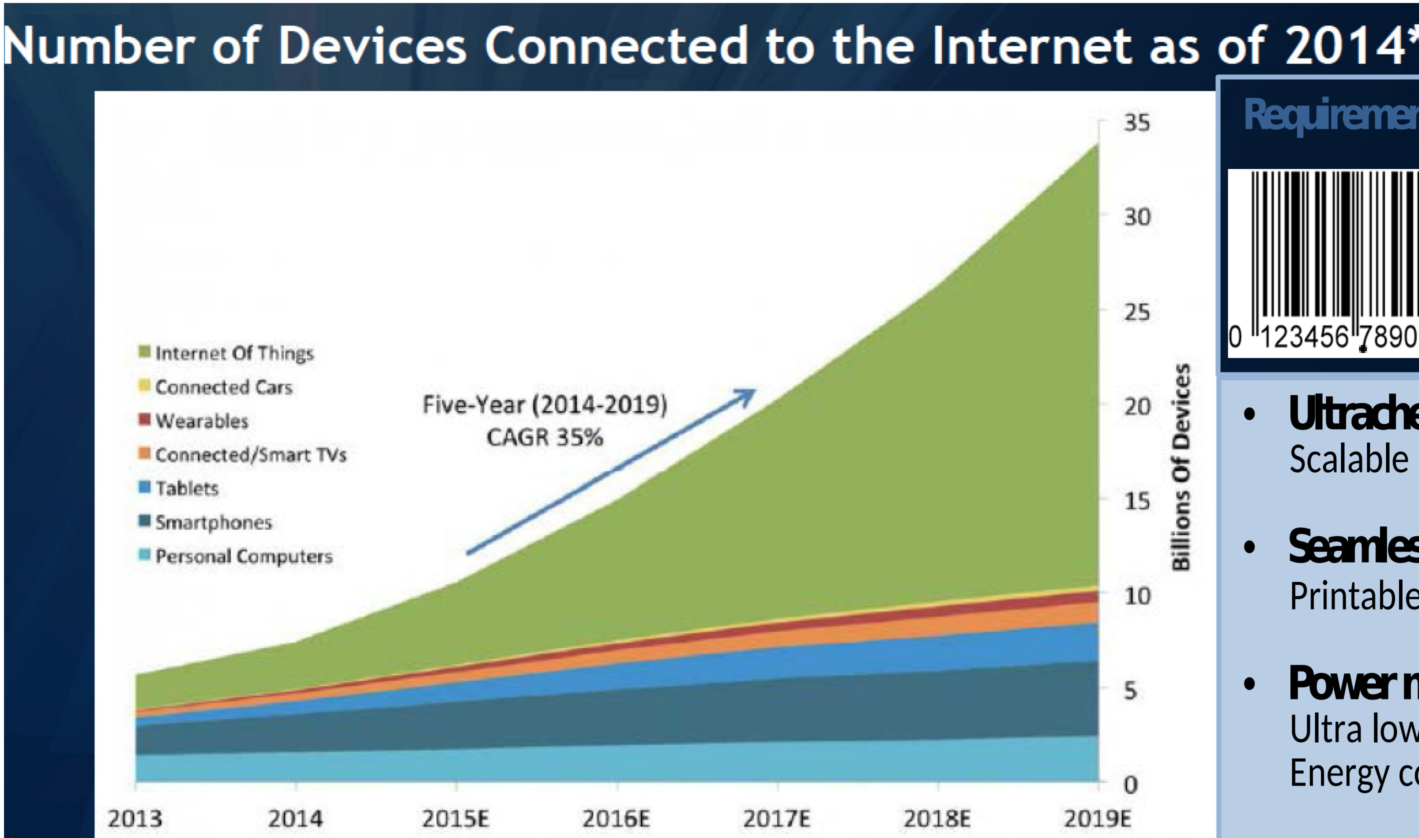
September 7th (Mon) - 11th (Fri), 2020, Louvain-la-Neuve, Belgium

General Outline

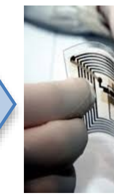
- Challenges
- Alternative Materials for Electronics
- The Missions and Metro Station Concept
- OIxides
- Responsibility
- AlmaScience

Challenges Raised by the Internet of Things

Internet of Things Demands!



Requirements for Future Ubiquitous Elec



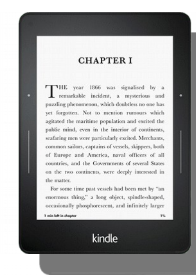
- **Ultracheap/disposable**
  Scalable production of electronic inks
- **Seamless integration**
  Printable flexible electronics
- **Power management**
  Ultra low power electronics/
  Energy conversion/storage
- **Efficient wireless communication**
  High speed electronics/
  New devices for WIFI

Smart World

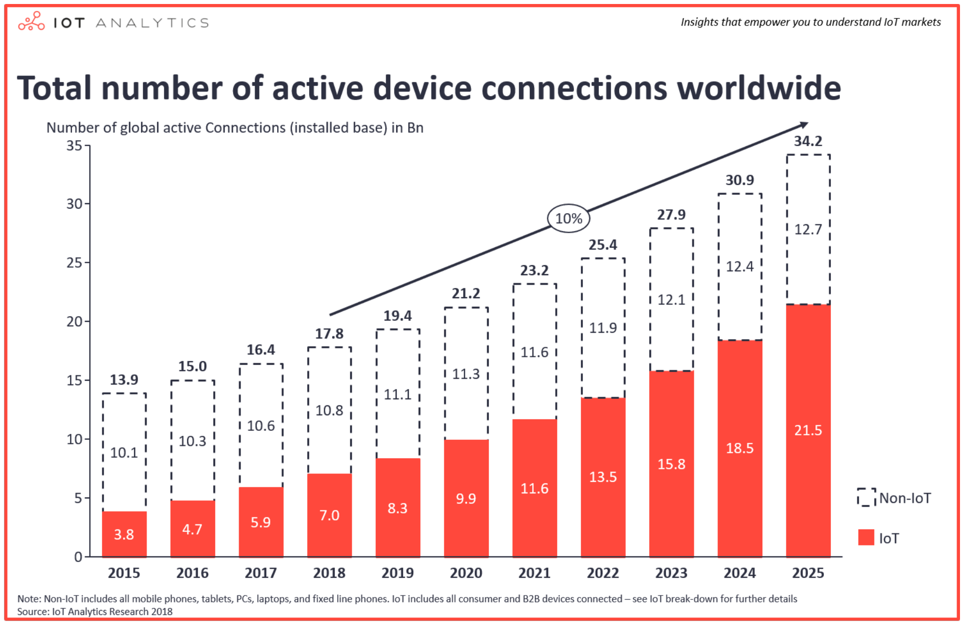
Everything connected with wireless

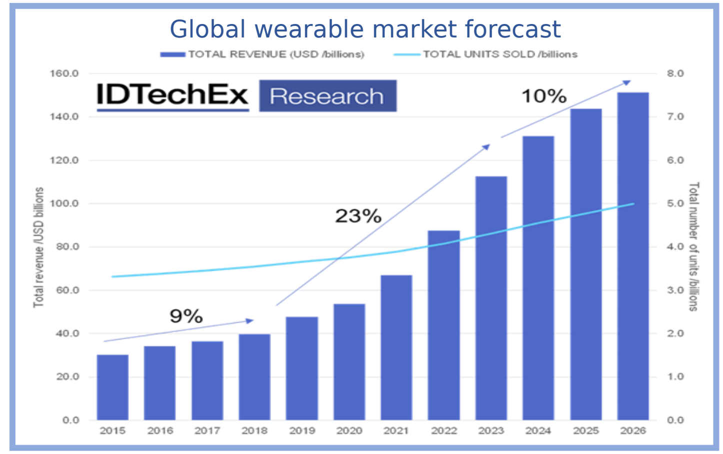
198
0

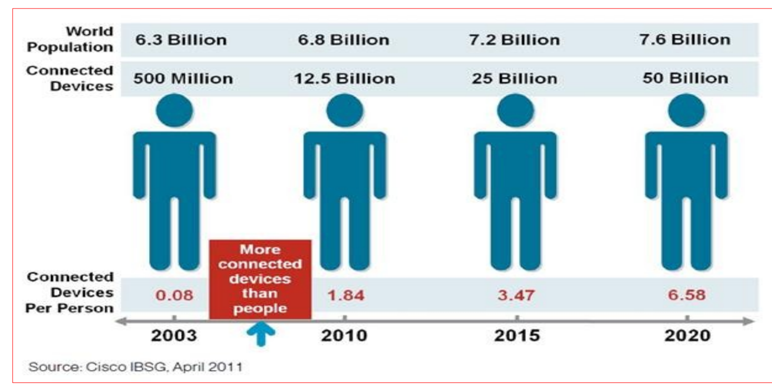
201
9



Current Scenario: Smart Devices and Wi-Fi







The smart cities market size to grow from US$ 308.0 bn in 2018 to US$ 717.2 bn by 2023, at a Compound Annual Growth Rate (CAGR) of 18.4% during the forecast period.

In 2020, the number of connected devices per person is expected to be 6.58

The Challenges for a Better Life

The e-papers

UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes

FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

CENIMAT i3N

Changes of Paradigm: Mobile Revolution!

At the trains/Metro!

Before ...

Today!

Changes of Paradigm: Mobile Revolution!

At the restaurants!

Before ...

Today!

The Interfaces Evolution for a Better Life

Analog → Digital

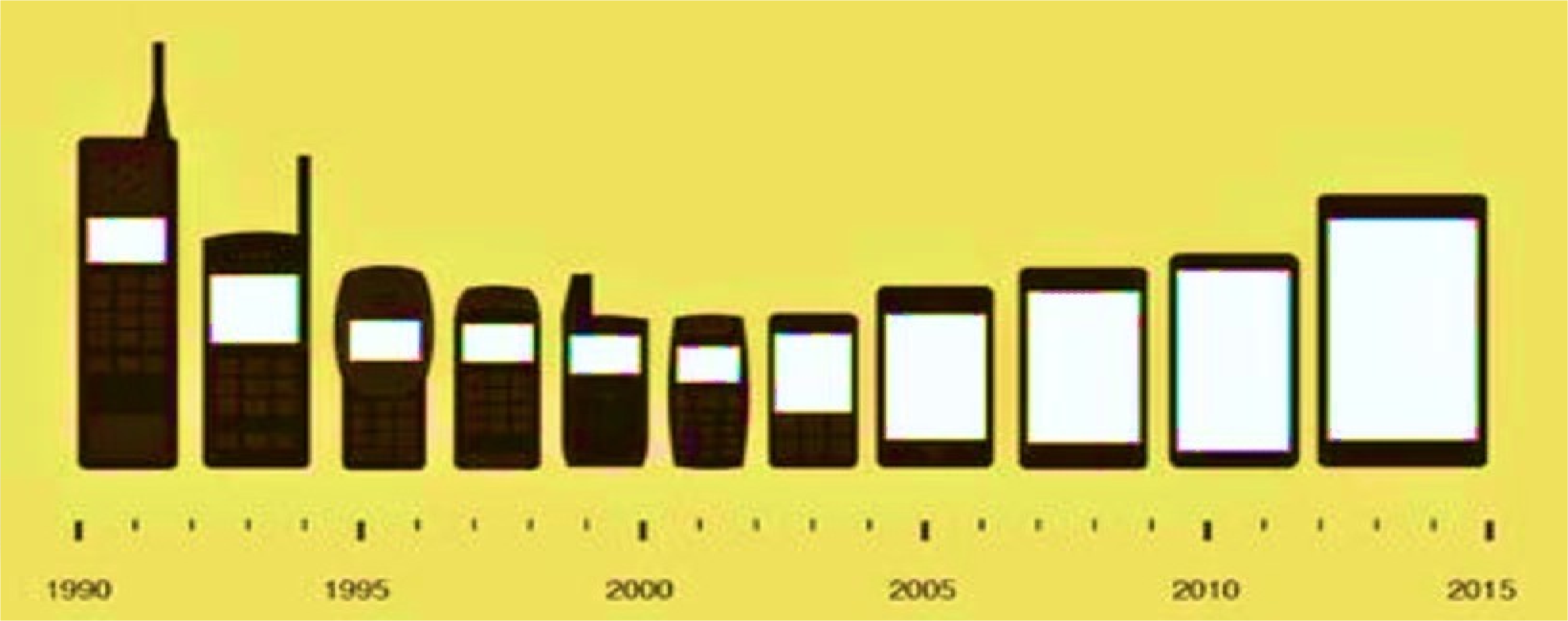
Feature displays → Smart displays

Big Data
Flexible Devices
IoT
Cloud
Touch Screen
Convergence
Wearable Devices

1990's — 2000's — Near Future

Mobile phones evolution

The display!



UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes

FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

CENIMAT i3N

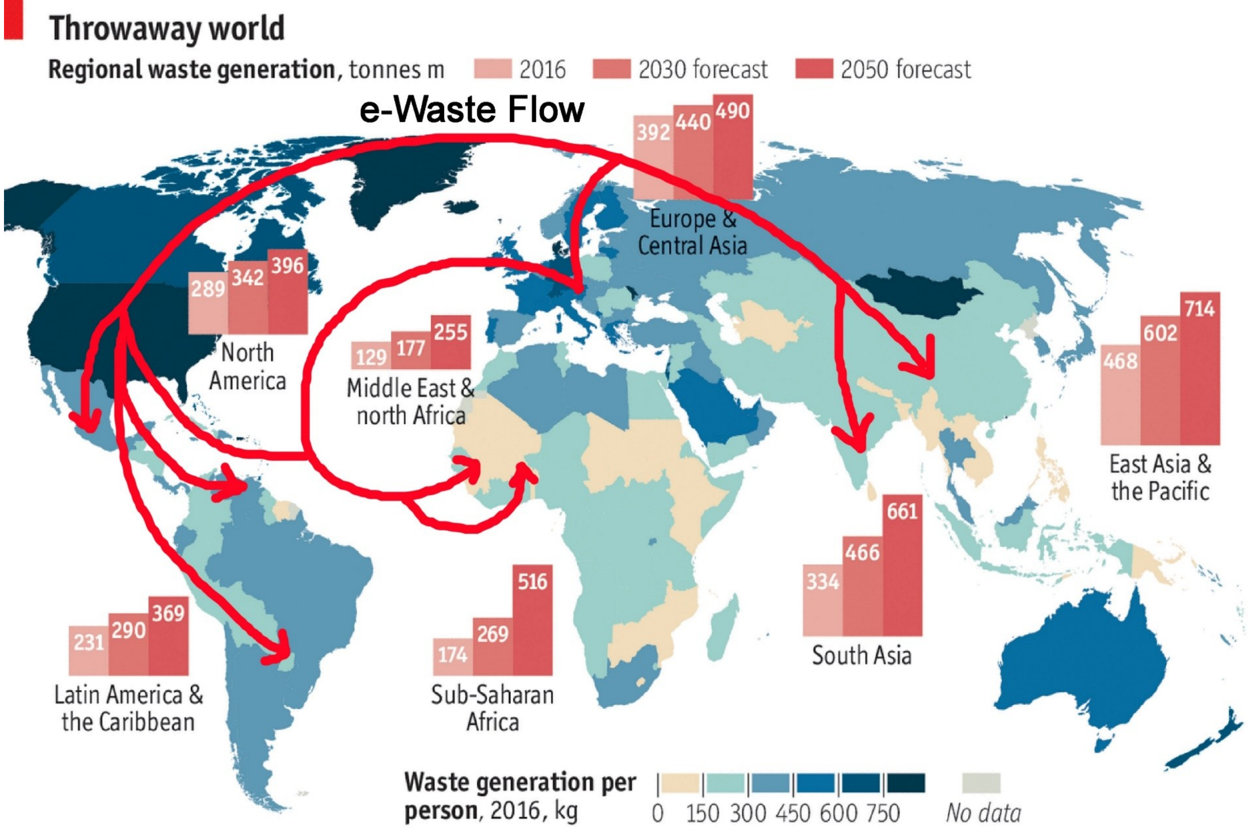
The Commodities for our Comfort

The Massification of Electronics


Alternative electronics is needed because ...

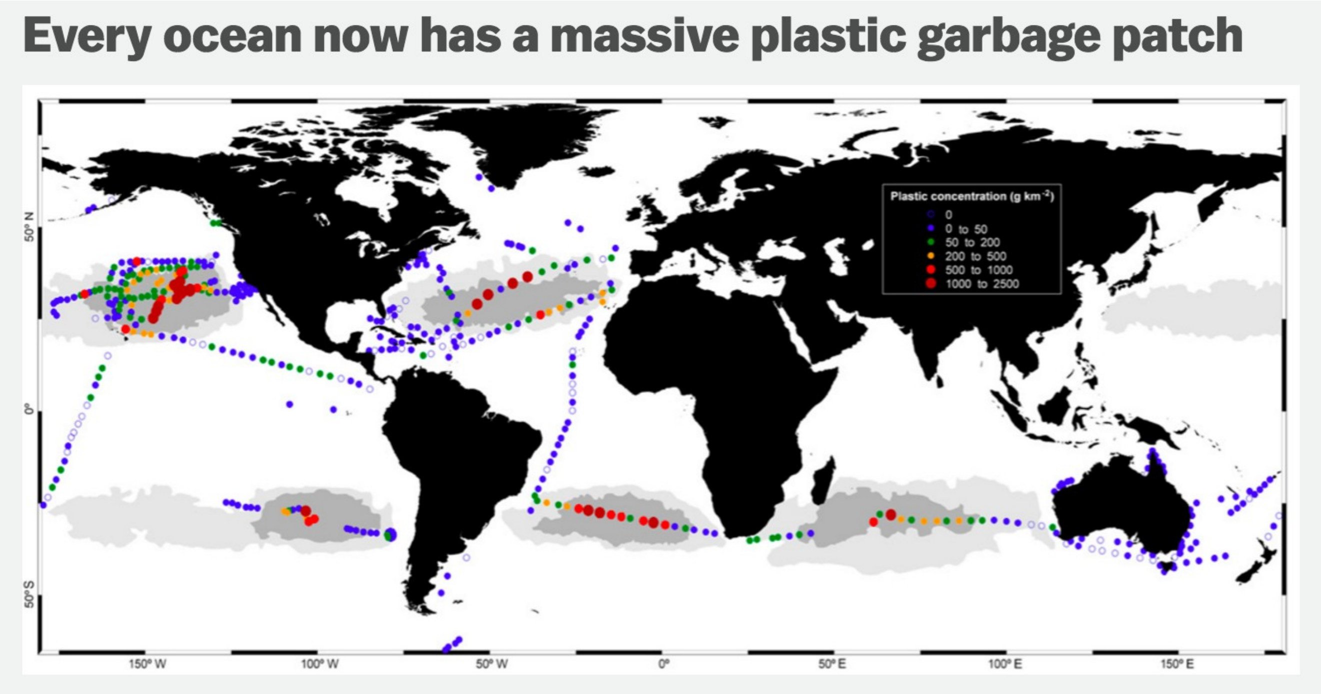
e-WASTE flow throughout the world....

Clean world f
futur



@ The Economist

We dump 8 million tons of plastic into the ocean each year. Where does it all go?



Concentrations of plastic debris in surface waters of the global ocean. Colored circles indicate mass concentrations

The Strategy to be Followed

◆ **Complexity:**

Move from Integrated circuits to functions

◆ **Energy**

Move from single to integrated systems

◆ **Green Materials:**

Abundant (non toxic) materials

◆ **Green Technologies:**

Simple and low energy processes

Visión

...and to continue this journey we need to invest our knowledge with choice in.....

Advanced Materials	Advanced Technology	Advanced Algorithms	Advanced Device Engineering

..but more than that our choice of vision should construct an eco-friendly society

Smart Green & Clean Technology

- Reducing environmental pollution
- Low-cost and affordable
- Low emission of CO_2
- Low-power consumption technology
- Minimising e-waste
- Reusable & Recyclable
- Reducing of hazardous materials
- Flexible

limate
e must do act

We have to creat a **SUSTAINABLE** & **GREEN** future adopting Green Technology....

CIRCULAR ECONOMY ...A different concept to move the planet in greener future

Re-thinking: Reducing-Reusing-Recycling....

GREEN and CLEAN technology:

Jsing more non-toxic, bio-compatable and bio-degradable materials.

Using low-cost and simple materials processing systems.

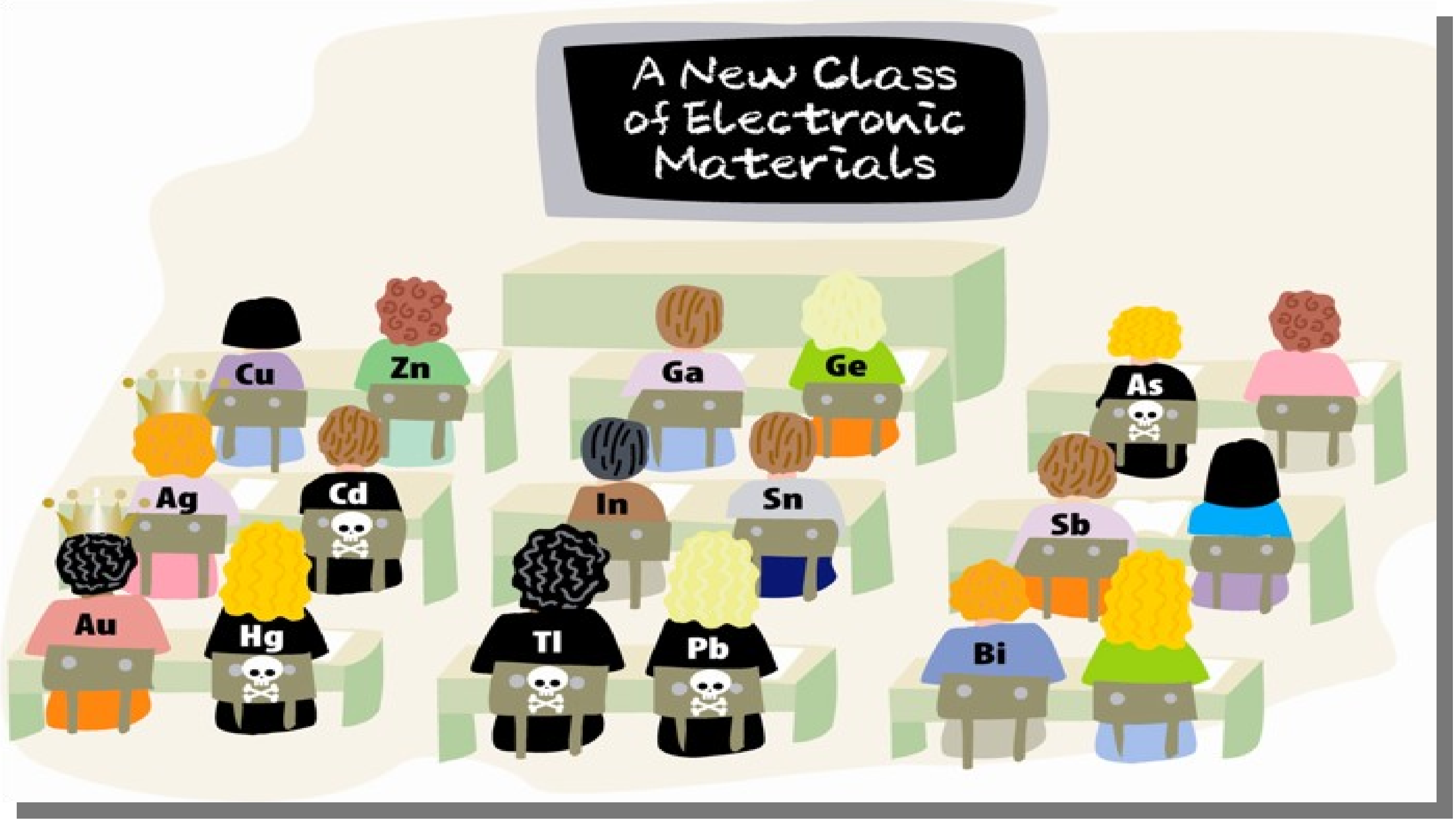
sing more and more flexible and nano- technology that will minimize the roduct size....so minimize the raw materials

- ✓ Packaging Strategy : Design new bio-degradable materials for packaging. Less packaging Less Garbage

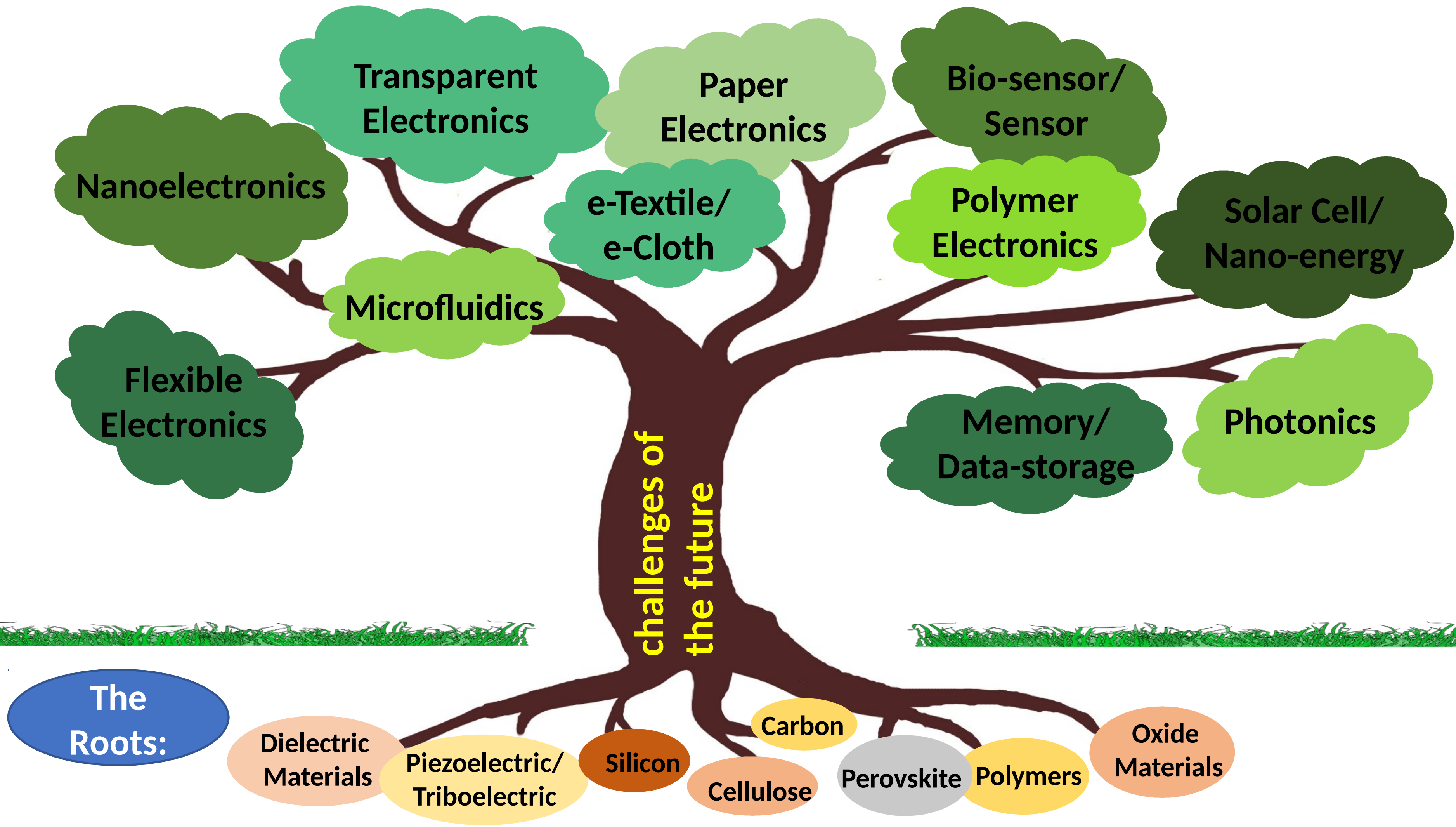
The specific vision of the research work should be to build effective cooperation between science and society, to materialize new smart technology for science and to pair scientific nobility with social awareness and responsibility.

Idea is to SEE the world through Sustainability-Environment-Economy

MATERIALS FOR A BETTER LIFE
MATCHING RECYCLABILITY AND SUSTAINABILITY



Materials for a Better Future

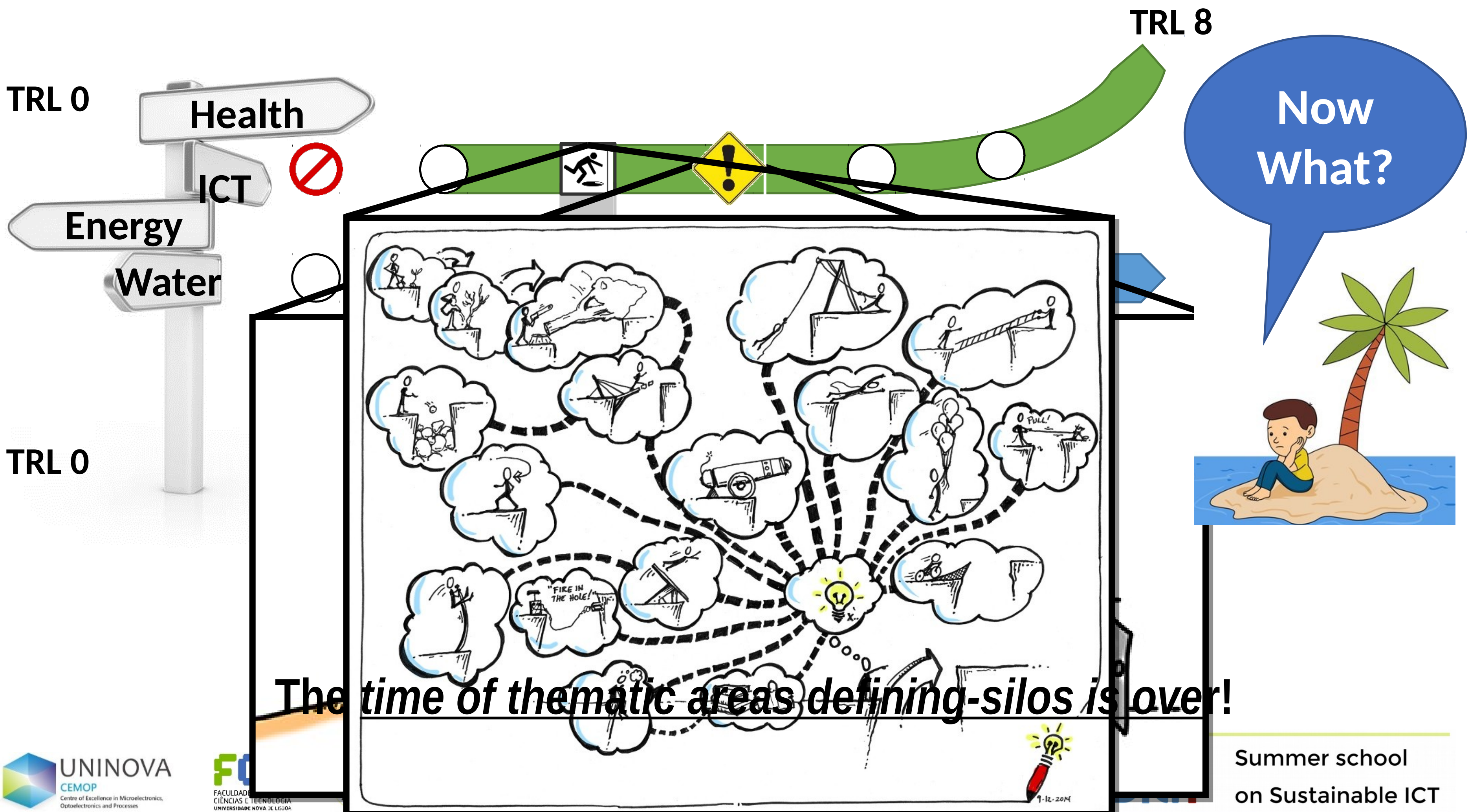


Summer school on Sustainable ICT

September 7th (Mon) - 11th (Fri), 2020, Louvain-la-Neuve, Belgium

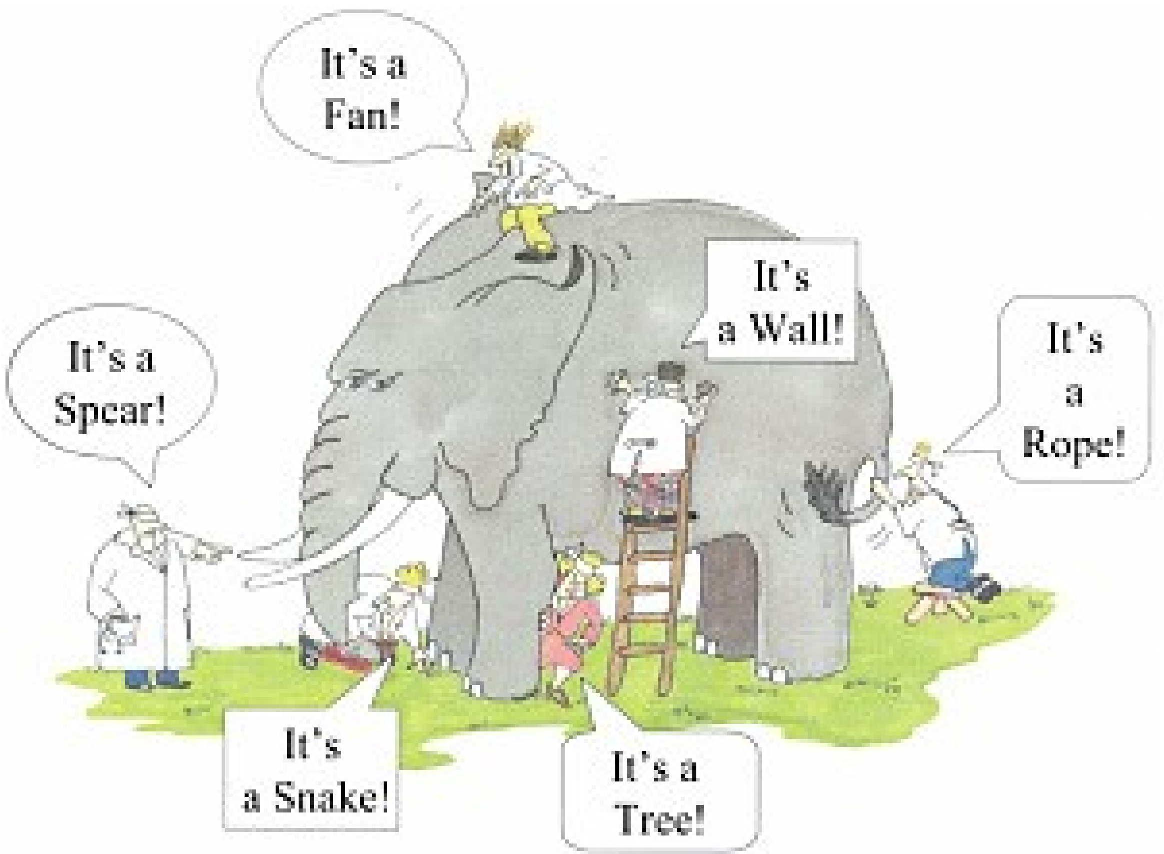
THE BOTTLENECKS OF THE SILOS

- **The road from idea to market is full of challenges and barriers.**
- **Independent and divergent R&D&I paths**



The time of thematic areas defining-silos is over!

The importance of Seeing the Big Picture!



The Mission must be dynamic, crosscutting lines and has... tro

Ene

ICT

Hea

Example:

Example:

Example:

Food: How to ensure a sustainable and safe feeding without waste? How to assure the food supply for an increasing population?

diagnosis and screening?

tions

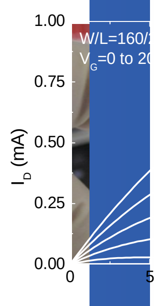
TRL 0

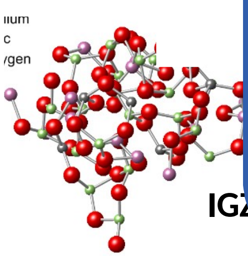
TRL 8

driving force of our development!

The success story of oxide thin-film transistors (TFTs)

From mat





IGZ

IEEE Spectrum, Vol.54, 7, 2017: Plotting a Moore's law for flexible electronics

NEWS

22

GENERATIONS OF MOORE'S LAW-LIKE DOUBLING NEEDED BEFORE THIN-FILM TRANSISTORS ARE AS DENSELY PACKED AS TODAY'S FASTEST GPUs AND FPGAs

PLOTTING A MOORE'S LAW FOR FLEXIBLE ELECTRONICS

At a meeting in midtown Manhattan, Kris Myny picks up what looks like an ordinary paper business card and, with little fanfare, holds it to his smartphone. The details of the card appear almost immediately on the screen inside a custom app.

It's a simple demonstration, but Myny thinks it heralds an exciting future for flexible circuitry. In January, he began a five-

NEAR FIELD COMMUNICATOR: There are 1,700 transistors on the flexible chip in this NFC transmitter.

22

GENERATIONS OF MOORE'S LAW-LIKE DOUBLING NEEDED BEFORE THIN-FILM TRANSISTORS ARE AS DENSELY PACKED AS TODAY'S FASTEST GPUs AND FPGAs

TFT integration starts being compared to MOS!

- Logic with 100k TFTs per cm^2
    - High freq, low power

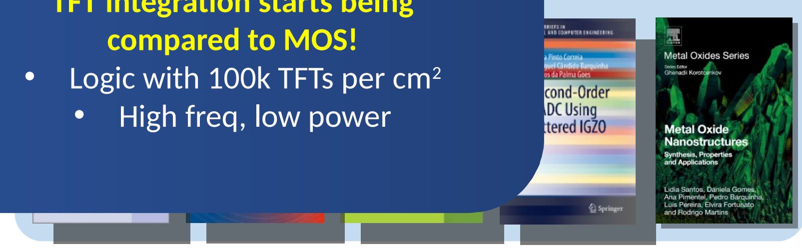
What else?

ing a-Si:H or poly-Si TFTs):

-area uniformity

ng T (polymer substrates)

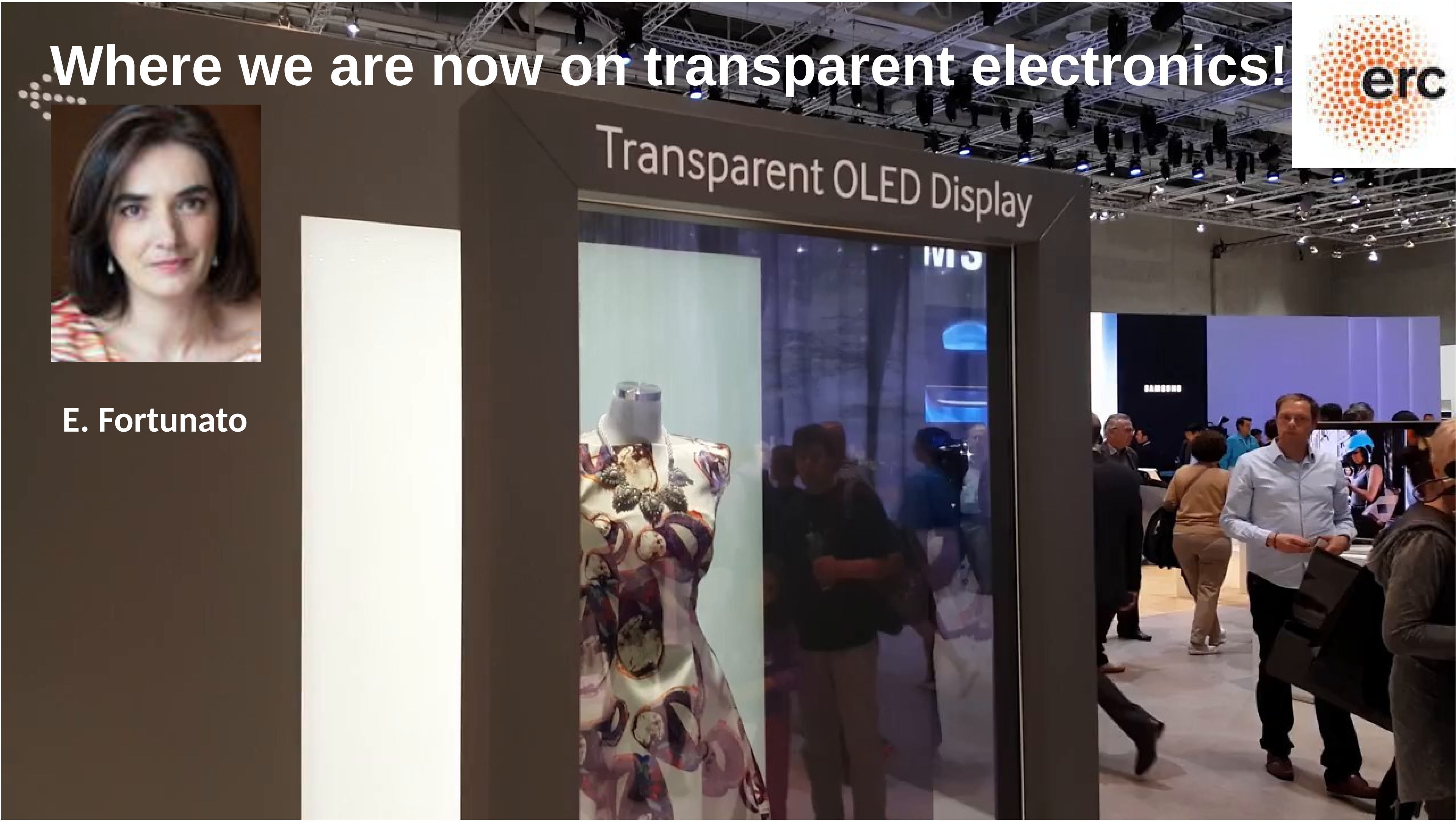
oxide electronics



How and where Transparent Electronics started in Europe!

Where we are now on transparent electronics!

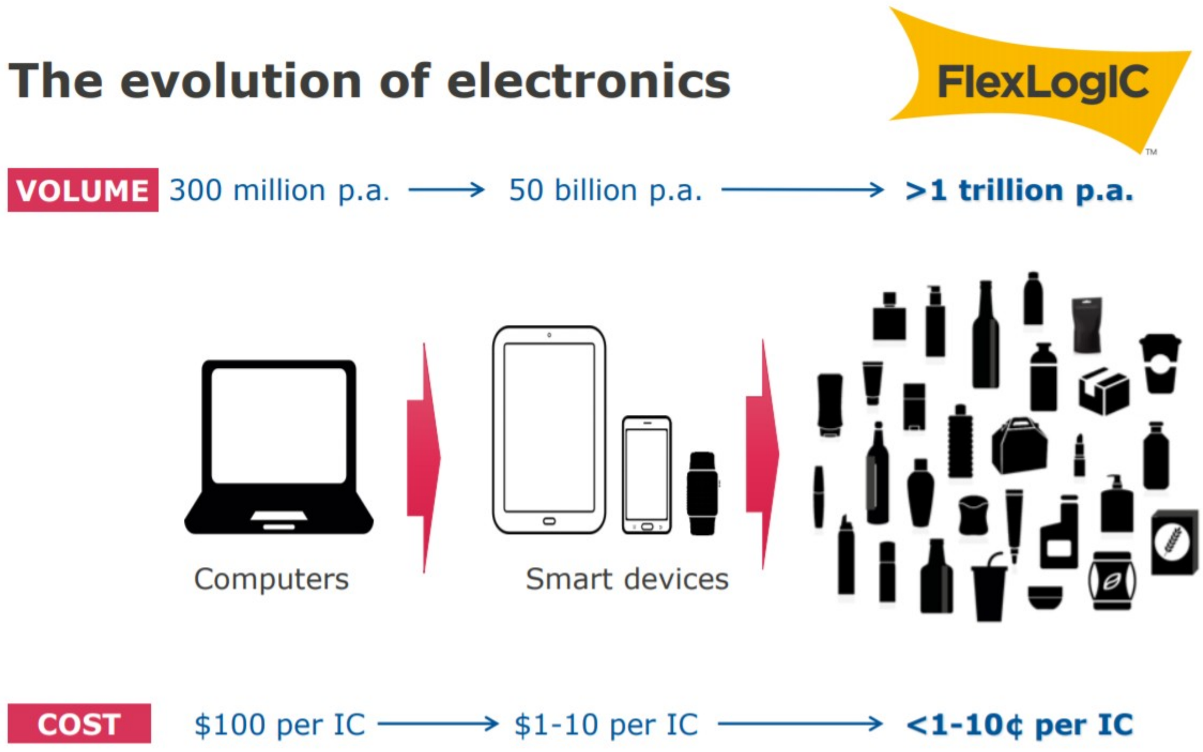
E. Fortunato



Flexible electronics: a golden opportunity for oxide TFTs

The emergent concept of thin film circuits: it's all about volume!

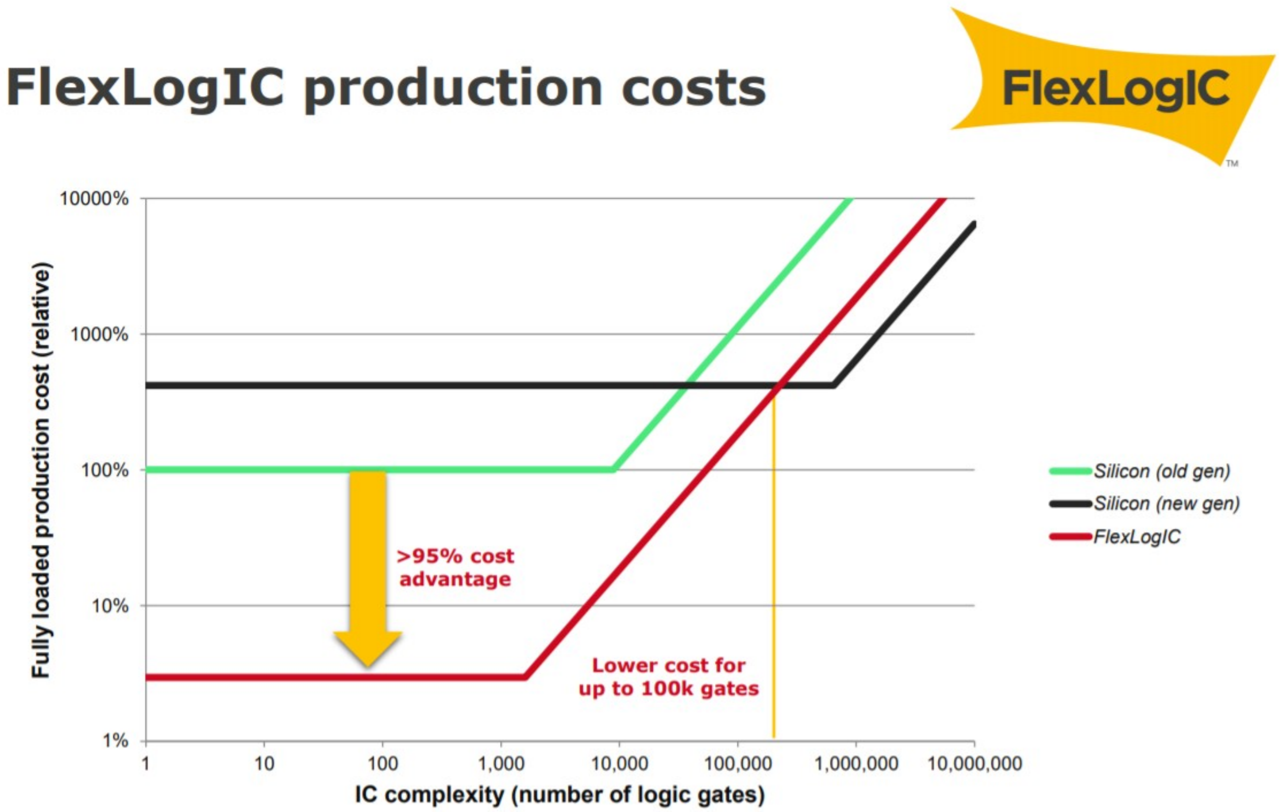
From www.pragmatic.tech



Flexible electronics: a golden opportunity for oxide TFTs

The emergent concept of thin film circuits: it's all about volume!

From www.pragmatic.tech

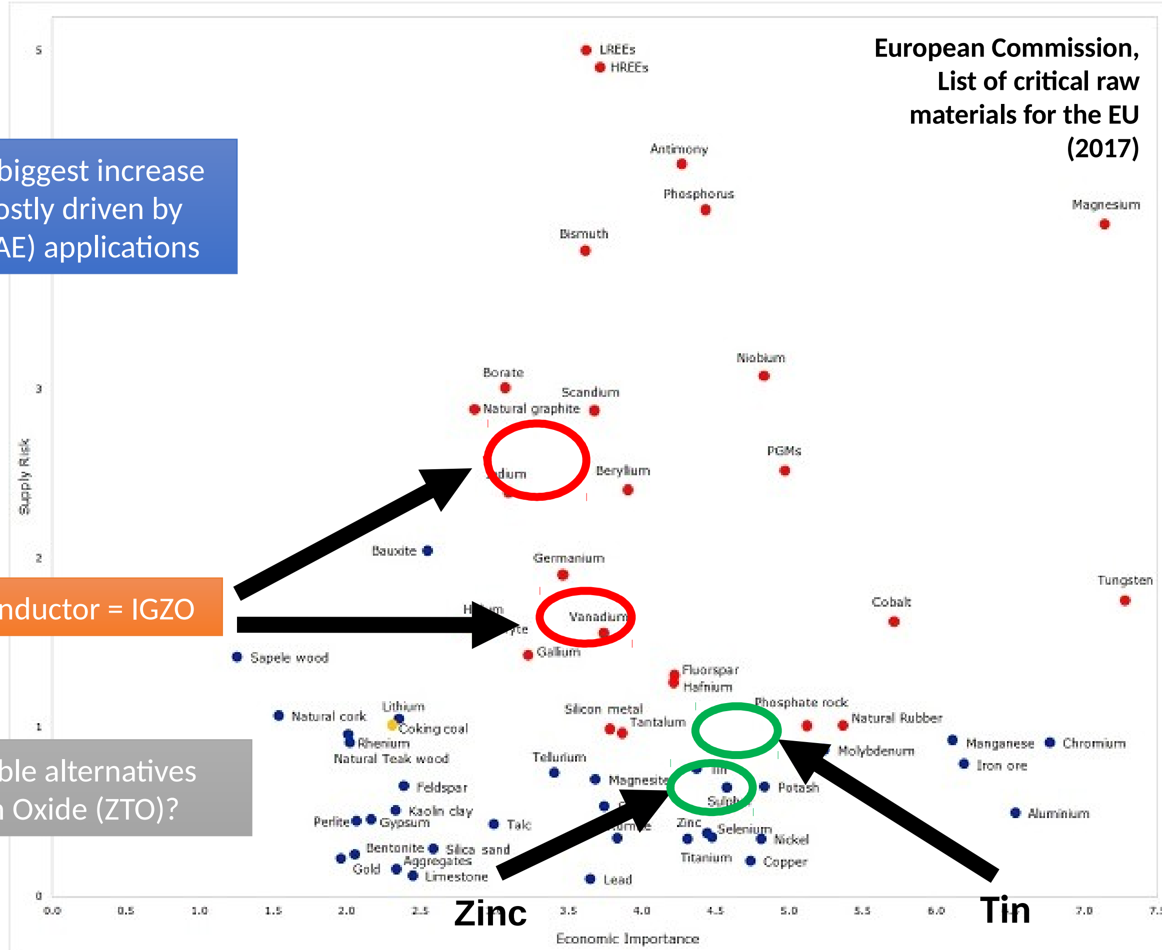


The need for sustainable approaches

Materials subject to the biggest increase in their demand are mostly driven by large area electronics (LAE) applications

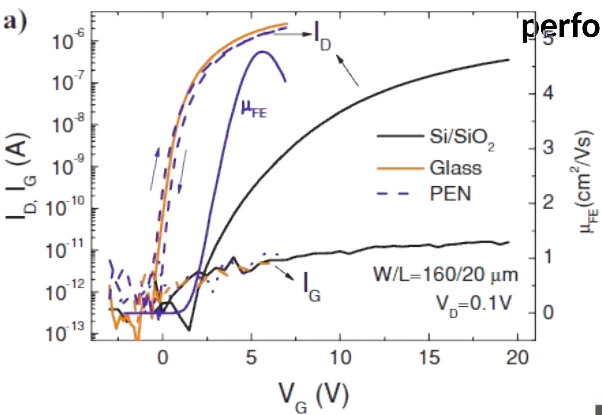
Oxide semiconductor = IGZO

Sustainable alternatives Zinc Tin Oxide (ZTO)?



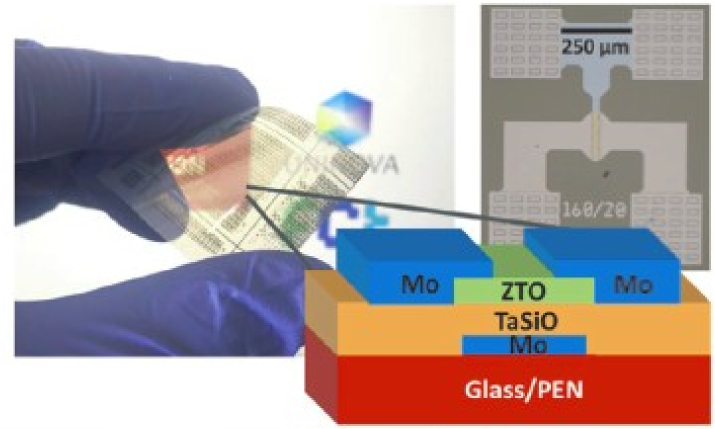
Flexible Zinc-tin oxide (ZTO) TFTs and circuits by sputtering

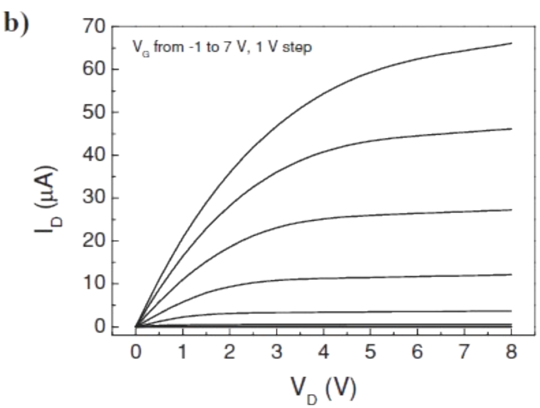
A sustainable oxide semiconductor @ 180 °C with performance comparable to IGZO!

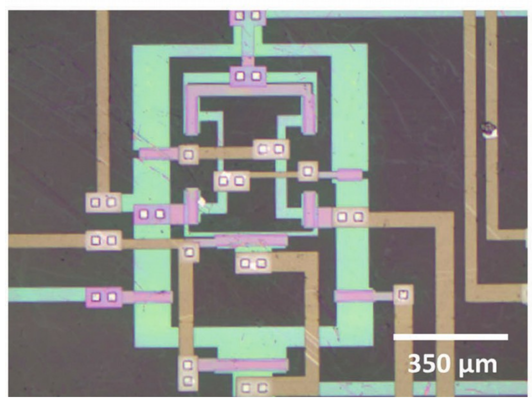


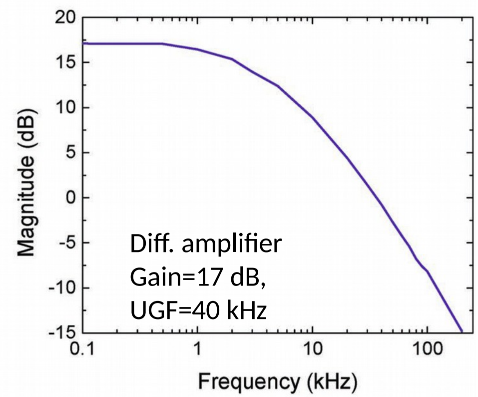
Performance on PEN:

- V_{on}=-0.19±0.03 V
- On/Off=5.2x10^6
- S=0.26±0.02 V/dec
- μ_{FE}=4.6±0.2 cm^2/Vs





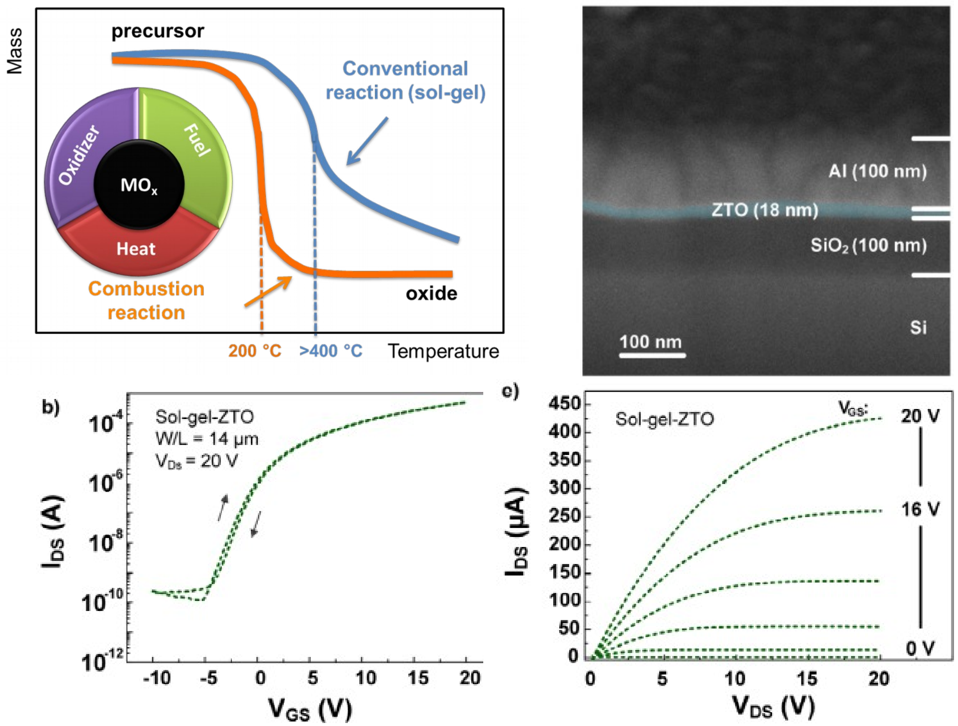




C. Fernandes et al, Adv. Electr. Mater. 2018, 1800032

ZTO TFTs by solution processing routes

- **Heading towards printed electronics, avoids lithography costs**
- **Combustion synthesis for lower-T solution processing**



<u>Spin-coated ZTO</u>

μ_{sat}=4-5 cm^2/Vs

On/Off>10^6

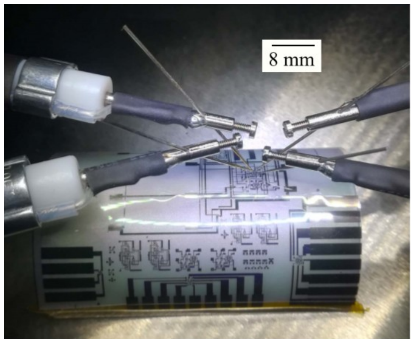
S≈0.25 V/dec

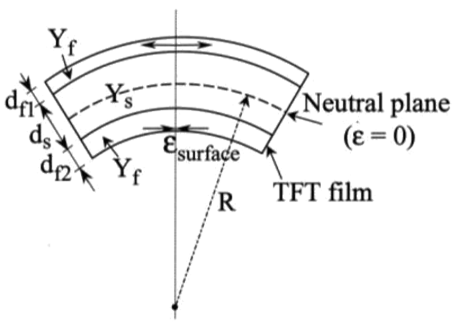
But required T still 250-350 °C

Salgueiro et al, J Phys D: Appl. Phys. **50** (2017)

Oxide TFTs can also be mechanically flexible!

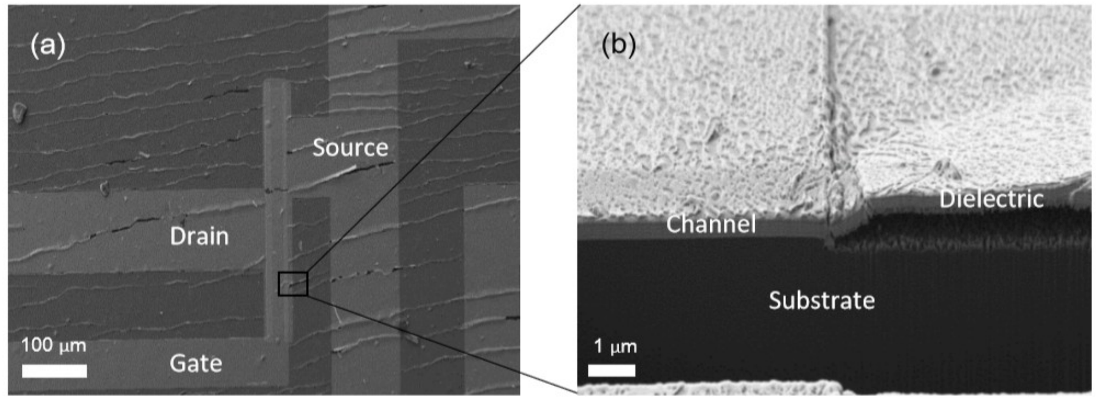
Flexible oxide TFTs can be taken to extreme flexibility (foldable) by placing transistors in a **neutral strain position** and/or using **ultrathin substrates**



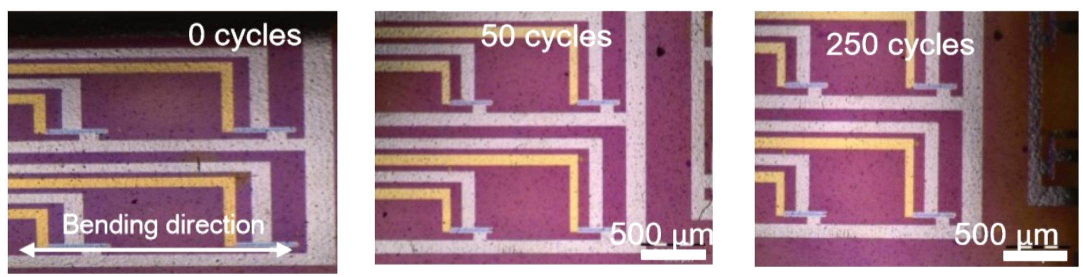


Magalhães *et al*, MSc thesis, FCT-NOVA + IKTS (2018)

Avoiding this…



250 cycles of tensile bending stress with r=1.25 mm, oxide TFTs on Kapton



Oxide TFTs on PEN foil as x-ray direct detectors

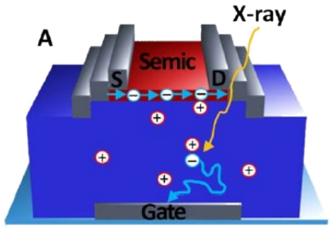
Cramer et al., Sci. Adv. 2018;4: eaat1
Cramer et al., Adv. Electron. Mater. 2016, 1500

SCIENCE ADVANCES | RESEARCH ARTICLE

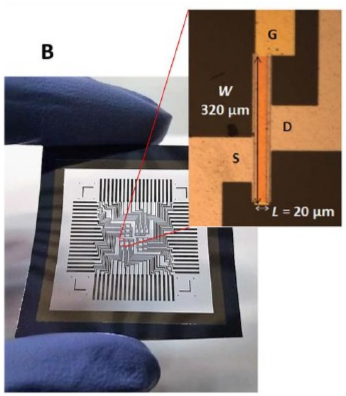
MATERIALS SCIENCE

Passive radiofrequency x-ray dosimeter tag based on flexible radiation-sensitive oxide field-effect transistor

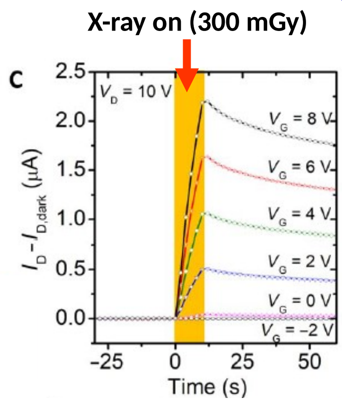
Tobias Cramer[1]*, Ilaria Fratelli[1], Pedro Barquinha[2], Ana Santa[2], Cristina Fernandes[2], Franck D'Annunzio[3], Christophe Loussert[3], Rodrigo Martins[2], Elvira Fortunato[2], Beatrice Fraboni[1]



Generation of trapped positive charge in the dielectric under x-rays. Negative carriers accumulating in the channel counterbalance the trapped positive charges

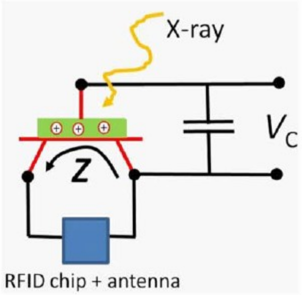


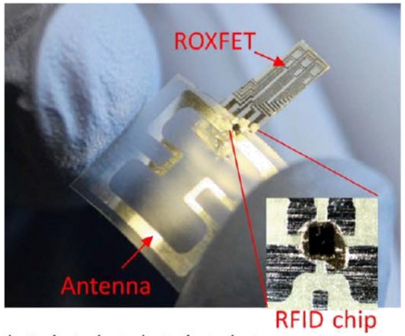
PEN foil with 36 ROXFETs

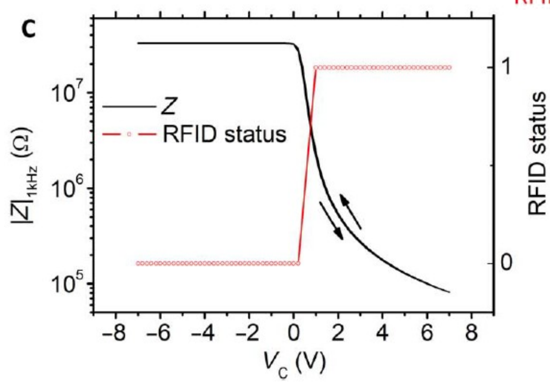


Variation of ROXFET drain current under x-rays, for different V_G

Programmable passive RFID radiation sensor based on ROXFET



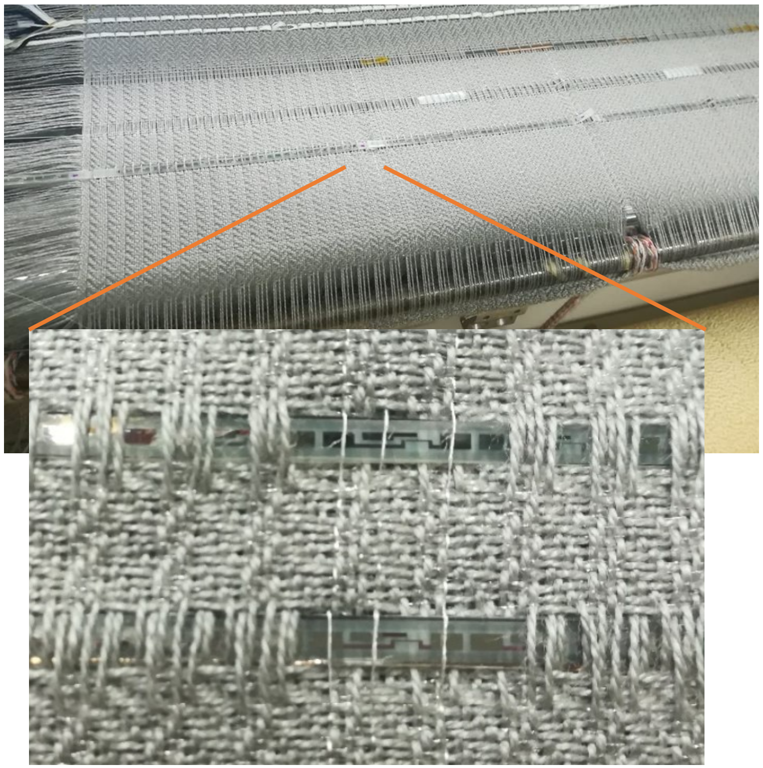


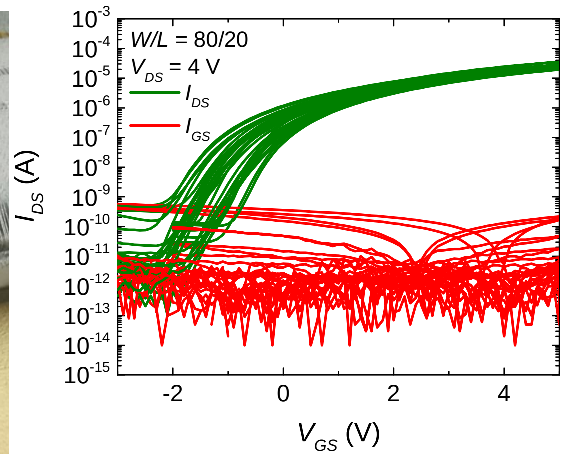


Oxide TFTs for electronic textiles

http://www.1d-neon.eu

Taking displays to all sorts of surfaces, including textiles

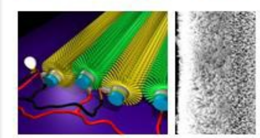




Oxide TFTs embedded in textiles

- Flexible polymeric stripes as substrates, under migration to extruded polymeric fibres
- Similar electrical performance to conventional oxide TFTs

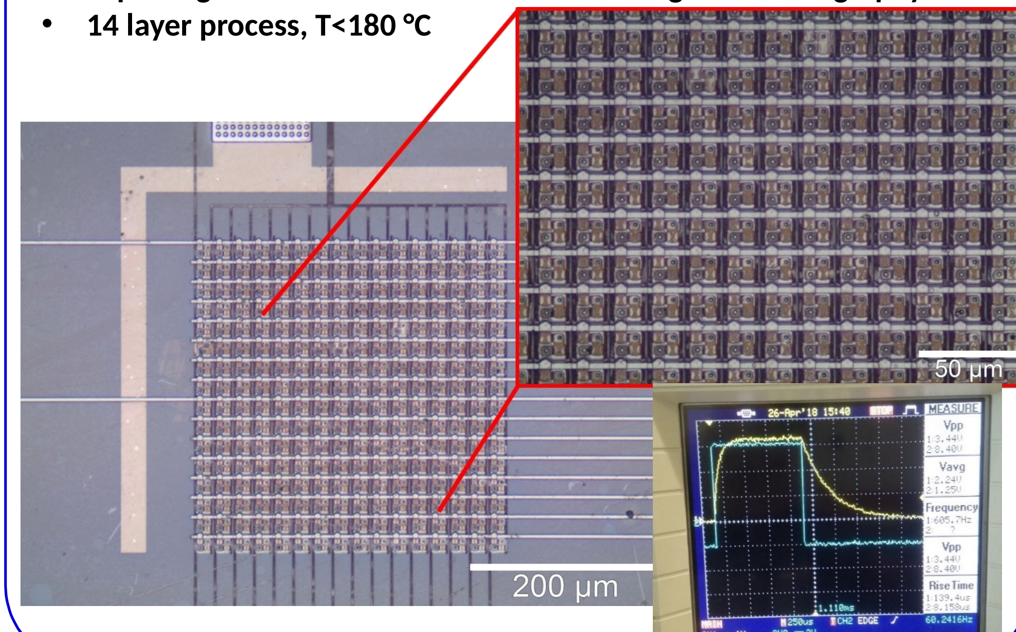
Applications:

	Market Impact	
Curtain lighting/display Textile 	Market Impact (2.5-4yrs beyond project)	
	SAM	$1.34Bn (2%TAM)
	License	$300Mn+
	Royalty(5%)	$33Mn+
Eco Energy Textile 	Market Impact (1.5-2.5yrs beyond project)	
	SAM	$0.15Bn (5%TAM)
	License	$100Mn+
	Royalty(5%)	$5Mn+
Tactile Sensor Textile 	Market Impact (4-5yrs beyond project)	
	SAM	$5Bn (5%TAM)
	License	$1Bn+
	Royalty(5%)	$25Mn+

Oxide TFTs for next generation displays

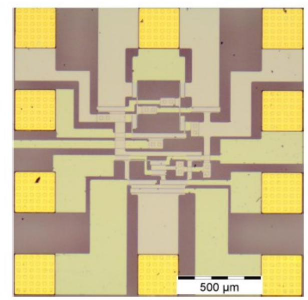
Ultra-high resolution displays

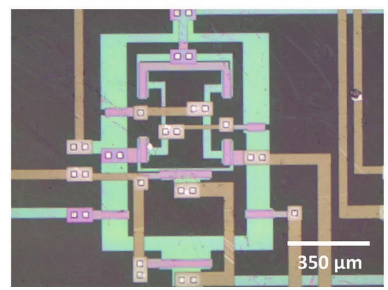
- Active matrix backplanes for Augmented-Reality displays (>1200 PPI)
- Exploring the resolution limits of current large area lithography tools
- 14 layer process, T<180 °C



Circuit blocks for system-on-foil

- Several digital and analog circuits fabricated with oxide TFT technology to enable full system-on-foil (e.g., gate/data drivers, signal processing…)





- Inverter, NAND, NOR, XOR rail-to-rail logic gates
- Current mirrors
- Adder-subtractors, multipliers
- Amplifiers (current, voltage, transimpedance)
- RF rectifiers
- Clock-generators
- C-V converters
- Comparators

Check papers Barquinha et al. @ IEEE EDL, JDT, JEDS… 2013 onwards

It seems hard to have a breakthrough in oxide electronics

- TFT performance essentially established and good enough for many low-cost applications
- Sustainable materials and processes available and being optimized
- Flexibility achievable with proper device stack engineering
- Lack of good p-type oxide semiconductor, but nMOS might be good enough
- Integration capability demonstrated, at least for small IC complexity

Can we think bigger than this?

OXIDES: Problems to Solve

Substitution and Response Speed

What?

- Replace conventional oxide thin films by random networks of NWs
- Future TCOs and ASOs

New materials and processes for conventional thin film technology

Ordered arrays of oxide semiconductor NWs for ultimate oxide nanoscale performance

Eco-Sustainability and Speed: scientific/technological challenges

How?

- Indium-free semic.
- Hybrid dielectrics…
- Solution processing

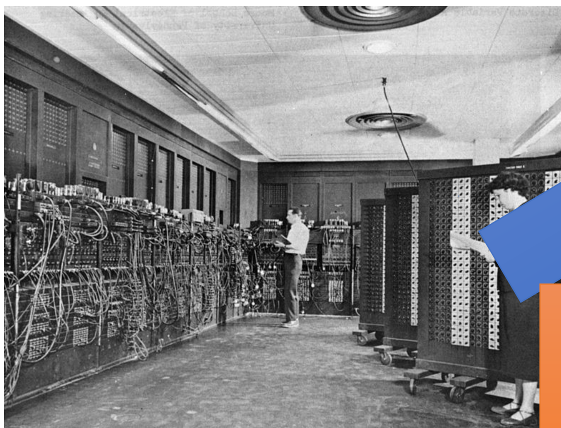
- Spin-coating or printing of NW solution in sub μm-scale devices.
- Grids/meshs of metallic NWs

- Transfer and direct grow methods
- Aligned and ordered arrays using NIL seed layers

Process and device simulation + novel circuit design for high performance/ultra low power consumption

Getting inspiration from electronic's evolution: Going smaller, faster and multifunctional

1st electronic computer:
ENIAC (Electronic Numerical Integrator And Computer), 1945

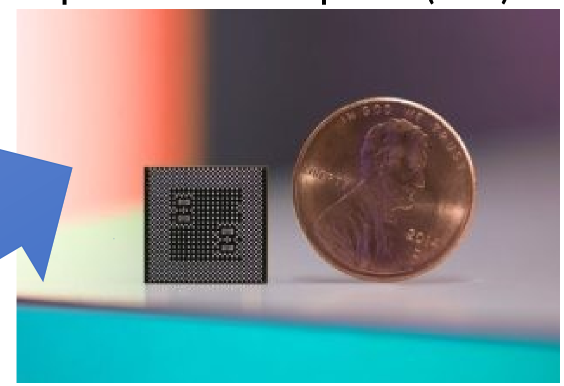


>30 tons, 19000 vacuum tubes, 1500 relays, 100k+ R, C, X, power consumption ~200 kW

Transistors
1947 (Shockley, Bardeen and Brattain, Bell Labs)

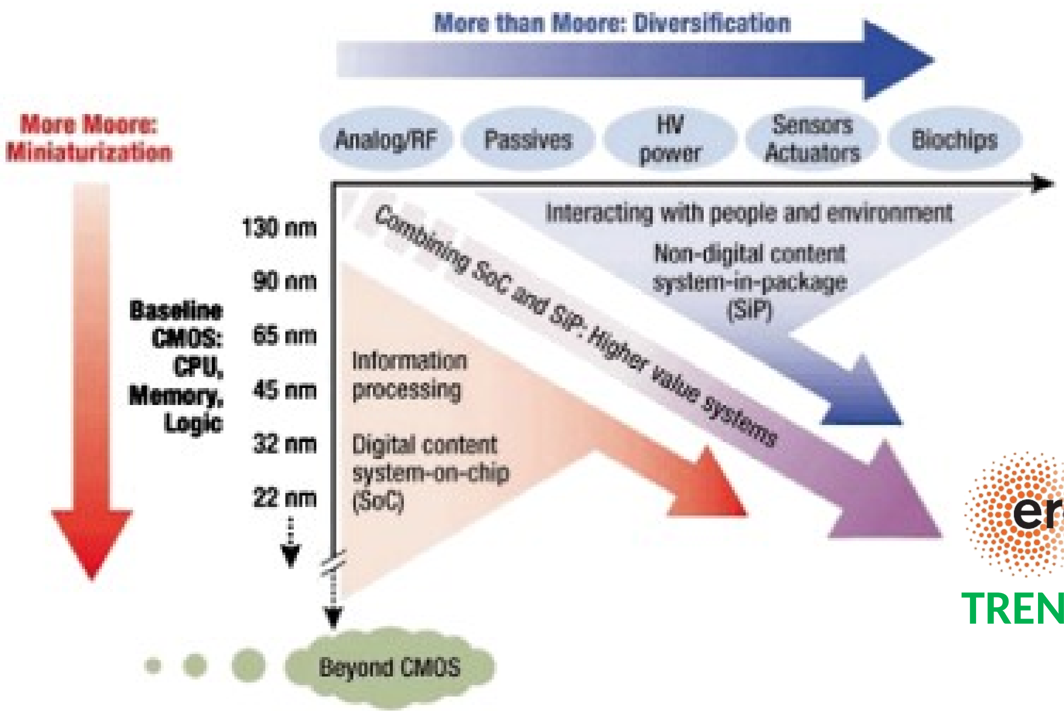
Miniaturization

Qualcomm Snapdragon 835 processor for smartphones (2017)



3 billion FinFETs, 10 nm tech, 8 cores, 2.45 GHz, power consumption ~ mW, truly multifunctional (CPU, GPU, Memory, Wireless...)

Can we do it with oxides and reshape Moore's law?



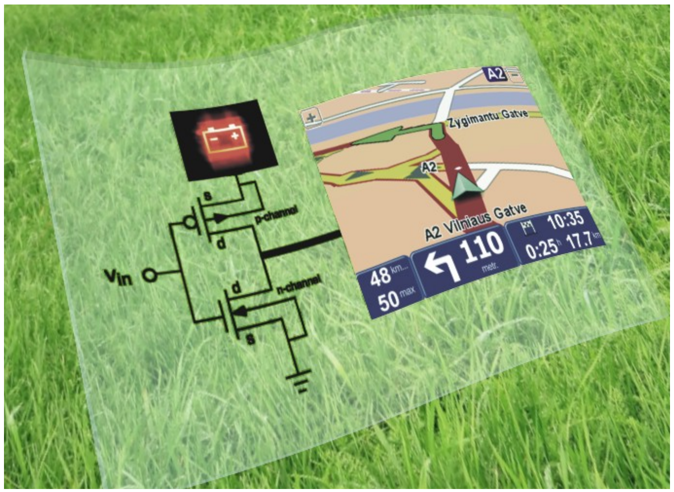
erc
TREND

Exponential growth in transistor count cannot continue, but from the consumer perspective
<u>"Moore's law simply states that user value doubles every two years"</u>.
In that form, the law will continue as long as the industry can add new functionality to its devices

Smart surfaces for all objects!

TREND

Self-powered multifunctional, high-speed transparent circuits on large area foils. The goal of TREND



A transparent and flexible substrate offering addressing, sensing, readout, processing and even energy harvesting capabilities, conformable to any shape, based on sustainable materials and processes.

ZnO NW synthesis is well established today

VLS provides high-quality NW, but T≈1000 °C

Yang et al., Adv. Funct. Mater. 12 (2002)

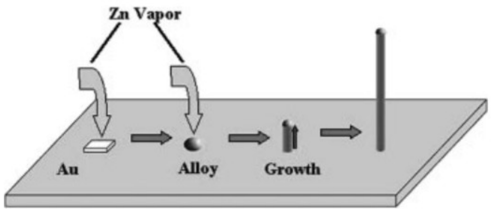
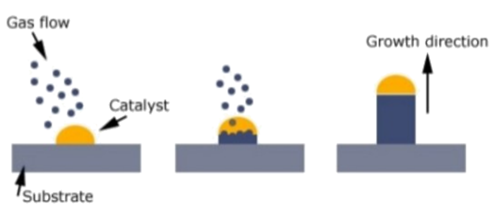


Fig. 2. Schematic representation of ZnO nanowire growth mechanism.

Spontaneous Growth,
Vapor Liquid Solid Growth (VLS)



Growth species in the catalyst droplets subsequently precipitates at the growth surface resulting in the ***one-directional growth***

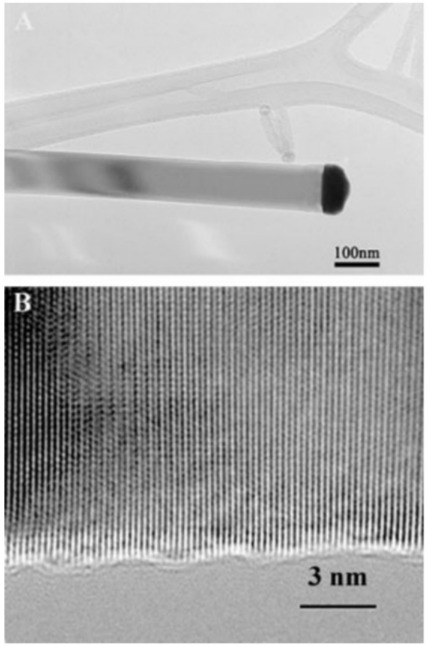
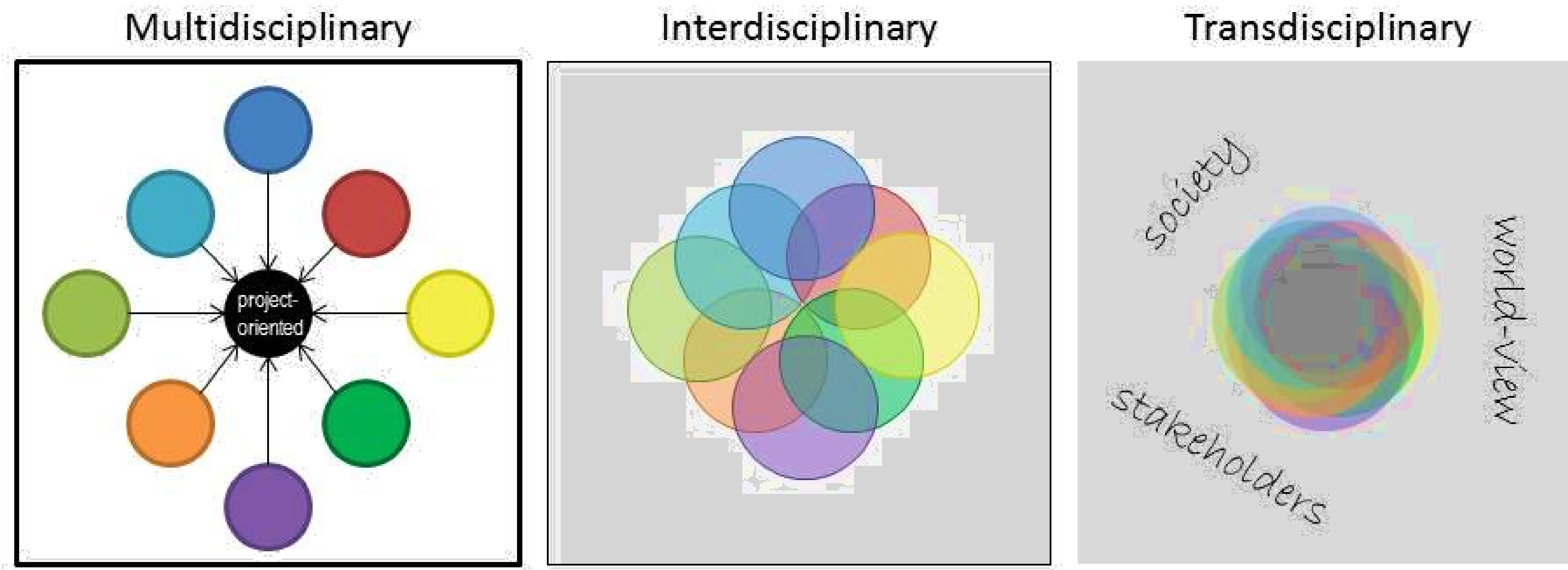


Fig. 5. A) TEM image of a ZnO nanowire with an alloy droplet on its tip. B) High-resolution transmission electron microscopy image of an individual ZnO nanowire showing its <0001> growth direction. Reprinted with permission from [7]. Copyright American Association for the Advancement of Science, 2001.

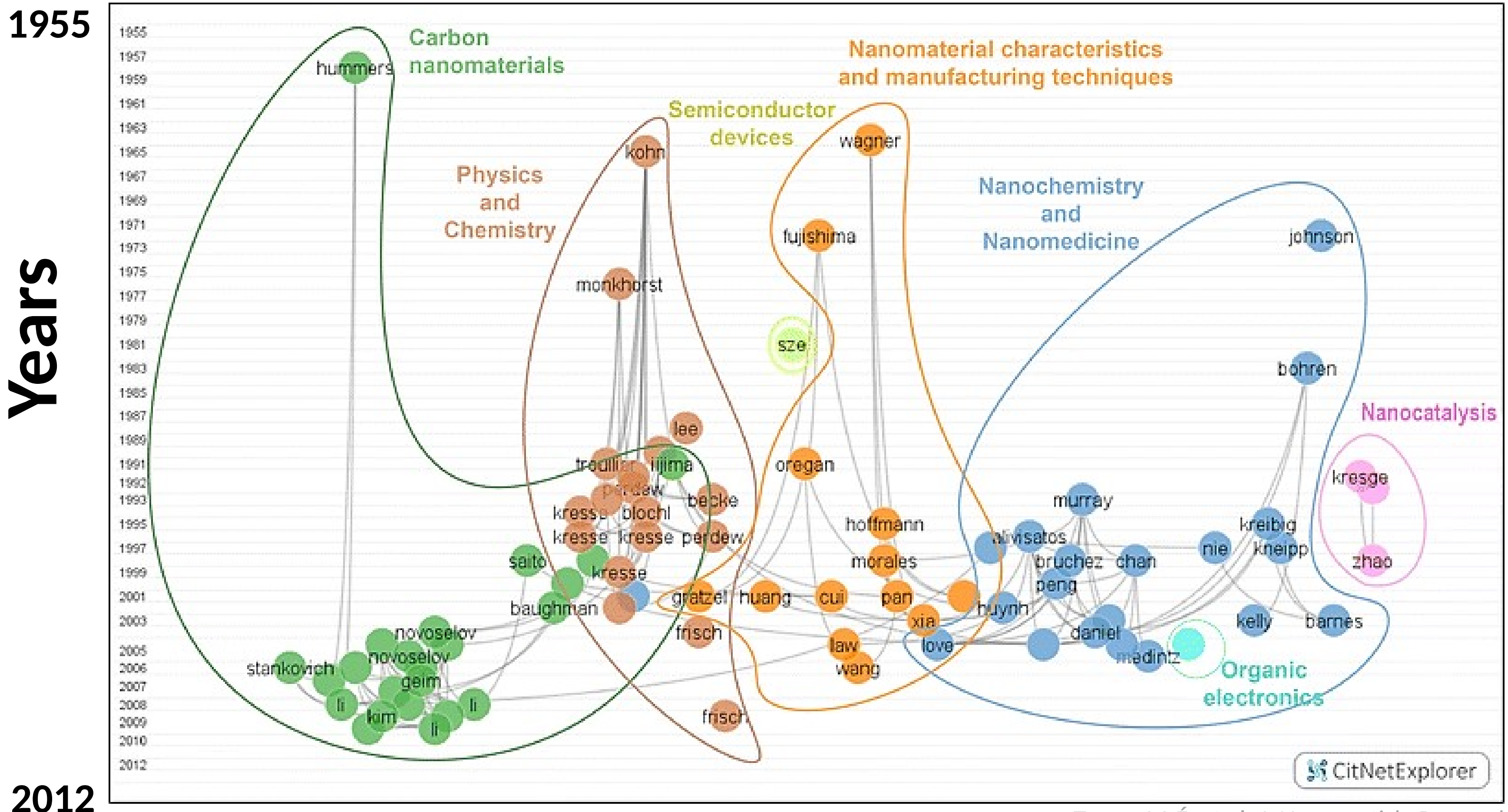
MISSION FOR THE FUTURE

Multi- → Inter- → Transdisciplinary



The *__MISSION concept should be aligned with the Transdiciplinary concept: it is here the key role of Materials science__*

Example of how to exploit the existing basis for a Mission: The strong Inter/Trans-disciplinary of Nanoscience, Chemistry, Physics, Electronics & Nanotechnology



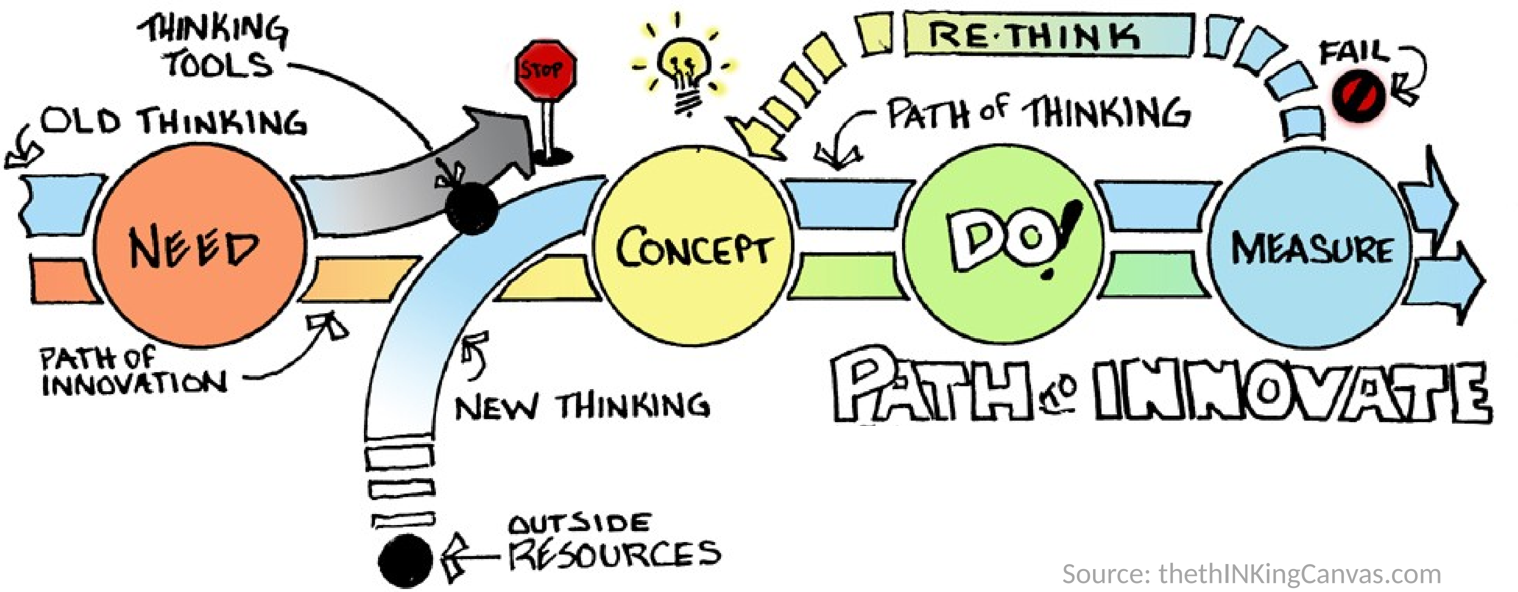
Teresa M-É, et al. *J. Nanoparticle Research*

80 most-cited works throughout 2000–2013 in nanoscience and nanotechnology.

THE FUTURE: Establishment of MISSIONS

- ***How we will communicate and establish real channels among Fields/Areas to address the Challenges of our Mission?***

- ***What can be done to avoid that novel ideas and innovative results get diffused and eventually faint in a maze of dazzling opportunities?***



Source: thethINKingCanvas.com

1968

Flexible circuits printed by machine on paper, aluminum foil, or film may make possible cheap, disposable radios, hi-fi's, and many other electronic devices

Now They're Printing TRANSISTORS ON PAPER!

Some 100 printed transistors decorate corner of playing card—a demonstration of new process that forms semiconductors and circuits on any material.

By W. STEVENSON BACON

Someday soon you may be able to buy a pad of operating electronic circuits just the way you now buy a pad of paper. On its pages will be printed amplifiers, radio receivers, computer circuitry, oscillators—anything you can name. They'll be so inexpensive you'll be able to tear them out, use them, and junk them.

It's made possible by a method of printing transistors on paper, film, plastic, foil, and many other materials. Developed by Westinghouse, the process is unbelievably simple and economical.

The art of depositing passive thin-film components (resistors, capacitors, and interconnects, for example) is well known. Design an automatic circuit-printing machine to deposit both active (transistors) and passive components and you can turn out circuits in continuous rolls for just pennies. Here are only a few of the possibilities:

- Credit and data cards, documents, checks, and other papers with flexible printed-component circuits will help speed identification and processing.
- Revolutionary new medical devices that can be implanted in the body will, for the first time, become really practical.
- A narrow-band TV system that can operate over ordinary telephone lines could become a reality. Such a project is now under way.
- Textbooks and teaching aids, toys, hobby kits, novelties will be based on flexible circuits.

How it's done. Thin-film components are made in a vacuum chamber by vaporizing conductors and other materials and then depositing them in layers on an ultrasmooth base. Thin-film transistors, a relatively recent development, go a step further. A sandwich of metals, insulators and semiconductors is laid down in several steps.

Transistors by the yard, hot off the printing press, are inspected by Westinghouse scientists. The two arrays of semiconductors at right (inset) total 1,316 transistors, some of which are shown in enlarged photomicrograph. Cage-like apparatus below is printing press that stencils thin-film transistors on paper, film, foil. They're flexible but durable.

Phonograph uses an amplifier (in model's hand) printed on kitchen foil. In addition to making cheap electronic devices, paper circuits may be printed in books, on credit cards and documents.

... the new process that it should lend itself to automation—machines that automatically turn out millions of circuits a year. According to Dr. Brody, such a machine would wind a roll of tape through a printing station, a testing station, and an encapsulating station, and onto a takeup roll—just like a movie camera.

... ter "t" and much thinner than the layer of ink used to print it, they have been operated for more than 1,000 hours with no measurable loss. They can be bent, twisted, and coiled. Cut them in half, and you have two transistors.

NOVEMBER 1968 | 125

"Someday soon you may be able to buy a pad of operating electronic circuits just the way you now buy a pad of paper. On its pages will be printed amplifiers, radio receivers, computer circuitry, oscillators—anything you can name. They'll be so inexpensive you'll be able to tear them out, use them, and junk them."

One of the first attempts of PE was suggested by Brody and Page at Westinghouse, when they used a stenciling method to produce inorganic thin-film transistors on paper for flexible circuits.

Europäisches Patentamt
European Patent Office
Office européen des brevets

Search | Website | Patents

Media Contact

English

Home | Searching for patents | Applying for a patent | Law & practice | News & issues | Learning & events | About us

Home › Learning & events › European Inventor Award › The finalists › 2016 › Fortunato

European Inventor Award

- Watch the ceremony
- The event
- The award
- The finalists
- 2016
- 2015
- 2014
- 2013
- 2012
- 2011
- 2010
- 2009

Elvira Fortunato and Rodrigo Martins (Portugal)

Print Share

Finalist for the European Inventor Award 2016

Videos:

Featured stories

RTP
Cientista portuguesa selecionada para prémio europeu

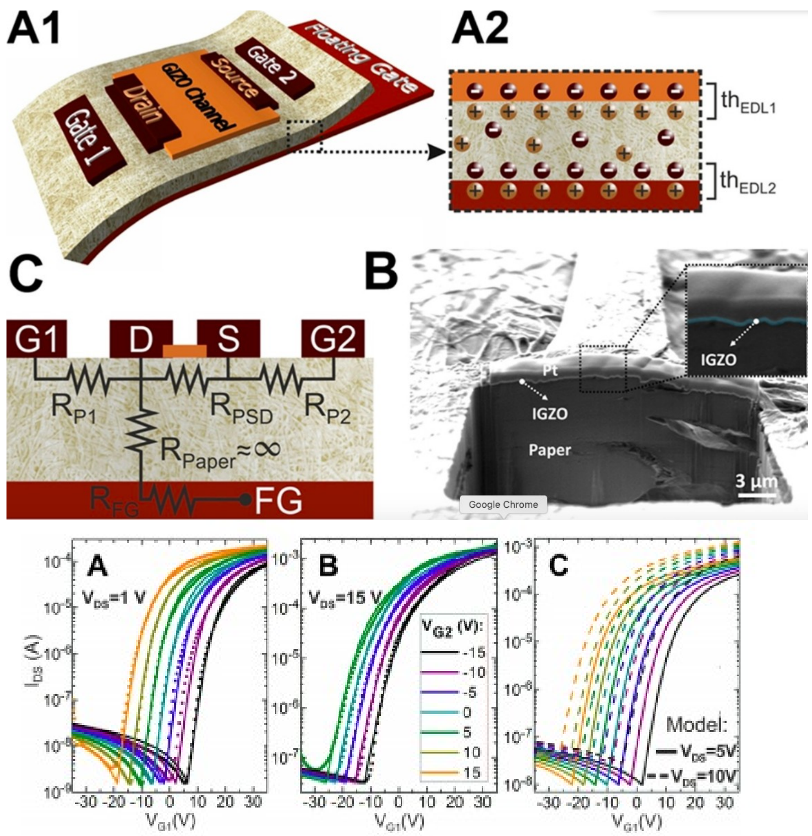
P3
Cientistas portugueses são finalistas em Prémio Europeu do Inventor

An example how a mission can be established: The Paper Electronics

Contents lists available at ScienceDirect
Applied Materials Today
journal homepage: www.elsevier.com/locate/apmt

Papertronics: Multigate paper transistor for multifunction applications

Rodrigo Martins[a,*], Diana Gaspar[a], Manuel J. Mendes[a], Luis Pereira[a,*], Jorge Martins[a], Pydi Bahubalindruni[b], Pedro Barquinha[a], Elvira Fortunato[a,*]



nature electronics

Editorial | Published: 13 August 2018

A lesson on paper

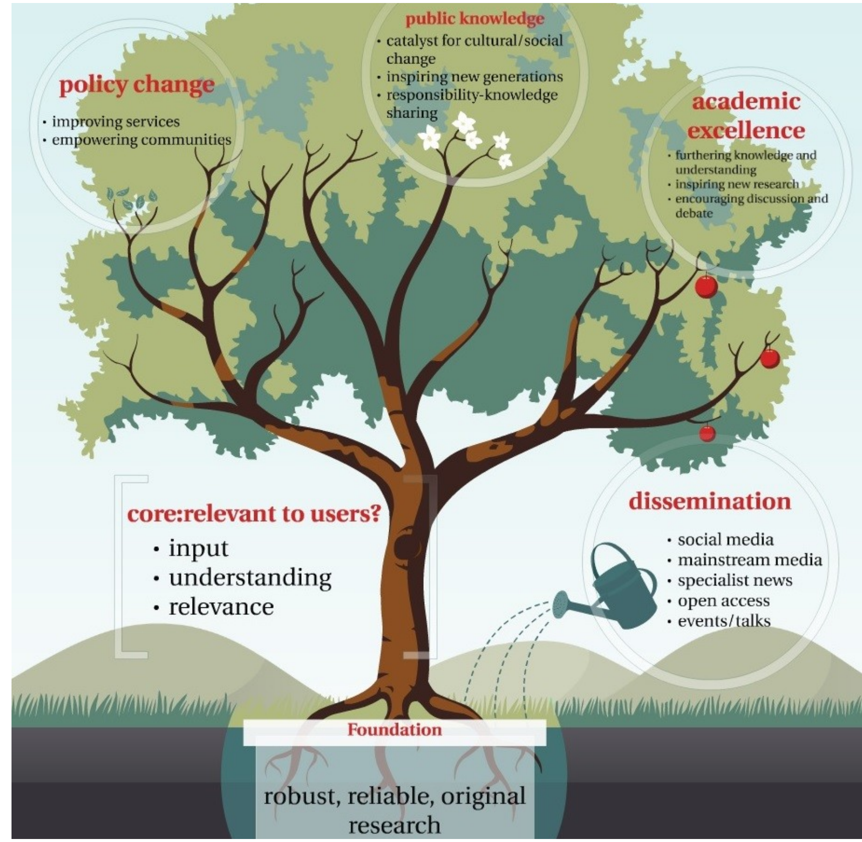
Nature Electronics **1**, 429 (2018) | Download Citation

UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes

FCT Faculdade de Ciências e Tecnologia Universidade Nova de Lisboa

CENIMAT i3N

Responsibilities



Source: https://meganbeech.wordpress.com/tag/social-impact/

1. Options for anticipating the social impact of R&D : idea of science for society or research on behalf of the people.

2. Research goals by ethical standards: For instance **<u>- realign the drug industry's interests </u>**with ***patient interests*** and analyze efforts to bring ethical standards to globalized food industry. Medical technology is another field in which moral demands feature prominently.

3. Institutional frameworks of responsible science: *shifted from considerations of individual scientists to suitably designed institutions* **on team work based**

*Könneker, C.; Lugger, B. "Public Science 2.0 – Back to the Future". **Science** (2013)*

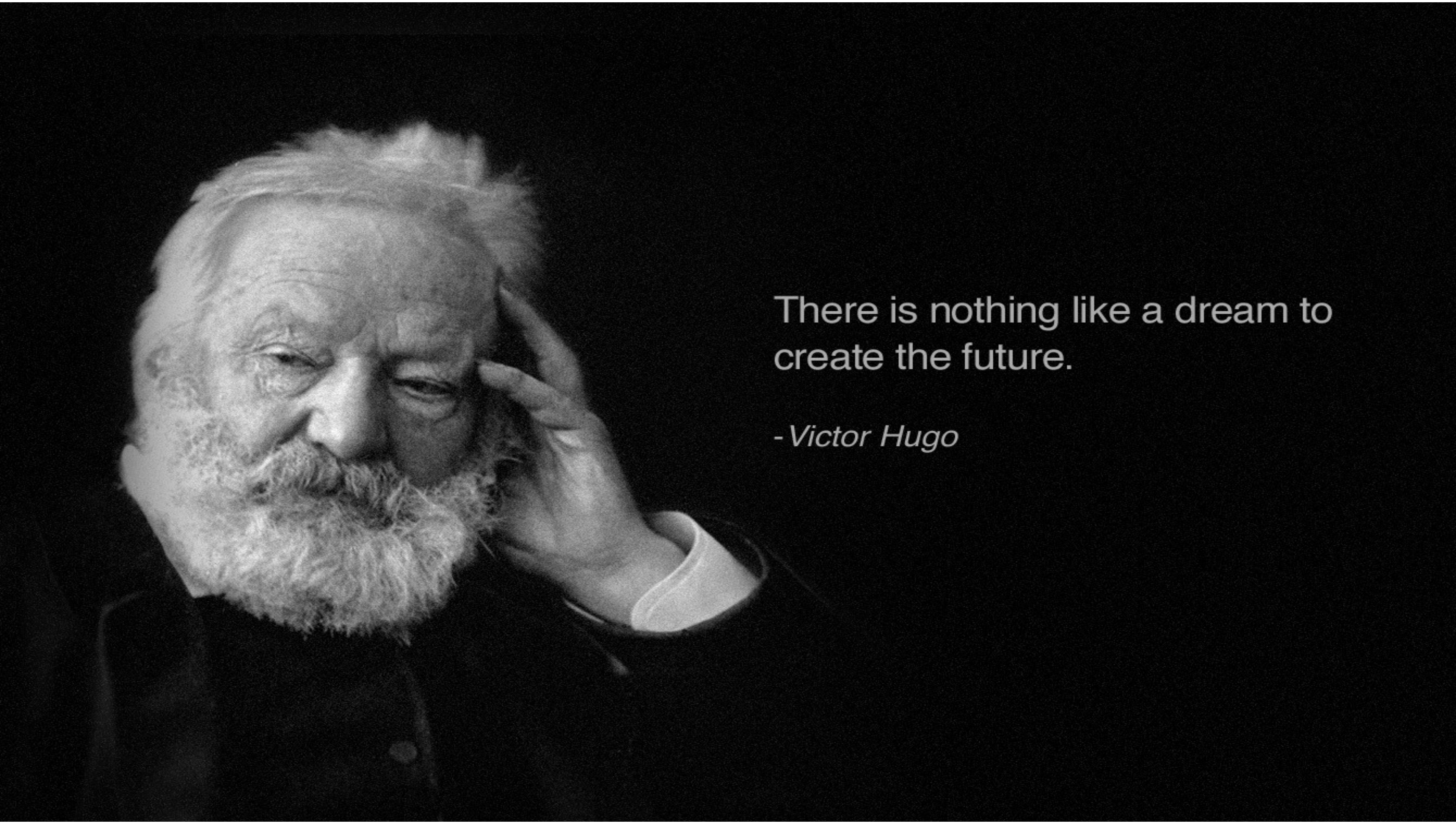
4. Epistemic responsibility and critical thinking: manifest in the combat against fraud and bias in research

5. Space for suggestions and responses from working scientists: reactions from the laboratory benches provide an important test bed for judging the viability of recommendations from the reflecting disciplines

Source: https://mind-mint.org/articles/research/why-it-matters

Science isn't finished until it is communicated

Sir Mark Walport,
U.K. Government Chief Scientific Advisor


There is nothing like a dream to create the future.
- Victor Hugo

The First European Paper Electronics Initiative Involving Region, Industry and RTOs

ALMASCIENCE
beyond paper

CORE PARTNERS

Industrial

INCM
THE NAVIGATOR COMPANY
claraSaúde

Scientific and Technological

We are Hiring 30 MSC and PhD + DIRECTOR for!

Fraunhofer PORTUGAL
RAIZ Forest and Paper Research Institute
UNINOVA
CENIMAT i3N

Scientific Literacy

ALMADA CÂMARA MUNICIPAL

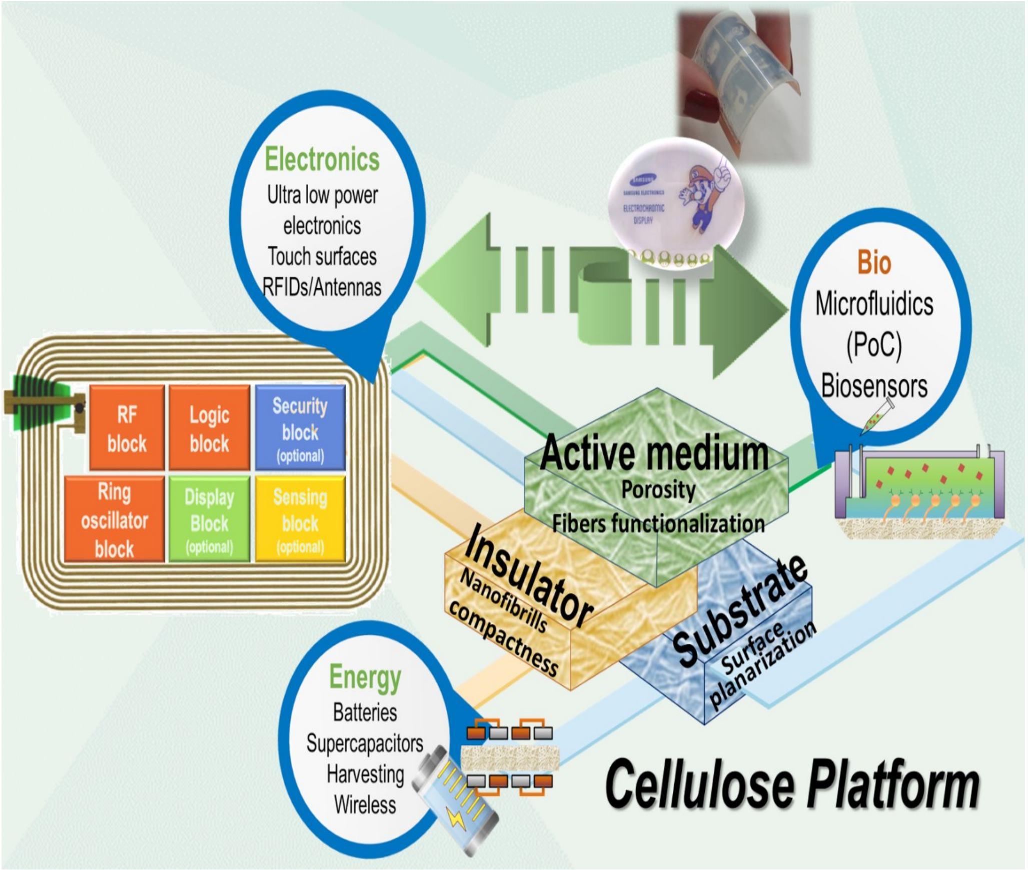
AlmaScience

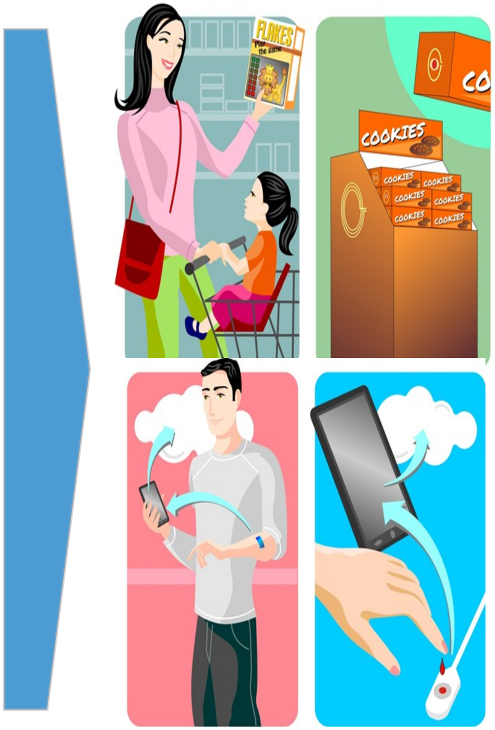
https://www.european-mrs.com/news/news-events

UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes
FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA
CENIMAT i3N

SicT Summer school on Sustainable ICT
September 7th (Mon) - 11th (Fri), 2020, Louvain-la-Neuve, Belgium

Scope, Strategy and Impact for Paper Electronics:
Multi-sectorial targets





"If you want to go fast, go alone.
If you want to go far, go together"

Acknowledgments – Current Projects

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

PORTUGAL 2020

4X

erc
European Research Council
Established by the European Commission
Supporting top researchers from anywhere in the world

HORIZON 2020

roll-out

1D NEON

MERCK

i-FLEXIS
Integrated flexible photonic sensor system

Symbiotic

BET-EU
MATERIALS SYNERGY INTEGRATION FOR A BETTER EUROPE

ETRI
한국전자통신연구원
Electronics and Telecommunications Research Institute

eit RawMaterials
Connecting matters

SUPERSMART

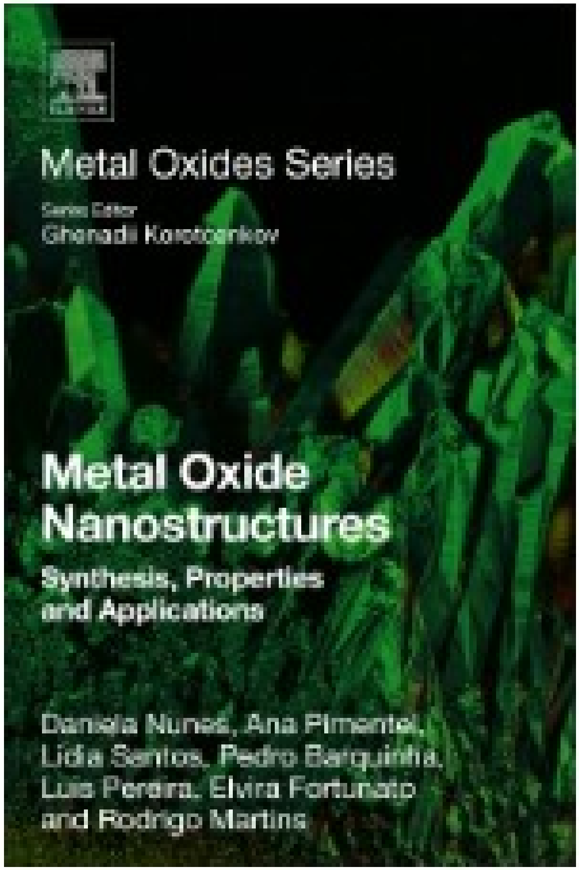
UNINOVA
CEMOP
Centre of Excellence in Microelectronics, Optoelectronics and Processes

FCT
FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

CENIMAT
i3N

SiCT
Summer school on Sustainable ICT
September 7th (Mon) - 11th (Fri), 2020, Louvain-la-Neuve, Belgium

Metal Oxide Series Book



Metal Oxide Nanostructures

1st Edition

Synthesis, Properties and Applications

- Hybrid structured metal oxides and their promising use in the next generation of electronic devices
- Synthesis, design and properties of metal oxide nanostructures
- In-depth overview of novel applications, including chromogenics, electronics and energy

ELSEVIER

Editor: Ghenadii Korotcenkov

https://www.elsevier.com/books/metal-oxide-nanostructures/nunes/978-0-12-811512-1

UNINOVA CEMOP Centre of Excellence in Microelectronics, Optoelectronics and Processes
FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA
CENIMAT i3N

SicT. Summer school on Sustainable ICT
September 7th (Mon) - 11th (Fri), 2020, Louvain-la-Neuve, Belgium

PAPER ELECTRONICS RELATED BOOKS