Emerging applications and opportunities

Content

- Driving forces for technology development
  - Discussion of solar cell, FPD and FPI cases
- New applications
  - Moore’s law
  - More than Moore evolution
  - New opportunities
  - Microfluidics
  - Emerging non-volatile memories
  - Transient electronics
- Final remarks

Devices and Applications

- Photodiodes
  - ★ Solar cells
  - ★ Particle detectors (X, α, β, γ)
  - Flat panel imagers (a-Si:H)
  - ★ Photodiodes (micro-systems)
  - Position detectors
  - Spatial modulators (optical valves)
  - ★ Bio-chips
  - Smart windows
  - …..
- Photoconductors
  - Xerography
  - Flat panel imagers (a-Se)
  - ……
- Transistors
  - ★ Flat panel displays
  - IR detectors
  - …….
- Other devices
  - ★ Memories
  - ★ Micro-chanel plates (MCP)
  - ★ Printed electronics
  - Reflect array antennas
  - Resistive layers
    - Charge spreading
    - Spark protection
    - …
  - ….

Large-area electronic devices and applications

★ **Active research**

Driving forces

- **…similar for many technologies**

- **Better product (improvement of current technologies)**
  - Better performance
  - Larger device
  - New functionalities
- **New product (application of new technologies)**
  - New application
  - Paradigm shift (change of technology)
- **Synergies (between technologies or applications)**
  - Speed up development
  - Lower costs
- **Legal aspects**
  - Toxic materials
  - Liabilities, risks
- **Cost**
  - improvement in design and manufacturing
  - Material costs
- …

Driving forces for large-area electronics

N. Wyrsch

Some examples:

- **Solar cells**
  - Lower cost/m^2
  - Lower cost/kWh
  - $\rightarrow$ Local energy production, renewable, compete with other forms of energy production
- **Flat panel displays**
  - Lower costs (consumer applications !)
  - Larger display (TV sets)
  - Higher display densities (mobile applications)
  - Flexible (or unbreakable) displays
  - Low consumptions
- **Flat panel imagers**
  - Higher sensitivity (for lower dose)
  - Better spatial resolutions
  - Lower cost (for large area devices)

Solar cells case

Depends on market segment:

- Power market (on grid):
  - reach grid parity, compete with other forms of energy production
    - Lower price of manufacturing (larger volume → larger device)
    - Lower price of materials (less material → thinner device, no rare materials)
    - Higher efficiency
  - Scaling up (sustainability for TW production capacity, >10^4 km^2/ year!)
  - Long lifetime (>25 year in "harsh" environment)

→ **Inorganic thin-film ?**

- Consumer product
    - Very low cost
    - Compatibility with thin film electronics (printed ?) electronics?
    - Flexibility ?

→ **Organic ?**

- Other niche markets (space, off-grid power, etc)

→ **Application dependent**

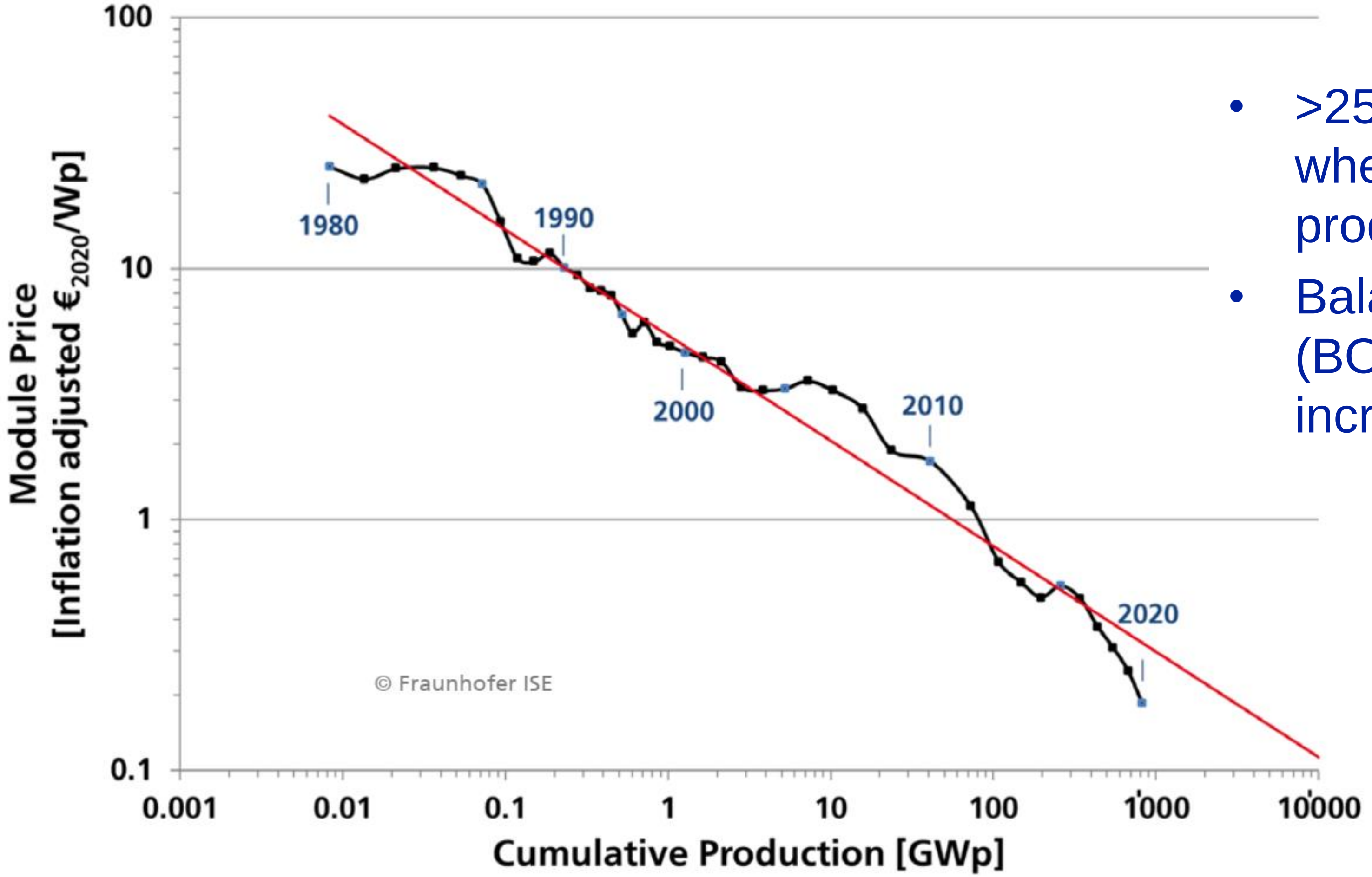
LCOE : Levelized cost of electricity

$$LCOE = \frac{\sum_t^n = 1 \; \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_t^n = 1 \; \frac{E_t}{(1+r)^t}}$$

- LCOE = average lifetime levelised electricity generation cost
- I_t = investment expenditures in the year *t*
- M_t = operational and maintenance expenditures in the year *t*
- F_t = fuel expenditures in the year *t*, which is zero for PV electricity
- E_t = electricity generation in the year *t*
- r = discount rate
- n = financial lifetime of the calculation

http://www.nrel.gov/analysis/tech_lcoe_documentation.html

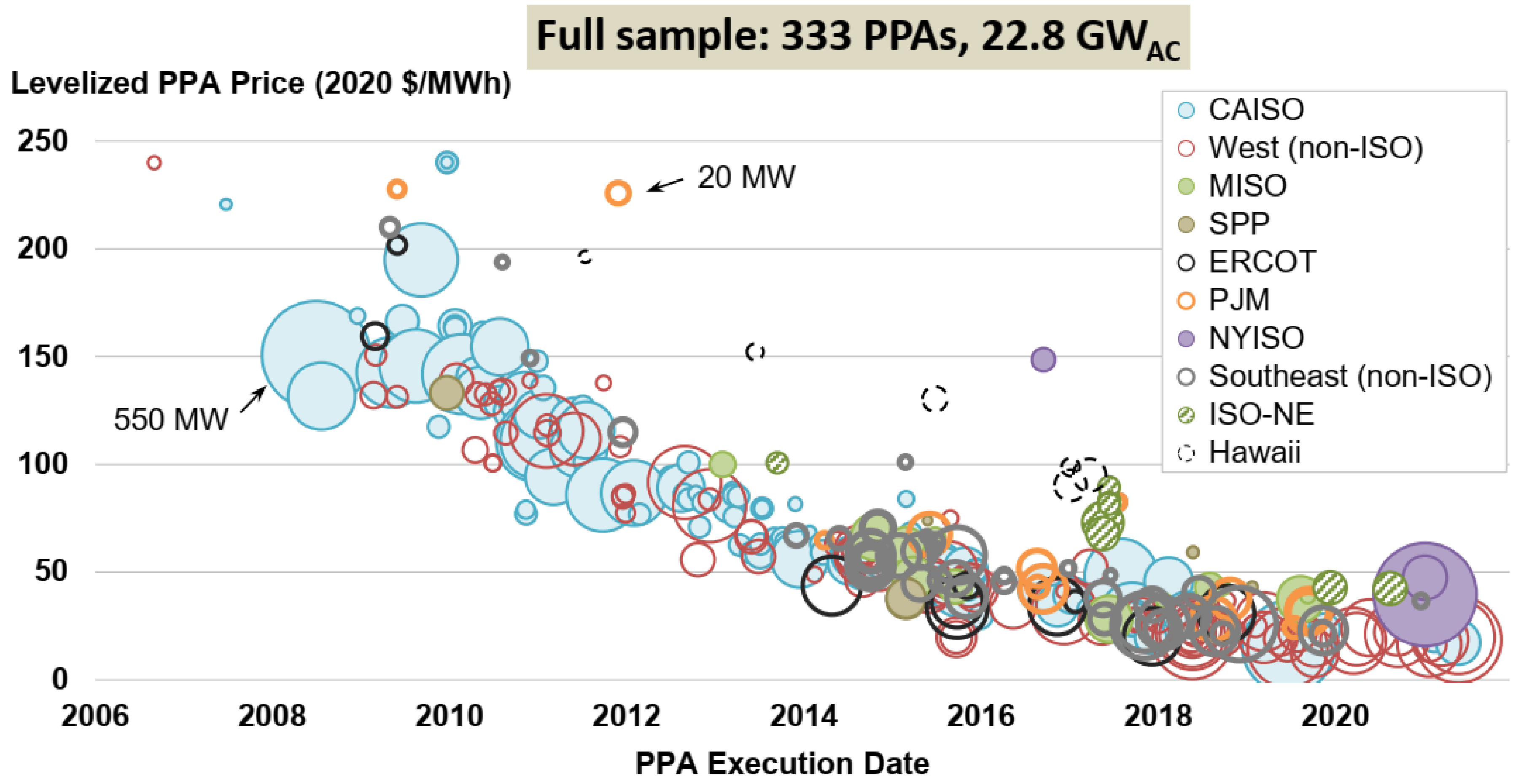
Experience / learning curves



Data: from 1980 to 2010 estimation from different sources: Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit; Graph: PSE 2021

- >25% decrease in price when cumulated PV production is doubled
- Balance of system (BOS) costs play an increasing role !

PV Energy Costs



https://emp.lbl.gov/utility-scale-solar

- PV electricity already offered in sunny countries at <0.015 $/kWh !
  (PPA – power purchase agreements, bids for long term energy purchase)
- PV is the cheapest way of producing electricity !!

FPD case

Depends on market:

- TV sets, information screens:
  - Larger size
  - Lower consumption
  - Better contrast and luminosity
  - Lower costs
  - Higher integration

→ **a-Si for AMLCD**
Other display technologies ?
Organic ?

- Mobile phones & tabletts
  - Lower consumptions
  - Better contrast and luminosity
  - Lower costs
  - Higher integration
  - Unbreakability (flexibility?)

→ **LTPS**
Metal oxides
Organic (longer term) ?

- Consumer applications (info display, etc)
  - Very low cost

→ **Organic ?**

Other considerations

- FPD technology development
  - From AMLCD toward light-emitting displays
  - Successful technology is not always the “best” one
    - Cost structure
    - Legal aspects
    - Strategic aspects
    - Development timing
- Synergies with other fields or applications
  - with solar cells (large area deposition equipments)
  - with thin-film electronics (printed or deposited electronics)
- Material costs (e.g. In for ITO or CIGS)

→ **Full organic displays ?**

FPI case

Driving forces

- Lower dose (single photon detection / counting)
- Higher spatial resolution
- Higher integration (e.g. pixel level amplifier or signal processing)
- Lower cost
- PET / CT scanner integration
- Synergies with FPD

New developments

- CCDs for high spatial resolution
- Energy-resolved methods
- Photon-counting detection
- Phase contrast imaging
- Terahertz imaging

LTPS / a-Si:H hybrid AMFPI?

Compatibility with organic ?

New FPI technology ?

PV-lab
IEM NEUCHATEL

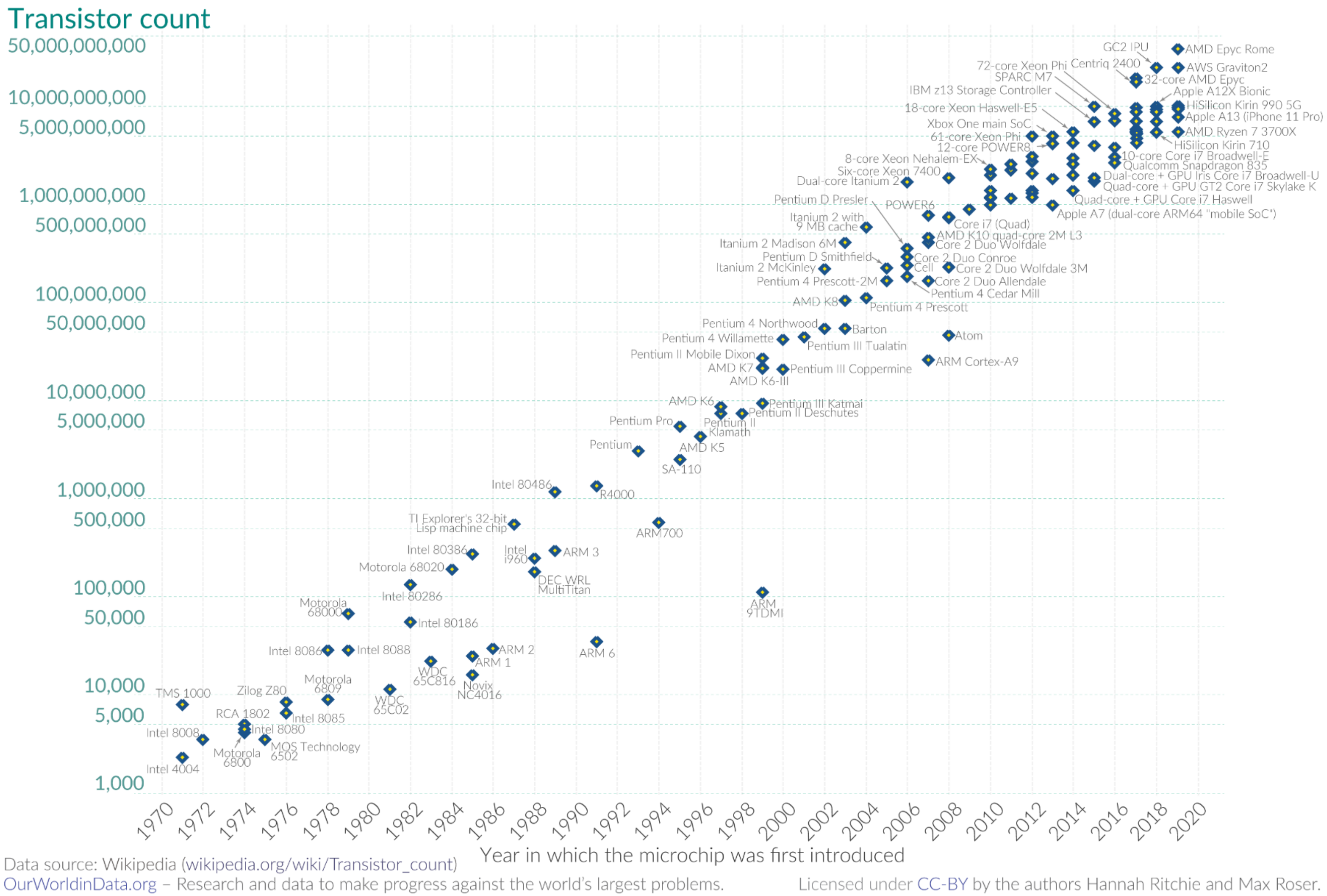
Other applications / opportunities

- **Electronics**
  - Moore’s law bottleneck $\rightarrow$ beyond CMOS
  - More than Moore
  - Deposited / printed electronics
- **Memories**
  - Design rule limit
  - New memory technologies
- **System integration**
  - Hybrid technologies
  - Deposited electronics /detection

EPFL

Physical limits

- The number of transistors that can be placed inexpensively on an integrated circuit double approximately every two years

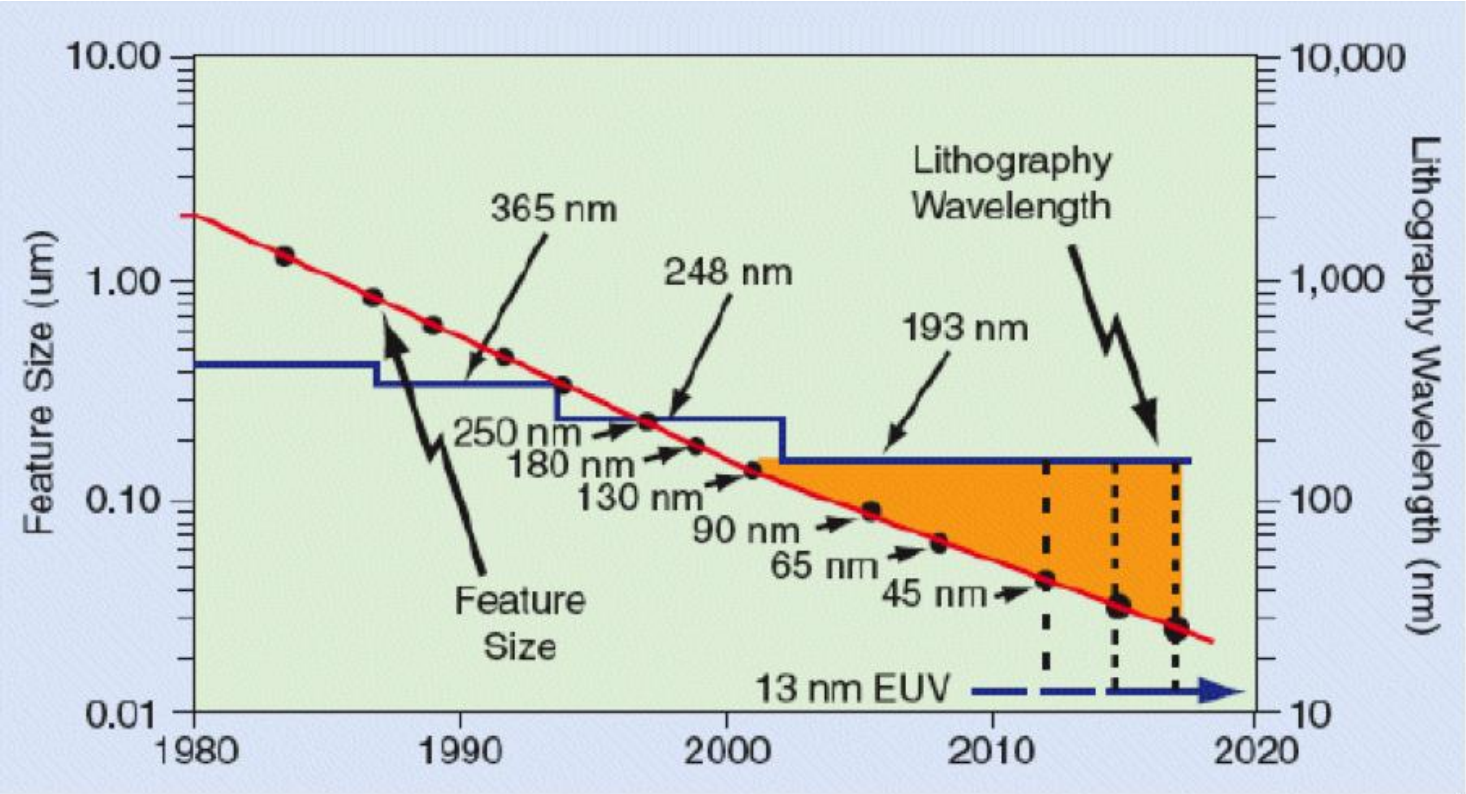


Wikipedia

PV-lab
IEM NEUCHATEL

Limit of Moore’s law

- Limits of feature size given by lithography wavelength



http://semiengineering.com/euv-matter/

- Physical limits to be attained soon for current CMOS technologies

More than Moore

IEEE 2008 Custom Intergrated Circuits Conference (CICC)

Microelectronics for the Real World: "Moore" versus "More than Moore"

John P. Kent, IEEE, Senior Member and Jagdish Prasad, IEEE, Senior Member
ON Semiconductor
2300 Buckskin Road
Pocatello, Idaho 83201 USA

Microsyst Technol (2010) 16:1051–1055
DOI 10.1007/s00542-009-0976-1

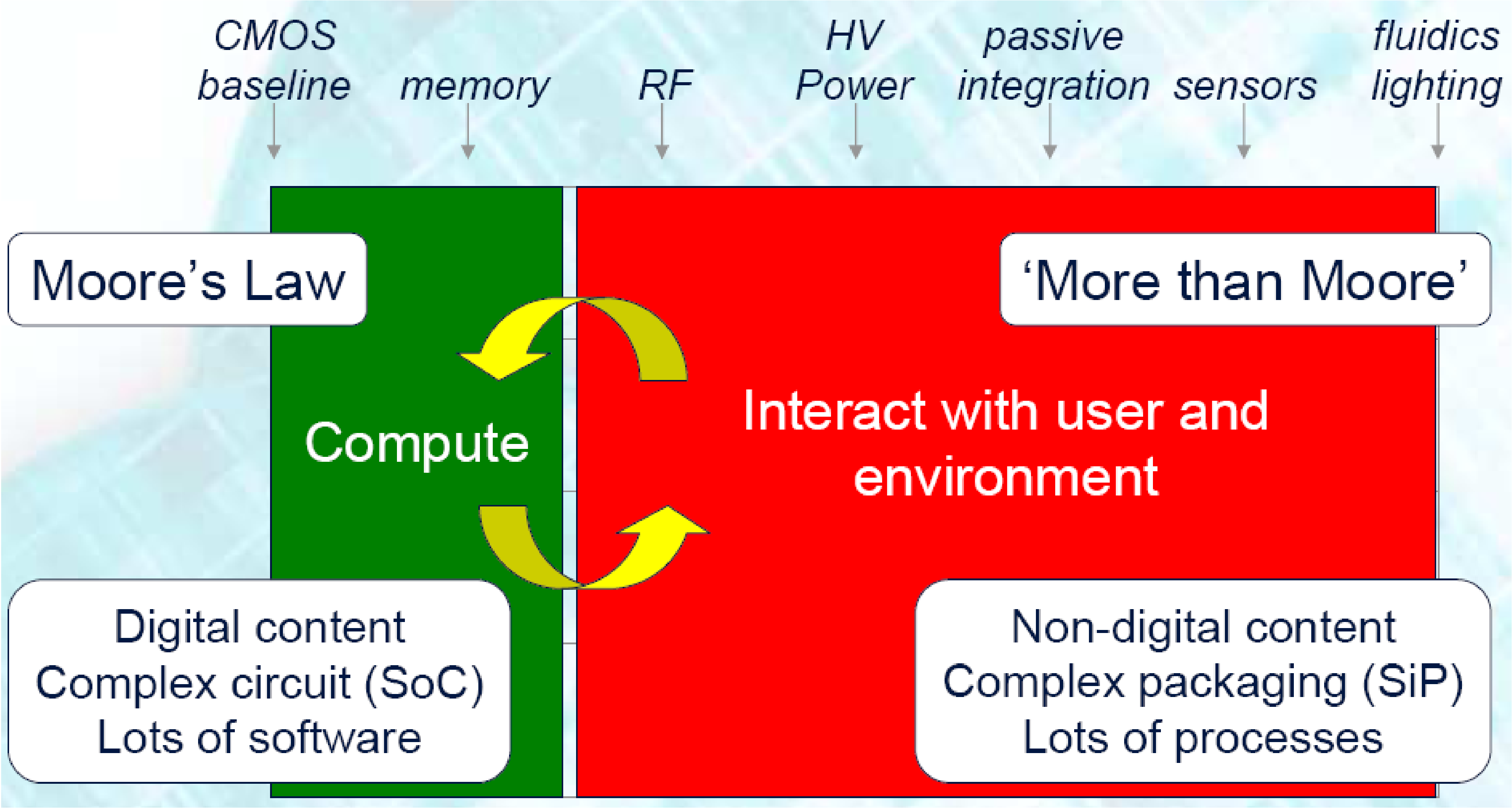
TECHNICAL PAPER

3D System-on-Chip technologies for More than Moore systems

Peter Ramm · Armin Klumpp · Josef Weber · Maaike M. V. Taklo

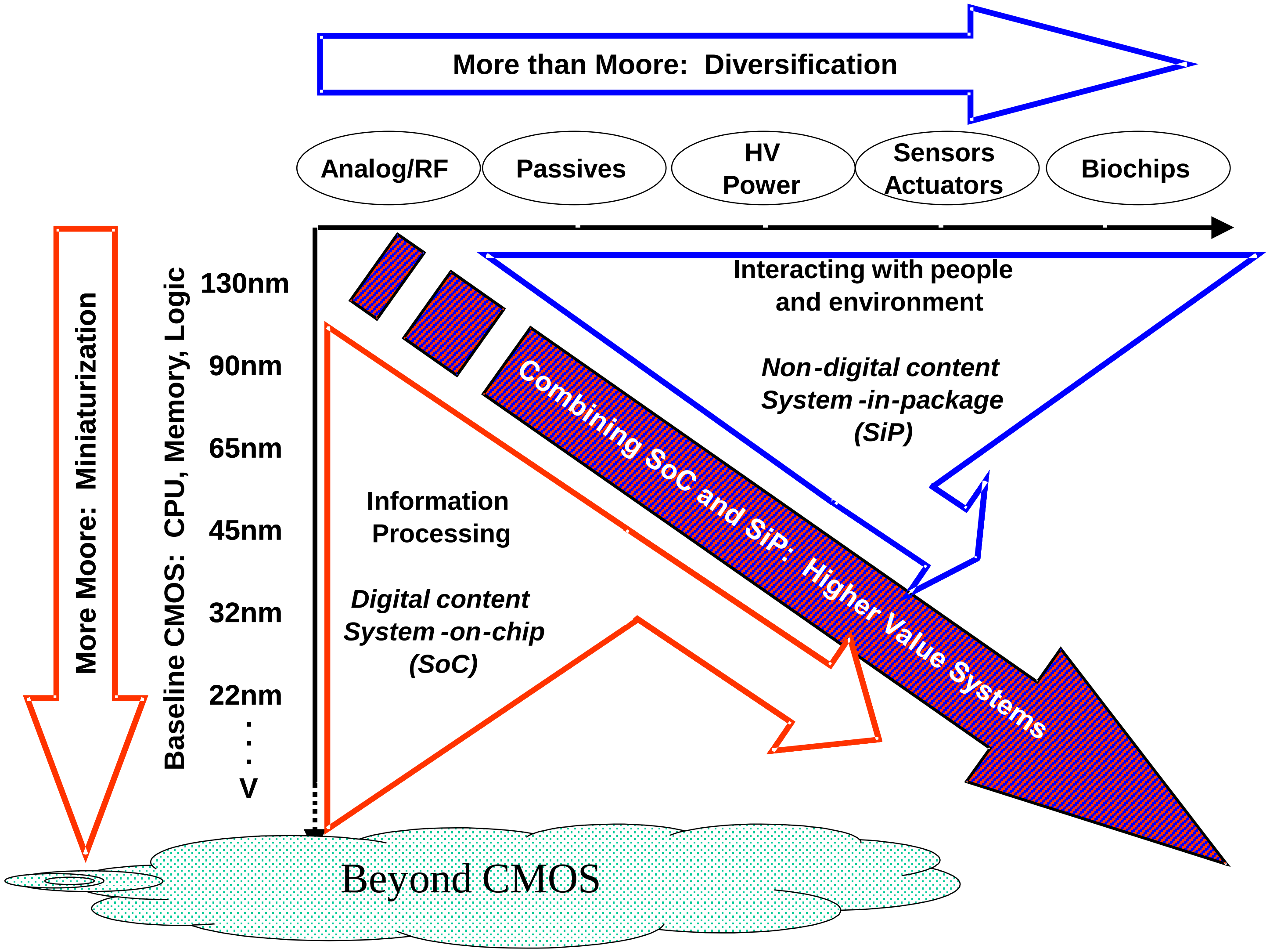
- Focus on system integration rather transistors density
- Integration of more functionalities (beside pure electronics) on the same substrate / chip
- Micro / Nanoelectronics systems, system in package (SIP), system on chip (SOC)
- Combination of current Si wafer technology with other materials and/or technologies
- New markets, new applications

“More than Moore”



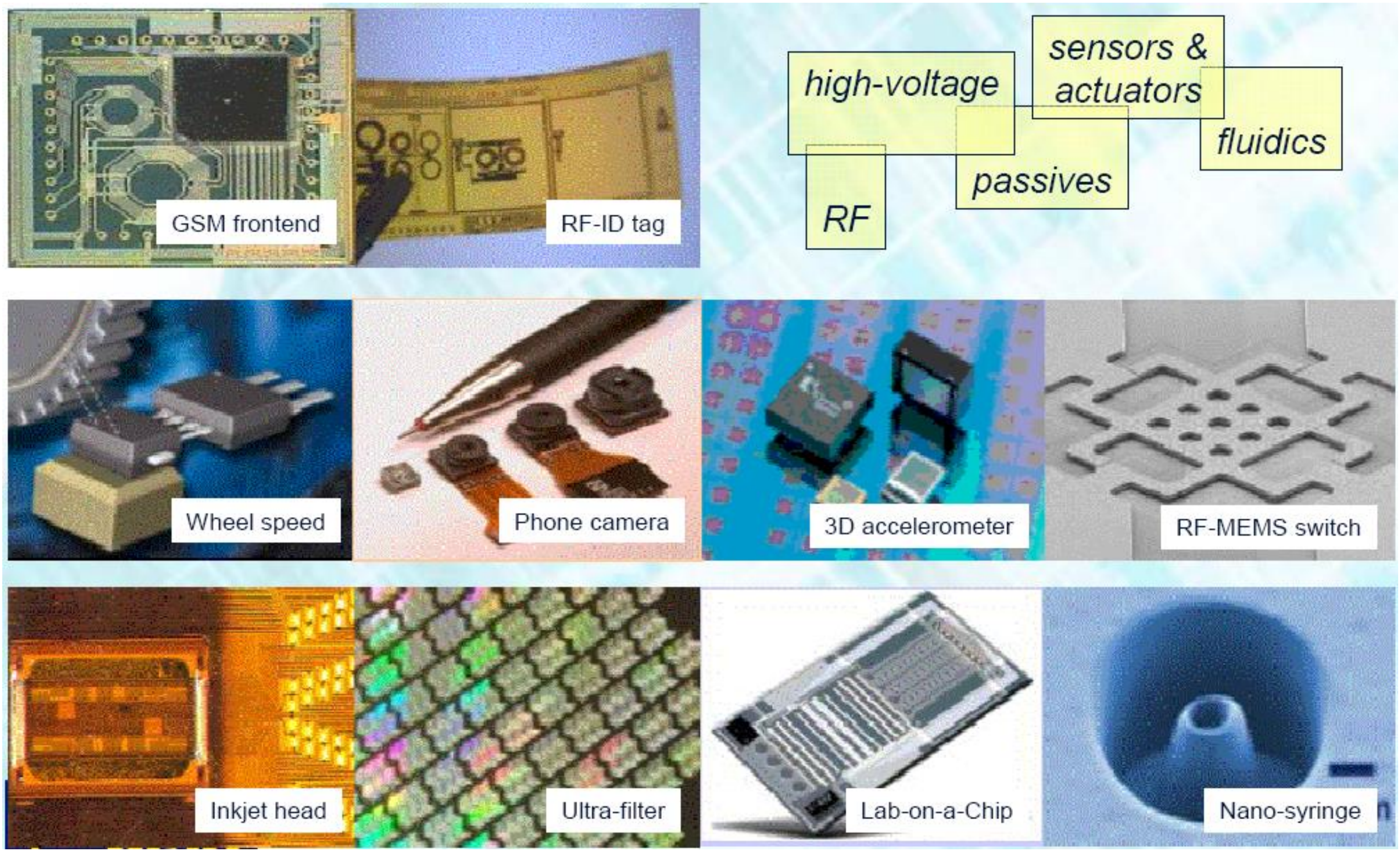
ENIAC : European Nanoelectronics Initiative Advisory Council

“More Moore” and “More than Moore”



Source: ITRS roadmap 2007

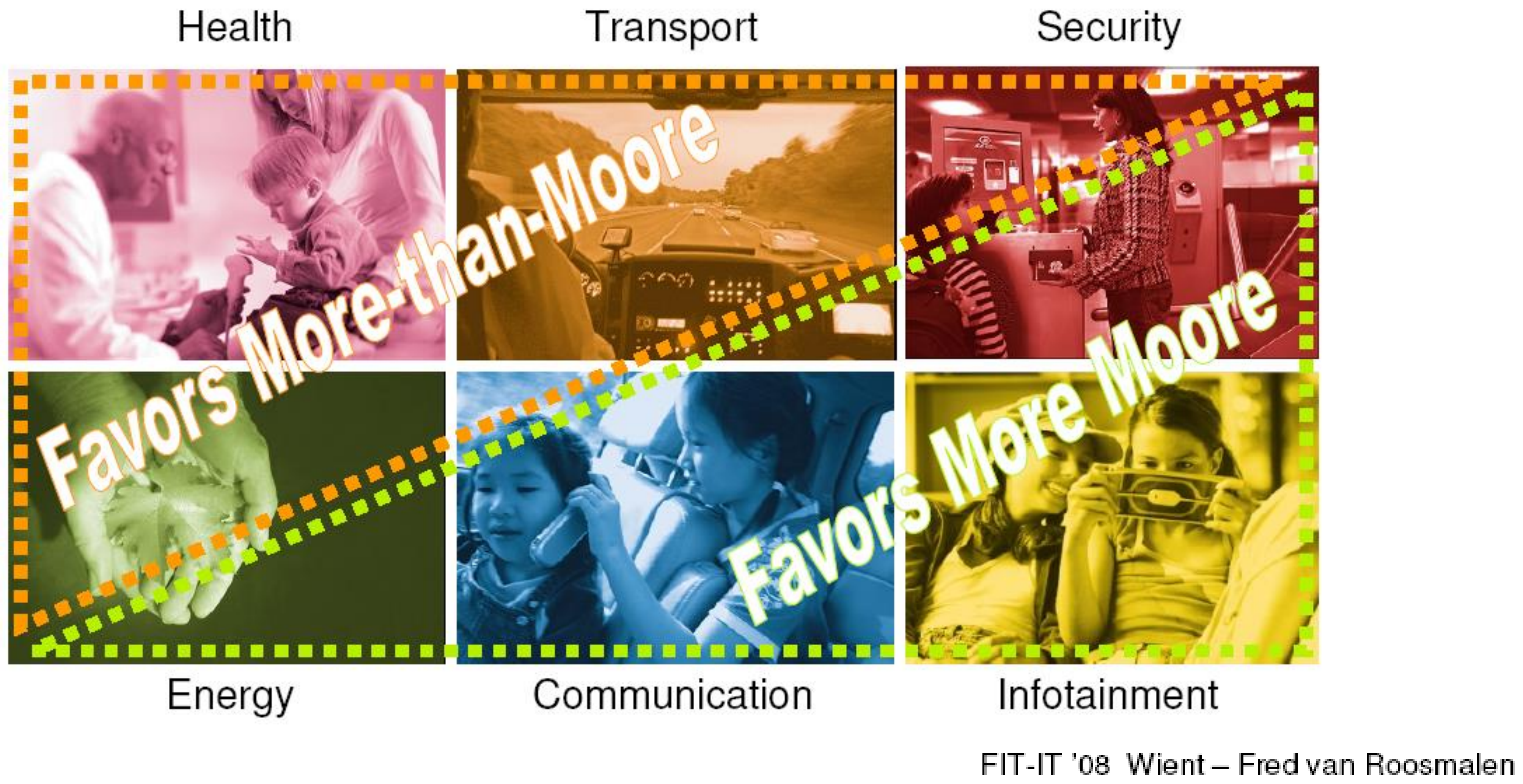
More than Moore examples



ENIAC : European Nanoelectronics Initiative Advisory Council, Lugano 2006

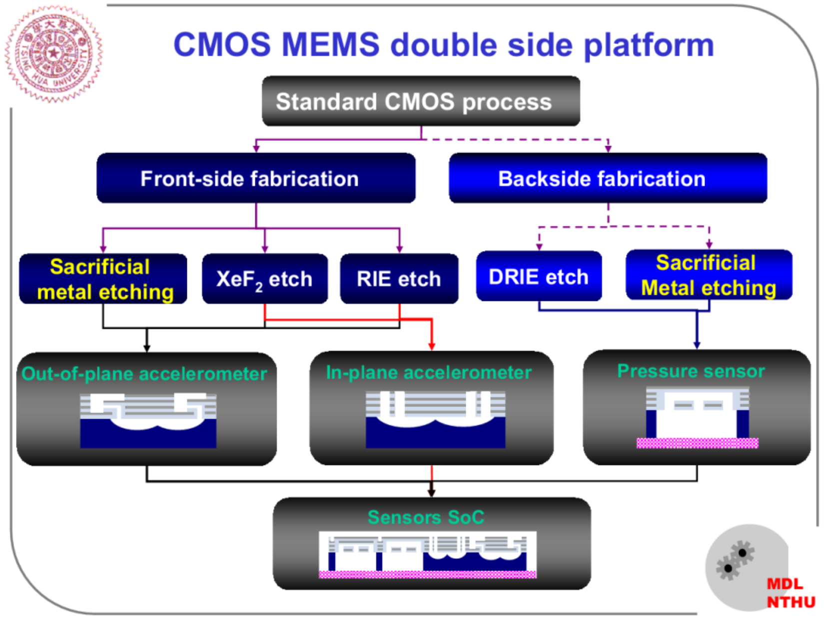
- EPFL very active ! (See also CMI review meeting poster booklet)

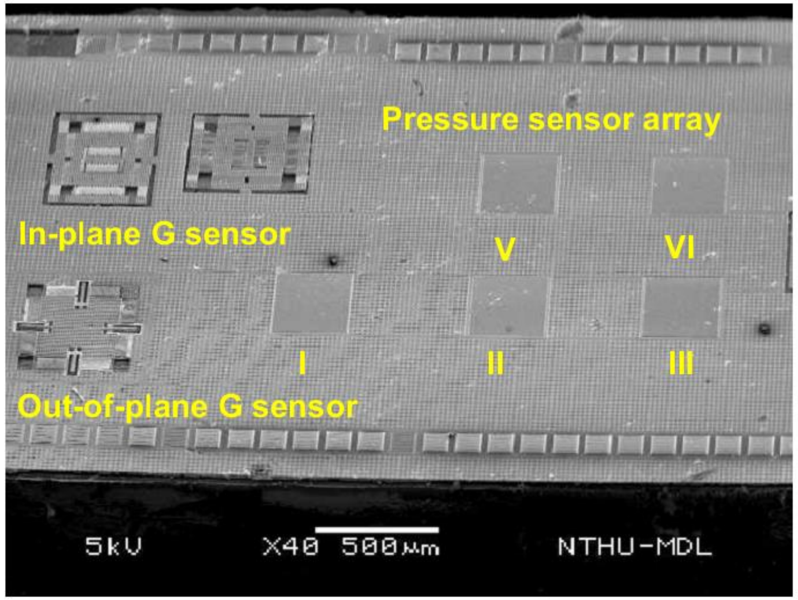
Opportunities



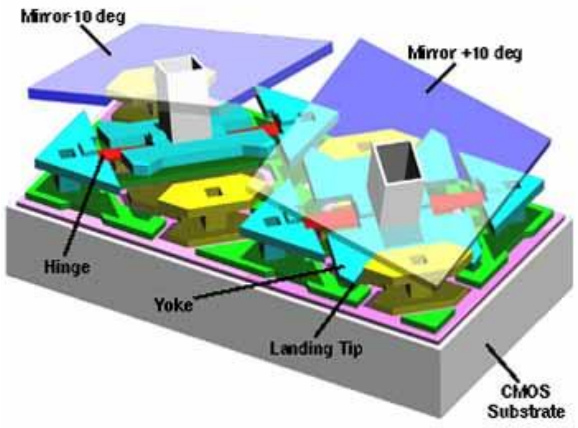
- Many opportunities of macroelectronics and/related technologies (deposited or printed electronics)

CMOS/MEMS combinations

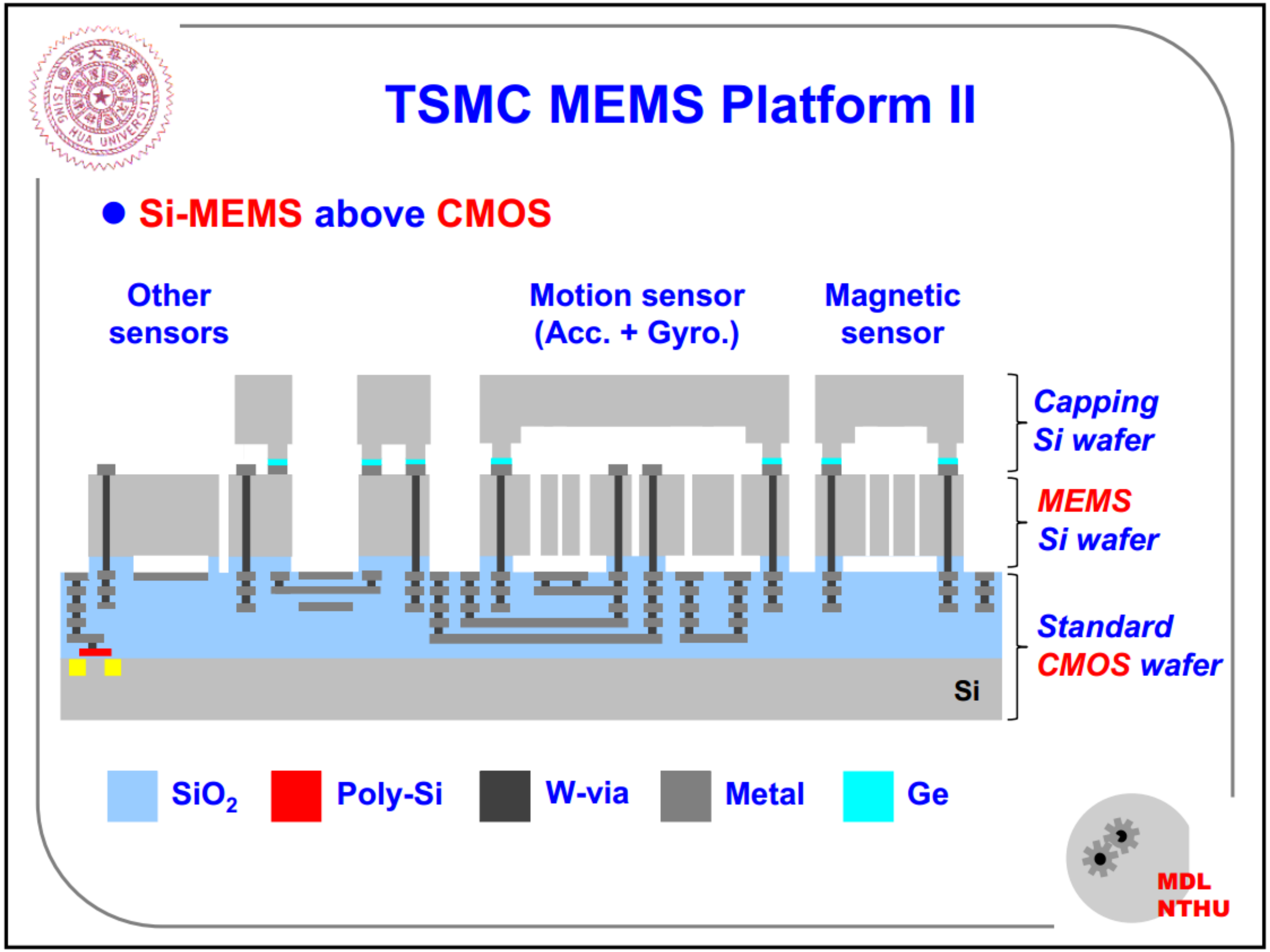




Prof. Fang (MDL NTHU), TSMC plateform



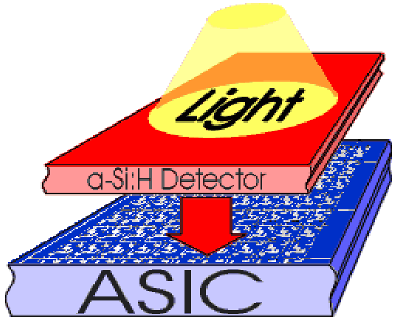
Hybrid technology plateform

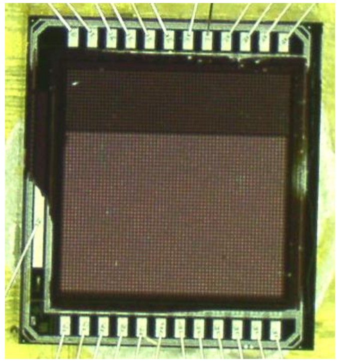


Prof. W. Fang
National Tsing
Hua Univ.,
Taiwan

Some a-Si:H "More than Moore" examples

- TFA detectors (vertical integration of a-Si:H photodiode array on CMOS readout chips);for light or particles





- Bolometer arrays

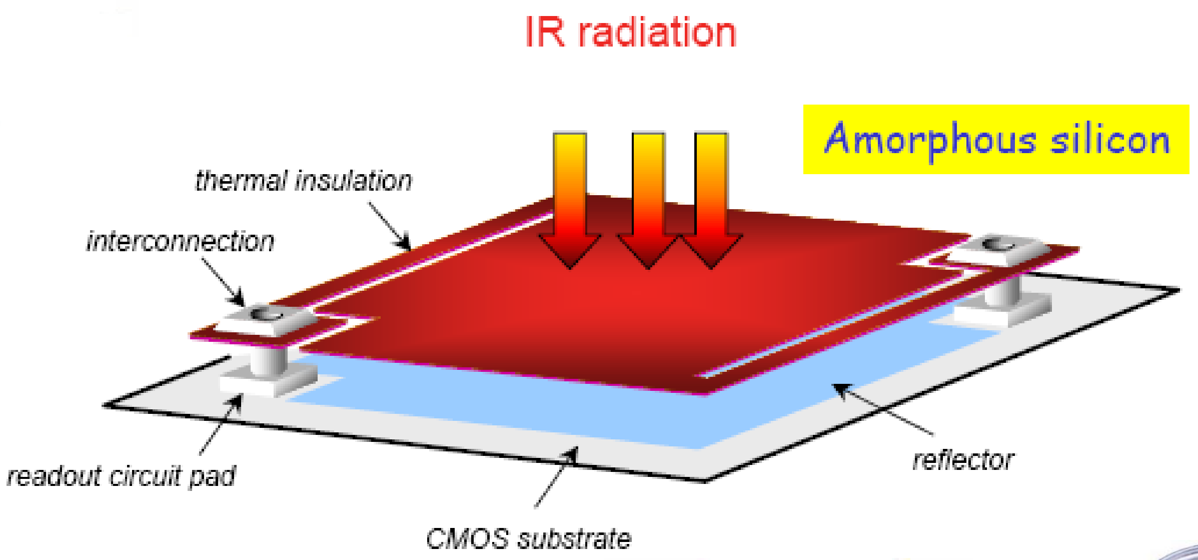
ULIS

- Biochips

- Microfluidic systems

- Particle detectors

Bolometer array



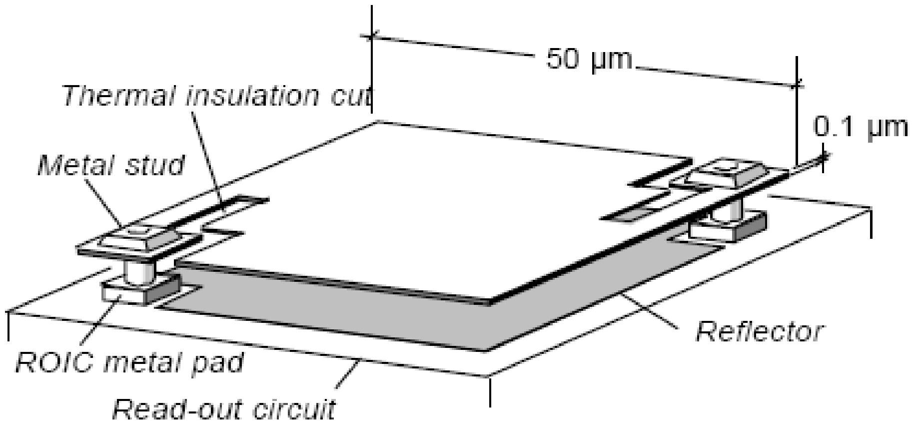
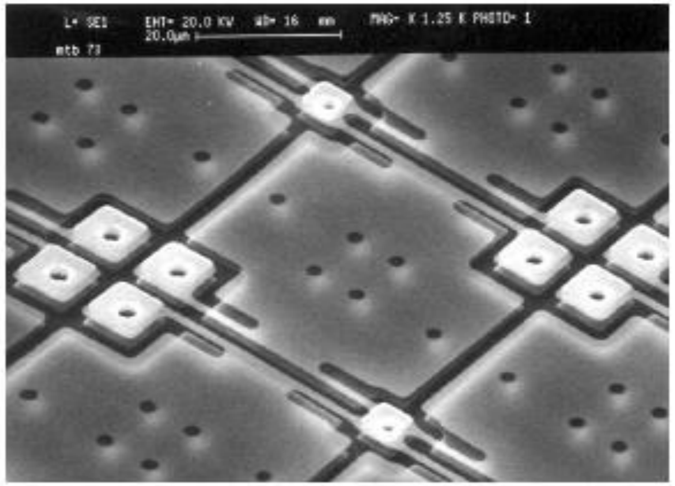


Figure 1: Schematic of microbolometer pixel

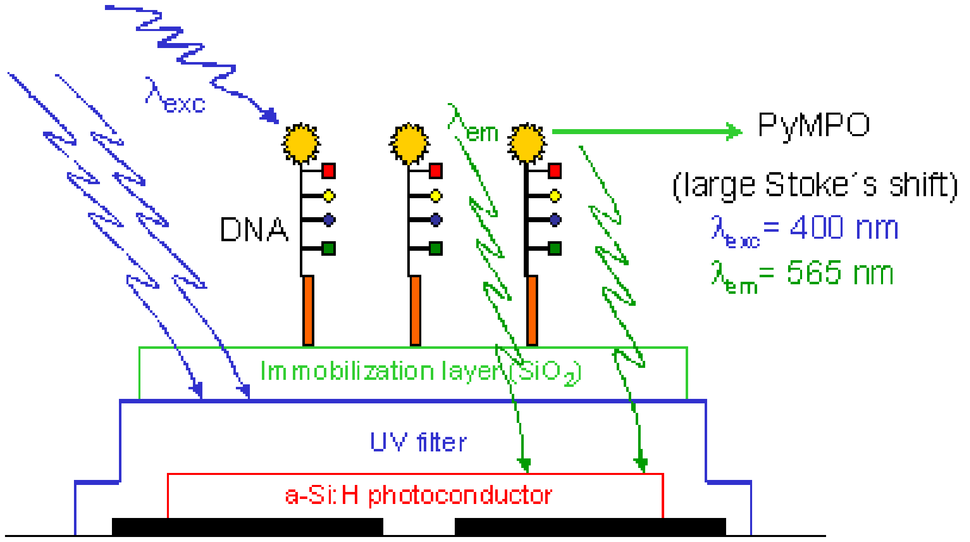
ULIS

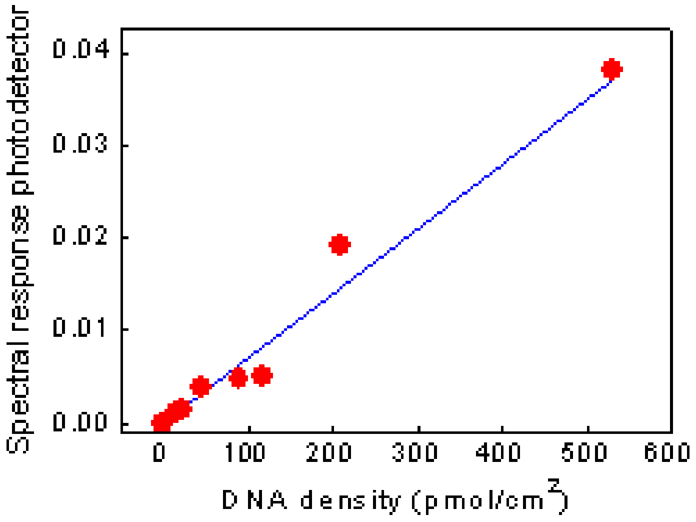


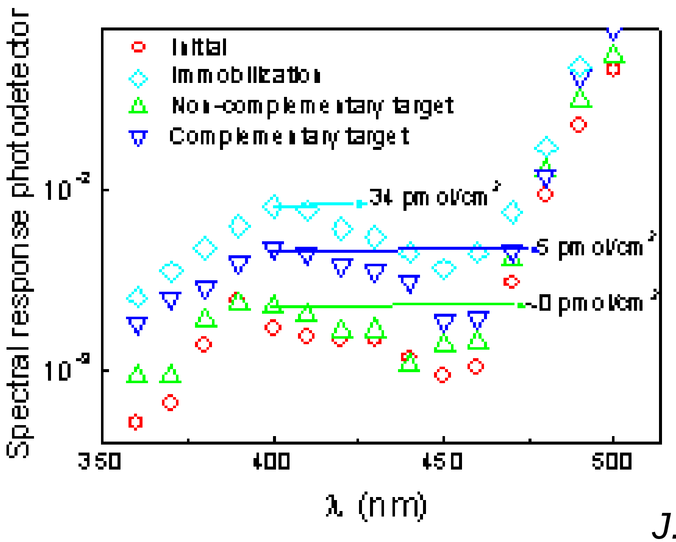
E. MOTTIN et al., LETI

BioMEMS

- DNA Detection

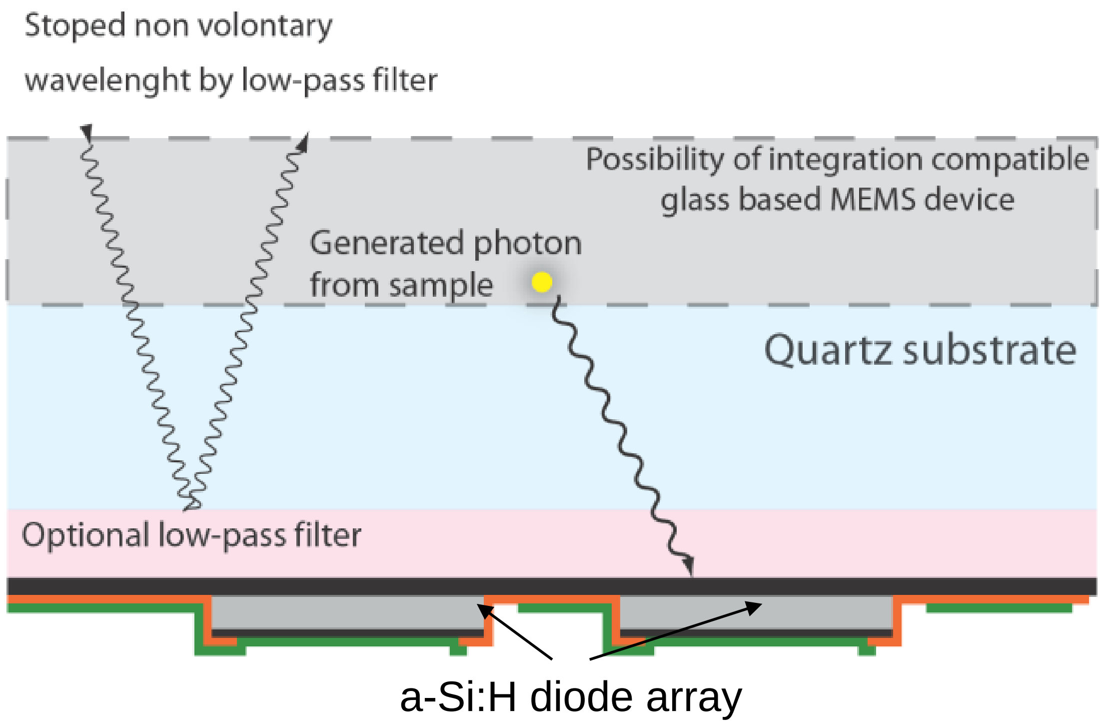


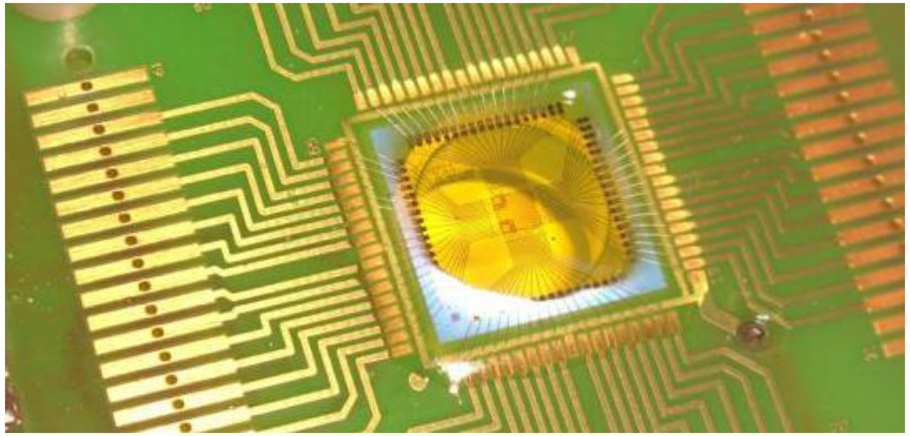


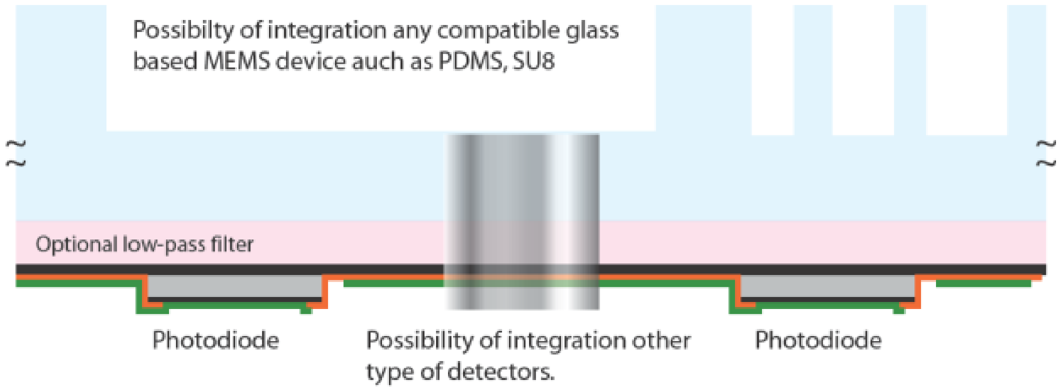


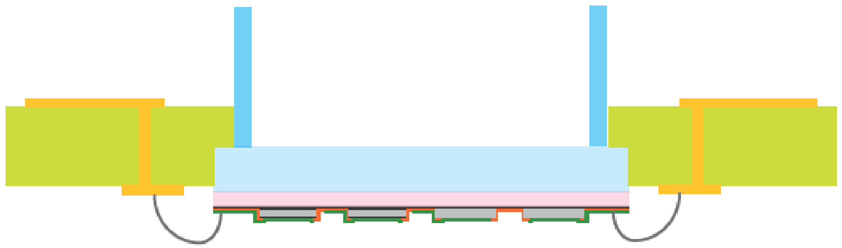
J. Conde, INESC, Lisbon

BioMEMS





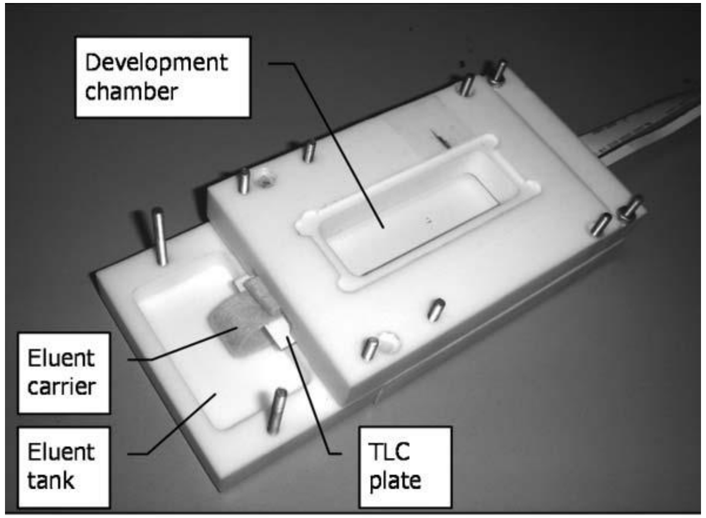




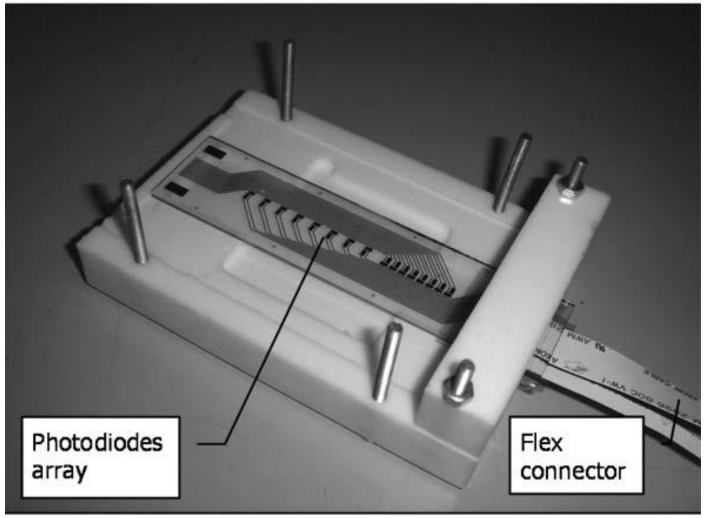
M. Moridi, EPFL

Chromatograph

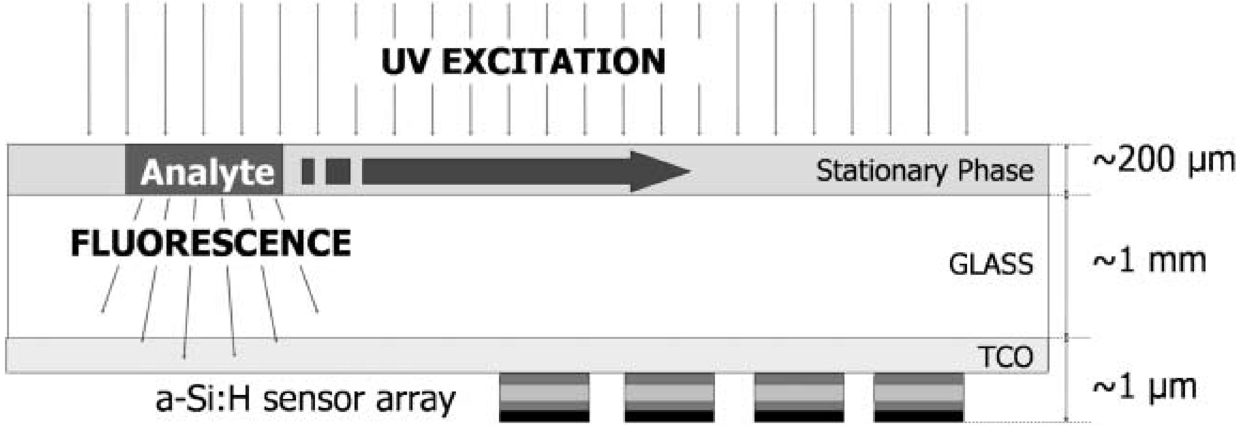
N. Wyrsch



(a)



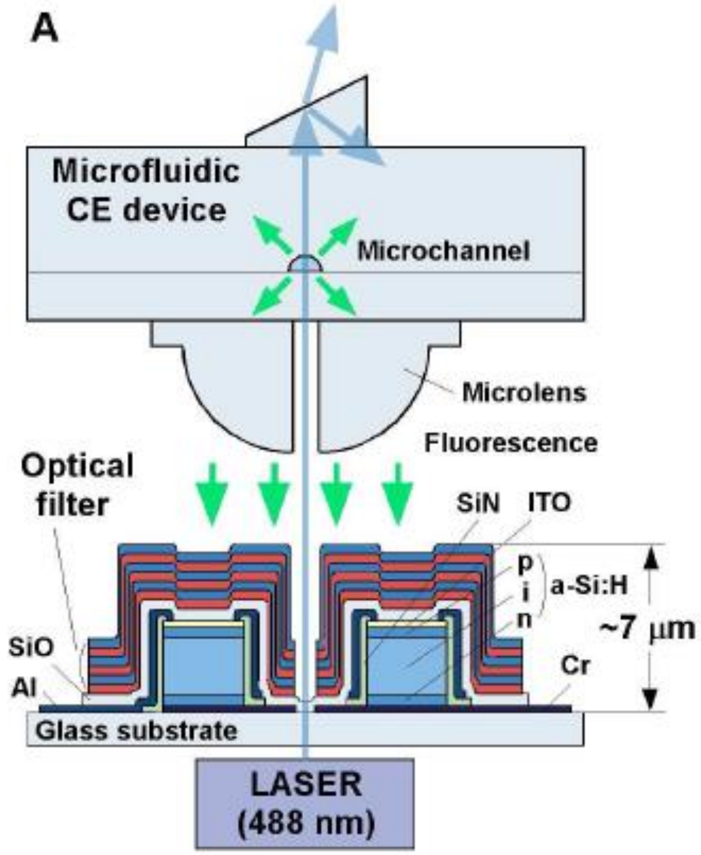
(b)

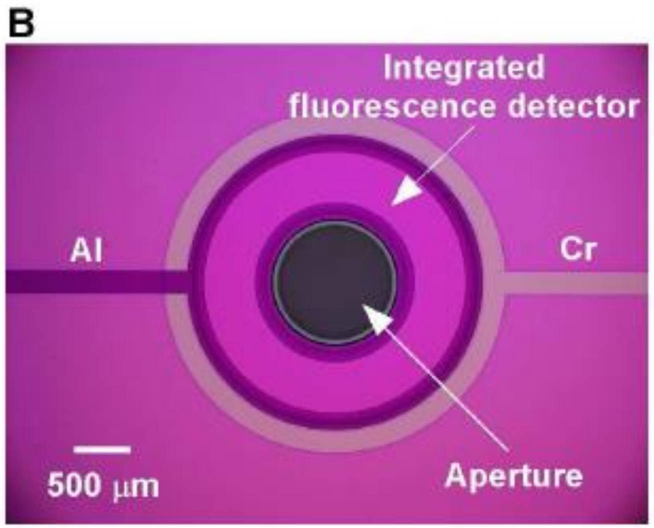


D.Caputo, 2007

Fluorescence detector

N. Wyrsch



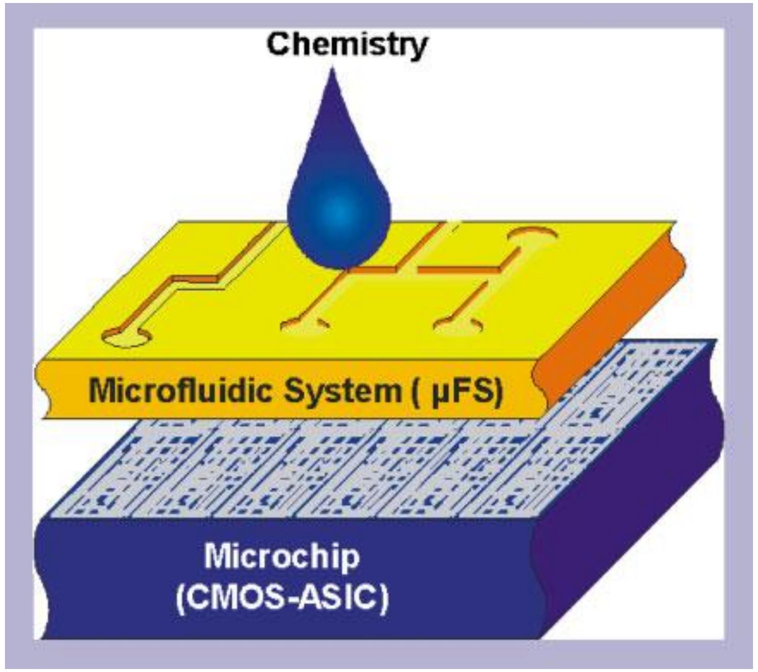


A Schematic crosssectional view of a microlens and an integrated a-Si:H fluorescence detector, forming a compact platform where microfluidic CE device is mounted.

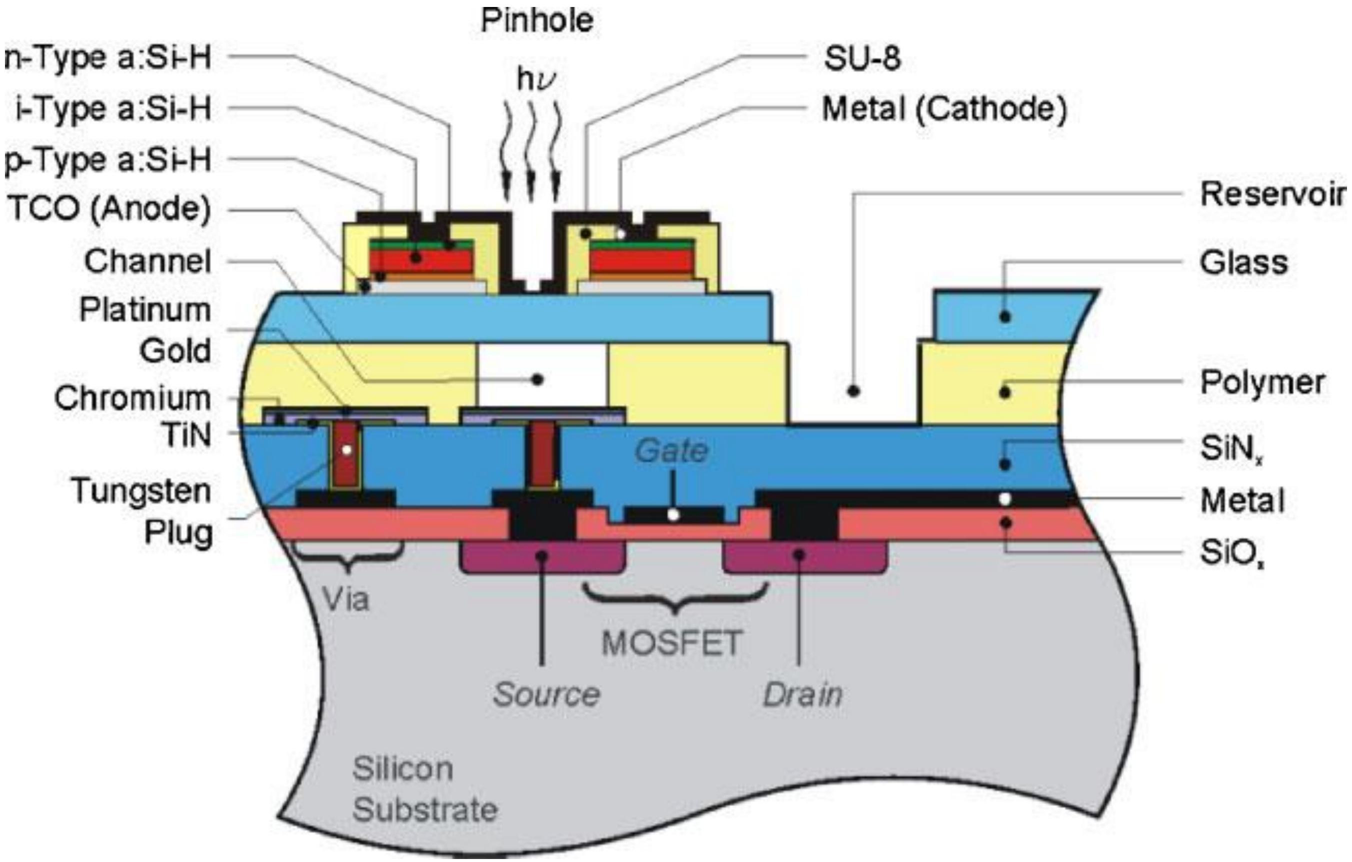
B Optical micrograph of the top view of the integrated fluorescence detector.

Kamei, MRS 2010

Sensors for microfluidic



electrophoresis separation microchip with monolithic integrated excitation light source and variospectral photodiodes for absorption detection



K. Watty, 2010

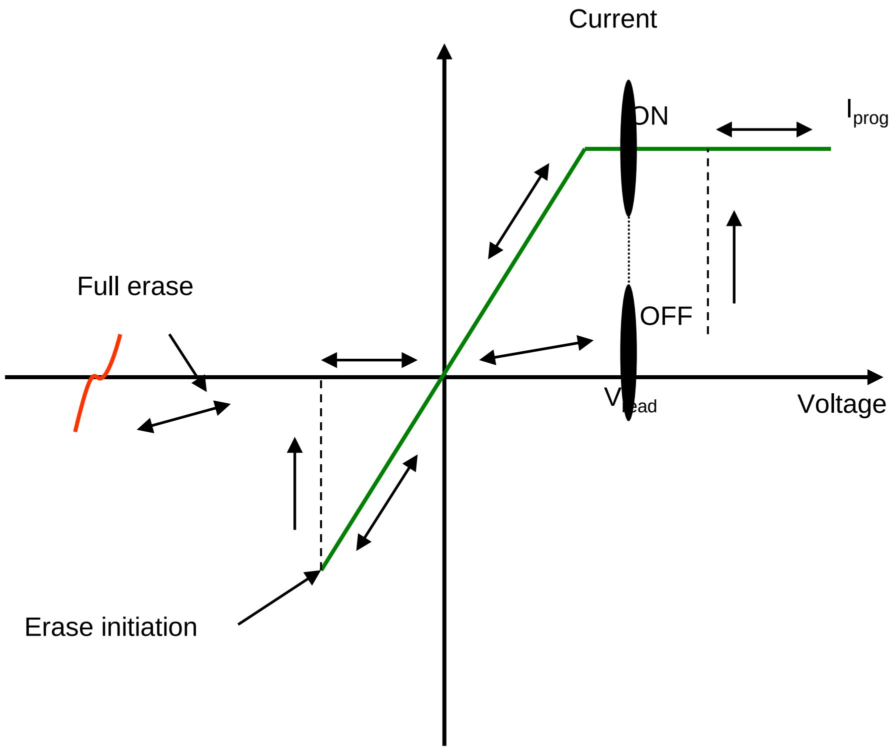
Emerging non-volatile memories, memristors

N. Wyrsch

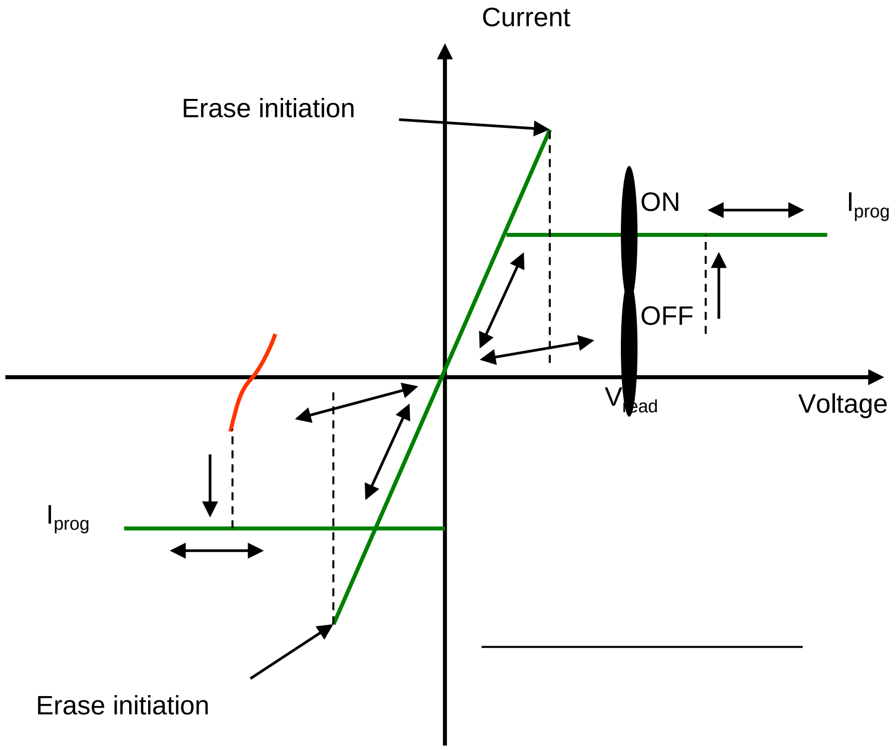
- Current technologies to be limited by the feature size
- New material and memory technologies needed for Tb memories
- Resistive memories is an option
  - Change in resistance upon application of a voltage or current
    - Device exhibit a high resistance state and one or more low resistance state
  - Many materials or material combinations (amorphous materials including semiconductors)
  - Variety of mechanisms
  - Many device configurations
  - Very small cell volume
  - Low cost potential (large-area deposition possible)
  - Usually non compatible with CMOS electronics

Switching mechanism

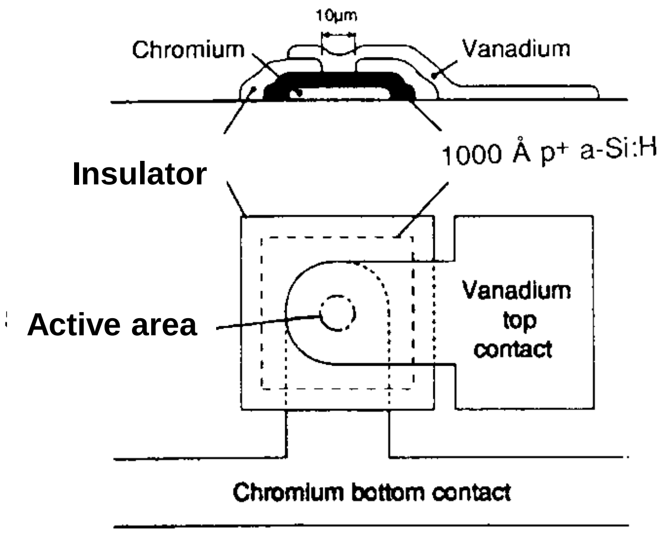
- Bipolar
  - Opposite polarity required for write and erase
  - Device not symmetric
  - Different electrode materials



- Unipolar
  - Same polarity (but different current magnitude) required for write and erase
  - Device usually symmetric

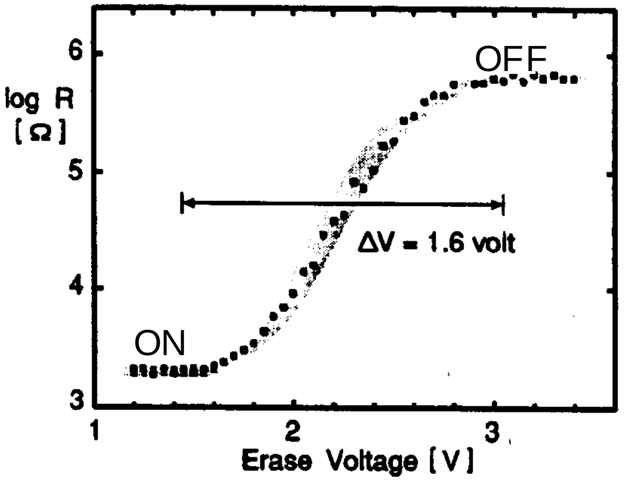


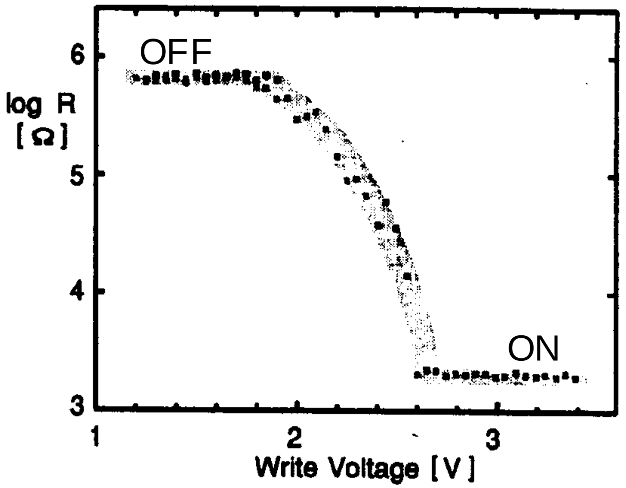
Switching in amorphous semiconductors



- First observed in metal / chalcogenides /metal structures
- Switching behavior depends on contact
- Resistivity of a-SiH controlled by a a filament inside between the contacts (metal diffusion during initial forming of the device)

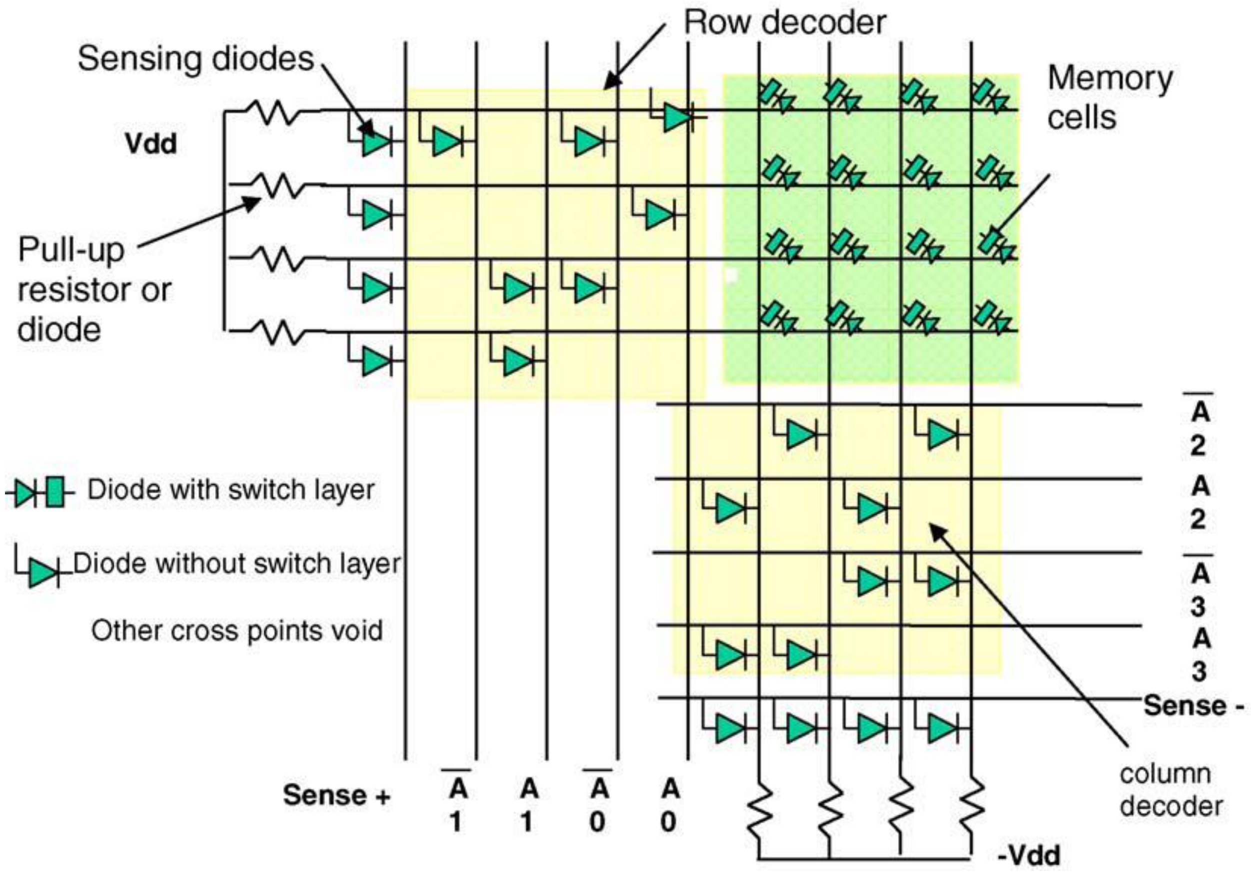
Example of switching device with a-Si:H (Hajto, 1991, 1992)

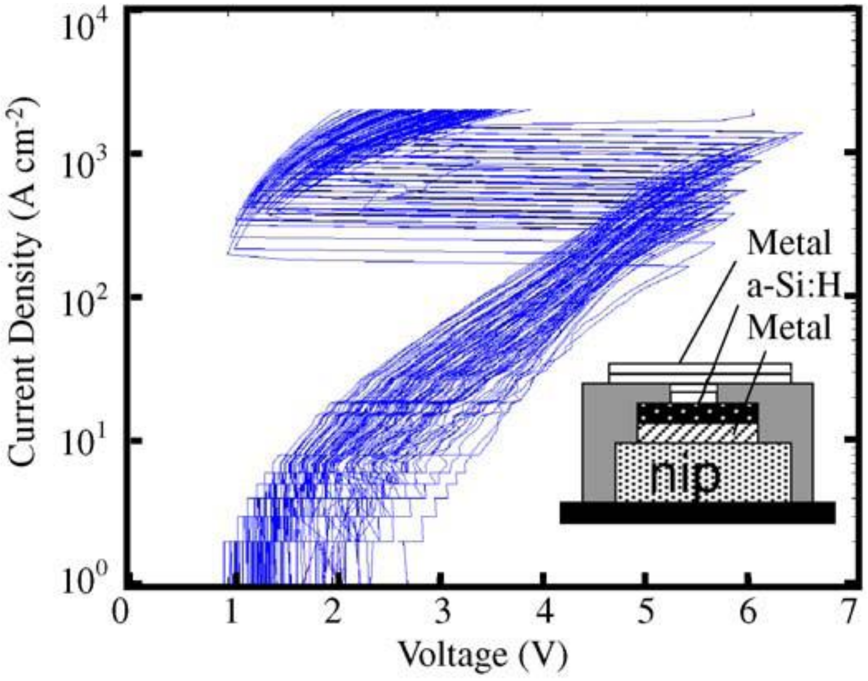




- Reading voltage: < 1 V
- Writing voltage: +1-5 V (pulsed)
- Reading voltage: -1- -5 V (pulsed)

a-Si:H memory implementation

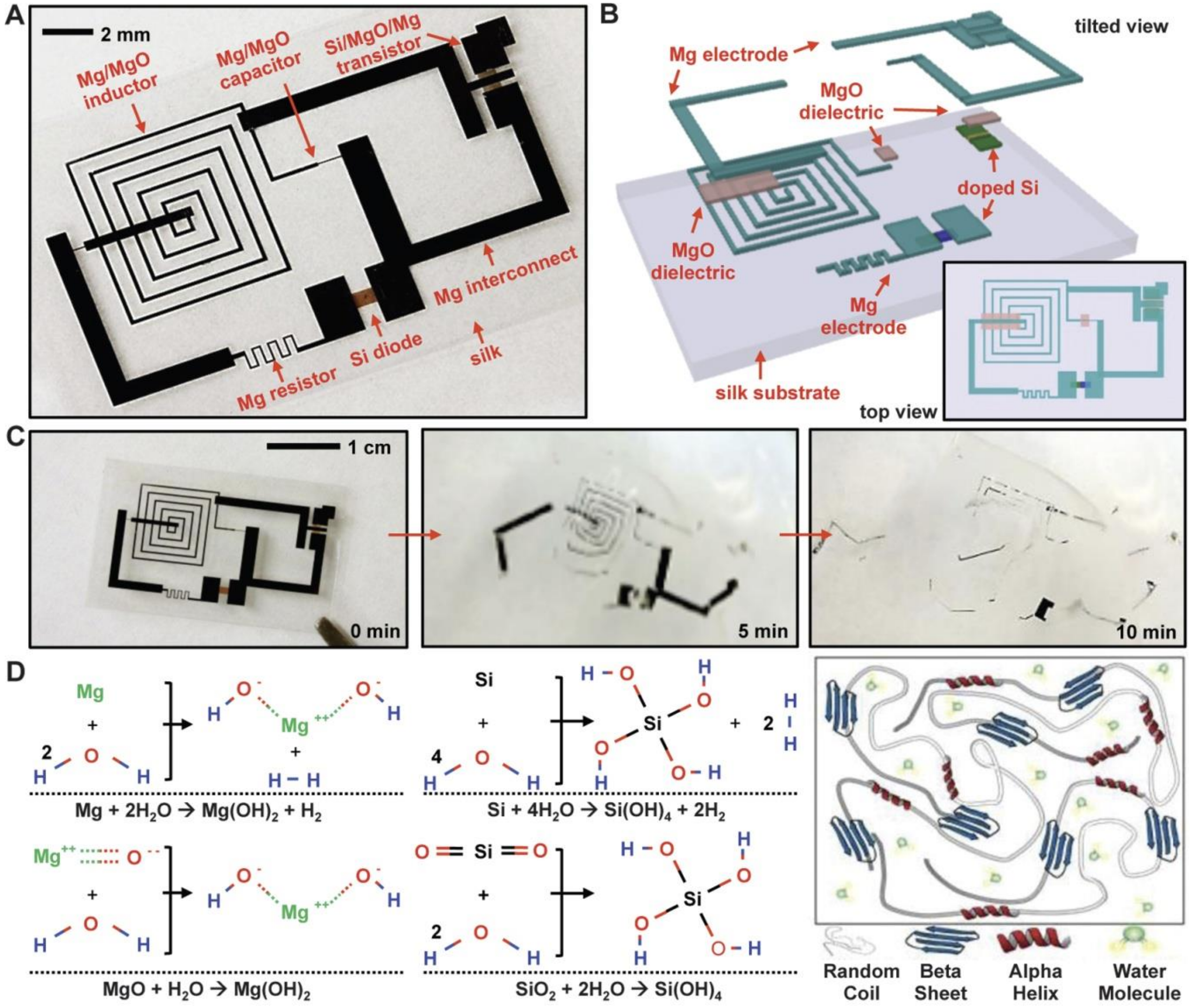




Switching characteristics of metal/a-Si:H/metal/nip/metal cross point memory structures in a 10 x 10 array fabricated by imprint lithography.

W.B. Jackson 2006

Transient electronics



Suk-Won Hwang et al., Science 337 (2012)

- Short lifetime electronics
- Implantation in body
- Bio compatible
- Fully resorbable / degradable
- Deposited on «silk» (water solvable and enzimatically degradable)

D.-H. Kim et al., Nat. Mater. 9, 511 (2010)

- Possible applications: post operation monitoring, local medical treatment, …

Final remarks

- Macroelectronics enabled by deposited (amorphous/disordered) semiconductors (mainly a-Si:H, printed organic maturing)
- Performing devices can be fabricated despite rather poor electronic properties
- Speed of devices limited by traps, defects or disorder
- Variety of new semiconductors with similar properties (e.g. metal oxides, organics)
- Thin-film (a-Si:H, organics,…) technology can be applied successfully for integrated devices / system ("More than Moore" approach)
- Bright future for thin-film devices and hybrid technologies