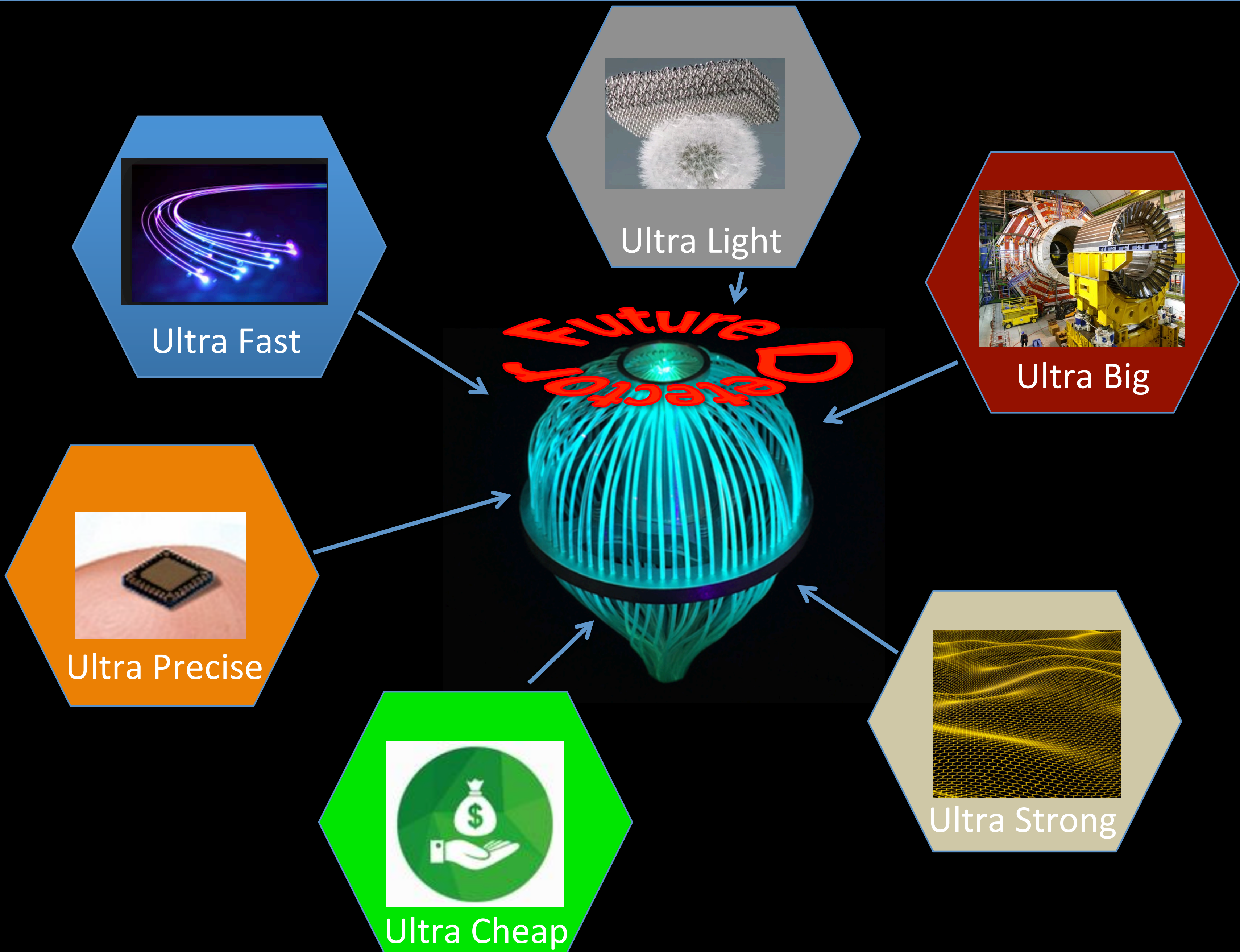
"3D"

A personal view of possible future trends in radiation detection

Cinzia Da Vià, The University of Manchester, UK

- 3D sensors
- 3D systems
- 3D printing
- 2D materials!

Introduction: The Ultra Detector..



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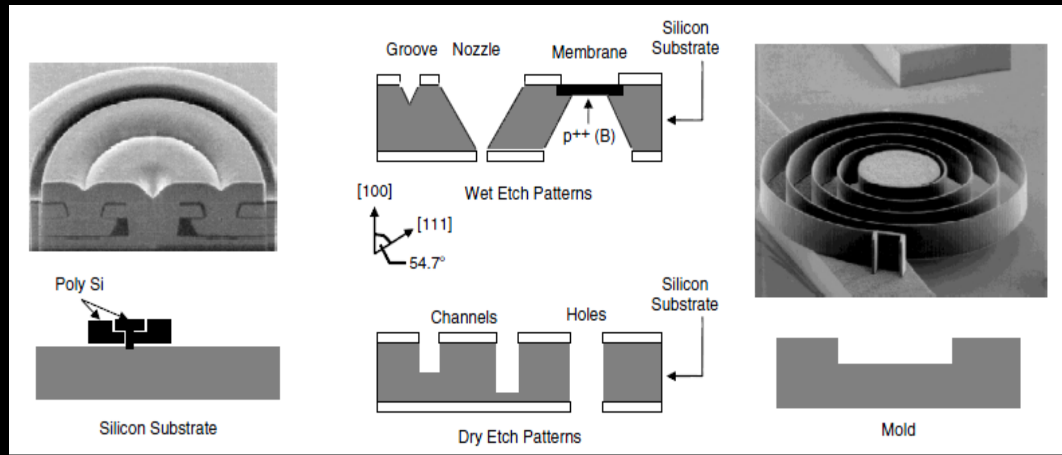
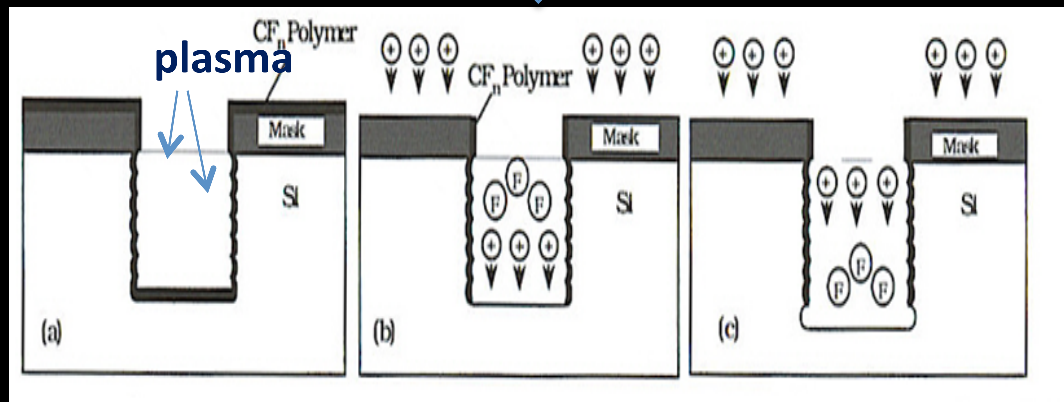
Ultra precise→ Micro-Fabrication-MEMS

In Micro-fabrication, used mainly for Micro-Electro Mechanical Systems (MEMS), the process is performed 3 dimensionally within the silicon volume

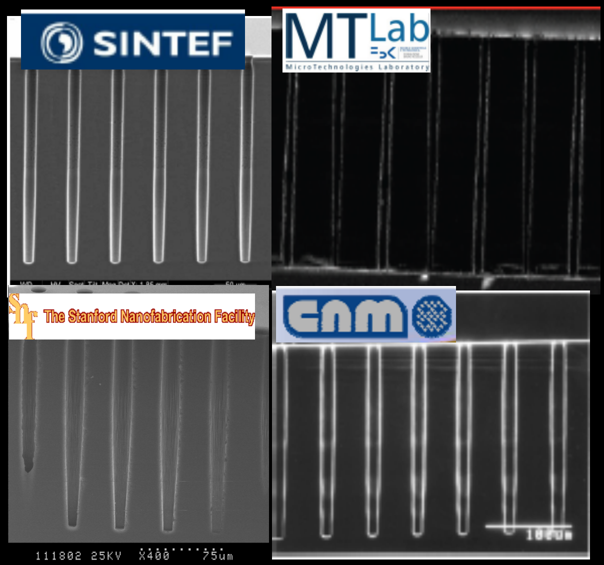
- Surface: Structures are formed by deposition and etching of sacrificial and structural thin films
- Bulk, Volume: 3D structures formed by dry or wet etching of silicon substrates
- LIGA: 3D structures formed by mold fabrication followed by injection molding or electroplating

surface bulk Liga



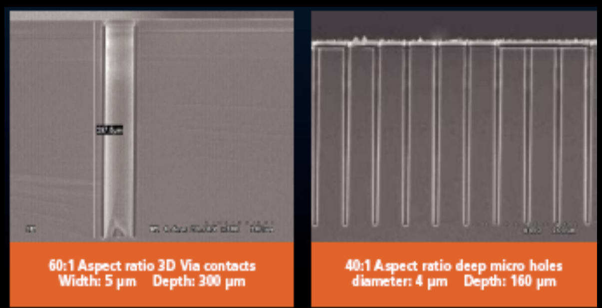


Developments in Bulk Micro-Fabrication

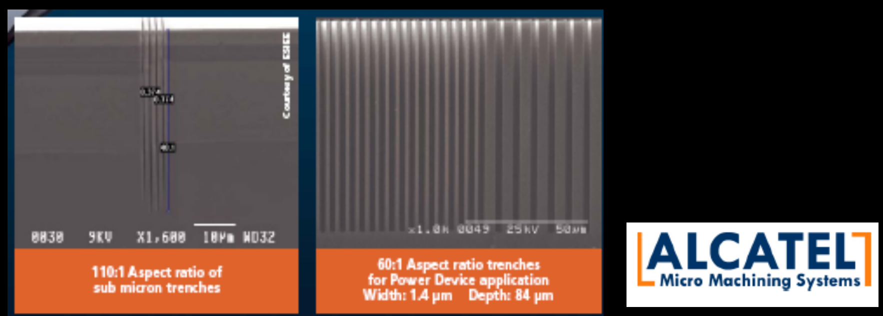


11:1
1997

24:1
today



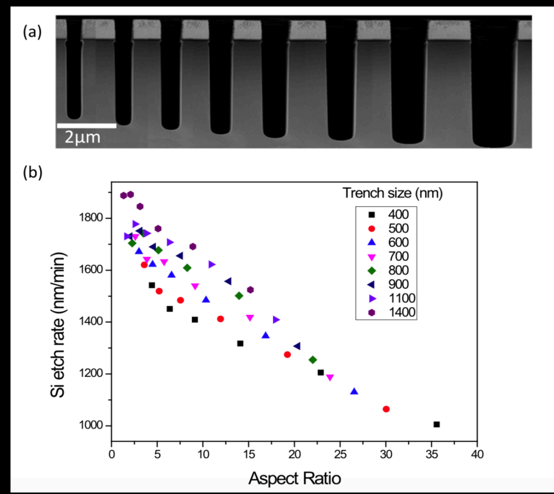
40-60:1

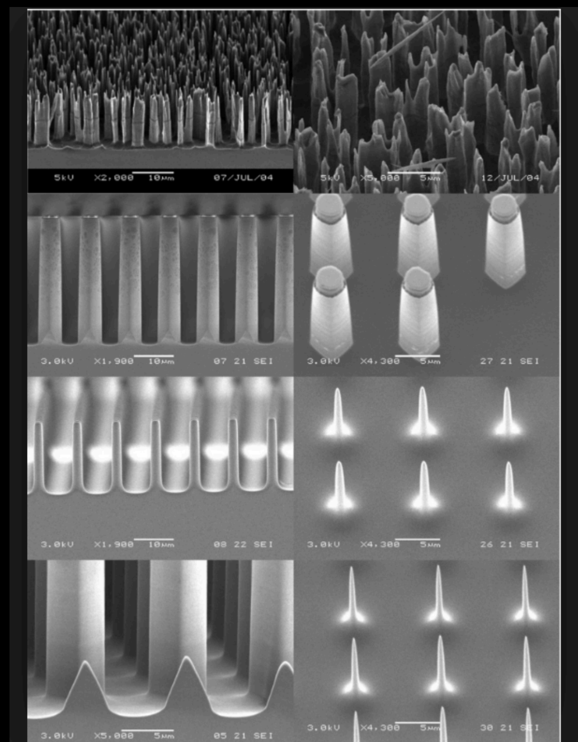


110:1!!!

Deep Reactive Ion Etching

Cryo-etching





Every Day MEMS & Market driven development

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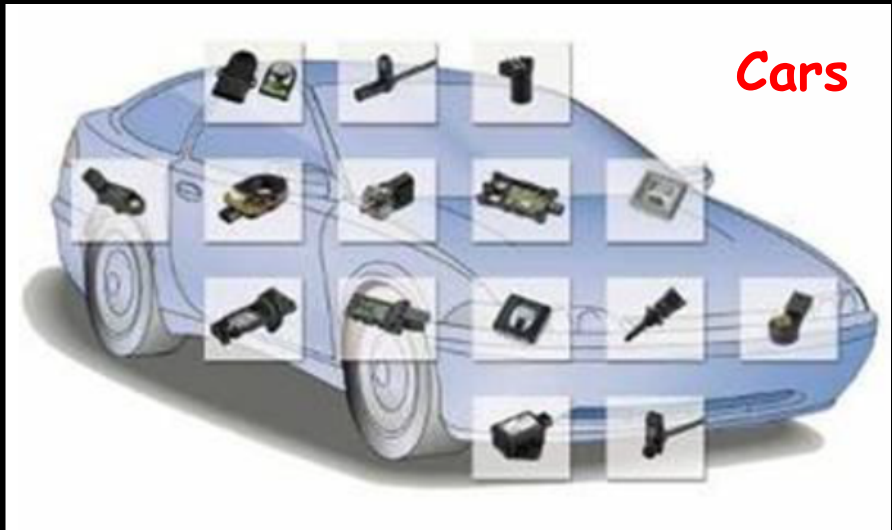
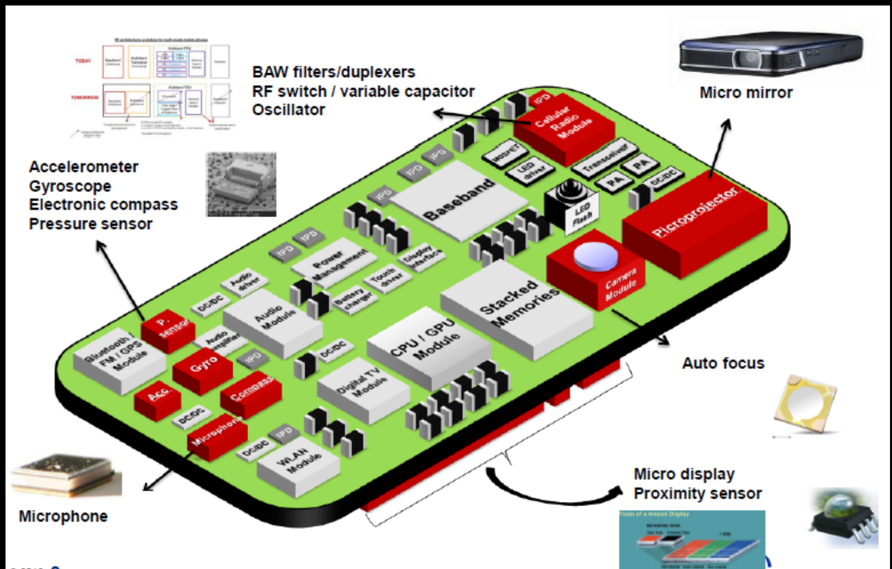
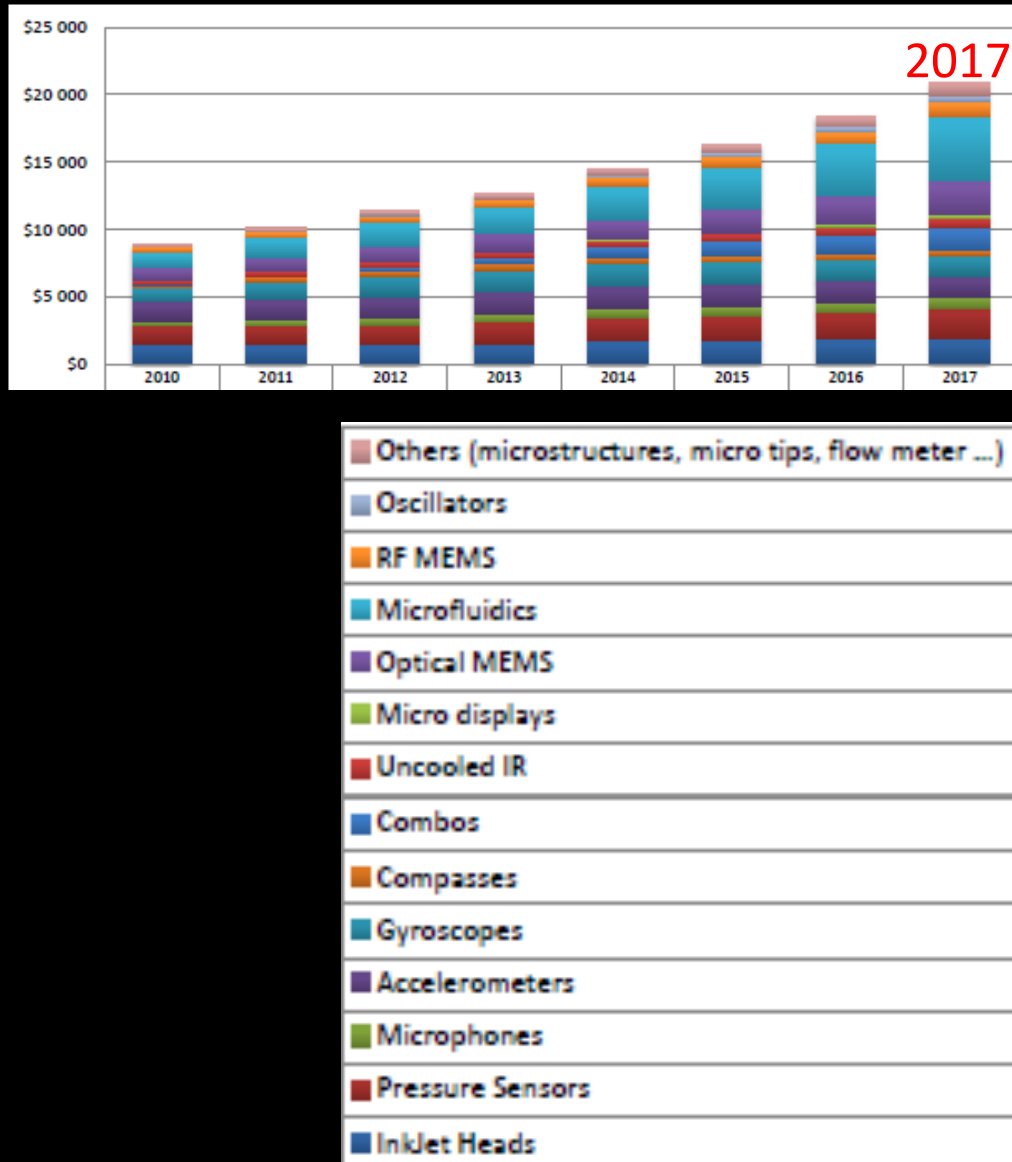
TODAY





Smartphones



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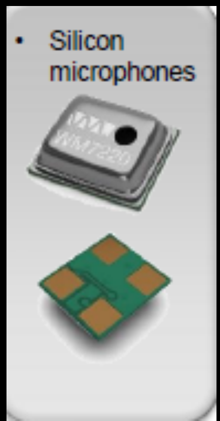
Industry: MEMS Sensors and actuators

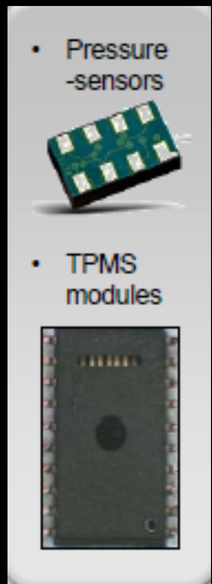
Sensing Applications

Voice/ sound



Motion/ position

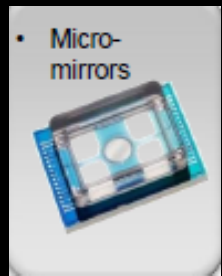
Pressure/ monitoring



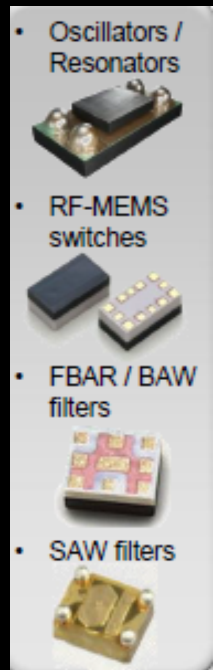
TPMS
Tire pressure m onitoring system

Actuating Applications

Projecting Receiving light

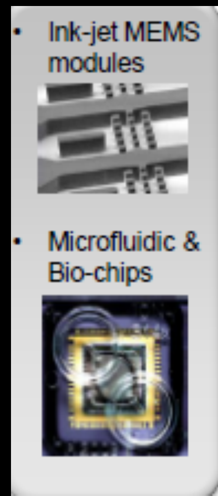


RF Related functions

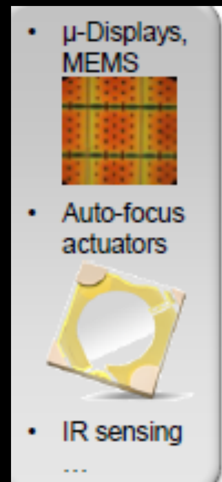


Surface acoustic wave

Managing fluids



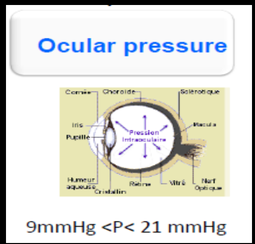
Emerging MEMS

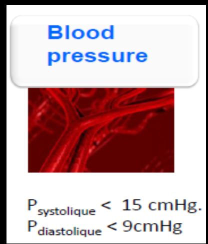


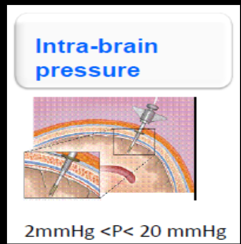
Applications in Bio-Medicine

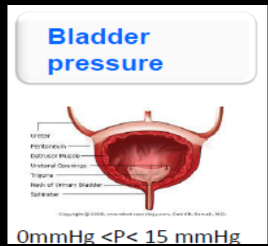
Source: Lami EpoSS 2012

Pressure Sensing



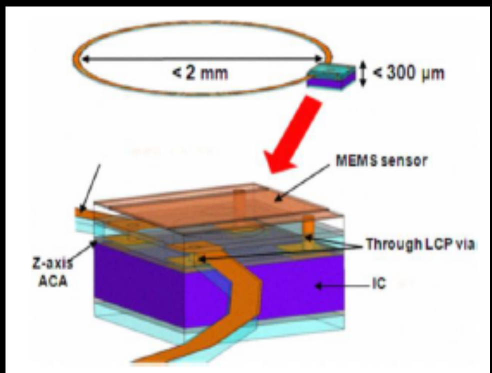




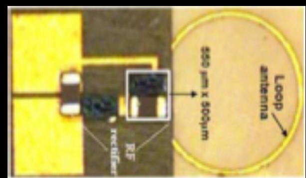


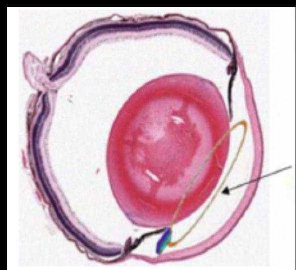
Glaucoma diagnosis

D. Ha et al. IMS 2010



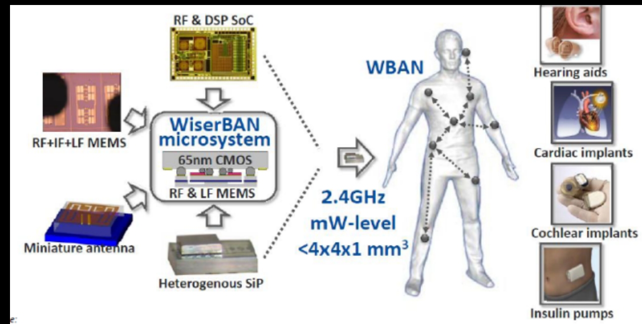
3D IC and MEMS stacking



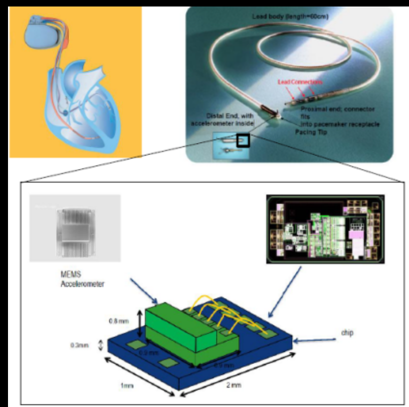


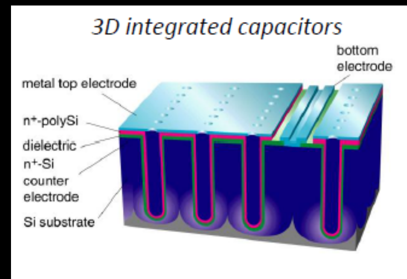
Inserted in a mouse's eye

Implantable Devices

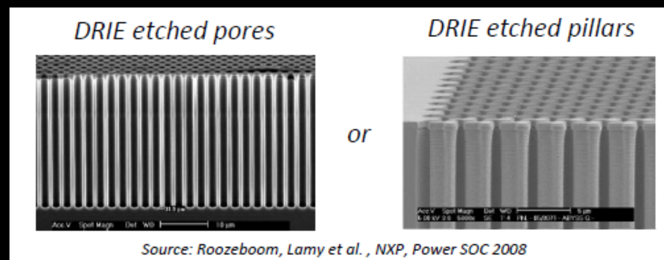


Acceleration monitoring in pacemakers





Energy Management
500 nF/mm
Using high k dielectrics



Source A. Rippart INEMI 2011

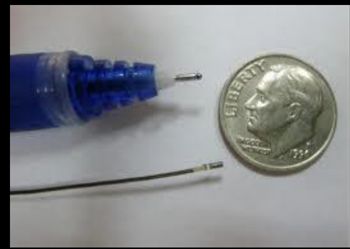
Applications in Bio-Medicine

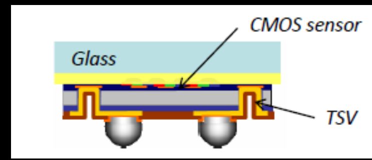
Source: S. Bhansali

MEMS sensors in the biomedical field maybe used as:

- Critical sensors, used during operations.
- Long term sensors for prosthetic devices.
- Sensor arrays for rapid monitoring,
- Diagnosis at home.

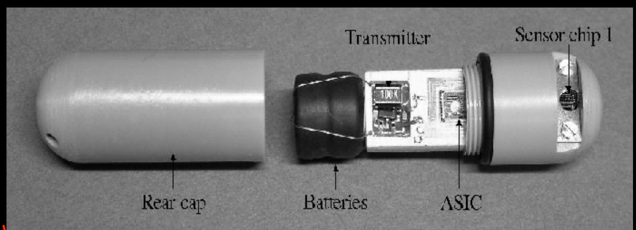
"Ultra miniaturized camera for endoscopy with TSVs"





Source: I-Micronews May 2011

http://www.spie.org/web/oer/august/aug00/cover2.html
http://www.see.ed.ac.uk/~tbt/norchip2002.pdf



35mm

"lab on a pill"

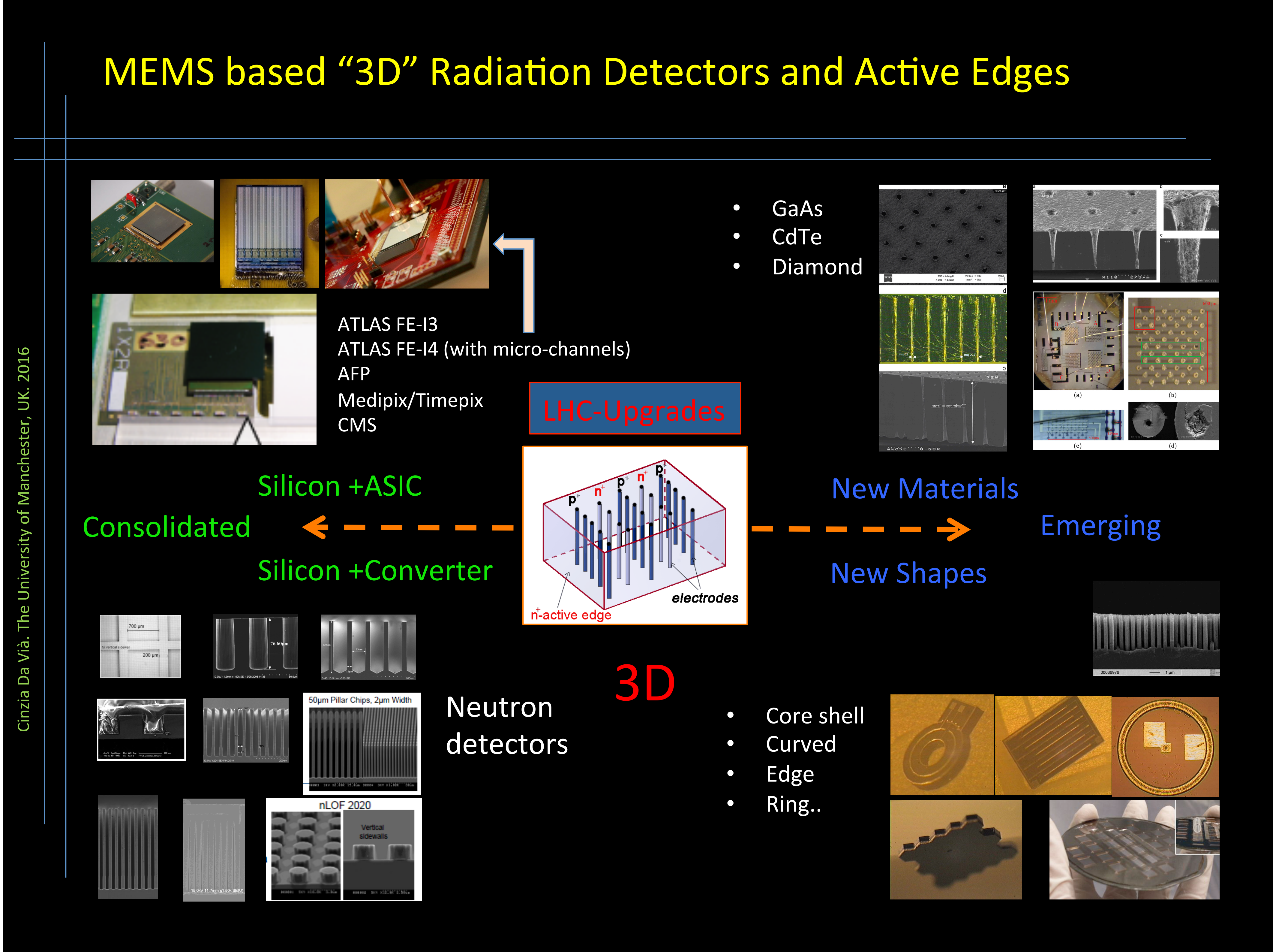
- Digital camera (CMOS Technology)
- Light source
- Battery
- Radio transmitter
- Sensors (MEMS Technology)

"Precision scalpels"

MEMS piezoelectric motor help to accurately position the scalpel.
MEMS pressure sensors incorporated on the scalpel, can help to measure the force exerted on the area operated upon. Accordingly, the scalpel can he handled.

http://www.ee.ucla.edu/~jjudy/publications/conference/msc_2000_judy.pdf

-The pill is intended to be swallowed like any normal pill.
-Once within the body, the pill's sensors sample body fluids and pick up "meaningful patient data" such as temperature, dissolved oxygen levels and pH.
-The pill is expected to retrieve all data over a 12-hour period and disposed off,
-This data is transmitted wirelessly to a card attached to the wrist of the individual.



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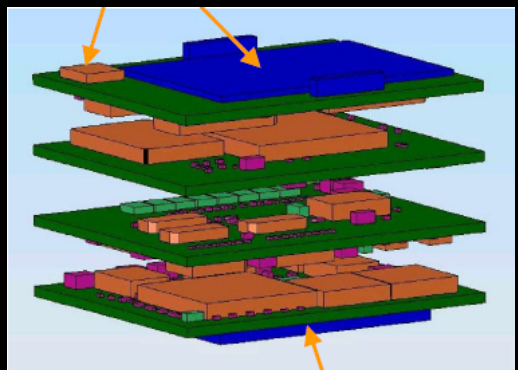
MEMS based "3D" Radiation Detectors and Active Edges
ATLAS FE-I3
ATLAS FE-I4 (with micro-channels)
AFP
Medipix/Timepix
CMS
LHC-Upgrades
• GaAs
• CdTe
• Diamond
Silicon +ASIC
Consolidated
Silicon +Converter
New Materials
Emerging
New Shapes
electrodes
n+-active edge
700 μm
200 μm
76.60μm
50μm Pillar Chips, 2μm Width
nLOF 2020
Vertical sidewalls
Neutron detectors
3D
• Core shell
• Curved
• Edge
• Ring..

3D vertical integration, Micro-Systems and "More than Moore"

- 3D-"System-in-a-Package" (3D-SIP):Integration on the package level. Where multiple dies are integrated in the same package. The resultant packages are afterwards stacked on top of each other using flip chip technology.
- 3D-"Wafer level packaging" (3D-WLP): Integration at wafer level. Interconnection is usually made by through wafer "vias" with a relatively large diameter of e.g. 150 um
- 3D-"Stacked IC" (3D-SIC): Integration on IC foundry level

L1-Opto-electronic

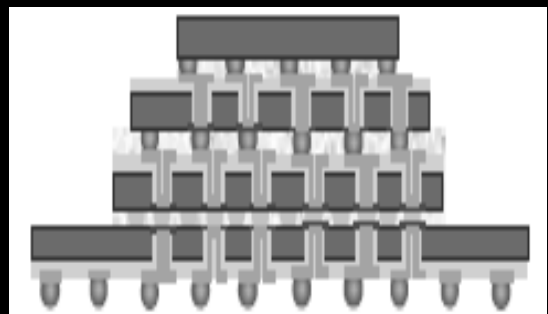


L2-FPGA

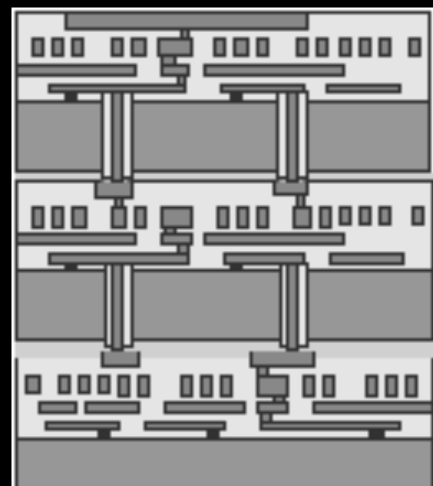
L3-Bus

L4-IC

3D-SiP



3D-WLP



3D-SIC

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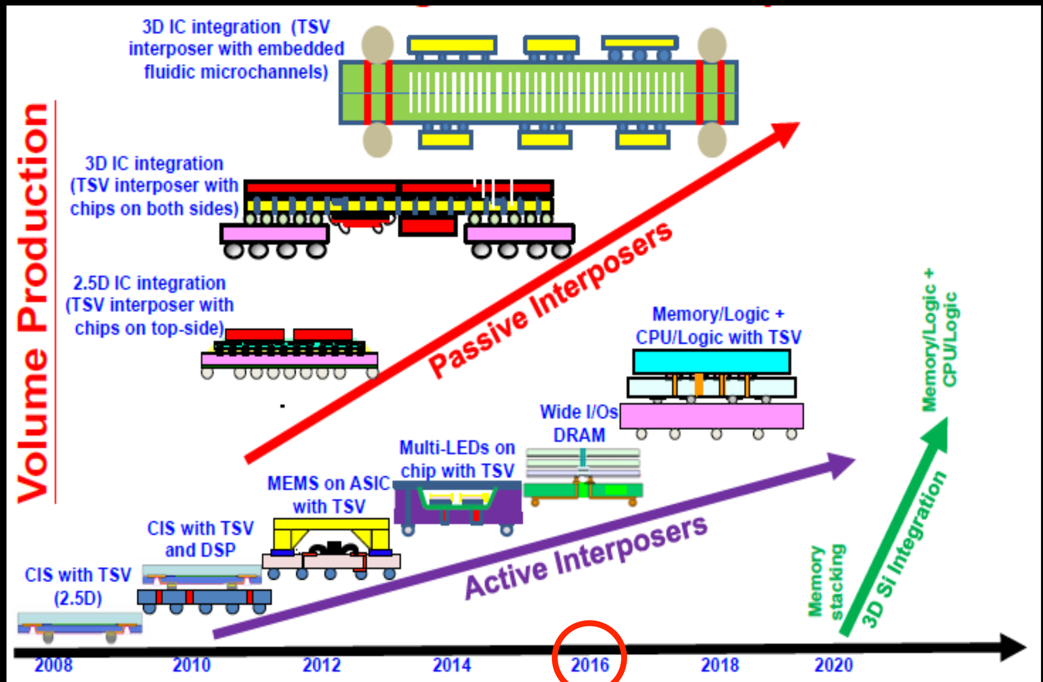
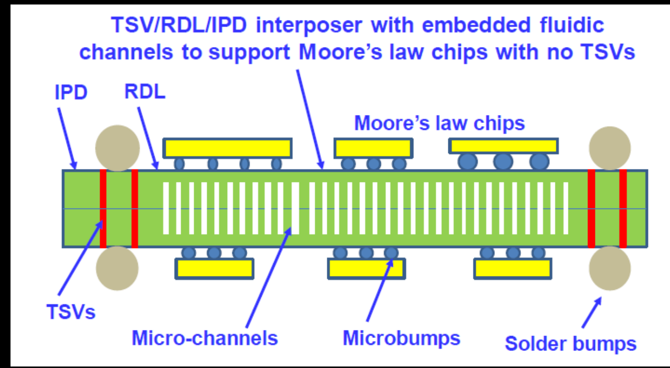
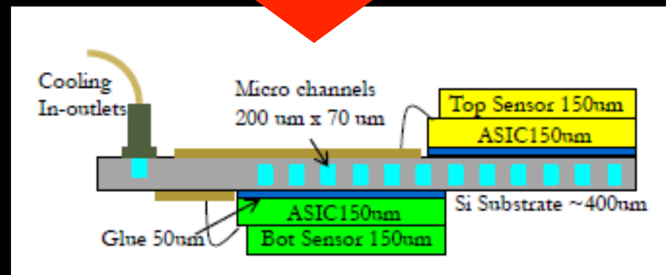
More than Moore: 3D integration roadmap



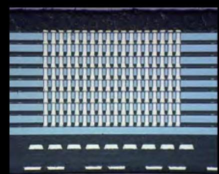
Source: John Lau, ITRI, InterPACK 2011

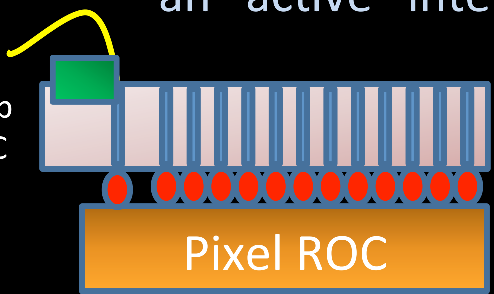


LHCb layout

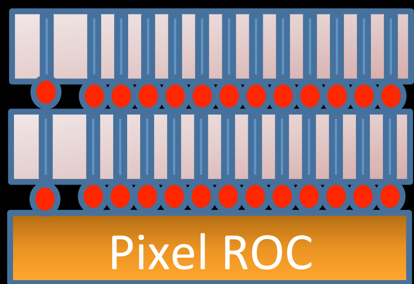


3D sensor can be used as an "active" interposer

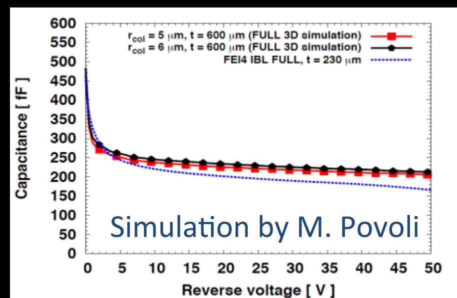




Dual readout



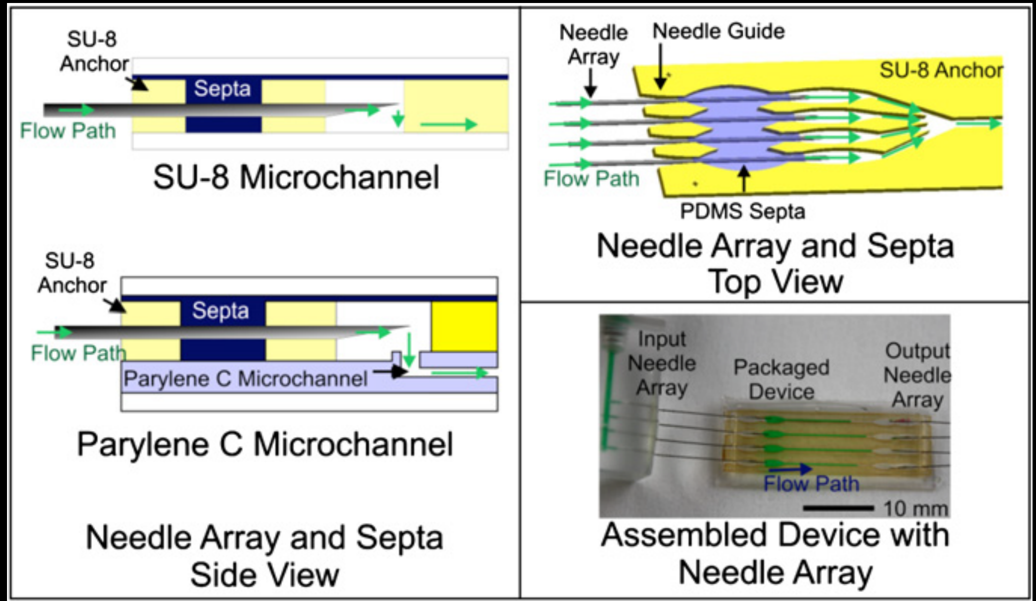
"Stacked " 3D sensors

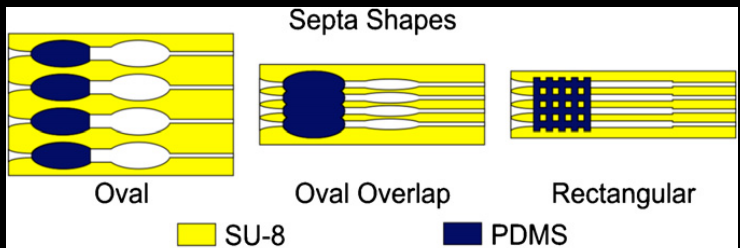


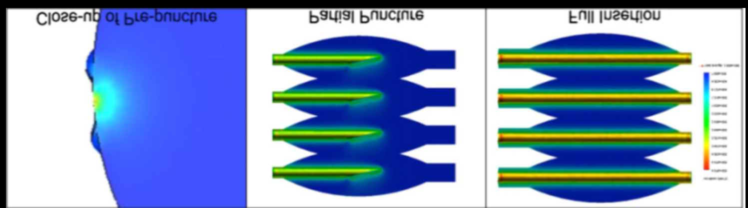
Applications on momentum Discrimination and "charge-share" free x-ray imaging

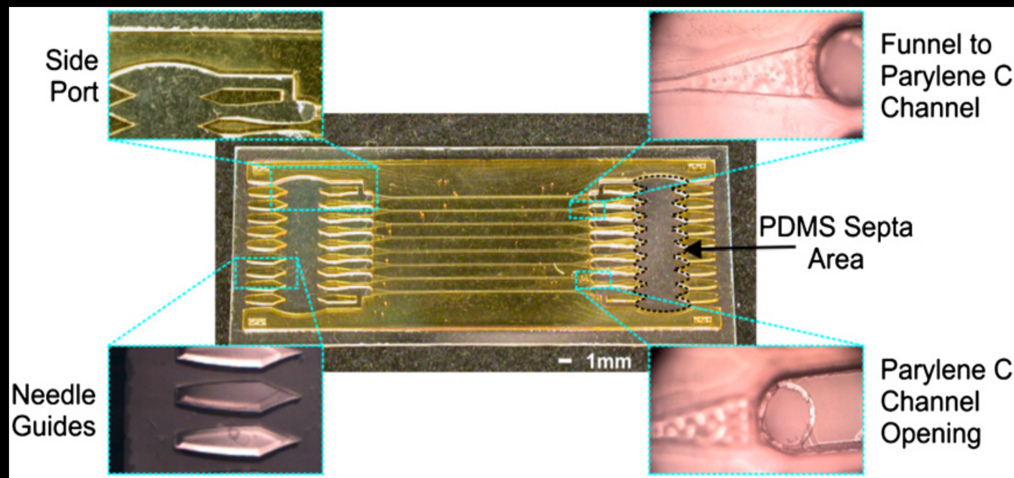
Micro total-analysis systems (μTAS) and lab-on-a-chip (LOC)

- microfluidics are used in applications such as chemical synthesis, genetic analysis, drug screening and single cell/ molecule analysis
- in-plane interconnect using a 'pin-and-socket' approach in which a single commercially available non-coring needle (33G) accessed a microfluidic device by puncturing a polydimethysiloxane (PDMS) septum









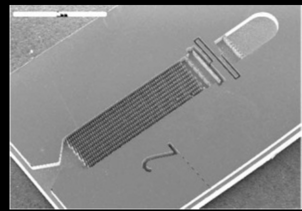
R Lo1 and E Meng
Department of Biomedical Engineering, University of Southern California, 149 Commonwealth Drive, Menlo Park, CA 94025, USA

Applications in Space

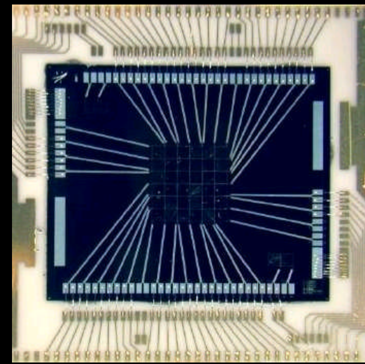
MEMS and Microstructures in A erospace
Applications
Published in 2006 by RC Press Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742

The MEMS technologies included in the NASA inventory:

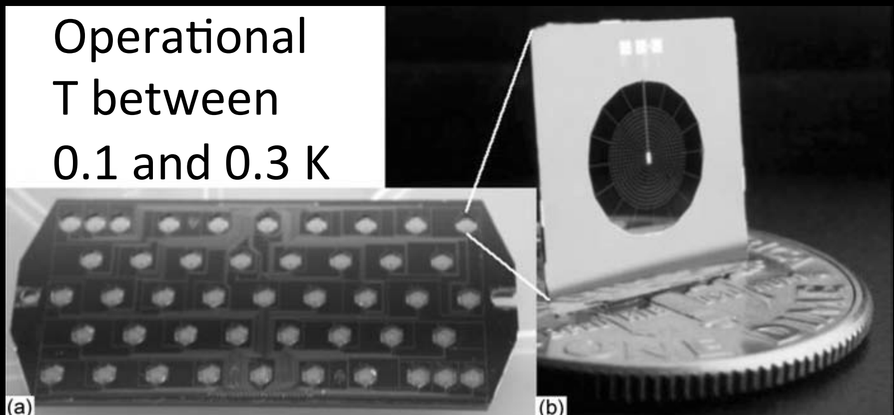
. Stirling coolers
. liquid–metal micro-switches
. inertial sensors
. microwave RF switches and phase shifters
. thrusters
. deformable mirrors
. pressure or temperature sensors
. power supplies
. sensors

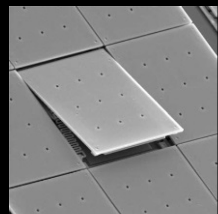


Propulsion thrusters

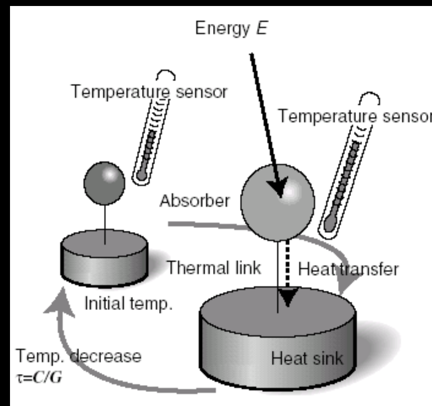


X-Ray sensor being used
For the SUZAKO x-ray
spectrometer





m-mirrors



microfabricated "Spider Web" bolometers, JPL

high-purity, neutron transmutation doped (NTD), single crystal Ge thermistor chip mounted on a "spider web" suspension comprising metallized, suspended SiN filaments

Used as a very sensitive T
Sensor T prop to E (x-ray)

Cinzia Da Vià. The University of Manchester, UK. 2016

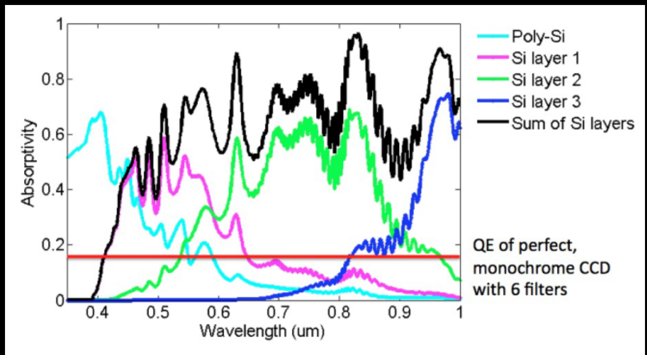
Multi-Layer Polychromatic CCD

Astronomy, Cosmology

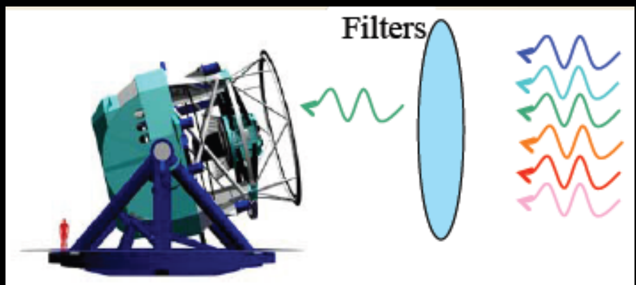
Chu-En Chang, J. Segal, R. Howe, A. Roodman, SLAC
Material from C. Kenney

Imager, which can record the intensity of light within multiple color bands and with high quantum efficiency

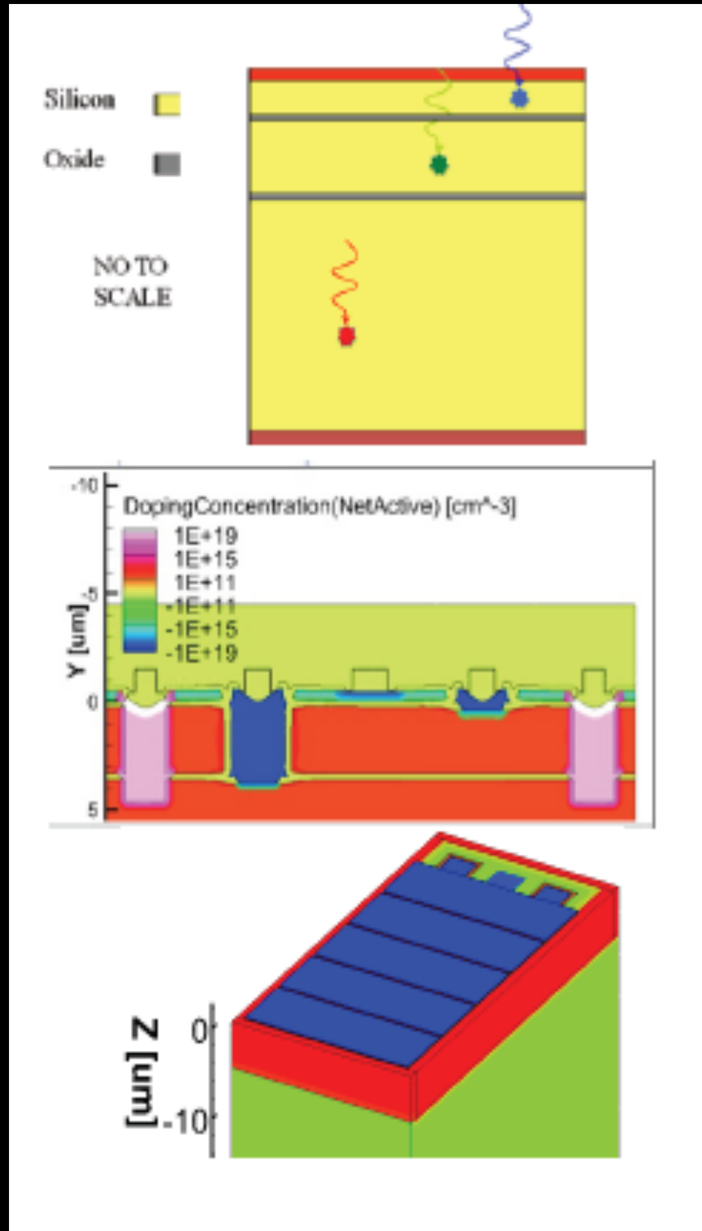
- Basic idea is to make a multi-layer CCD to replace a monochromatic CCD with a ‘color-sensitive” device
- All layers are clocked out simultaneously by the same set of gate electrodes
- Each layer readout separately, but simultaneously
- Employ micro-machining technology for channel stops and read-out contacts – similar procedure used for 3D sensors



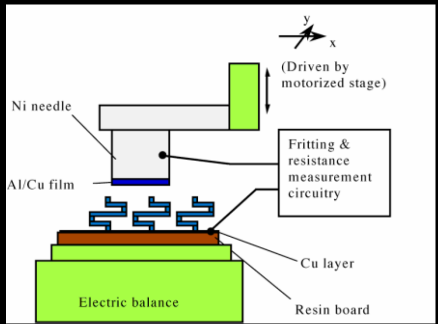
Simulation of quantum efficiency for Poly-chromatic versus mono-chromatic CCDs

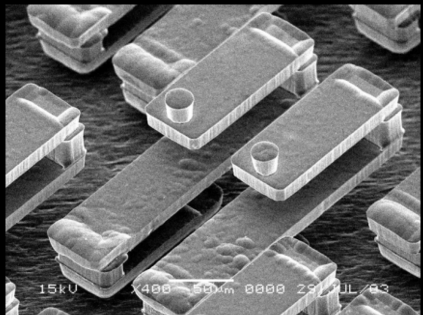


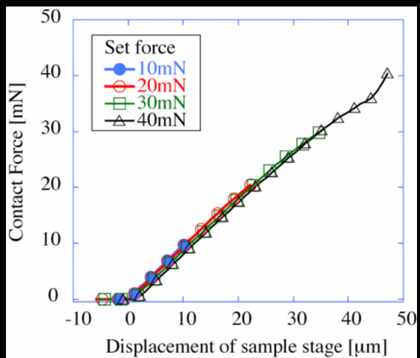
Application in wide-area Optical surveys for cosmology



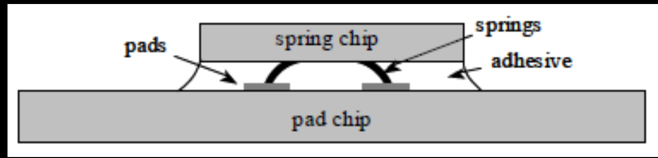
"Wire/bump-bonding free" electrical connectors

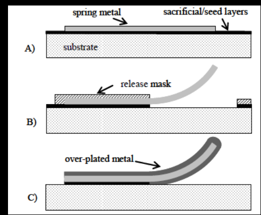


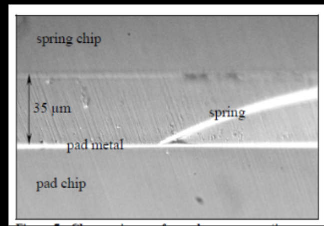


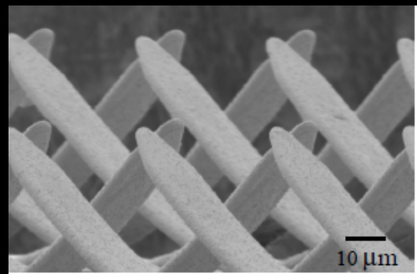


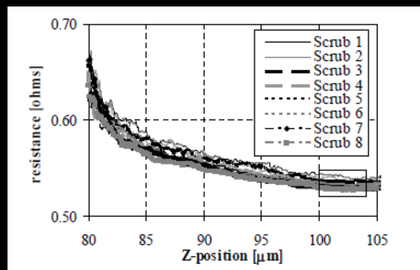
Kenichi Kataoka
Research Center for Advanced Scienceand Technology,
The University of Tokyo





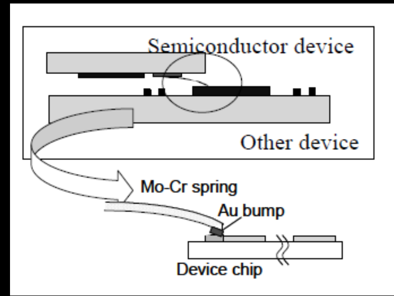






Solder-Free Pressure Contact Micro-Springs in High-Density Flip-Chip Packages

Eugene M. Chow, Chris Chua, Thomas Hantschel, Koenraad Van Schuylenbergh, David K. Fork
Palo Alto Research Center (PARC)



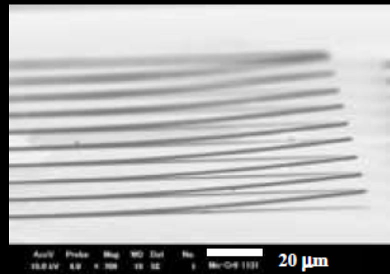


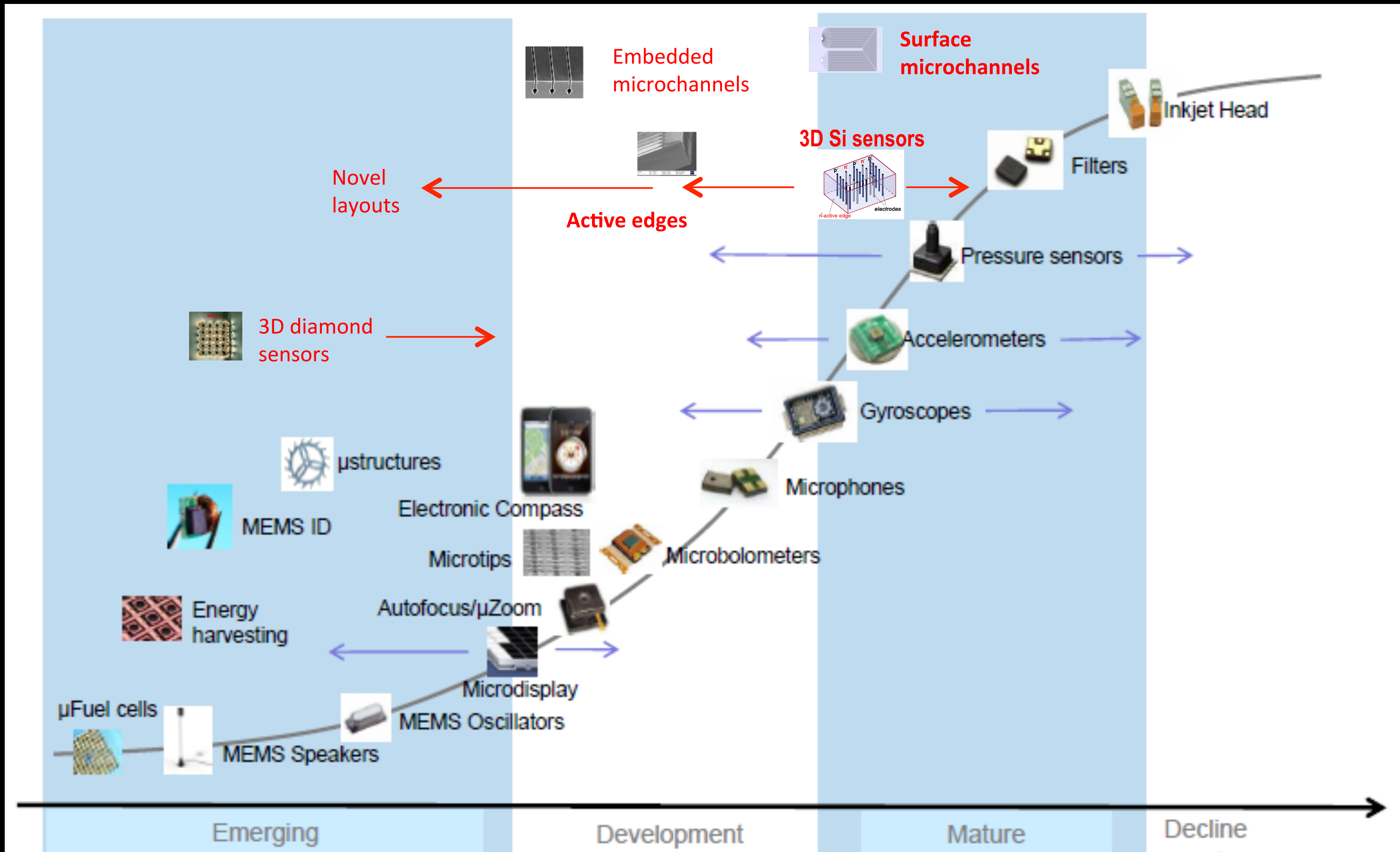
Table I Contact resistance and sheet resistance of metals deposited using various process.

Material	Contact resistance (Ω)	Sheet resistance (mΩ/□q.)	Particle size (nm)
Mo-Cr	0.0628	192.5	-
Au (EB deposition)	0.044	12.8	unable to measure
Au (pulse plating (i))	0.0314	18.15	50-500
Au (pulse plating (ii))	0.0078	9.72	50-500
Au (ultrasonic plating)	0.0035	6.7	250

Chip-Bonding for Integrated Circuit by using Micro-spring Probe

Chinami Kaneshiro, Kohji Hohkawa
Kanagawa Institute of Technology

MEMS Evolution



IBL 3D sensors are here

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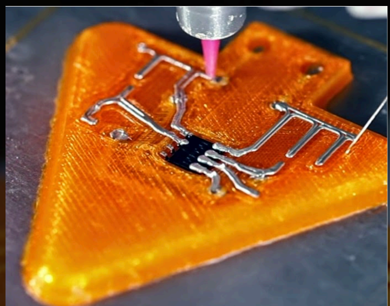
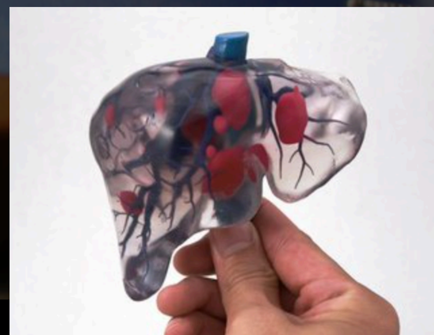
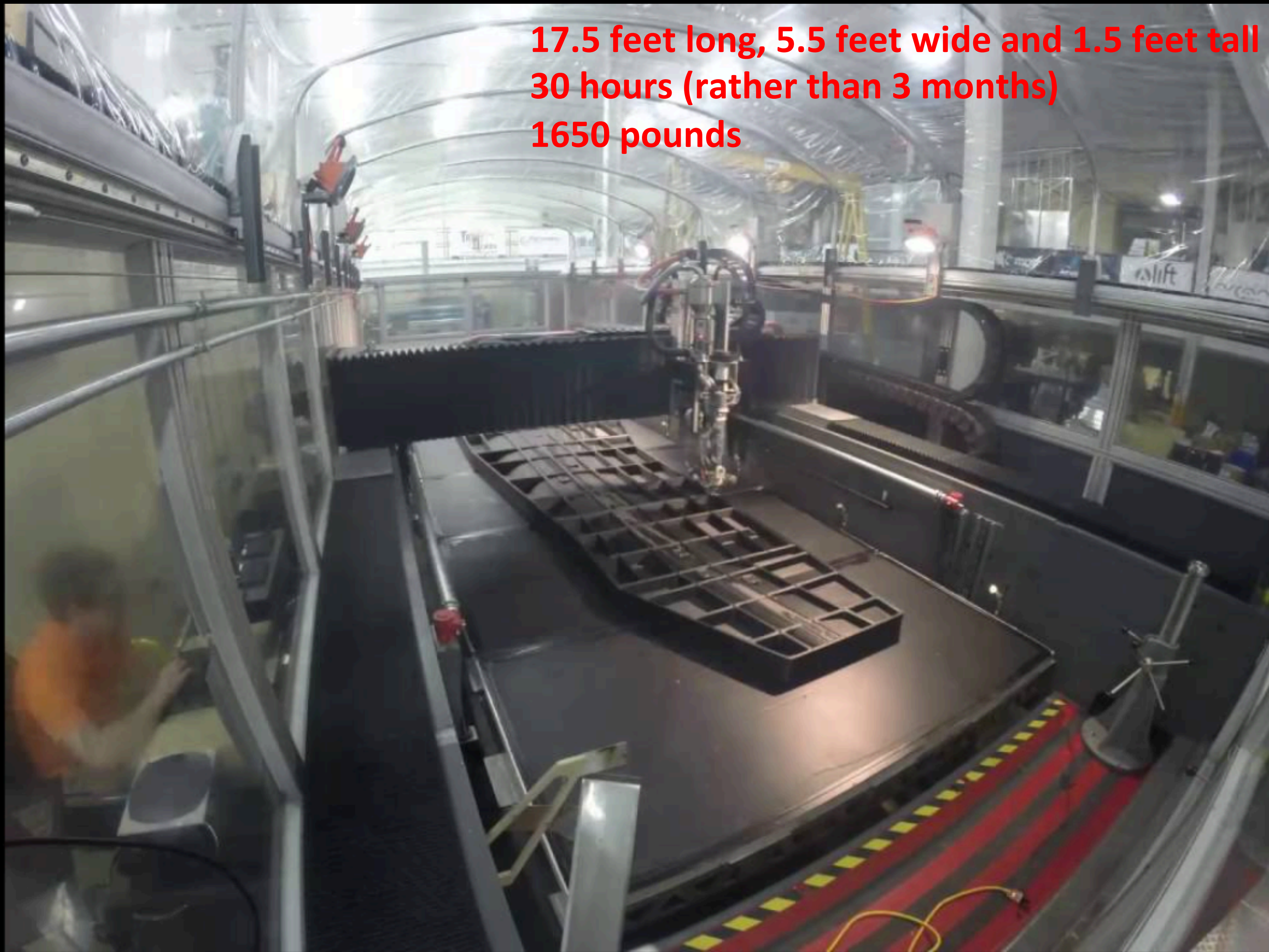
BIG and CHEAP: 3D printing

Fused Deposition Modeling (FDM) Technology	plastic	Material extrusion
SelectiveLaser sintering (SLS) Technology	plastic	Powder bed fusion
Stereolithography (SLA)	resin	Powder bed fusion
Digital Light Processing (DLP)	resin/metal	Powder bed fusion
Continuous Liquid Interface Production (CLIP)	resin	Photo-polymerization
Direct Metal Laser Sintering (DMLS)	metal	Powder bed fusion
Electron Beam Melting (EBM)	metal	Powder bed fusion
Multi/Poly Jet printers	multiple	Material jetting





The Largest 3D printed object: a Boeing 777x wing



17.5 feet long, 5.5 feet wide and 1.5 feet tall
30 hours (rather than 3 months)
1650 pounds

3D printing materials-processes and applications

Processes	Materials	Applications
Direct Metal Laser Sintering (DMLS)	Stainless Steel Steel Nickel Titanium and Aluminum Alloys	Aerospace Dental Medical Implants Medical Devices Tooling
Electron Beam Melting (EBM)	Titanium Alloys	Medical Implants Aerospace
Fused Deposition Modelling (FDM)	Thermoplastics Eutectic Metals Food ingredients	Aerospace Tissue Engineering Commercial Products Food Industry
Selective Heat Sintering (SHS)	Thermoplastics	Tooling Industry Consumer Products Building and Construction
Selective laser sintering (SLS)	Metal Alloy Thermoplastics Ceramics Composites Carbon fibers	Aerospace and Defense Automotive Manufacturing Building and Construction
Selective laser melting (SLM)	Steel Stainless Steel Metal Alloys	Aerospace and Defense Tooling Gas Turbines
Laminated Object Manufacturing (LOM)	Paper Metal foils Plastic films	Consumer Goods Sporting Goods

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3D printing timeline

3D PRINTING TECHNOLOGY READINESS

	Consumer Applications (2014–2015)	Medical, Automotive, Retail Applications (2016–2018)	Industrial Applications (2019–2020)
Commercialized	Hobby (arts and crafts) Jewellery Household printing	Printing small to medium medical prosthetics Prototypes for automotive industry (for example, instrument panels) Retail prototypes	Rapid prototyping for large industrial applications Components for aerospace (*for example*, air ducts, hinges, jet engine parts, wing spares, spare parts) and defence research and development
To be Commercialized	Printing chocolate Printing food	Printing toys Printing bicycles Clothing and apparel in fashion industry 3D printed furniture	Building construction Industrial tools manufacturing Life sciences R&D
Ongoing R&D	Digital and memory equipment Digital and memory equipment and rechargeable batteries 3D printed consumer electronics	3D printed semiconductors/ICs Smart prosthetics Artificial ears 3D printed organs	3D printed complex metal systems 3D printed energy harvesters for power stations Large aircraft parts

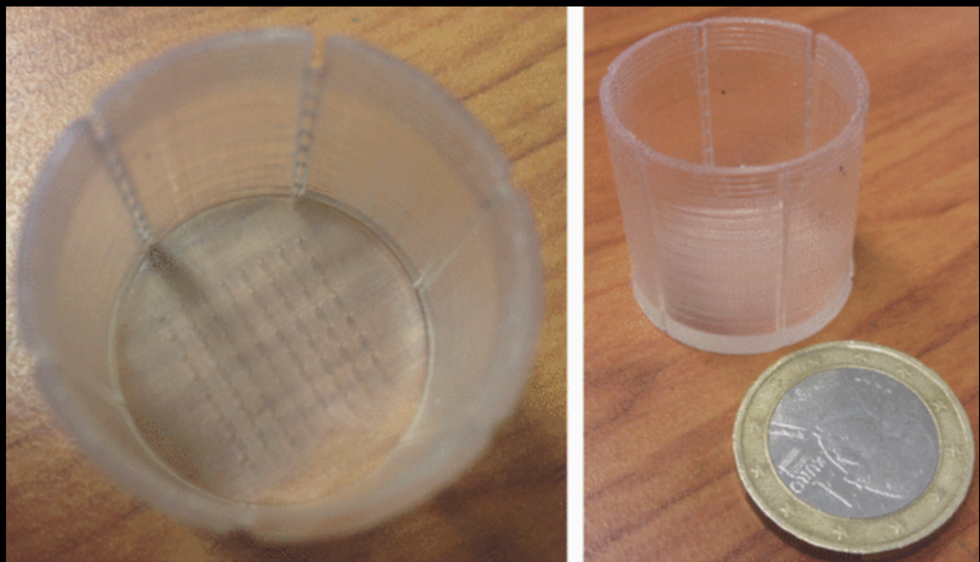
We are here

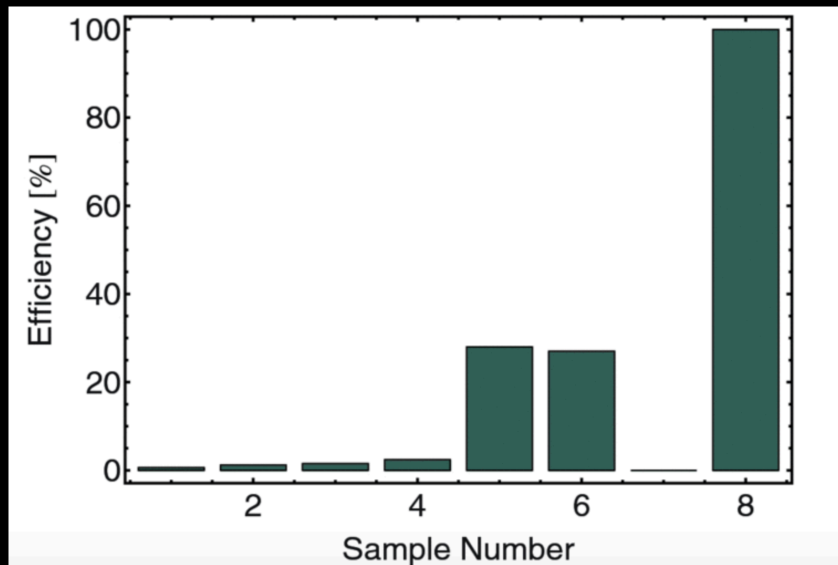
3D printed plastic scintillators

Rev. Sci. Instrum. 85, 085102 (2014)

UV-polymerizable, based on an acrylic monomer, and doped with different fractions of scintillating and wavelength shifting materials

Number	Layer thickness (μm)	Naphthalene content (%)	PPO content (%)	POPOP content (%)	Efficiency (%)	Comments
1	127	...	1	0.05	0.6	...
2	127	3	1	0.05	1.2	...
3	127	3	1	0.05	1.5	...
4	25	3	1	0.05	2.4	...
5	25	15	1.5	0.08	28	...
6	127	15	1.5	0.08	27	...
7	...	...	...	...	0	Clear sample
8	...	...	...	...	100	EJ-204 scintillator





Cinzia Da Vià. The University of Manchester, UK. 2016

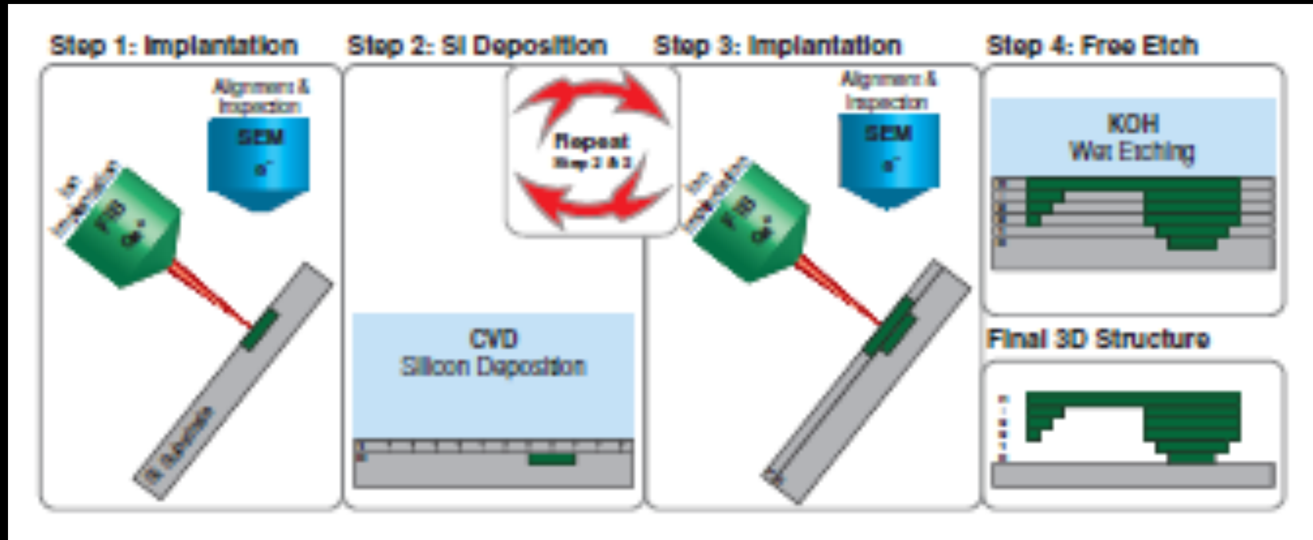
3D printed silicon

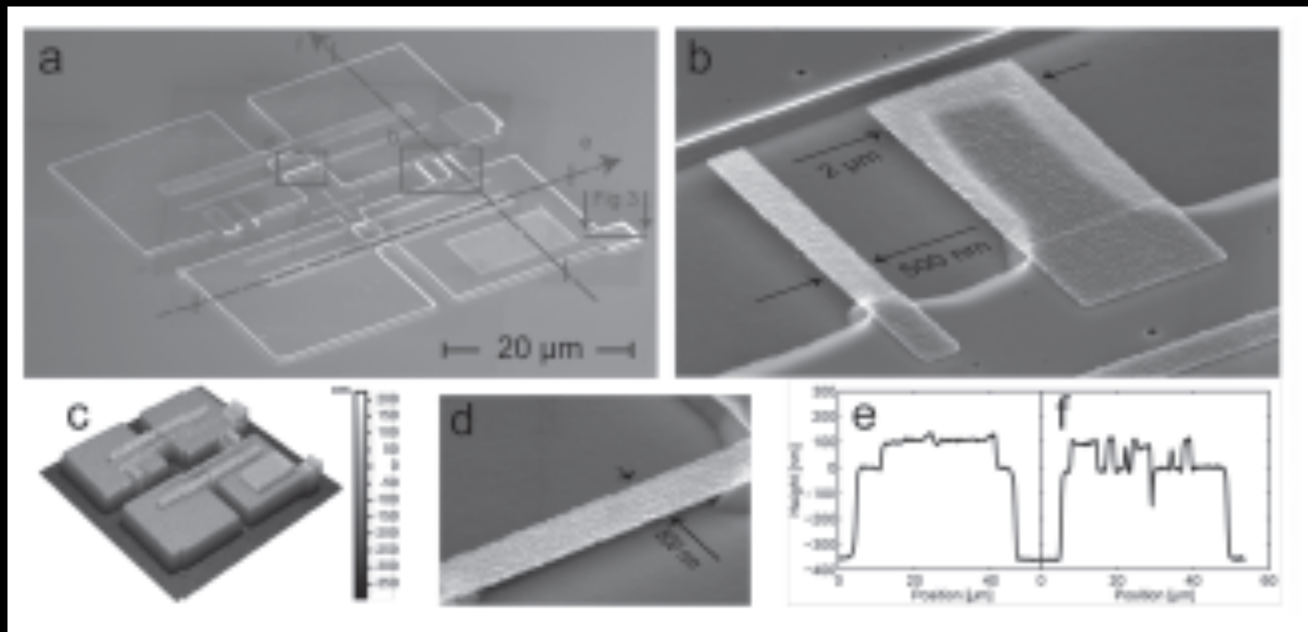
Adv. Funct. Mater. **2012**, *22*, 4004–4008

The layer-by-layer fabrication is based on alternating steps of chemical vapor deposition of silicon and local implantation of gallium ions by focused ion beam (FIB) writing.

In a final step, the defined 3D structures are formed by etching the silicon in potassium hydroxide (KOH), in which the local ion implantation provides the etching selectivity.

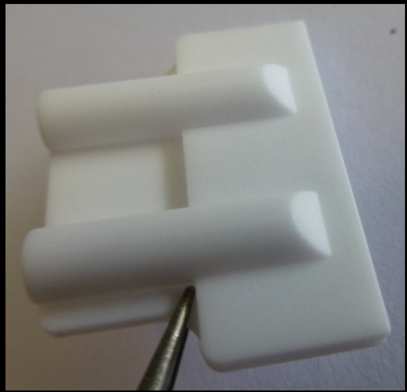
The method is demonstrated by fabricating 3D structures made of two and three silicon layers, including suspended beams that are 40 nm thick, 500 nm wide, and 4 μ m long, and patterned lines that are 33 nm wide.

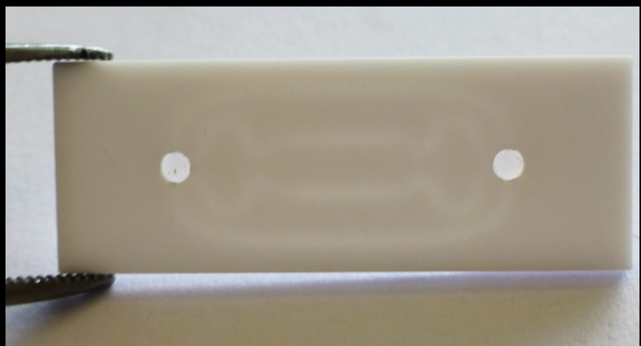


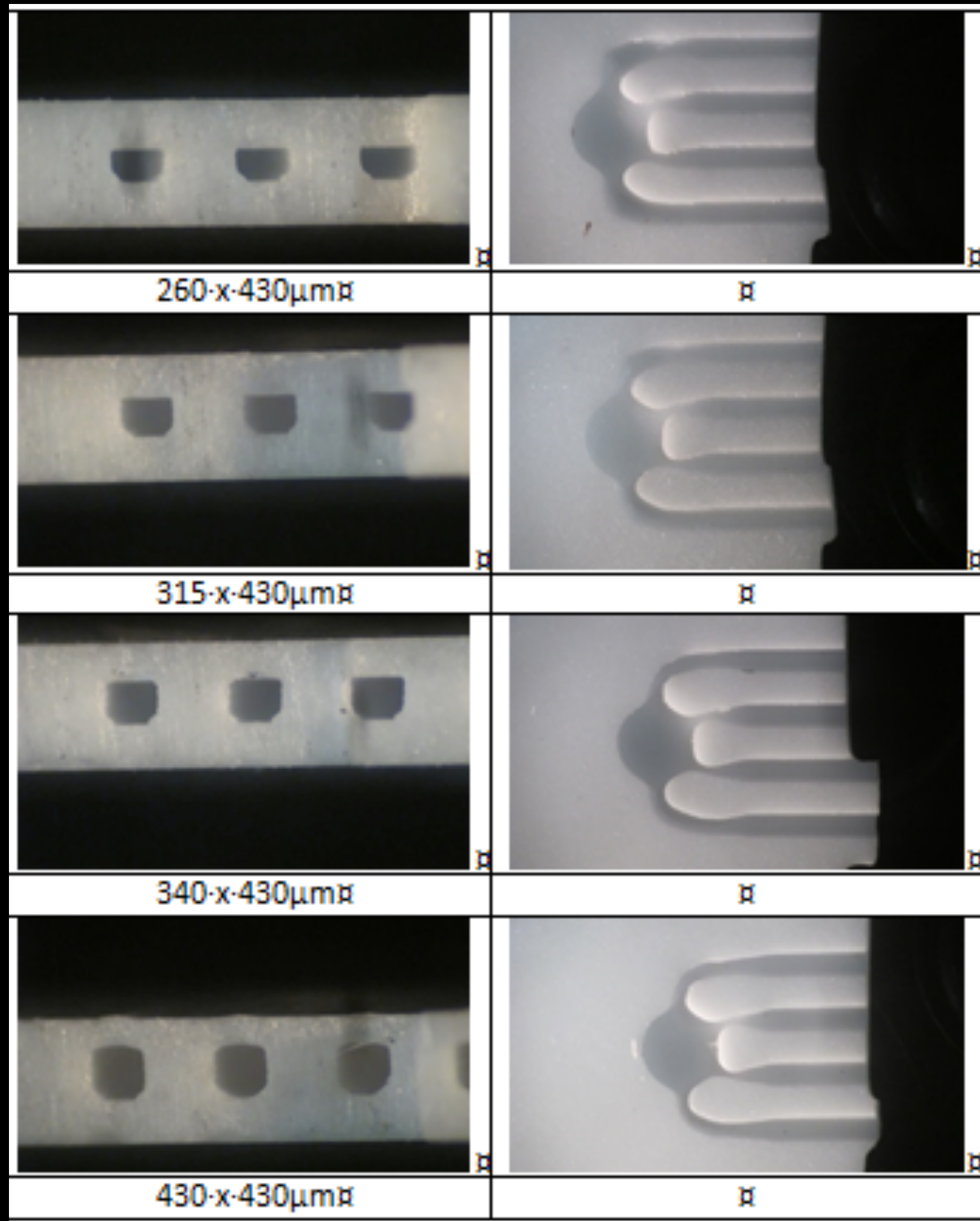


Alumina micro-channels and connectors prototypes

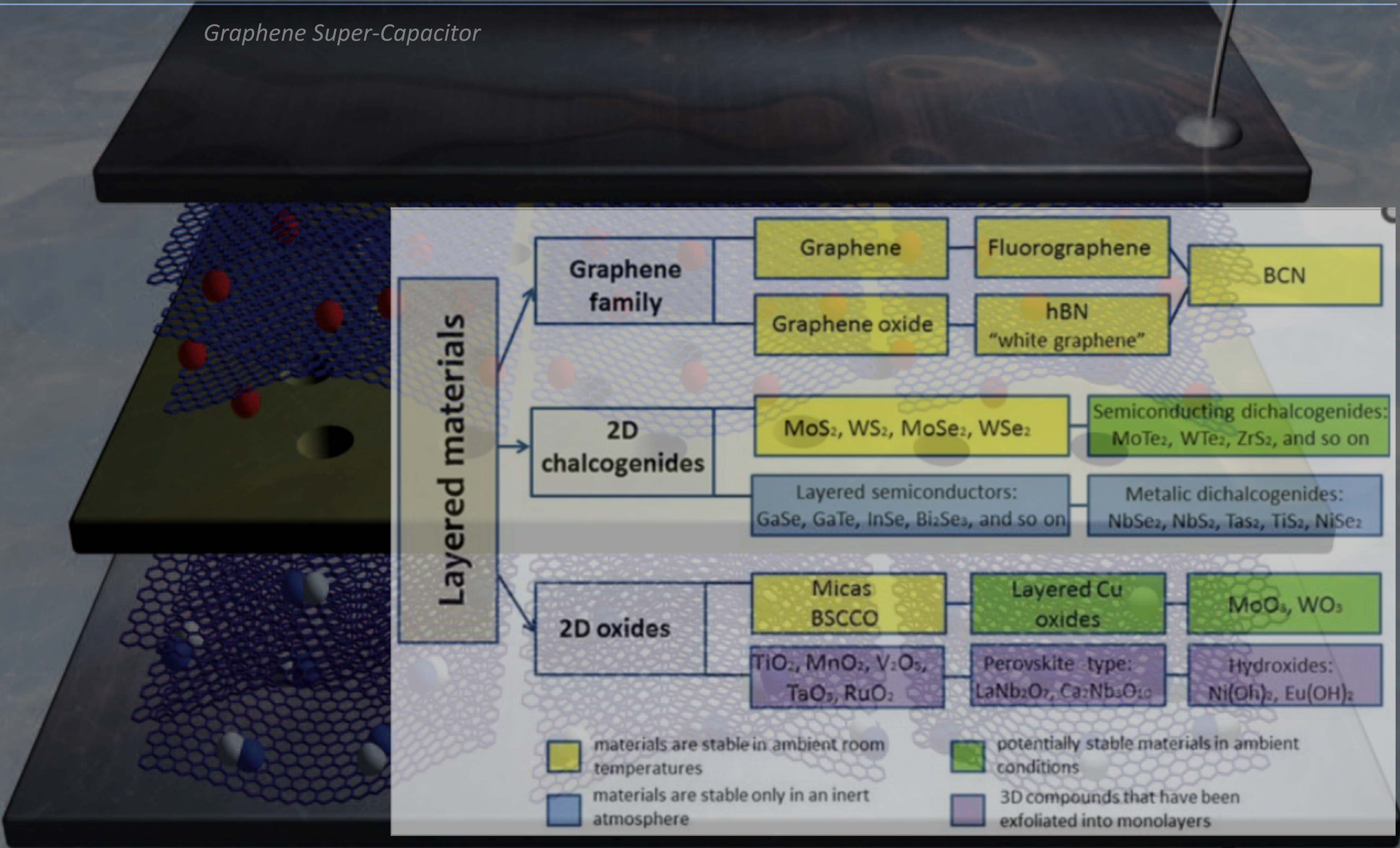
C. DaVia et al VCI Conference 2016







Strong and Fast: 2D materials



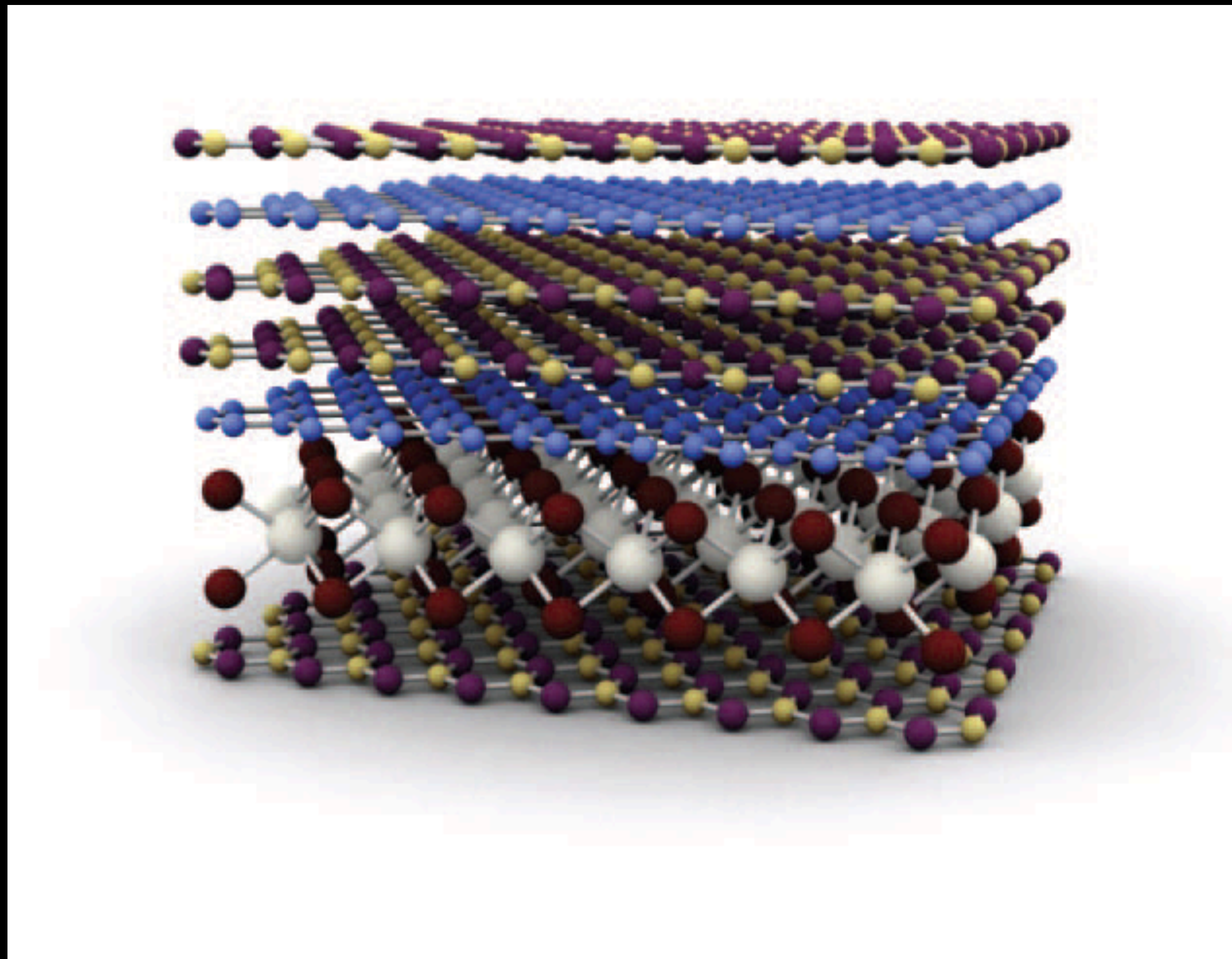
Sensors (Basel). 2016 Feb; 16(2): 223.

Sensors with 2D materials → 3D

192 | NATURE | VOL 490 | 11 OCTOBER 2012

Two graphene layers are separated by several layers of boron-nitride, which serve as a tunnelling barrier.

A built-in electric field (created by the proximity of one of the graphene layers to a monolayer of MoS_2) separates the electron–hole pair, which is created by an incoming photon, resulting in a photocurrent.

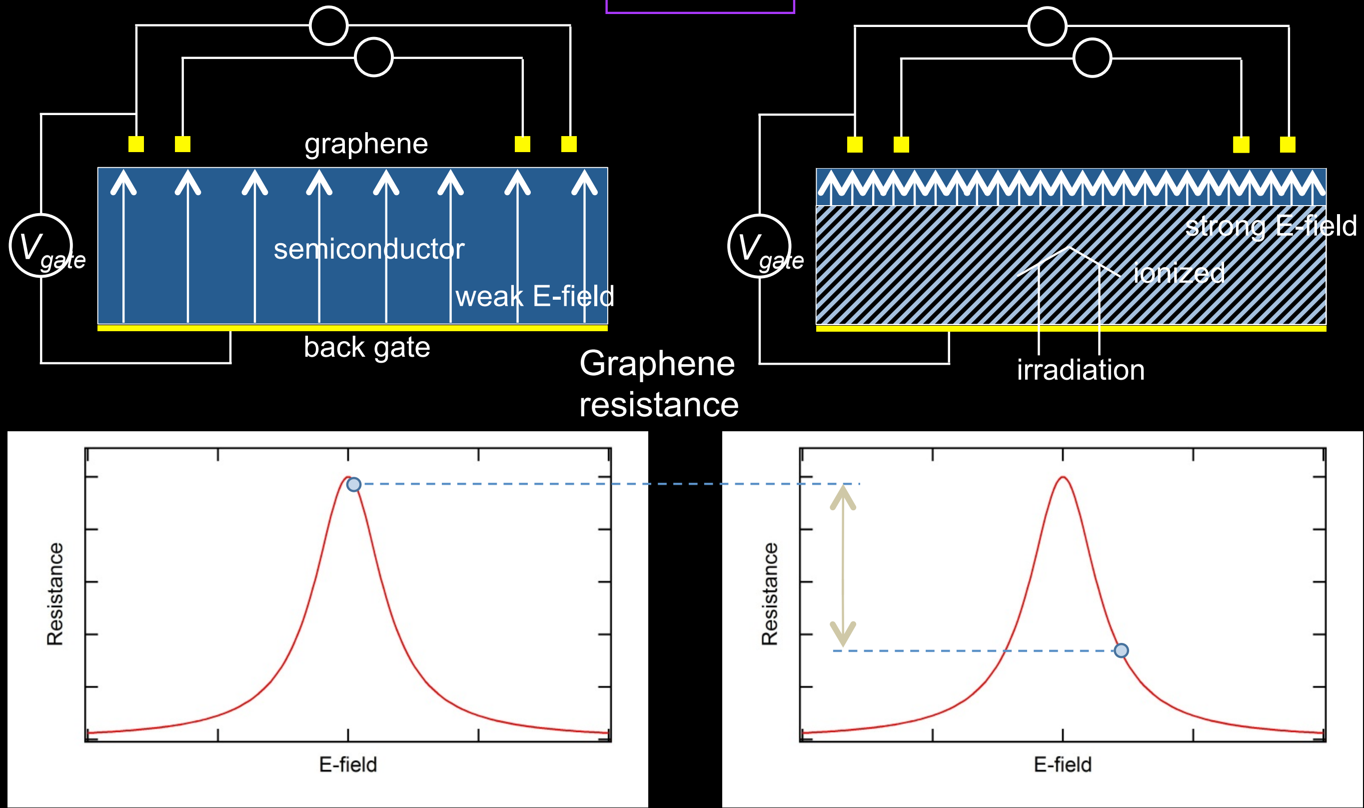


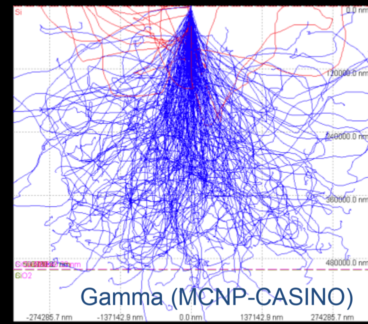
Optically active 2D-based heterostructure.

Graphene Radiation Detectors

M. Foxe et al. IEEE Trans. Nanotech. 11, 581 (2012)

$E=V/d$





Graphene as built-in room-T low-noise pre-amp, and it is:

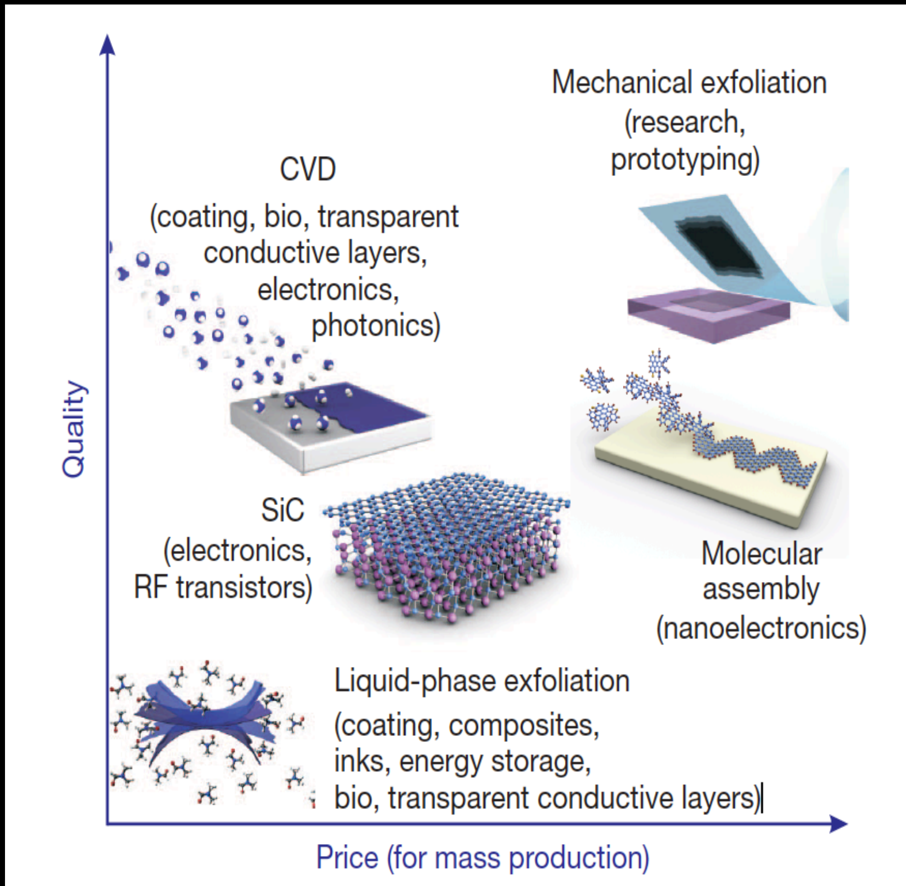
- light
- transparent
- flexible
- low-cost

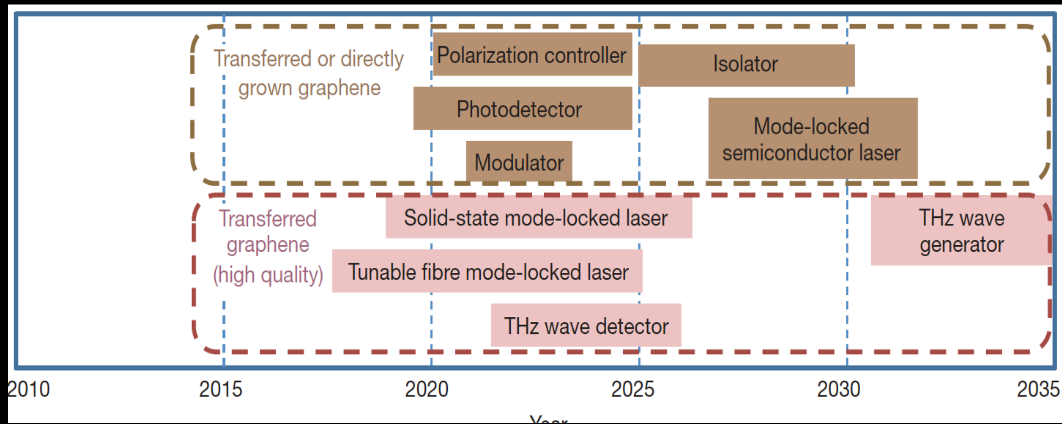
- Graphene a highly sensitive to detect local E-field change: *"sharp" feature*
- NOT relying on collecting ionized charges; *appearance* of ionized charges changes electric field
- can work with variety of absorber substrates best suited: gamma/neutron interaction; room-T (wide bandgap); energy resolution (narrow bandgap) - less stringent requirement on substrate mobility etc.
- low noise (even at room T), graphene (semimetal) resistance stays finite unlike MOSTFET channel

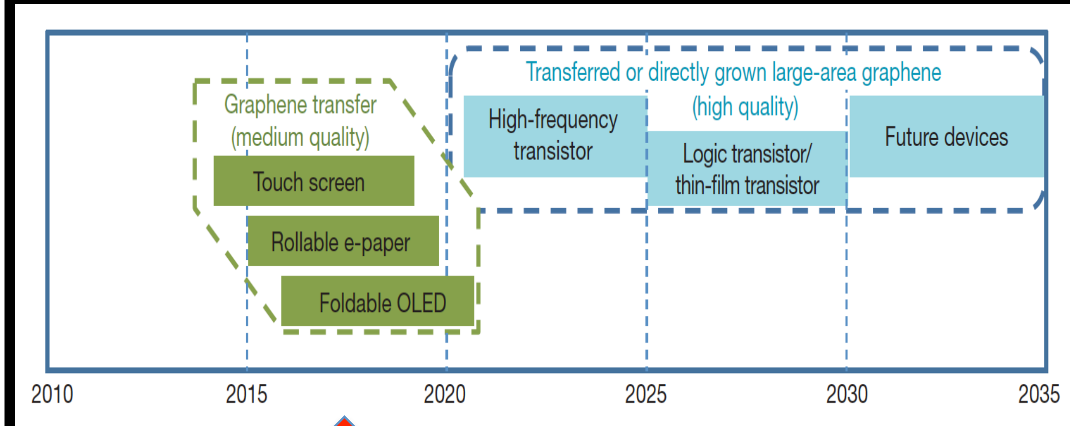
Graphene Road Map, Quality and Price

doi:10.1038/nature11458

Cinzia Da Vià. The University of Manchester, UK. 2016







We are here

Composite materials, paints and coating

Graphene-based paints can be used for conductive ink, antistatic, electromagnetic-interference shielding, and gas barrier applications.

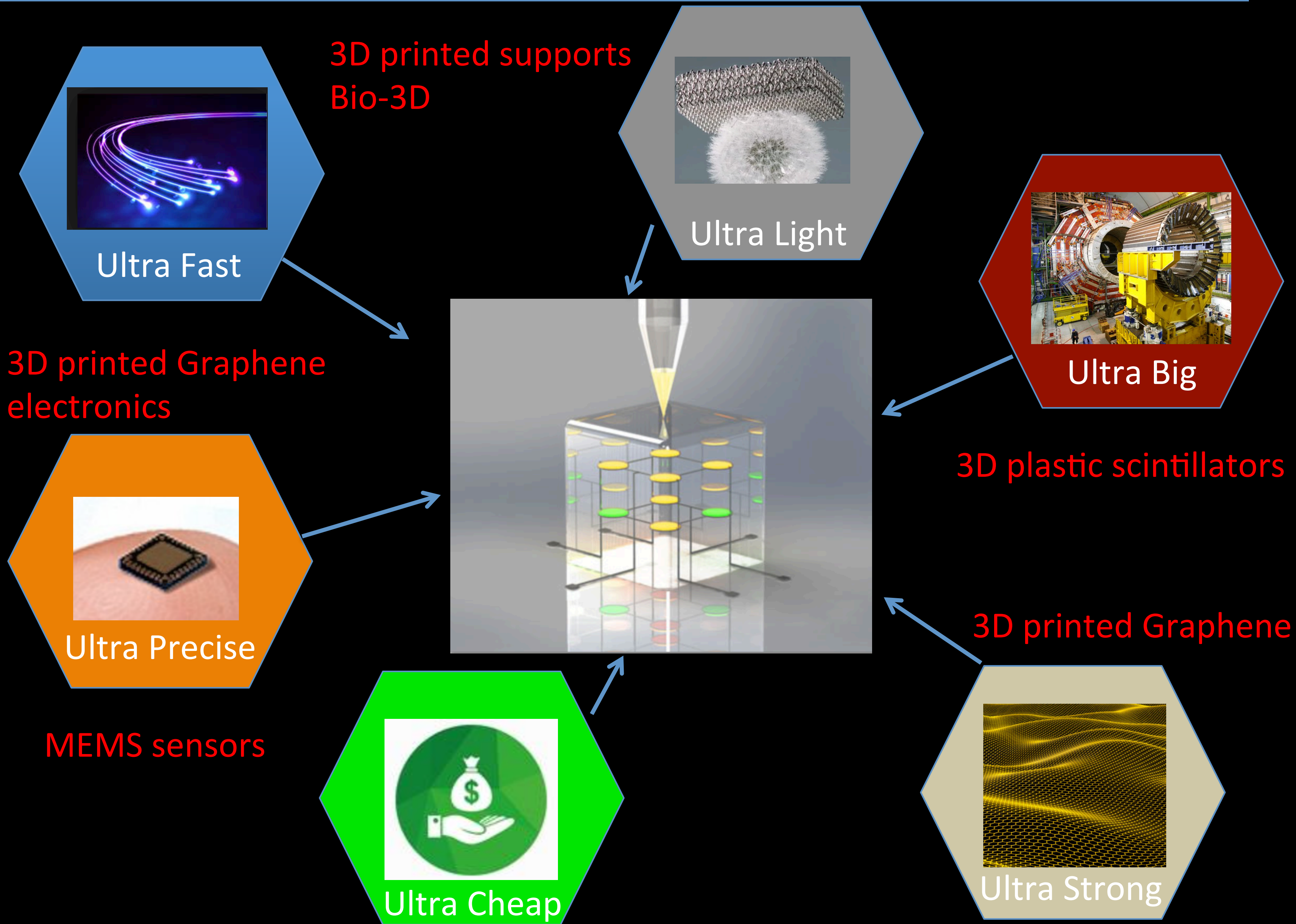
Very strong: Composite materials, paints and coating

Graphene-based paints can be used for conductive ink, antistatic, electromagnetic-interference shielding, and gas barrier applications.
In principle, the production technology is simple and reasonably developed, with most of the major graphite mining companies as well as new start-up companies having programmes on liquid-phase or thermally exfoliated graphene.

Graphene is highly inert, and so can also act as a corrosion barrier against water and oxygen diffusion. Given that it can be grown directly on the surface of almost any metal under the right conditions, it could form a protective conformal layer, that is, it could be used on complex surfaces.

Mechanical Strength The mechanical, chemical, electronic and barrier properties of graphene along with its high aspect ratio make graphene attractive for applications in composite materials. The commercial position held by carbon fibres, however, is so strong that graphene will need substantial development before it will be economically feasible to use it as the main reinforcement component.

In summary



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