European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

2nd International Workshop *EuNetAir* on

New Sensing Technologies for Indoor and Outdoor Air Quality Control

ENEA - Brindisi Research Center, Brindisi, Italy, 25 - 26 March 2014

CMOS-BASED SENSORS FOR UBIQUITOUS GAS DETECTION: CHALLENGES AND OPPORUNITIES

CAMBRIDGE CMOS SENSORS

WWW.CCMOSS.COM

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COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

Contents

About Cambridge CMOS Sensors

Established in 2008, Spin-out from Cambridge University & University of Warwick
(seed funded by Cambridge Enterprise)

Strong Patent portfolio in CMOS MEMS Micro-hotplates and sensors for ubiquitous applications

Key Product Focus:

- **Ultra-low power gas sensors for mass-market application**
- **Micro-Hotplates for resistive gas sensing applications**
- **Broadband Infrared Sources for a range of infrared based sensors**
- **High Performance Infrared detectors**

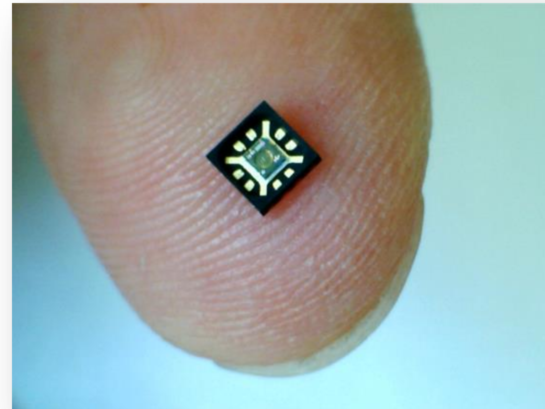
The founders, Prof. Florin Udrea (Cambridge), Prof. Bill Milne (Cambridge) and Prof. Julian Gardner (Warwick)

CEO: Nat Edington (Previously at Wolfson Microelectronics)

Currently: 17 employees -> 20 to 25 Q4 2014

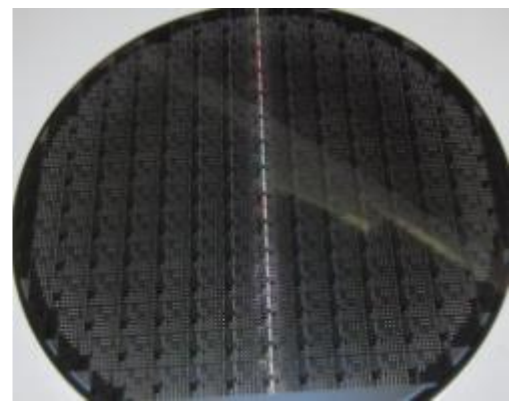
Core Technology: Micro-hotplate

What is a Micro-hotplate?



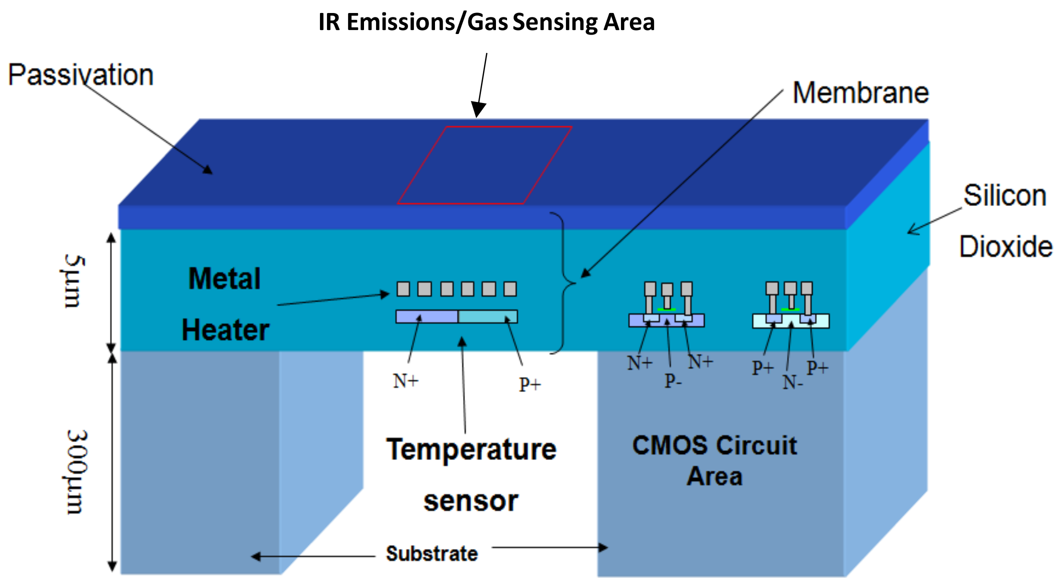
Well it is like an electric cooker, but we have integrated on a silicon chip!

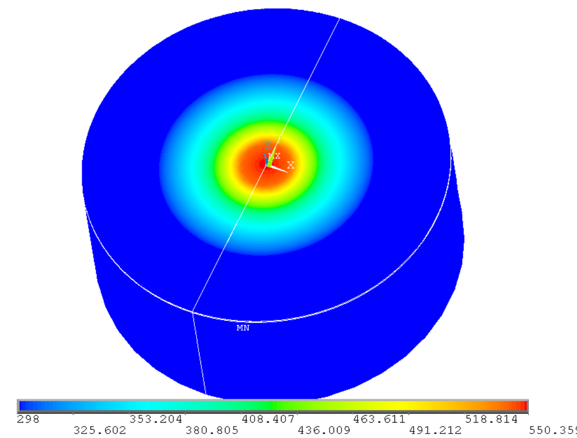
You can have about 10K of these hotplates on a single 6" wafer!

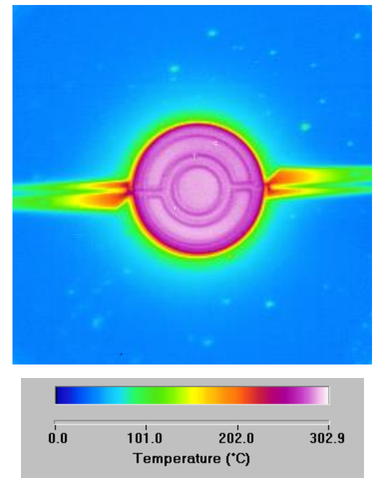


As we know heat is a source of everything!

Technology Breakthrough







Successfully integrated micro-hotplate on standard CMOS process and enabled:

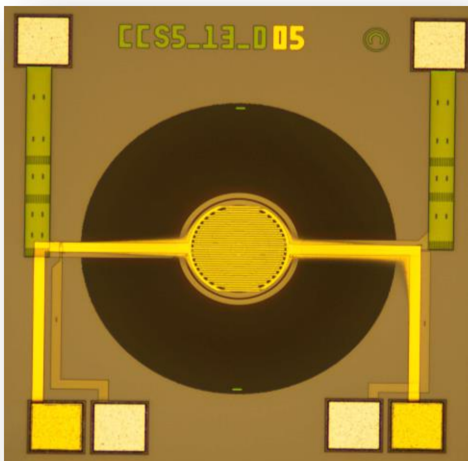
- **High Temperature**
- **High stability**
- **High reproducibility**
- **High reliability**
- **Preparatory know-how and strong patent portfolios**

Products & Applications

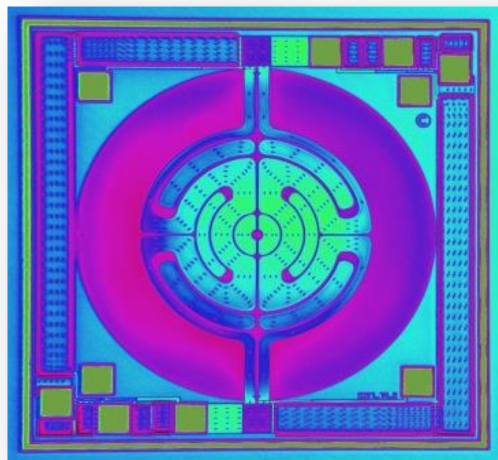
Technology offers wide range of applications

Resistive Gas Sensing

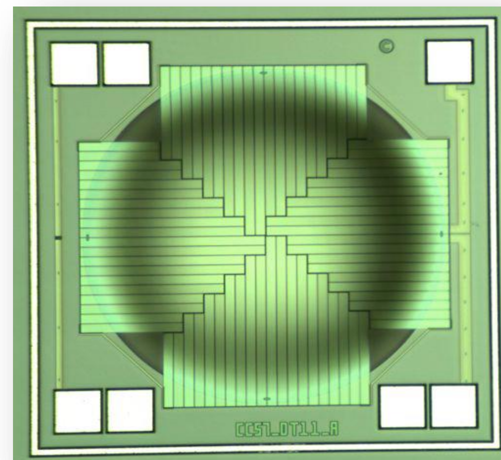
Infrared Sensors
Gas & Materials sensing
Proximity, Gesture, IR Imaging



Micro-Hotplate



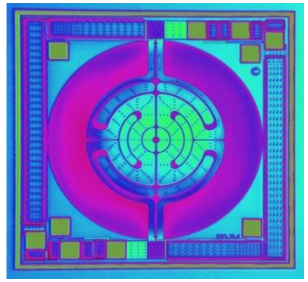
Infrared Emitter

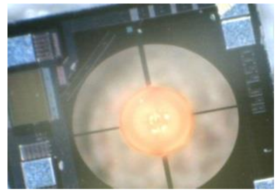


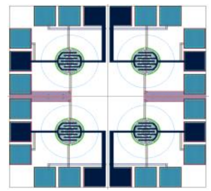
Thermopile Detector

Key Benefits

- Ultra-low power consumption –
  - μW average for gas analysis
- Fast thermal transient response –
  - 20ms thermal transitions to max temp
- Cost-effective and high volume manufacturing
- Miniaturised system
  - 100μm diameter hotplates – or smaller!
- Broadband IR Emissions – longer wavelength IR applications
- Improved reliability and stability
- On-chip integration of drive and signal processing electronics for a "system-on-a-chip" solution.





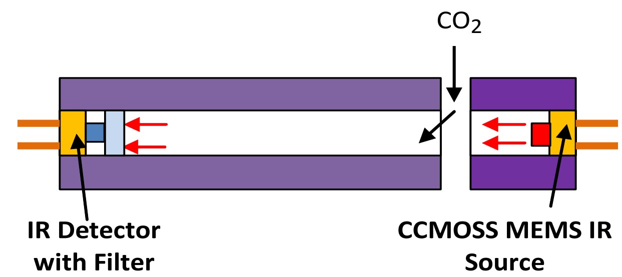


Array of MHP on 1mm x 1mm die.

Sensor Applications

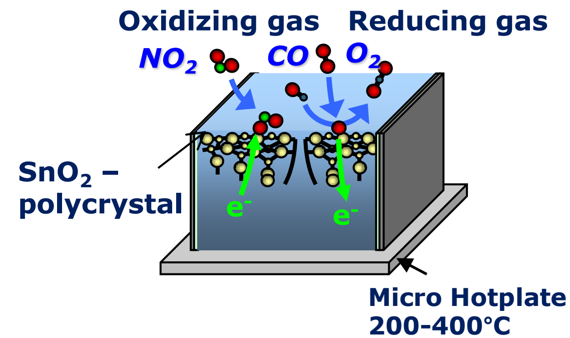
Non-Dispersive Infrared Sensors (NDIR)

- CCMOSS Broadband IR Sources enable detection of a wide range of gases
- Optical IR sensing using gas absorption



Resistive Gas Sensors

- Enabling single or multi-gas sensing with CCMOSS Micro Hotplate single die, or die arrays
- Detection of gases through catalytic reactions on sensor surface causing resistance changes

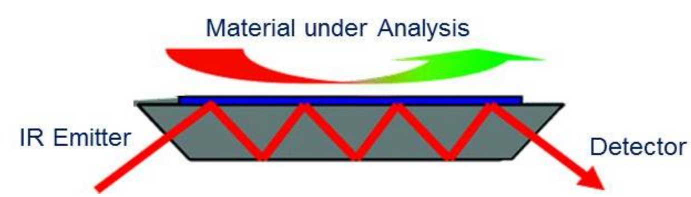


Attenuated Total Reflectance (ATR) Sensors

- CCMOSS IR Sources enable Miniature sensors for detection & analysis of gels, liquids, solids (powder)

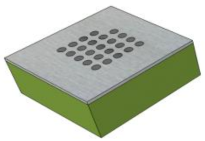
Miniature proximity sensors

- CCMOSS Mid-IR Sources & Detector arrays enabling Motion detection & Gesture control



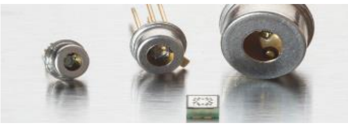
Examples of Current Products

Sensors



Gas Sensors

Product	Description	Power Consumption[1 2]	Heat Resistance	Heater Voltage	Package
CCS801	Ultra-low power multi-gas sensor for air quality monitoring	~0.12 - 0.23mW	50Ω ± 10%	0.87 – 1.27V	SMD 3x2mm
CCS802	Ultra-low power gas sensor for monitoring carbon monoxide	0.12mW	48Ω ± 10%	0.87V ± 0.05V	SMD 3x2mm
CCS803	Ultra-low power gas sensor for monitoring ethanol	0.18mW	47Ω ± 10%	1.1V ± 0.05V	SMD 3x2mm



IR Emitters

Product	Description	Power Consumption[1]	Heat Resistance	Heated Area	Heater Voltage	Frequency[2]
CCS101	Ultra-low power IR source device	72mW ± 5mW	80Ω ± 25%	0.05mm² MIN	2.4V ± 0.3V	70Hz
CCS102	Low-power IR source device	160mW ± 15mW	33Ω ± 25%	0.28mm² MIN	2.3V ± 0.2V	36Hz
CCS103	Low-power IR source device	140mW ± 15mW	21Ω ± 25%	0.5mm² MIN	1.7V ± 0.2V	30Hz
CCS104	High-output IR source	500mW ± 50mW	9Ω ± 25%	3.0mm² MIN	2.1V ± 0.2V	16Hz

Micro-hotplates

Product	Description	Power Consumption[1]	Heat Resistance	Heater Voltage	Diode Temp Coefficient
CCS301	High-temperature MEMS micro-hotplate	72mW ± 5mW	80Ω ± 25%	2.4V ± 0.3V	1.3x 10^{-3} V/K

Global Sensors Market

Global Sensor Market predicted to grow from $62B (2011) to $92B (2016)*

Key growth markets - Automotive, Consumer Products & Medical healthcare

Sensor Market driven by 4 Key Technology Trends

- **Lower Cost**
- **Lower Power**
- **Smaller**
- **Wireless Connectivity**

Enabled through CCMOSS Technology

* Sensors: Technologies and Global Markets, BCC, March 2011

Market Focus

Consumer *($22B: 2015***)*

- Smartphone Ambient Air Quality Monitoring
- Gesture-based Interfacing, Zero Touch Technologies
- Personal Sports monitoring

Medical/ Home Healthcare *($12.5B: 2015**)*

- Personalised healthcare monitoring
- Breath Analysis for diagnosis

Automotive *($14B: 2011*)*

- In-Vehicle AlcoLocks for alcohol detection
- In-Vehicle Air Quality
- Emissions Testing & Monitoring

Domestic & Industrial Security *($7B: 2011+)*

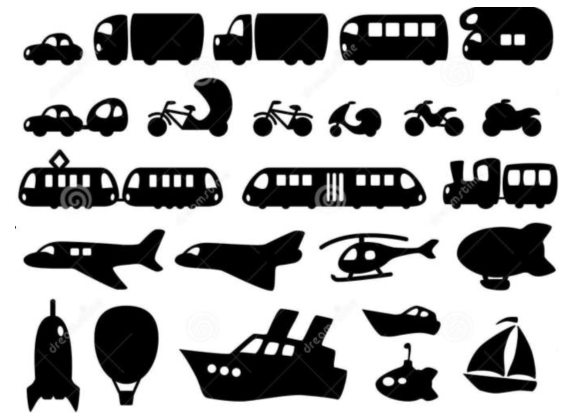
- Refrigerant leak detection
- Fire Detection
- Ambient Air Quality Monitoring

*** Strategy Analytics, 2011 **Frost & Sullivan, 2010 ***MarketsandMarkets, 2010 +Decision, 2007 + CCS Estimates**

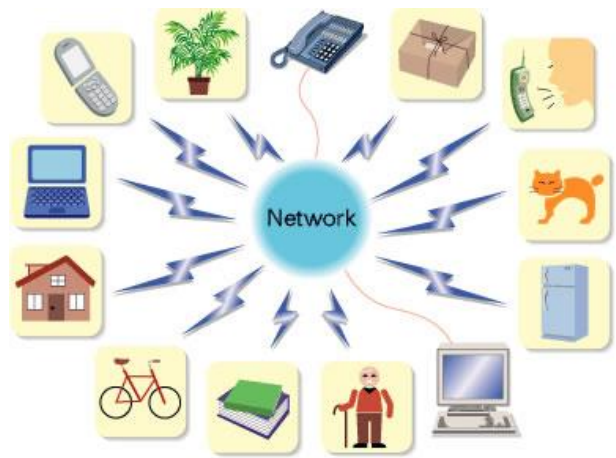
Meaning of Ubiquitous

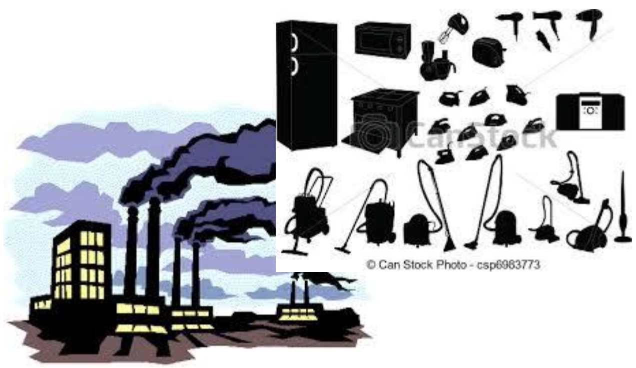
Medical/ Home Healthcare

Consumer



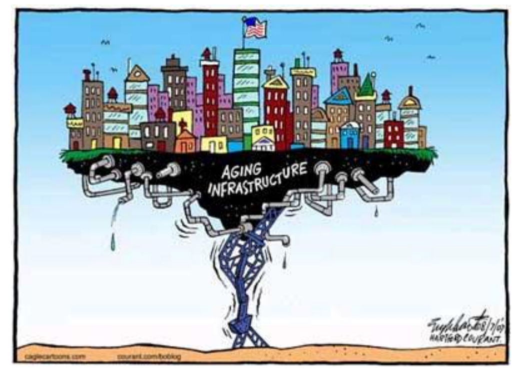
Transportation & Automotive





Domestic & Industrial Security

Truly potential for trillions sensors!!



Infrastructures

ANYWHERE, ANYTIME, BY ANYONE AND ANYTHING

Trillion Sensors Summit (Oct 2013)

Introduction to TSensors and TSensor Systems

Dr. Janusz Bryzek, VP Development, MEMS and Sensing Solutions, Fairchild Semiconductor

While in 2007, 10 million sensors were absorbed, in 2012 the MEMS sensor absorption in mobile devices grew to 3.5 billion sensors, representing about 220%/y compounded growth rate.

As sensors are becoming part of global problem solutions … sensor volumes to exceed trillions by 2022. .. drive semiconductor to $2 trillion.

Overcoming Systems Hurdles for a Trillion Sensor World … trillion sensors could overwhelm current internet capability

… more viable system level energy efficient solutions like self or low power sensor will have to be the norm in a ubiquitous sensing world.

TSensor Systems is developing three focus groups:

1. Sensor technology
2. Data transmission technology
3. Data processing technology

Marketing Evolution Enabling TSensors Revolution

Sensor-based Revolution to Change Redistribution of Global GDP, Vijay Ullal, President, Fairchild Semiconductor

Countries with fastest adoption of sensors based systems are likely to free the largest number of people for creative work, thus start dominating the global economy.

http://www.tsensorssummit.org/Resources/TSensors%20Summit%20Abstracts.pdf

Trillion Sensors Summit

Digital Health to Drive Trillion Sensors

Monitoring Environment to Stay Healthy, Sywert Brognersma, IMEC

High Sensitivity Multigas sensors for Air Quality Monitoring and Breath Analysis

Sensory Swarms/Internet of Things and Everything

3D Printed Smart Systems

Mobile and Wearable Market

Phase 1:
Development of a visionary 10 year market forecast ,, $1T by 2023

Phase 2:
The collected emerging sensor applications will be split into number of categories

Phase 3:
Based on the above, we plan to form working groups to make a recommendation

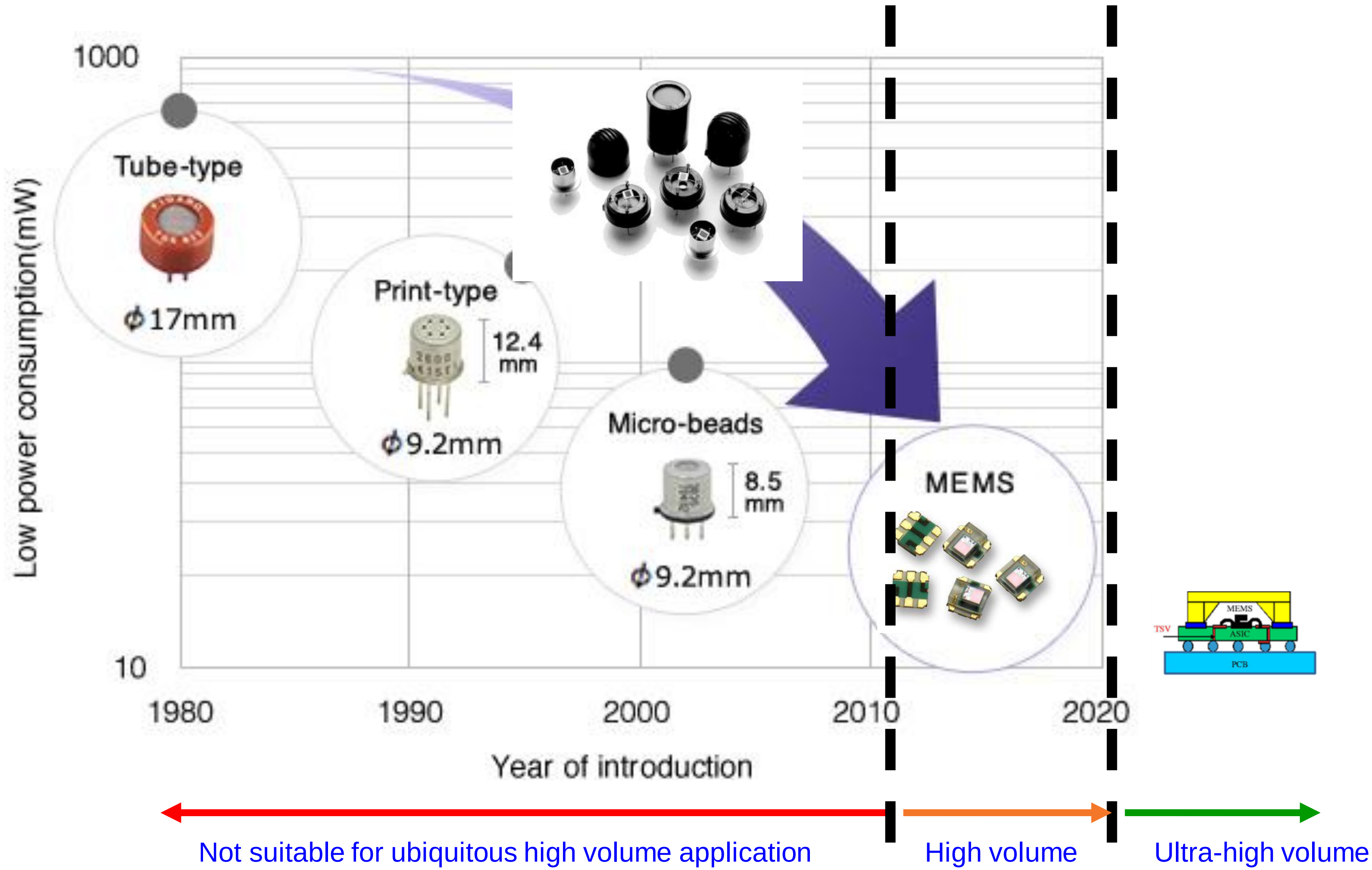
Just Make It

Sean Stetson, TPL - Advanced Technology and Products Group, Motorola Mobility
One of the biggest challenges we face as a Nation is the decline in our ability to make things. Americans today consume more goods manufactured overseas than ever before. … This decline has a severe impact on the Nation's economic vitality and security; because quite simply, to innovate, we must make. **Same story is for EU.**

Applications and required infrastructure to support a trillion sensor market
Jean-Christophe Eloy, President and CEO, Yole Développement, France

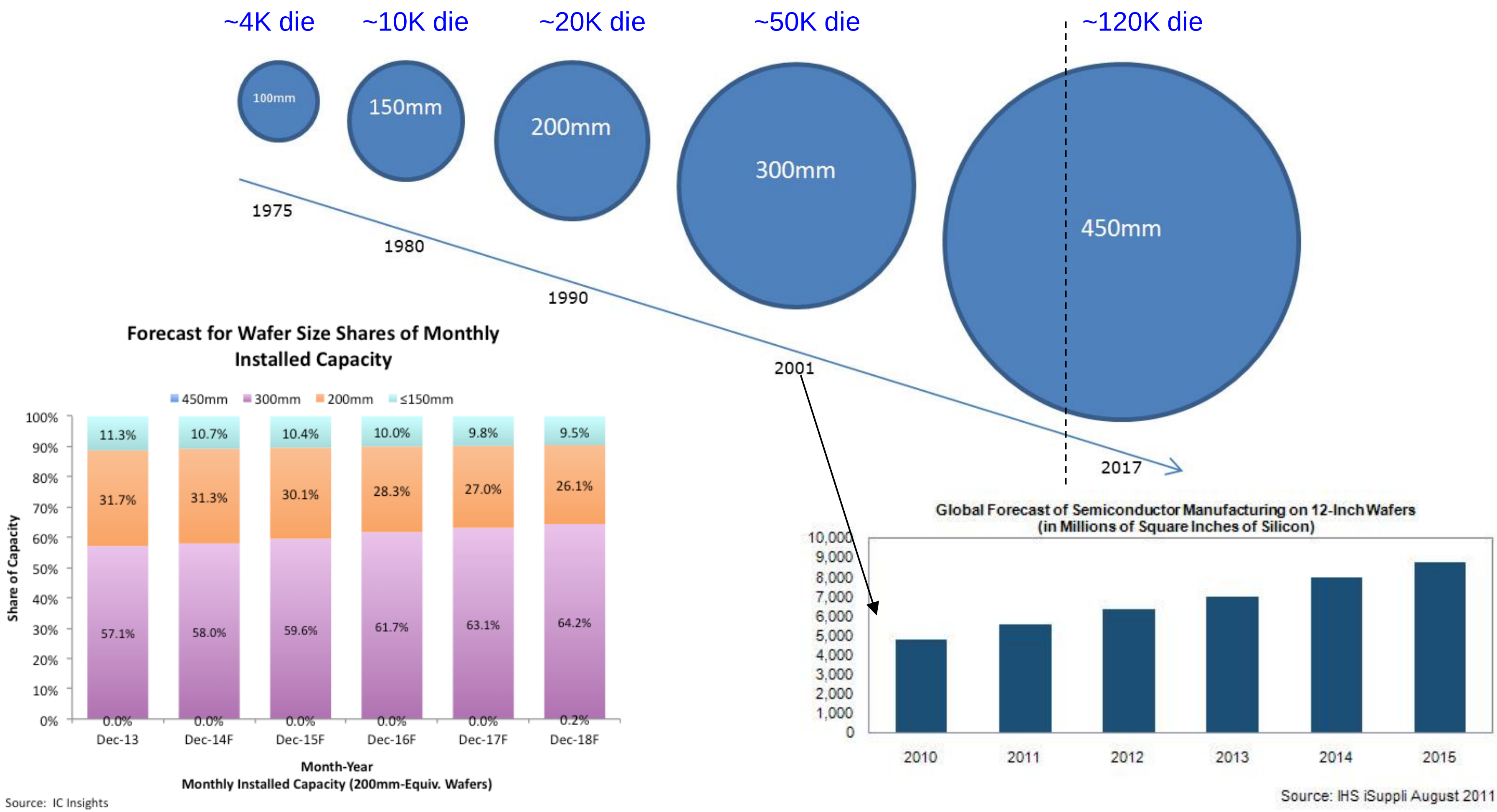
…. sensor designs are not currently adapted to support a higher growth

Reason for New Generation of Gas Sensors



Courtesy Figaro for the base graph

CMOS Enabling True Ubiquitous Sensors



Silicon is the material cheap high-quality materials and with electronic functionality makes it attractive for a wide variety of MEMS applications. In single crystal form, silicon is an almost perfect - when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. As well as making for highly repeatable motion, this also makes silicon very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking.

Towards Ubiquitous Sensors Manufacturing

Technology
CMOS-SOI
NON-SOI
Bulk
Others

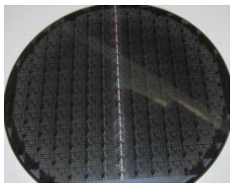
Post_Proc
IDE
Plating
Special
Others

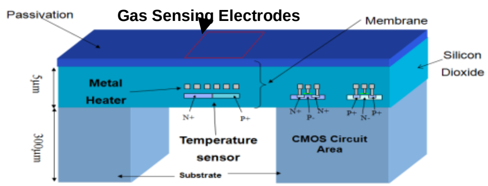
MEMS
DRIE
KOH
Topside
Others

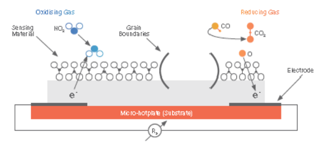
Sensing Material
MOX
Polymer
Pellistor
CNT/Others

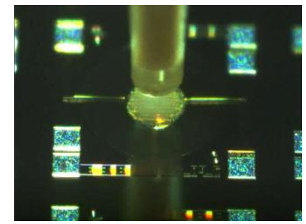
Deposition
Drop
Print
CVD/Others

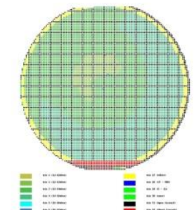
Custom
Test
Moulding
Trench











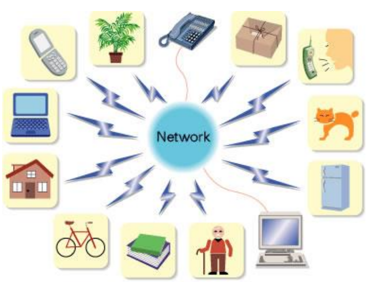
Dicing
SAW
Stealth
Fracture

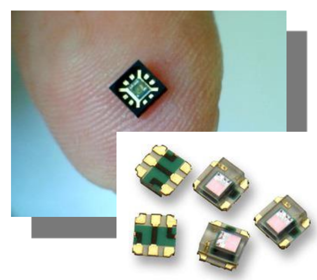
Packaging
SMD
Die on PCB
TSV
3D

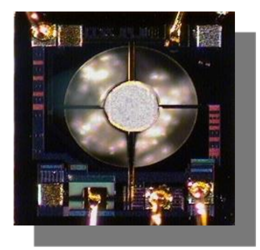
Assembly Test
Batch
Sample
All
Others

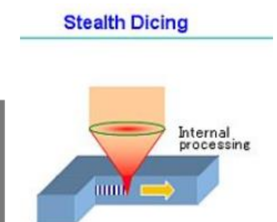
QualRel
Burn-in/HTOL etc
Certification
Others

Ubiquitous Appl
Consumer
Automotive
Others



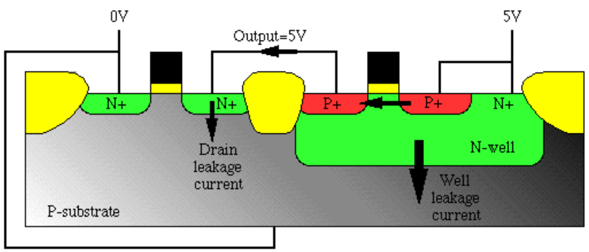




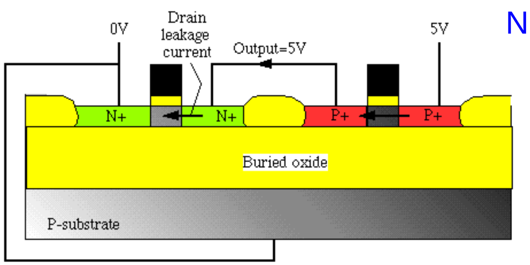


Challenges: Technology

Technology
CMOS-SOI
NON-SOI
Bulk
Others



NON-SOI



SOI

- Silicon foundry must offer high temperature metallisation
- Offer ALL post-CMOS services at the foundry
- Provide adequate volume capacity
- Competitive cost per wafer
- Process migration
- High yield > 95%

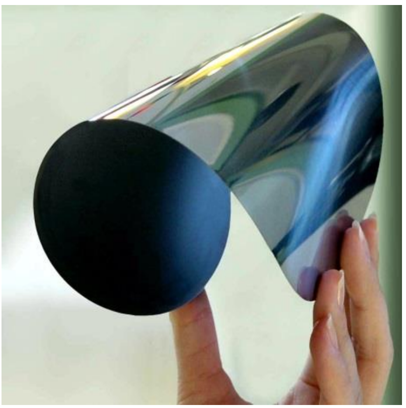
Bulk is just metals – without CMOS

Bulk + Flexible

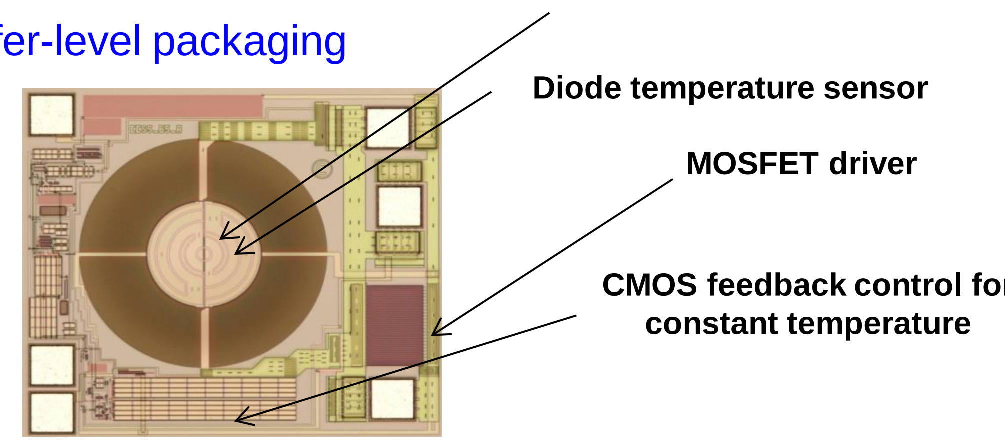
Opportunities: Technology

Technology
CMOS-SOI
NON-SOI
Bulk
Flexible

- Process migration – larger wafer
- Further miniaturisation
- Bring some post-CMOS steps and part of CMOS
- Smart sensor – Lab-on-chip
- Wafer thinning
- TSV
- Wafer-level packaging



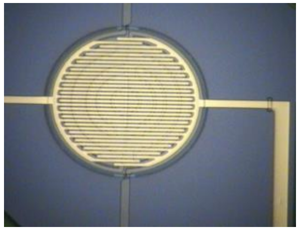
300mm, 50µm thick silicon wafer!



Cost reduction: SOI -> NON-SOI -> Bulk -> Plastic(?)

Challenges: Post-CMOS Processing

Post_Proc
IDE
Plating
Special
Others



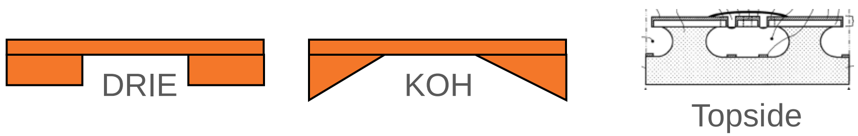
- Interdigitated Electrodes (IDE)
- Plating of IDE
- Surface processing for adhesion
- Reproducibility
- Reliability
- High temperature capability
- High yield >95%

Opportunities: Post-CMOS Processing

- Multi-sensing platform
- Novel designs
- Nano-material platform
- High volume production capabilities

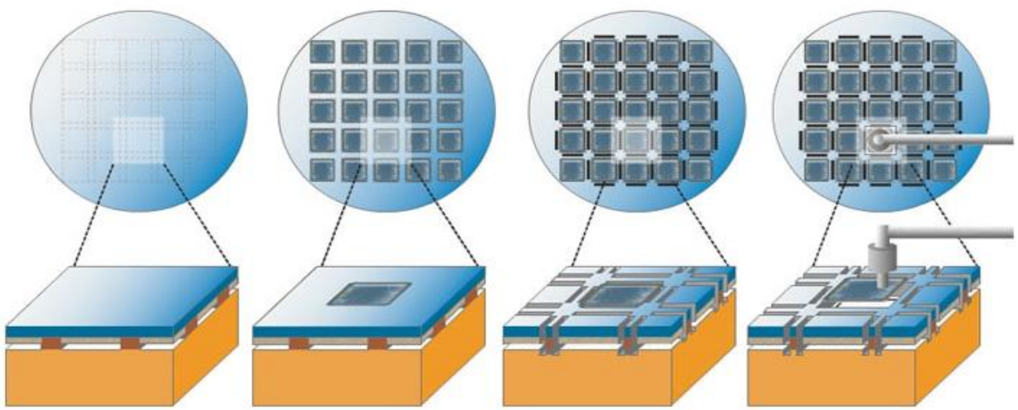
Challenges: MEMS Processing

MEMS
DRIE
KOH
Topside
Others



- DRIE at commercial foundry
- Accuracy
- Reproducibility
- High yield > 95%
- Migration

Opportunities: MEMS Processing



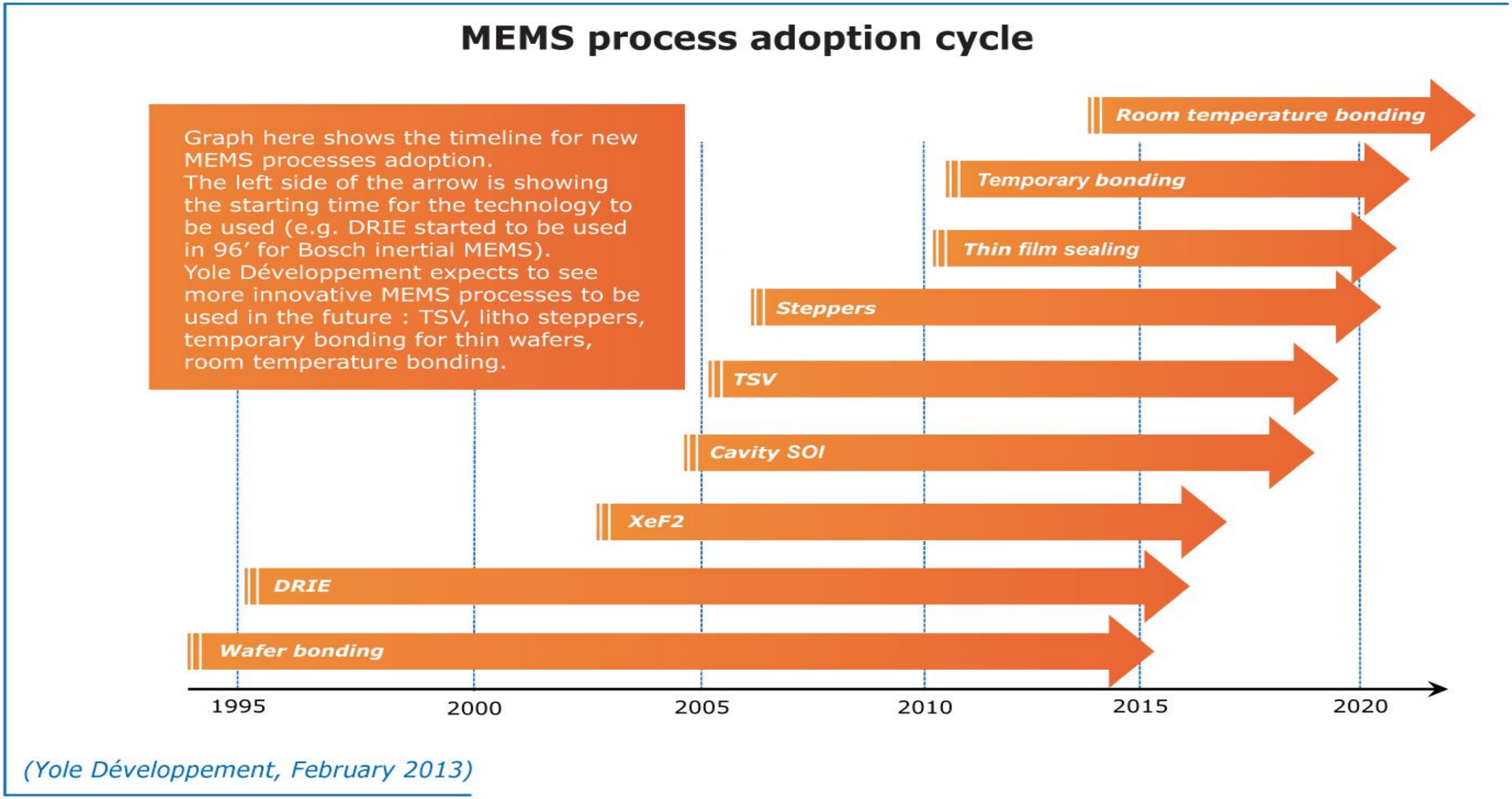
(Example DRIE machine)

- DRIE offers compact arrays
- Further miniaturisation
- Top-side and back-side etch
- 3D Packaging
- TSV
- Eliminate dicing - trench

Both CMOS & MEMS done at the same commercial foundry

(Some sensors may not require MEMS, but CMOS platform still enables ubiquitous capability with on-chip circuits)

MEMS Roadmap



Challenges: Sensing Materials

Sensing Material
MOX
Polymer
Pellistor
CNT/Others

- Expertise
- Type of material
- Sensitivity & selectivity
- Reproducibility
- Reliability
- High temperature capability
- High yield >95%

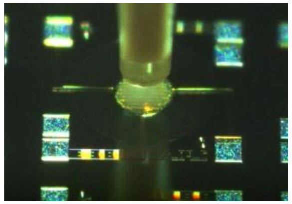
Opportunities: Sensing Materials

- CNT and Graphenes
- Innovation
- Multi-sensing + Redundancy
- CMOS process integration

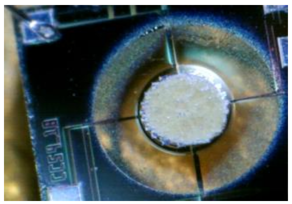
CCMOSS is actively involved in FP7, EU project (GRAFOL) helping to enable this capability!

Challenges: Sensing Materials Deposition

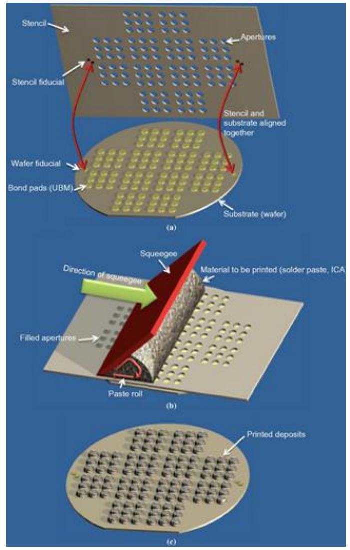
Deposition
Drop
Print
CVD/Others



Drop



CVD/Other



Print

- Coating
- Composition
- Sintering
- Adhesion
- Controlled thickness
- High volume production
- Fragile surface
- High yield >95%
- New tooling

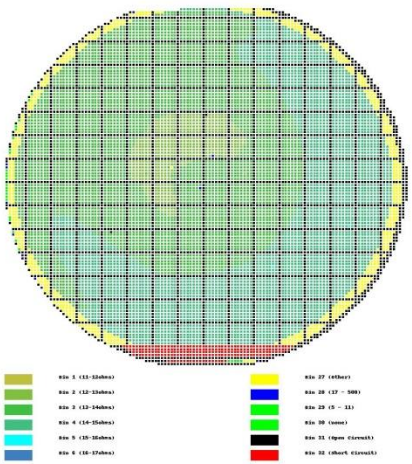
Opportunities: Sensing Materials Deposition

- Develop process at CMOS level
- Other method
- Improved Yield
- Process control
- New tooling

Wafer-level Test

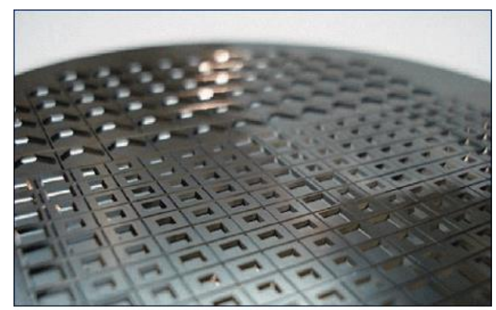
Custom
Test
Moulding
Trench

- Fully-automatic probe tests
- Heater resistance measurements
- Sensing parameter measurements
- Power consumption
- Optical Test



- **Wafer map showing results of wafer level test**
- **Yellow edge dice are not etched under emitter**
- **>99% yield to spec**

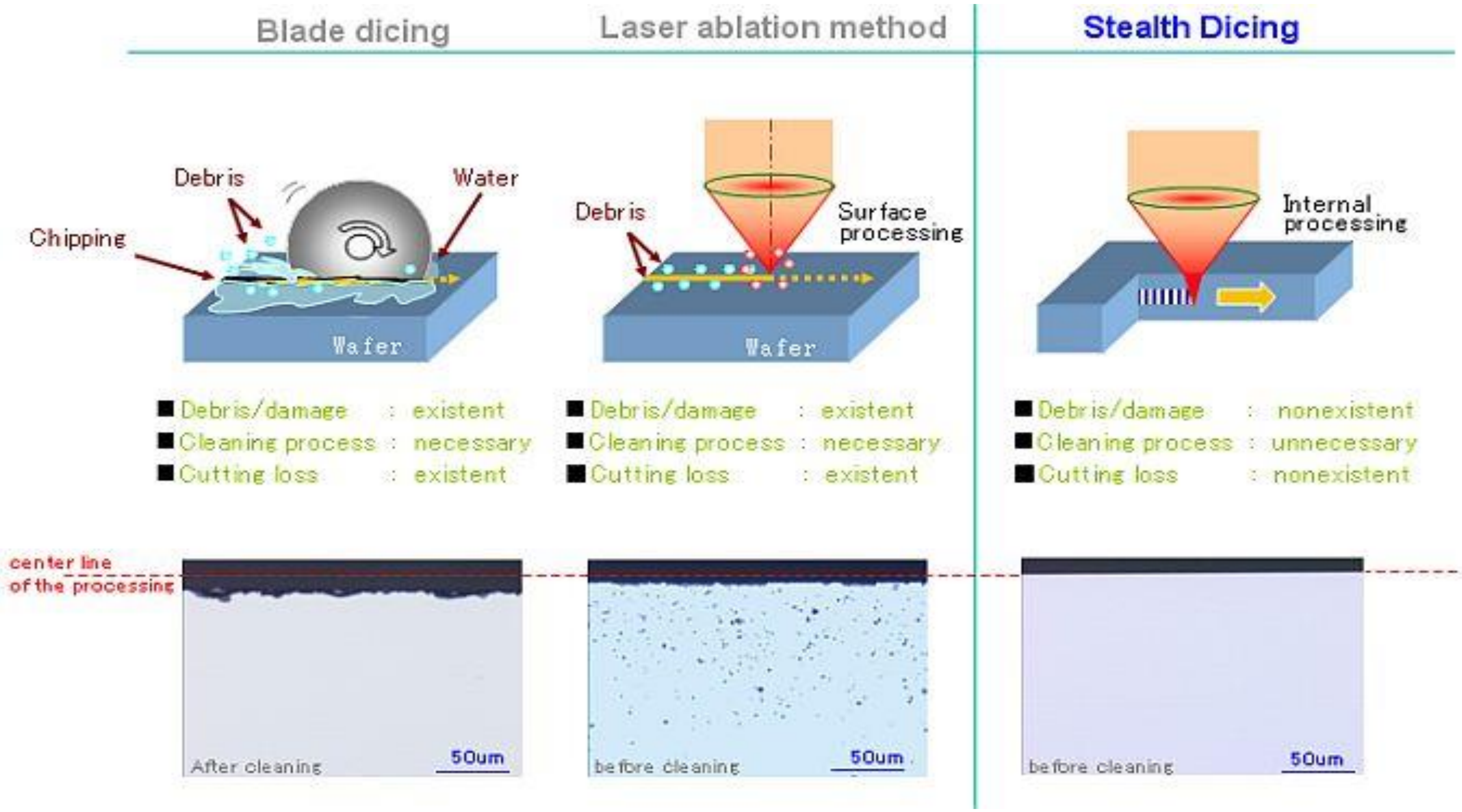
MANUFACTURABLE IN HIGH VOLUME!



Wafer-level moulding

Dicing

Dicing
SAW
Stealth
Fracture

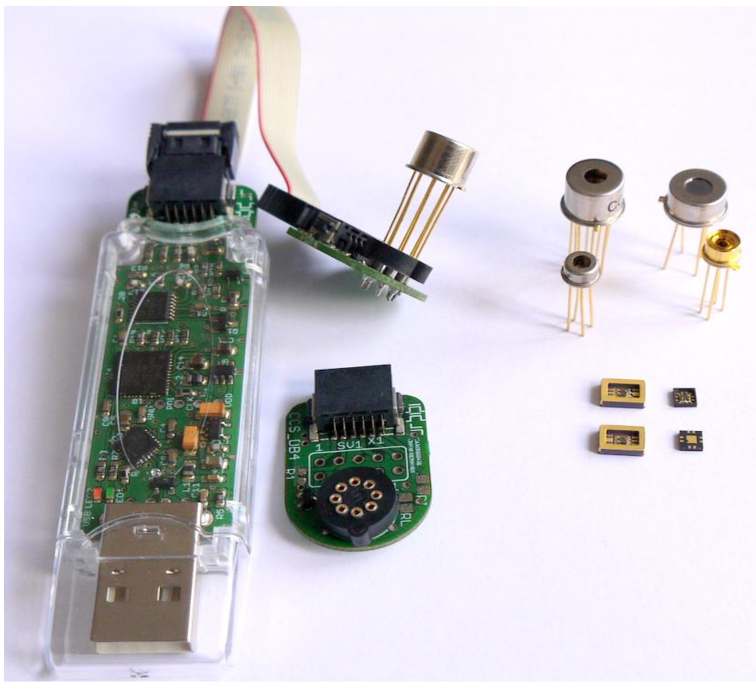


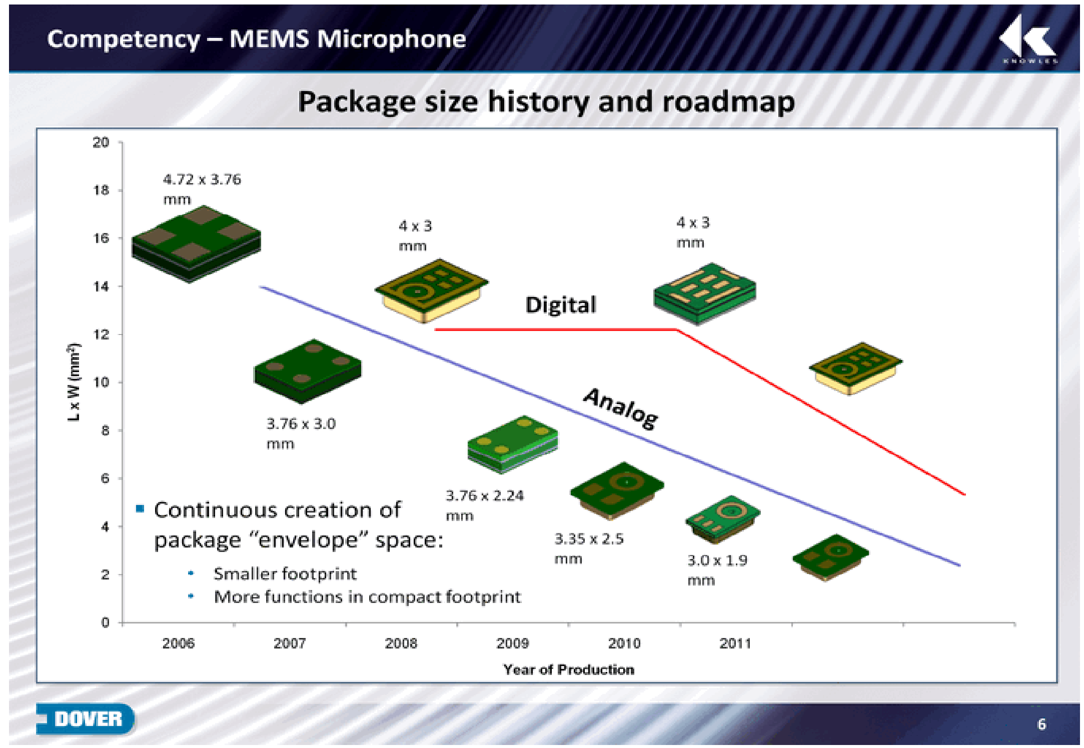
If dicing can be eliminated then significant cost advantage can be achieved!

Packaging

Packaging
SMD
Die on PCB
TSV
3D

- Die exposed
- Environmental protection
- High volume
- Small form factor
- Low cost
- High reliability

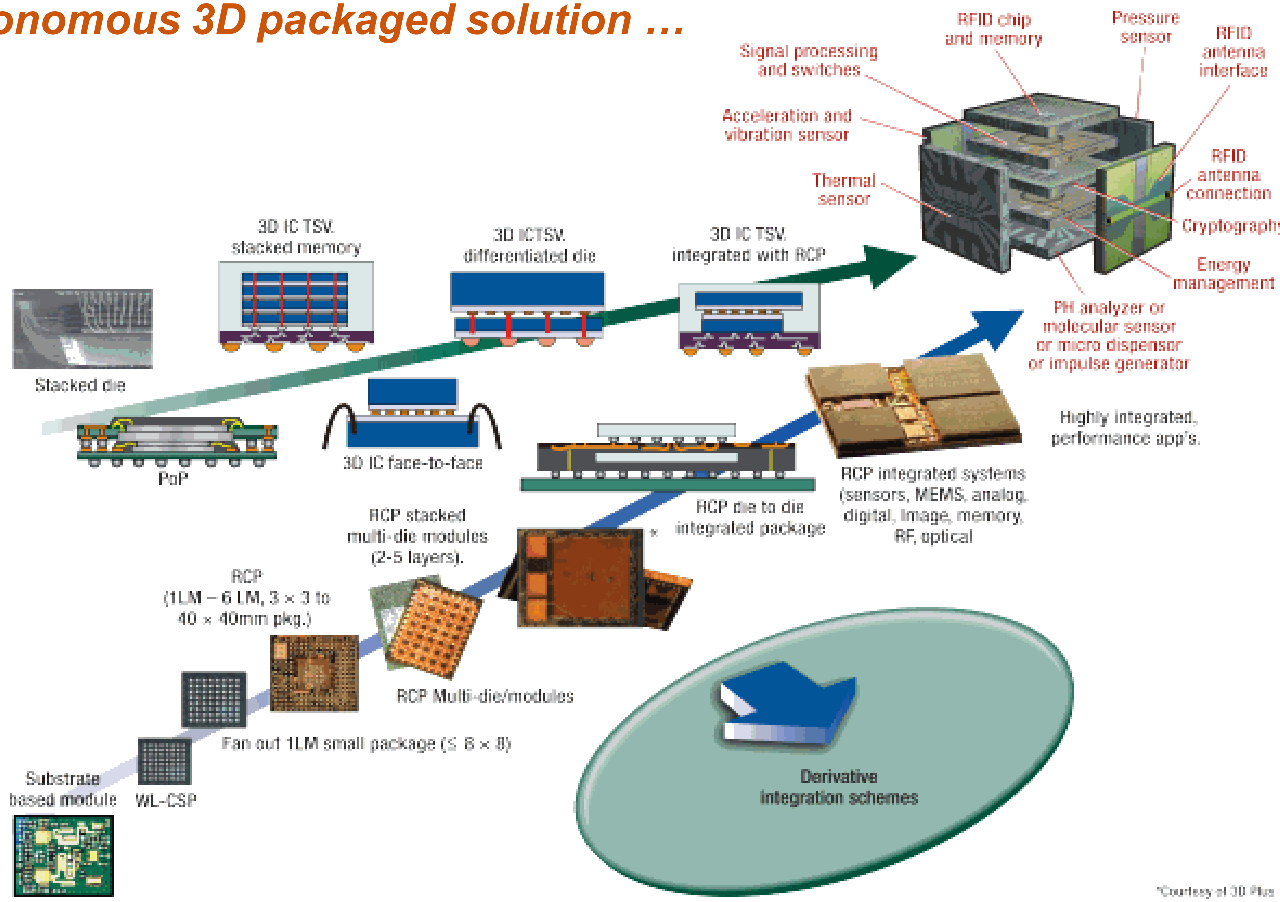




- Through hole
- SMD
- Die on PCB
- 3D TSV

Packaging Opportunities

Future is autonomous 3D packaged solution …



CCMOSS is actively involved in FP7, EU project (MSP) helping to enable this capability!

Qualification and Reliability

QualRel
Burn-in/HTOL etc
Certification
Others

- Reliability Testing
  - Environmental Testing
    - Burn-In
    - HTOL
    - Temp. Cycle
    - HAST
    - Hight Temp. Storage
    - 85°C/85%
    - Autoclave
    - Moisture Test
    - Salt Atmosphere
  - Mechanical Testing
    - Bond Strength
    - Die Shear
    - Lead Integrity
    - Solderability
    - Salt Atmosphere
  - Electrical Testing
    - Latch-up
    - ESD
    - Production Testing
    - Characterization

We need local cost-effective quick turn-around solutions!

CCMOSS is actively involved in FP7, EU project (SOIHITS) helping to enable this capability!

EU Manufacturing Scenario

Foundry
Europe - couple
US - couple
Asia – few

→

Wafer-level test
Europe - few
Asia - many

→

Dicing
Europe - few
Asia - many

→

Assembly and Test
Europe - few
US - few
Asia - many

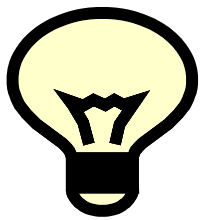
→

QualRel
Europe - few
Asia - many

Sensing Material
Europe - couple
US - couple
Asia - couple

Packages
Europe - couple
US - couple
Asia - many

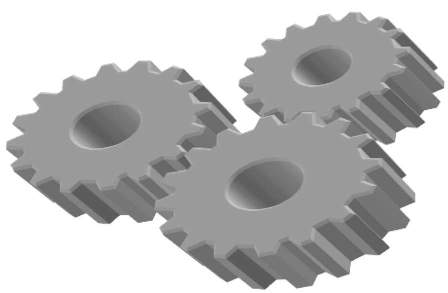
MEMS
Europe - few
US - few
Asia - few



In UE

We are Brilliant at innovations!

Original Ideas
Europe - Many
US - few
Asia - few



In EU

lagging manufacturing!

Conclusions

- CCMOSS has built know-how to enable ubiquitous gas sensing
- Working with leading partners for high volume production capabilities
- High volume production turnkey in place
- For high manufacturing establish global partnership
- More challenges and opportunities are created for diverse sensing application – not just gas sensing.

Acknowledgements

- CCMOSS Team

UNIVERSITY OF CAMBRIDGE

THE UNIVERSITY OF WARWICK

UNIVERSITY OF CAMBRIDGE enterprise

SEVENTH FRAMEWORK PROGRAMME

Investors