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COST Action TD1105

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

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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 –
  - \(\mu W\) average for gas analysis
- Fast thermal transient response –
  - 20ms thermal transitions to max temp
- Cost-effective and high volume manufacturing
- Miniaturised system
  - 100\(\mu m\) 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

## Gas Sensors

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Power Consumption</th>
<th>Heat Resistance</th>
<th>Heater Voltage</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCS801</td>
<td>Ultra-low power multi-gas sensor for air quality monitoring</td>
<td>-0.12 - 0.23mW</td>
<td>50Ω ± 10%</td>
<td>0.87 - 1.27V</td>
<td>SMD 3x2mm</td>
</tr>
<tr>
<td>CCS802</td>
<td>Ultra-low power gas sensor for monitoring carbon monoxide</td>
<td>0.12mW</td>
<td>48Ω ± 10%</td>
<td>0.87V ± 0.05V</td>
<td>SMD 3x2mm</td>
</tr>
<tr>
<td>CCS803</td>
<td>Ultra-low power gas sensor for monitoring ethanol</td>
<td>0.18mW</td>
<td>47Ω ± 10%</td>
<td>1.1V ± 0.05V</td>
<td>SMD 3x2mm</td>
</tr>
</tbody>
</table>

## IR Emitters

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

## Micro-hotplates

<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Power Consumption</th>
<th>Heat Resistance</th>
<th>Heater Voltage</th>
<th>Diode Temp Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCS301</td>
<td>High-temperature MEMS micro-hotplate</td>
<td>72mW ± 5mW</td>
<td>80Ω ± 25%</td>
<td>2.4V ± 0.3V</td>
<td>1.3 x 10⁻³ V/K</td>
</tr>
</tbody>
</table>
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

* 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

Meaning of Ubiquitous

ANYWHERE, ANYTIME, BY ANYONE AND ANYTHING
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.

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**

*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

**Mobile and Wearable Market**

**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

Not suitable for ubiquitous high volume application
High volume
Ultra-high volume

Courtesy Figaro for the base graph
Silicon is the material that is 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

- **Ubiquitous Appl**
  - Consumer
  - Automotive
  - Others

- **QualRel**
  - Burn-in/HTOL etc
  - Certification
  - Others

- **Assembly Test**
  - Batch
  - Sample
  - All
  - Others

- **Packaging**
  - SMD
  - Die on PCB
  - TSV
  - 3D

- **Dicing**
  - SAW
  - Stealth
  - Fracture

- **Gas Sensing Electrodes**
- **Deposition**
- **Custom**

- **Network**
  - Cost
  - European Cooperation in Science and Technology
## Challenges: Technology

<table>
<thead>
<tr>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMOS-SOI</td>
</tr>
<tr>
<td>NON-SOI</td>
</tr>
<tr>
<td>Bulk</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

- 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%

**SOI**

**NON-SOI**

Bulk is just metals – without CMOS

**Bulk + Flexible**
Opportunities: Technology

- 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

Cost reduction: SOI -> NON-SOI -> Bulk -> Plastic(?)
Challenges: Post-CMOS Processing

- 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

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

Opportunities: MEMS Processing

- 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

MEMS process adoption cycle

Graph here shows the timeline for new MEMS processes adoption. The left side of the arrow is showing the starting time for the technology to be used (e.g. DRIE started to be used in 96’ for Bosch inertial MEMS). Yole Développement expects to see more innovative MEMS processes to be used in the future: TSV, litho steppers, temporary bonding for thin wafers, room temperature bonding.

(Yole Développement, February 2013)
Challenges: Sensing Materials

- 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

- 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

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

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

Packaging

SMD
Die on PCB
TSV
3D

Competency – MEMS Microphone

Package size history and roadmap

- 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

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

MEMS
- Europe - few
- US - few
- Asia - few

In UE
We are Brilliant at innovations!

In EU
lagging manufacturing!

Original Ideas
- Europe - Many
- US - few
- Asia - few

Sensing Material
- Europe - couple
- US - couple
- Asia - couple

Packages
- Europe - couple
- US - couple
- Asia - many

In UE
We are Brilliant at innovations!
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

Investors