High Volume Chemical Gas Sensors: Collision of Two Worlds
Semi-Fab&Chemi-Product

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What Gases, When & Why?

“To measure is to know” and “if you cannot measure it, you cannot improve it”
[Lord Kelvin/William Thompson 1824-1907]

GAS Sensors that create meaningful data and enable knowledge are the first step in both understanding and controlling our environment.
The Current Situation

- The understanding of effects of air quality on our health and the environment is increasing fast!

- The demand for low-cost, high performance, precise, small gas sensors is increasing driven by IoT, smart cities, wearables, …

- Current gas sensors are:
  - Too large, too costly, power hungry.
  - Hard to produce for mass markets.
  - Less stable/reliable than needed.
How are humans exposed? Think global!

- Air, dermal, ingestion are the three routes for human exposure!
- Gases and vapors are inhaled, contaminate foods, and penetrate the skin.

Current practice [Nepal]

Government programs - 2015
We do need a better CO sensor? **YES, EVEN CO!**

- Health effects for CO begin at 1 ppm!
- Pregnancies affected at 5 ppm
- Permanent damage to fetus at 25 ppm
- Heart Disease Increased at 10 ppm
- Exercise performance lower at 20 ppm
- Beijing has 5-25 ppm ambient CO!
- Home CO alarm starts alarm at 30 ppm in 28 days! Not good for health!

<table>
<thead>
<tr>
<th>CO Level</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 ppm</td>
<td>Natural atmosphere level or clean air.</td>
</tr>
<tr>
<td>1 ppm</td>
<td>An increase of 1 ppm in the maximum daily one-hour exposure is associated with a 0.96 percent increase in the risk of hospitalization from cardiovascular disease among people over the age of 65. <em>(Circulation: Journal of the AHA, Sept, 2009)</em></td>
</tr>
<tr>
<td>3-7 ppm</td>
<td>6% increase in the rate of admission in hospitals of non-elderly for asthma. <em>(L. Sheppard et al., Epidemiology, Jan 1999)</em></td>
</tr>
<tr>
<td>5-6 ppm</td>
<td>Significant risk of low birth weight if exposed during last trimester - in a study of 125,573 pregnancies <em>(Ritz &amp; Yu, Environ. Health Perspectives, 1999)</em>.</td>
</tr>
<tr>
<td>9 ppm</td>
<td>EPA and WHO maximum outdoor air level, all ages, (TWA, 8 hrs). Maximum allowable indoor level <em>(ASHRAE)</em>. Lower CO level producing significant effects on cardiac function (ST-segment changes, angina) during exercise in subjects with coronary artery disease. <em>(Allred et al., Environ. Health Persp., 1991)</em>. Most common indoor air level triggering action by local Authorities of Jurisdiction. <em>(CAL, Penny)</em>.</td>
</tr>
<tr>
<td>10 ppm</td>
<td>Significant increase in heart disease deaths and hospital admissions for congestive heart failure <em>(JAMA, Morris, Penny)</em>.</td>
</tr>
<tr>
<td>15-20 ppm</td>
<td>World Health Organization lists as causing impaired performance, decrease in exercise capability, shortened time to angina response and vigilance decrement <em>(WHO, 13)</em>.</td>
</tr>
<tr>
<td>20 ppm</td>
<td>Typical concentration in flue gases (chimney) of a properly operating furnace or water heater/boiler. <em>(T.H. Greiner, ISU)</em>.</td>
</tr>
<tr>
<td>25 ppm</td>
<td>Chronic exposure during pregnancy to miniscule levels of carbon monoxide damages the cells of the fetal brain, resulting in permanent impairment. <em>(UCLA Study, BMC Neuroscience, June 22, 2009)</em></td>
</tr>
<tr>
<td>27 ppm</td>
<td>21% increase in cardio-respiratory complaints. <em>(Chest, Kurl et al., 1978)</em>.</td>
</tr>
<tr>
<td>30 ppm</td>
<td>Earliest onset of exercise induced angina <em>(HBCO 4.96% - World Health Organization, 13)</em>.</td>
</tr>
</tbody>
</table>
Where SPEC Sensors and IoT Intersect Today

- **Air Quality for Health, Safety, Security.**
  - Precise measurement of US EPA Criteria Pollutants
    - CO – combustion, most prevalent
    - NO\textsubscript{2} – diesel exhaust
    - SO\textsubscript{2} – Coal power and industrial
    - Ozone - atmospheric

*Smart home & City, Food Quality, wearables-mobile, Industrial safety, environmental awareness/protection!*

- **Consumer & Medical Devices**
  - Breath Analysis
    - Alcohol (EtOH)
    - Asthma (NO)
    - Bad Breath (VSC’s or Sulphur)
    - Metabolic rate (Ketones)

*Telemedicine, Oral Hygiene, wellness, …*
Background Issues

- Lack of understanding of the electrochemical sensing
  - SPEC is beyond MEMS! Unique contribution.
- Insight – what is the comparison to more conventional MEMS approaches or how does SPEC fit in with MEMS! Compare electrochemical sensing & solid state [HMOx]
**Typical Industry Questions**

- What is electrochemical sensor working Principal & Construction?

- How does your technology compete or compare with HMOx?

- What data can you share that shows the accuracy of ES sensors!

- The main push for gas sensing technology is for portable. How does your technology fit portable roadmap?

- What is the roadmap for getting smaller?

- Do you really have the worlds smallest EC Sensor?
  - Scalable-Mass Manufacture, low cost, high performance.
Q. What is Electrochemical Sensor Working Principal?

- Catalytic, no moving parts, no consumables, self-contained, zero power consumed!

Sensor allows gas permeation into sensor for reaction at two electrodes:

For CO - The reaction at the sensing electrode (where *anodic oxidation occurs*) is:
\[
\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + 2\text{H}^+ + 2e^-
\]

Simultaneously, the reaction at the counter electrode (the *cathode - reduction occurs*) is:
\[
\text{O}_2 + 4\text{H}^+ + 4e^- = 2\text{H}_2\text{O}
\]

Adding the two reactions yields:
\[
\text{CO} + \frac{1}{2}\text{O}_2 = \text{CO}_2
\]

*nothing consumed in sensor!*
Answer To The Questions

Q. How is the Electrochemical Sensor Constructed?

- Printed Electronics approach to assembly
  - Electrodes & Contacts
- Proprietary Inks
- Proprietary Electrolytes
- Proprietary Scalable Processing
- Unique thin Planar Geometry!
- Low cost batch plastic processing.
- Assembled In Wafer-die Process!!!
  - Takes advantage of semiconductor infrastructure!
SPEC High Volume/Low Cost Production
(Parallels Scalable Wafer Level Processing – current size is 8 inch wafer)

- **Wafer**
  - 16x10 cm
  - 60 die
  - 15x15 mm
  - 10x10 mm
  - >150 die
  - 4x4 mm
  - >500 die

- Plastic cost <<<Si per mm²
How does your technology compete with HMOx?

- Ans:

**Advantages of SPEC Approach to sensing toxic gases**
- Linear Response
- High repeatability and accuracy
- Very quick response times up and down – Seconds
- Ultra low or no power! Long battery life.
- Accurately measure in the PPB range.
  * relevant to environment, health, safety, wellness.
- Selectivity with resistance to interferences
- SPEC demands premium price due to value of high performance at low cost

**Comparison of HMOx and MEMS vs SPEC**
- Humidity can affect immediate sensor readings – not SPEC!
- High temperature reflow (HMOx is ceramic; SPEC plastic!)
- Higher Power needed for HMOx or IR vs SPEC [spec is near zero power]
- Lithography size limits for HMOx and today SPEC limited by PE size.
Why SPEC Electrochemical Sensors?

Selectivity & Precision Better for SPEC target gases
Non-selective sensing of Energy gases with HMOx

THE WORLD NEEDS BOTH!
HMOx vs. SPEC Sensors

**Variation**

- **HMOS**
  - mA
  - High power
  - Non Linear complex

- **ECS**
  - uA
  - Zero power
  - Linear simple

**Precision with SPEC**

SPEC = Precise; Ultra Low Power; Easy to implement
Answer To The Questions

Q. What data can you share that shows the performance of ES sensors?

- Highest quality performance & fast response at a fraction of the size and cost
- Have tested millions of sensor-hours with MTBF measured in decades.
Basic Sensitivity Characteristics

Gas response –Linearity and Sensitivity Test (UL2034 Sec 38.3)

Figures show response of the sensor when exposed to 30, 70, 150 and 400 ppm CO. The sensor was exposed to each concentration for 10 minutes, with 10 minutes clean air between. Response time reflects chamber purge time.
# SPEC Sensor Detection Limits

Meets/exceeds Regulatory Measurement levels

<table>
<thead>
<tr>
<th>Gas</th>
<th>SPEC* Detection Limit (ppm)</th>
<th>EPA¹ (ppm)</th>
<th>OSHA‡ (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.080</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.020</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>O₃</td>
<td>0.020</td>
<td>0.075</td>
<td>0.1</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.020</td>
<td>0.075</td>
<td>5</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.005</td>
<td>NA</td>
<td>20</td>
</tr>
</tbody>
</table>

¹ EPA National Ambient Air Quality Standards 
‡ OSHA Permissible Exposure Limits

* Customer Measured Data for sensor system -2015
Answer To The Questions

Q. The main push for gas sensing technology is for portable. How does your technology fit a portable roadmap?

A: SPEC’s ES sensors

- Small (Volume < 0.16cc)
- Light Weight (< 1 Gram; < 0.03 Oz)
- Low Power Consumption [<2.0u-watts – includes electronics]
- Investment focus on miniaturization and cost reduction with no change in performance!

Bulk Materials

Large

Old-industrial sensors

Printable Laminates

Tiny

New-SPEC sensor

Wafer Level

Micro!

Coming soon
Q. What is the roadmap for getting smaller?

**Roadmap…**

- **Phase I** Printed Sensors – Size and Cost Advantage
- **Phase II** Printed Sensors – 10x size reduction, Standardization, Device Integration
- **Phase III** and Beyond: Wafer Level Electrochemical Mfg, Electrochemical & HMOS Array
- **Conformal Devices Diagnostics/Breath Lab on Chip**
- **TAM $10 Billion**
- **Smartphones Wearables Consumer Devices**
- **$200 Billion**
- **Smart Home/IoT Smart Cities Accessories Commercial**
- **$500 Billion**

**Thank You**

**What can we sense for you?**

Reference:
- A Non-Destructive Bulk Currency Detection System (BCDS) for Screening Smuggled Currency; J. R. Stetter, M.T. Carter, M.W. Findlay, Suiqiong Li, V. Patel, and M. Papageorge; IMAPS Symposium; October 15, 2014; San Diego

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[CO, CH4, H2S, Alcohol, NO2, O3, SO2, HC, O2, CO2, H2, and more]

SPEC’s Gas Sensors For The Measurement of Life

Simultaneously!

- **Important Measurements**~ Human Health & Env.

- **Small/Low Profile**~ Goes in/on/with Everything!

- **Ultra-Low Power**~ Goes Everywhere!

- **Reliable**~ Works All the Time for decades!

- **Size:Cost**~ Scalable to Trillions of Gas Sensors!

Bringing EPA, OSHA, Law Enforcement level performance to the consumer
Available Packages for Gases - 2015
CO, H2S, NO2, O3, NO, R-OH, SO2, …

With wireless or circuit or pcb or pins or die or flex mount.
Evolution of Electrochemical Sensors


- Past → Present → Future
# SPEC Packaging Approach 2015

<table>
<thead>
<tr>
<th>Sensor Only</th>
<th>Sensor + PCB (P-SPEC)</th>
<th>Sensor + PCB (C-SPEC)</th>
<th>Sensor + PCB + Lid (L-SPEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0x15.0x3.8mm</td>
<td>20.0x20.0x4.3mm</td>
<td>20.0x20.0x3.8mm</td>
<td>20.0x20.0x4.8mm</td>
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<tr>
<td>15.0x15.0x3.0mm</td>
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<td></td>
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KWJ Engineering – safety, security, surveillance, …
SIP [system in package] – wearable & IoT products

- Wireless 900 MHz, BTLE, cloud, …
- Analog and Digital out; compatible; evidential.
- Flex and Multisensor: CO, O3, NO2, H2S, SO2, NO, Alcohol, …
Opportunity

SPEC enables gas sensing to be used to protect and/or improve the lives of everyone, everywhere, everyday, and especially sensitive populations! [babies, children, pregnant, elderly and infirm, pets, …]
THANK YOU

WWW.SPEC-SENSORS.COM

Environmental Awareness in the Mobile Age

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