Sensors for Food Freshness and Quality

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CEO, C₂Sense, Inc.
MIT J-WAFS Food & Water Conference, April 27, 2016
Wasted Food is a Global Problem

1.3 billion tonnes of food waste per year

8-15% loss (by weight) due to spoilage

$2,500 annual food waste per household

$125 billion could be saved annually from eliminating global food waste

Need for:

- Longer shelf-life produce
- Better storage and shipping conditions
- Smarter logistics
- Accurate consume-by dates
- Convenient access to actionable freshness information
Protecting Plants in Greenhouses

Ethylene:
- Given off by produce during ripening
- Induces ripening/spoilage

Current Ethylene Sensor
Ultra-Low Cost Sensors
Precision Gas Detection

A Sense of Smell For The Digital World

Industry
Food
Home
Unique Technology: Selective, Chemiresistive Sensing

- Miniature
- Simple resistance measurement
- Only cents to produce each sensing element
- Scalable fabrication
- Protected by 20+ patents from MIT and C\textsubscript{2}Sense
Sensor Development in the Swager Laboratory


I like simple things.
C₂Sense – Developing Simple Sensors

• Launched in January 2014
• Active Product Pilot Program in Food Supply Chain (part of $850k Co-Development/Commercialization Program)
• Program on Smart Food Packaging and Program for Worker Safety in Preparation (Start in Early Summer 2016)
• $1.3MM in Investments plus $1MM of Non-dilutive Funding; Raising Series A in Summer 2016
C₂Sense – Steps Toward Commercialization

**2015**
- Jan 2015: First Successful Field Test
- Sales inquiries from ca. **100 companies** to date
- Established Relationships with first customers in **Food Transport** and **Food Storage** markets

**2016**
- Apr 2016: Preparation of co-development with partner in food packaging and of Worker Safety project
- $1.3MM Investments and $1MM non-dilutive capital received/committed to date

**2017**
- Fall 2016: Product Pilot Begins
- Fall 2016: Product Pilot Demo
- Aug 2017: Full Food Storage Product Roll-out
- Funded Co-Development in Food Packaging begins

**2018**
- Spring 2018: Shipping Product Pilot (Expected)
- Fall 2018: RFID Sensor Prototype Expected Completion
- Product Pilot Shipping Container

**Late Summer 2016**
- $3MM-$5MM Series A Funding Round

**Fall 2017**
- Shipping Product Demo

**Spring 2018**
- Shipping Product Pilot (Expected)

**Series A Funding Round**
- $1.3MM Investments and $1MM non-dilutive capital received/committed to date
- Sales inquiries from ca. **100 companies** to date

**Established Relationships with first customers in Food Transport and Food Storage markets**
Chemiresistive Sensing Technology

Simple design...
1. Two electrodes
2. Sensing materials for selectivity: SWCNTs, selector, matrix, additives
3. Applied Voltage
4. Measured Current – readout gives analyte concentration

...with powerful, disruptive characteristics

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<th>High Selectivity</th>
<th>Analyte Range</th>
<th>Portability</th>
<th>Recovery Period</th>
<th>Power Consumption</th>
<th>Multiple Gases?</th>
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Some Key Steps Toward a Commercial Product

Scalable Sensor Chip Cartridge Fabrication

Sensor Lifetime

![Graph showing percent of initial response vs. time since fabrication](image)

![Graph showing -DG/G0 vs. time](image)
Properties of Sensors

- **Sensitivity**
  - Graph showing response $\Delta G/\Delta G_0$ vs. analyte (ppm)

- **Limit of Detection**
  - Graph showing response $\Delta G/\Delta G_0$ vs. time (s)

- **Resolution**
  - Graph showing response $\Delta G/\Delta G_0$ vs. analyte (ppm)

- **Dynamic Range**
  - Graph showing response $\Delta G/\Delta G_0$ vs. analyte (ppm)

- **Selectivity**
  - Graph showing response $\Delta G/\Delta G_0$ for analyte, control 1, and control 2

- **Reversibility**
  - Graph showing response $\Delta G/\Delta G_0$ vs. time (s)

- **Response Time**
  - Graph showing response $\Delta G/\Delta G_0$ vs. time (s)

- **Linearity**
  - Graph showing response $\Delta G/\Delta G_0$ vs. analyte (ppm)

- **Hysteresis**
  - Graph showing response $\Delta G/\Delta G_0$ vs. analyte (ppm)

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The Journey to an Ethylene Selector

First Generation Fluorescence-Based Ethylene Sensor

- Conjugated polymer sensor
- Measurable response: change in fluorescence intensity

Challenges:
- Insufficient Limit of Detection
- Fluorescence Readout

Main Sensing Mechanisms of CNT-Based Sensor

**Intra-CNT**

- (similar for CNT-Electrode conductivity change)

**Inter-CNT**

SWCNT-based Ethylene Sensing: Concept


Sensing Results with [Cu]-SWNT Devices

Relative response of [Cu]-SWNT and SWNT devices to ethylene in nitrogen, 10 s exposure each (baseline corrected, for 0.5, 1, and 2 ppm floating average of 10 points plotted)

Relative responses of [Cu]-SWNT and SWNT devices to ethylene in nitrogen (10 s exposure), averaged over three devices with three exposures each

1000x Lower Limit of Detection
Can we detect ethylene in fruit?

Relative response of $\text{[Cu]}$-SWNT devices to 100 g of fruit relative to the response to 20 ppm ethylene.
Following Ripening and Senescence

Relative response of [Cu]-SWNT devices to 100 g of fruit relative to the response to 20 ppm ethylene monitored over several weeks. Apple 1 and the pear were stored in a fridge, all other fruit at room temp.
Ethylene Selector Development – 1st Generation Selector

Challenges:
- Limited Sensor-to-Sensor Reproducibility
- Limited Life-Time
2nd Generation Ethylene Selector

CoSel

ClO$_4^-$

- More reproducible
- Longer life-time (3+ months vs. 1-2 weeks)

Challenge:
- Low Sensing Response
Improved 2nd Generation Ethylene Selector Formulation

Challenge:
- Humidity Interference

Graph:
- Dry Nitrogen Background
- 10,000 ppm Water Background

10x Higher Sensing Response
3rd Generation Ethylene Selector

- Tetrazine (1) only showed low response, but 3rd generation metal-complex selector (2) responded well
- Interacts with ethylene in presence of water
- Higher humidity level leads to higher response (can be corrected)

Selector shows higher response with humidity
Early Applications

**Fruit Ripeness Detection:**
- Ship/Sell/Consume Before Fruit Spoils
- Protect Sensitive Fruit, Vegetables, Flowers

**Meat/Fish/Poultry Freshness:**
- Reduce Risk of Food-Borne Illness
- Use in Supply-Chain Management, Packaging and Smart Refrigerators

**Toxic Gas Sensors:**
- Real-Time Detection of Ammonia and Other Gases for Worker Safety
- Small and Lightweight: Wearable
The Avocado Problem...
... And The Avocado Solution
Ultra-Low Cost Sensors
Precision Gas Detection

A Sense of Smell For The Digital World

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Food
Home
C₂Sense, Inc.

Thank You

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