Implement smell and taste with nanosensors

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Acknowledgement

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A mobile sensing solution in a ‘Tricorder’

- Portable
- Fast
- Accurate
- Reliable
- Low Cost

food inspection

environmental protection

anti-counterfeiting

safe???
Raman Spectroscopy

Photon-Matter interaction

1/100,000,000 photons are Raman scattering

Require bulky, expensive instrument
Raman Spectrometer 85 Years Later

C.V. Raman, 1928

Mini-SERS prototype @ HP Labs

Laboratory Raman Instrument

2013
Surface-enhanced Raman scattering

Raman scattering enhanced by localized surface plasmon on nanostructure

SERS Enhancement Factor $\propto |E(\omega)|^2 |E(\omega')|^2$

also approx. to $\sim |E|^4$
Electromagnetic field induced EF: $10^6 - 10^{12}$

SERS will enable single molecule level detection with compact devices
Two Approaches to Nano-scale

Bottom-up synthesis

Advantage: low cost, close packing of NP possible.
Disadvantage: Random, difficult to produce long range order and uniform structure.

Top-down fabrication

Advantage: Uniformity over large area
Disadvantage: difficult to obtain nm spacing for ultrahigh enhancement.


Top-down meets self-assembly
— the leap from stochastic to deterministic SERS structures
Hybrid nanostructure to mimic “Venus Fly Trap”
-- Polymer Finger + Metal Nanotips

(a)

(b)

![Image of Venus Fly Trap]

![Diagram of hybrid nanostructure]

![Scanning Electron Microscope (SEM) images]

![Raman spectrum graph]

![Inset SEM image with scale bar]
Advantages of nanofinger structures

• Leverage advantages from both top-down and bottom-up approaches – No need of costly critical dimension control.
• Easy scale-up for large area uniformity and reliable hot spots – Nanoimprinting.
• Micro-capillary driven “finger” closing – Easy for fluidic interface, no power nor complicated controls needed.
• Molecule self-limiting of the gap sizes, as small as sub-nm – Physical limit of the smallest separation manufacturable, hence strongest coupling effect.
• Active molecule trapping by the fingers – Molecular tweezer with build-in sensing functionality.
Inexpensive Nanochips Fabrication Process

Si mold → imprint → UV Resist → gold deposit → Imprint on 8 inch wafer → roll-to-roll

Wafer scale | Chips | Strips
<table>
<thead>
<tr>
<th>Sensor Systems</th>
<th>Total # of Olfactory Receptor Cells</th>
<th>Total Olfactory Epithelium Surface Area</th>
<th>Receptor Area Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloodhound (the most sensitive animal on land)</td>
<td>4 billion</td>
<td>380 cm²</td>
<td>~10 million/cm²</td>
</tr>
<tr>
<td>Human Nose</td>
<td>12 million</td>
<td>10 cm²</td>
<td>~1 million/cm²</td>
</tr>
<tr>
<td>Nanofingers (man-made SERS sensor)</td>
<td>~1 billion</td>
<td>1 cm²</td>
<td>~1 billion fingers/cm²</td>
</tr>
</tbody>
</table>
Technology Advantages

Current molecular analytical process

- Sample
- Add isotope-labeled target
- Add extraction solution
- Shaking
- Centrifugation
- Solid phase extraction
- Detector
- HPLC - MS

complicated, expensive, time-consuming, labor-intensive, and limited to lab testing

Our solution: ‘Taste and Smell’ on a mobile device

- Soak nanosensor chip in sample solution
- Allow sample to air dry
- Take tricorder reading

simple-to-use, rapid, cost-effective, sensitive

Warning
OK
Demonstration of Melamine Sensing

Melamine contamination in milk, 300,000 victims in China 2008

Max. amount in infant formula (FDA): 1 mg/kg (1 part per million)


\[
I_{SERS} = V \Theta = V \frac{c^n}{k^n + c^n}
\]
Melamine Sensing Results

Melamine in whole milk or infant formula

Dialysis method:

Filtration method:

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Demonstration of Pesticide Sensing

Chloryrifos, is a **neurotoxin**, **carcinogen**, once popular pesticide used worldwide, and the residue can be found in vegetables, fruits, etc.

EPA regulation: 0.1 parts per million on citrus fruits

Detection limit of 35 parts per trillion

Chloryrifos concentration (mol/L) vs. Raman intensity (a.u.)
Demonstration of ‘Chemical Barcode’ for Authentication

Different molecules as “chemical barcode” based on their specific fingerprints on Raman spectrum

- Mix special marker(s) in product at trace levels
- Detect with SERS
- Real-time authentication
- Remote monitoring/reporting
**Future is around the corner!**

Nanosensor chip as consumables

Conceptual mobile device for data collection & on-ramp to cloud system

Data analysis, storage, networking as cloud service to government, enterprise, consumers
Thank you

Q&A