Implement taste and smell with nanosensors

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Microtechnology and semiconductor industry have revolutionized modern life
Milk adulteration with melamine
Pesticide residue?
Analysis of food contaminants in Lab

Extraction → Sample concentrator → Analysis (GCLC-MS)

Time-consuming: several hours (exclude sample shipping)
Expensive tools: hundreds of thousands dollar
Complicated: need professional operator (labor cost)
Safe, secure, sustainable world and people’s well-being demand more sensors
Nanosensor is the solution to implement smell and taste (chemical sensing or chemosensation)
Potential application of smell and taste nanosensors

- Food and agriculture: food contaminant test and monitoring, **$1.6 billion** market
- Healthcare: Disease diagnostic, patient monitoring, multi-function test strips **$53 billion** IVD market
- Drug regulations: supply monitoring, anti-counterfeiting, 5-10% of WW pharmaceutical annual sales of **$800 billion** is believed to be counterfeit
- Chemical industry: industrial chemical monitoring
- Government: environmental monitoring, security and defense applications, food, agriculture and drug regulations
- R&D organizations: developing new apps
Silicon ChemFET Nanosensor

Low-cost high-value sensor technology for parallel detection of 100s – 1000s of bio-molecular species.

- Circuitry at nanoscale
- I/O interfacing
- Selective surface functionalization
- Specificity and sensitivity
- Bio-compatibility
- Power
- Stability & reliability
Sensing proton to DNA

**pH sensing**

**DNA sensing**

Z. Li, et al, Nanoletter, 2004, 4, 245
Smelling the hydrosulfide gas

Surface Enhanced Raman Spectroscopy (SERS) – enabling "molecular fingerprinting"

Localized surface plasmon on nanostructure can enhance the Raman scattering process -- SERS

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

also approx. to $\sim |E|^4$

Electromagnetic field induced EF: $10^6 - 10^{12}$

Gain $10^6 - 10^{12}$

DNT

SERS

No SERS
Surface Enhanced Raman Scattering (SERS)

1974 – M. Fleischman studied pyridine on roughened silver with increased surface area.

1977 – Rick Van Duyne and Alan Creighton reported enhancement of $\sim 10^5 - 10^6$ -- much too large to account for, by the increased surface area alone.

![Graph showing publications in SERS area over the years from 1979 to 2009.](image)
HP’s SERS Technology Evolution

- **Black Silicon (Etched Silicon Cones)**
- **Polymer Cones (nanoimprinted)**
- **Periodic Cones (nanoimprinted)**
- **Periodic Gold Fingers (nanoimprinted)**
- **Deterministic Gold Fingers (nanoimprinted)**

Years:
- 2008
- 2009
- 2010
- 2011
Molecular Trapped in SERS “hot-spots”

Top view of nanofingers

Cartoon of molecular Trapping

Field map of closed nanofingers

Top-down meets self-assembly
— the leap from stochastic to deterministic SERS structures
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 – Roll-to-roll plastic fab.
• 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.

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CAN WE DESIGN FINGER SYMMETRY?

SERS of nanofinger of different symmetry

BPE sensing

![Chemical structure of BPE](image)

Ethanol solution

Raman intensity (arb. unit) vs. Raman shift (cm⁻¹)

Detection limit of 0.02 parts per trillion

**Data:** Data2_B
**Model:** Hill
**Equation:** \( y = \frac{V_{\text{max}}x^n}{k^n + x^n} \)
**Weighting:** y Statistical

\[ \frac{\text{Chi}^2}{\text{DoF}} = 248.95693 \]

\[ R^2 = 0.98792 \]

\[ V_{\text{max}} = 46682.94086 \pm 2689.4077 \]

\[ k = 3.1412 \times 10^{-7} \pm 1.1879 \times 10^{-7} \]

\[ n = 0.55525 \pm 0.04936 \]

BPE sensing was performed using a Hill model with the equation \( y = \frac{V_{\text{max}}x^n}{k^n + x^n} \). The statistical analysis yielded a Chi squared value of 248.95693 and a coefficient of determination \( R^2 = 0.98792 \). The parameters were determined as follows:

- \( V_{\text{max}} = 46682.94086 \pm 2689.4077 \)
- \( k = 3.1412 \times 10^{-7} \pm 1.1879 \times 10^{-7} \)
- \( n = 0.55525 \pm 0.04936 \)

The detection limit of BPE was calculated to be 0.02 parts per trillion. The Raman intensity data is presented for various BPE concentrations ranging from 1 nM to 100 fM, with corresponding Raman shifts.
**Demonstration A:**
Melamine sensing with HP nanofinger SERS: >10,000× better than competitors

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

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

Detection limit of 100 parts per trillion
Demonstration B:

Chloryprifos sensing with HP nanofinger SERS: >1,000× lower than EPA regulation

Chloryprifos, 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