Implement taste and smell with nanosensors

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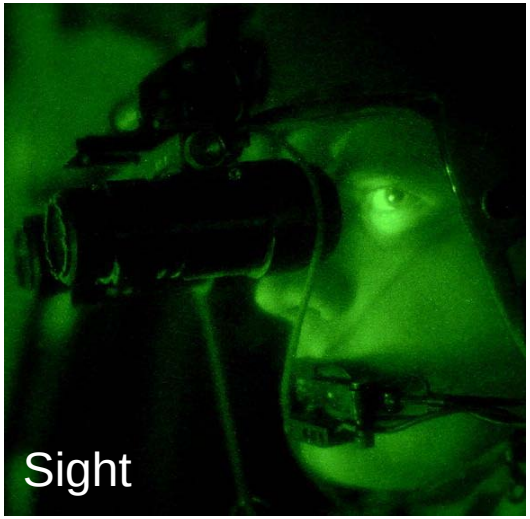
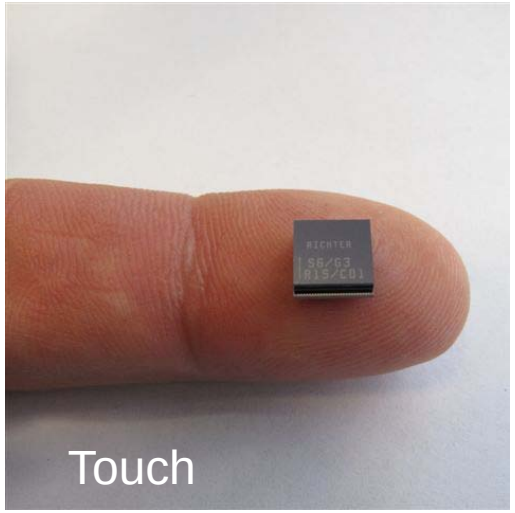
Microtechnology and semiconductor industry have revolutionalized modern life





Smell

Taste

?

San Bruno Fire

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

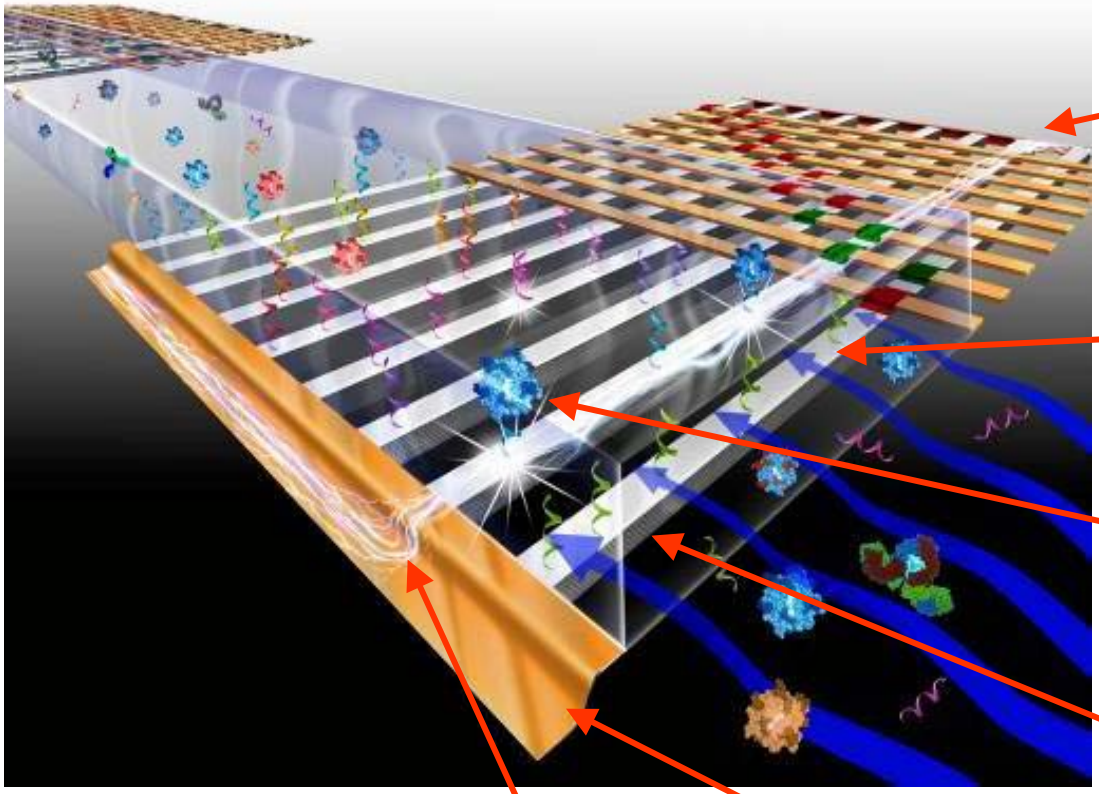
Nanosensor is the solution to implement smell and taste (chemical sensing or chemosensation)

Potential application of smell and taste nanosensors

- Food and agriculture: food contaminant test and monitoring, **$1.6billion** market
- Healthcare: Disease diagnostic, patient monitoring, multi-function test strips **$53billion** IVD market
- Drug regulations: supply monitoring, anti-counterfeiting, 5-10% of WW pharmaceutical annual sales of **$800billion** 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

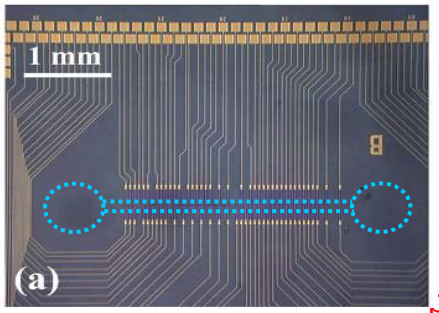
Bio-compatibility

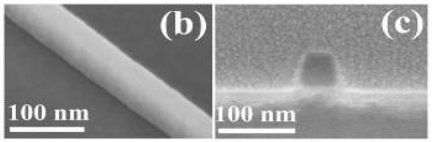
Stability & reliability

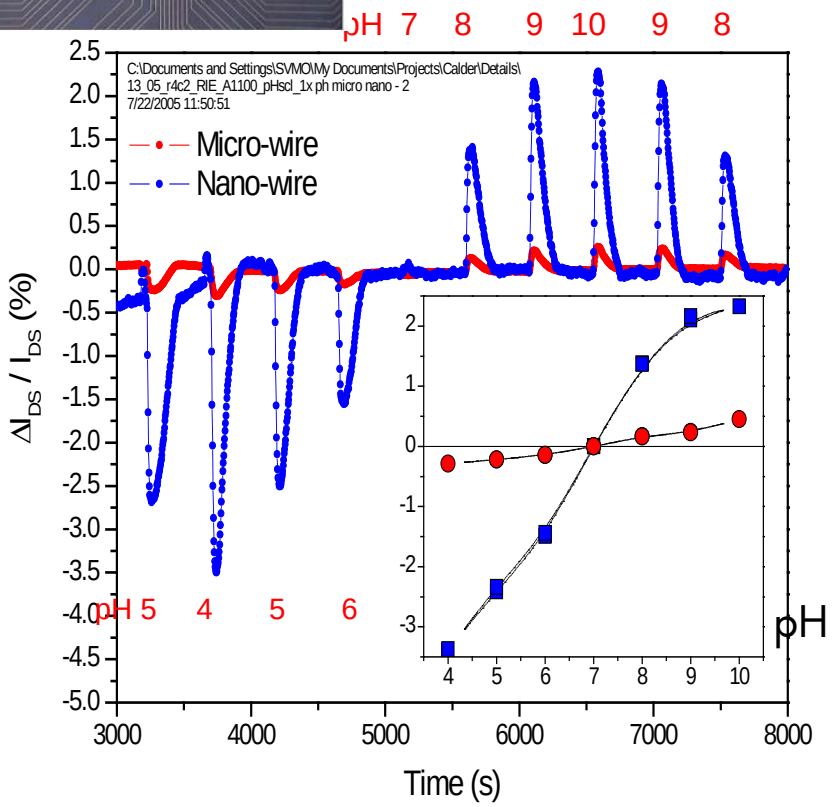
Power

Sensing proton to DNA

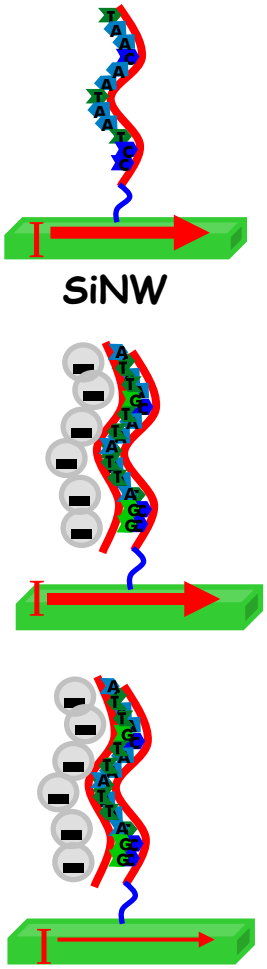
pH sensing

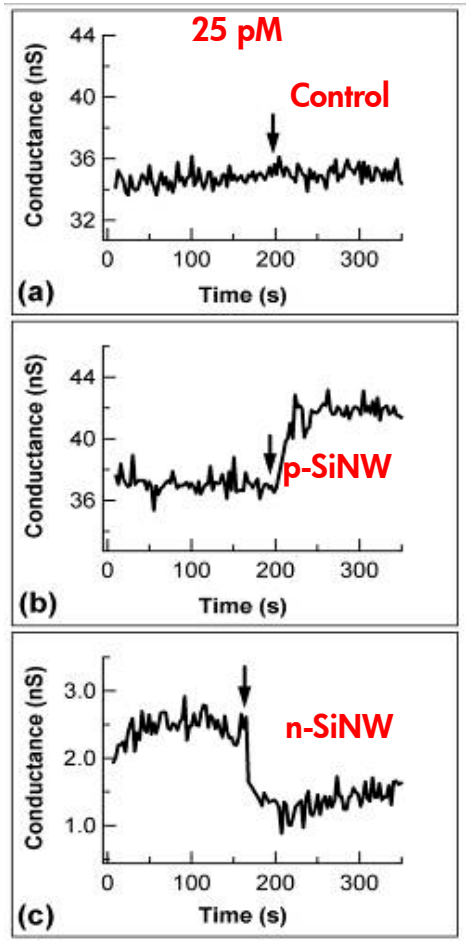






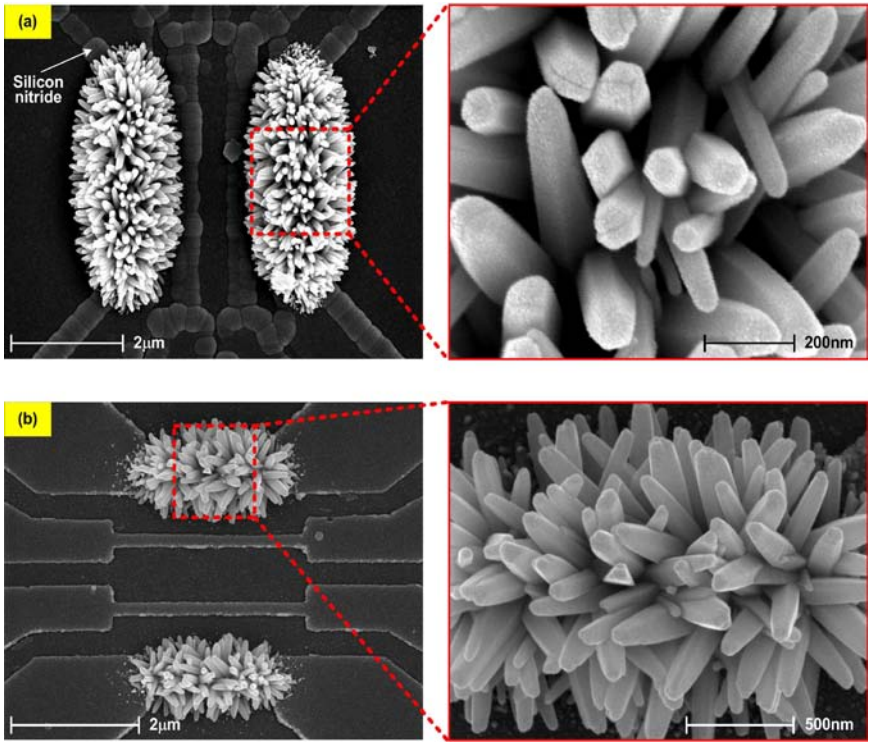
DNA sensing

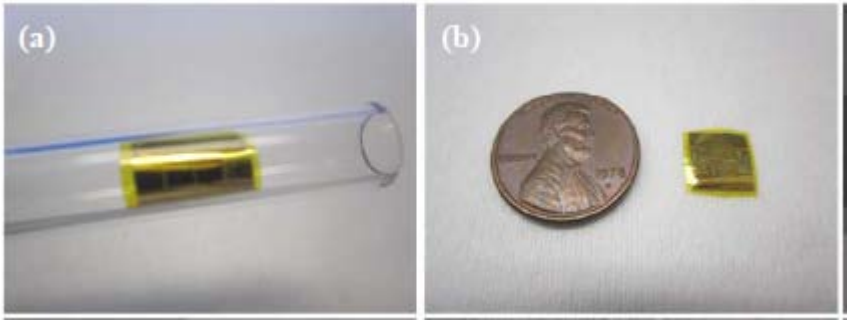


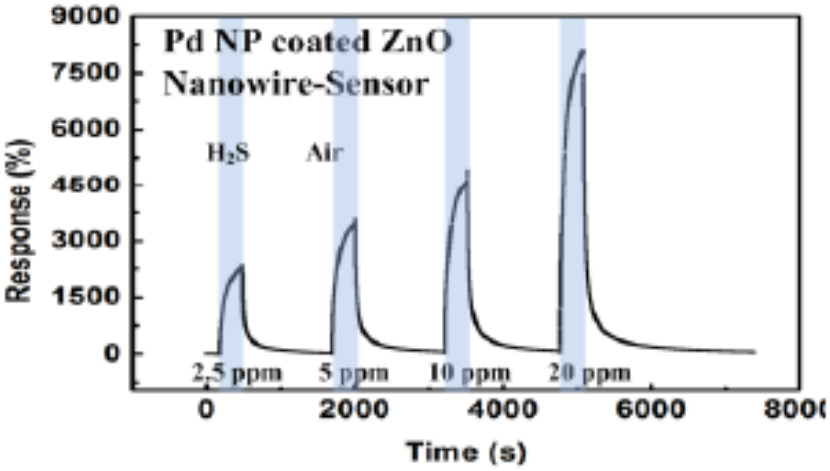


Z. Li, et al, Nanoletter, 2004, 4, 245

Smelling the hydrosulfide gas



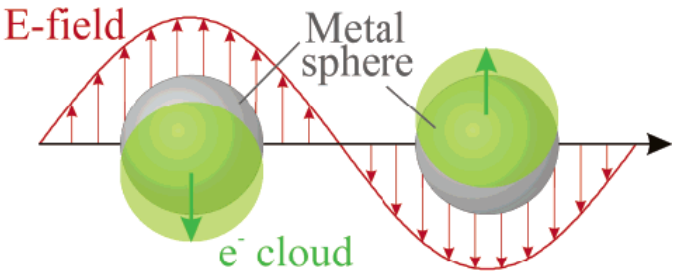


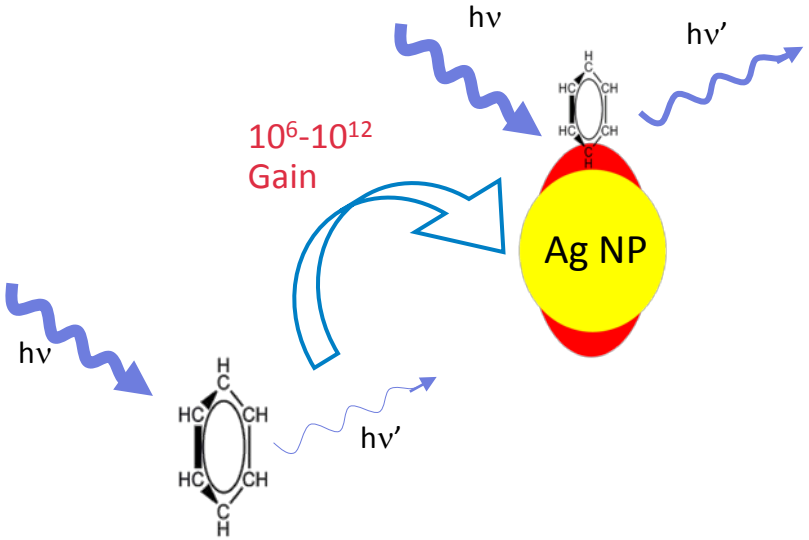


I. Park, Z. Li et al, Nano Letters, 2007 and 2011

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

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

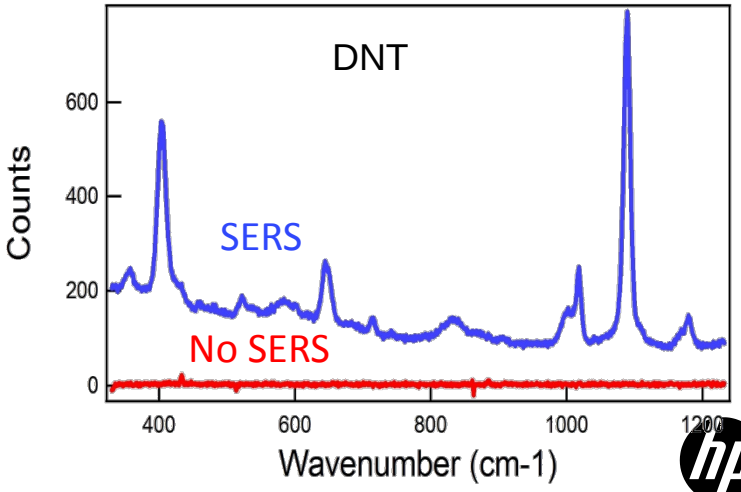




SERS Enhancement Factor $\propto |E(\omega)|^2 |E(\omega')|^2$

also approx. to ~ $|E|^4$

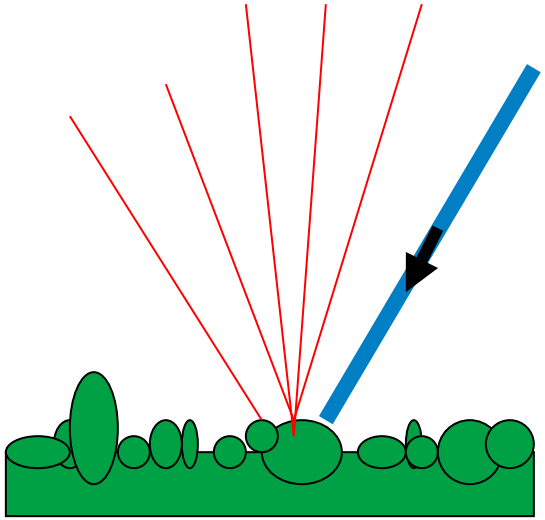
Electromagnetic field induced EF: 10^6 - 10^{12}

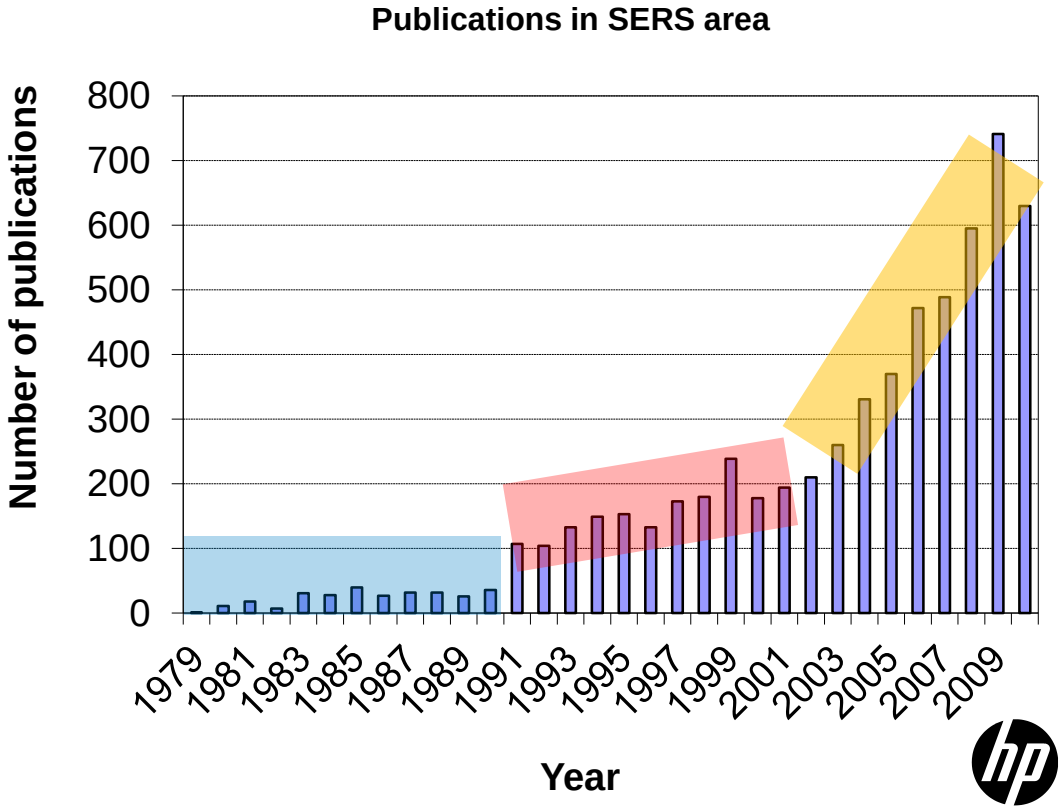


Surface Enhanced Raman Scattering (SERS)

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

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





HP's SERS Technology Evolution

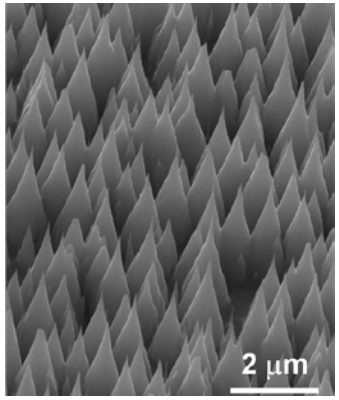
Black Silicon
(Etched Silicon Cones)

Polymer Cones
(nanoimprinted)

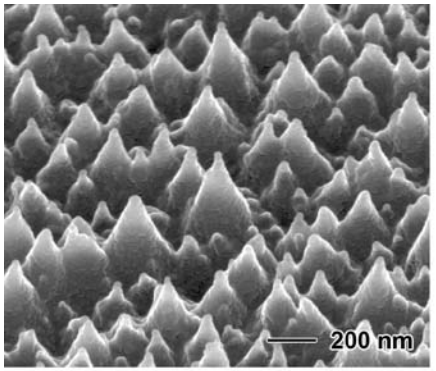
Periodic Cones
(nanoimprinted)

Periodic
Gold Fingers
(nanoimprinted)

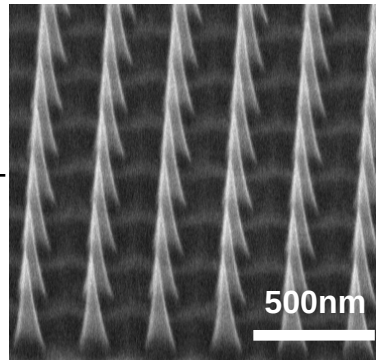
Deterministic
Gold Fingers
(nanoimprinted)

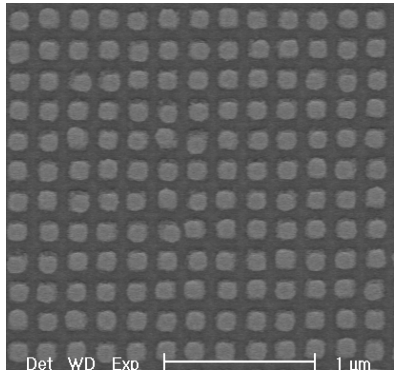


2008



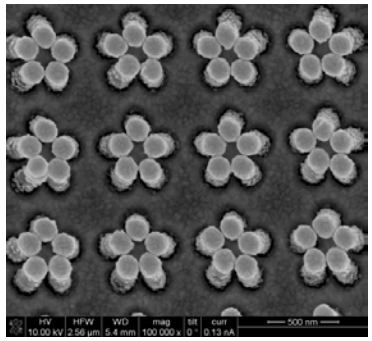
2009





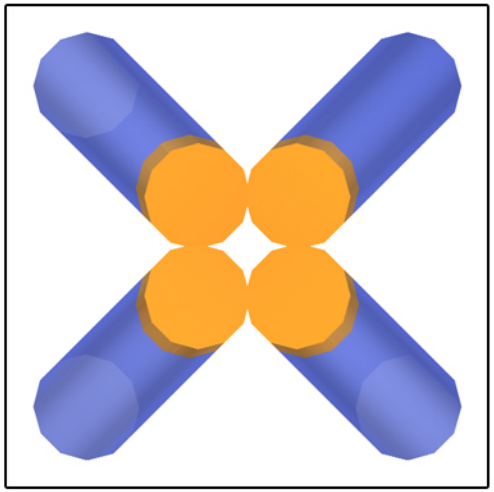
2010

2011

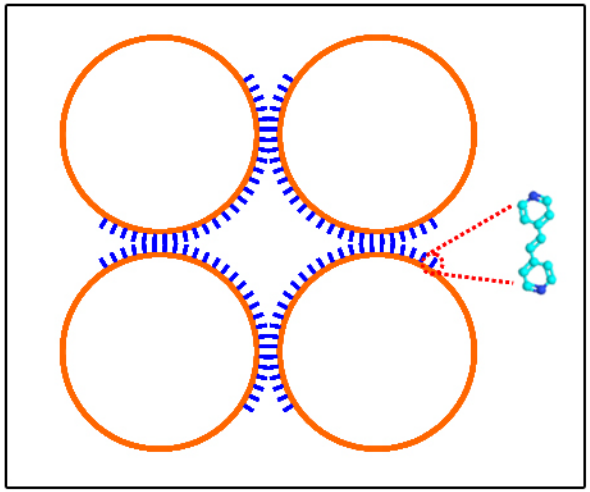


Molecular Trapped in SERS “hot-spots”

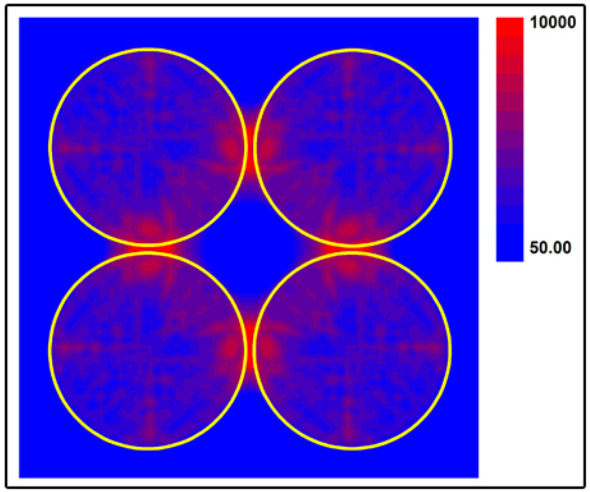
Top view of nanofingers



Cartoon of molecular Trapping



Field map of closed nanofingers



Hu, M. et. al. *J. Am. Chem. Soc.* **2010**, *132*, 12820.

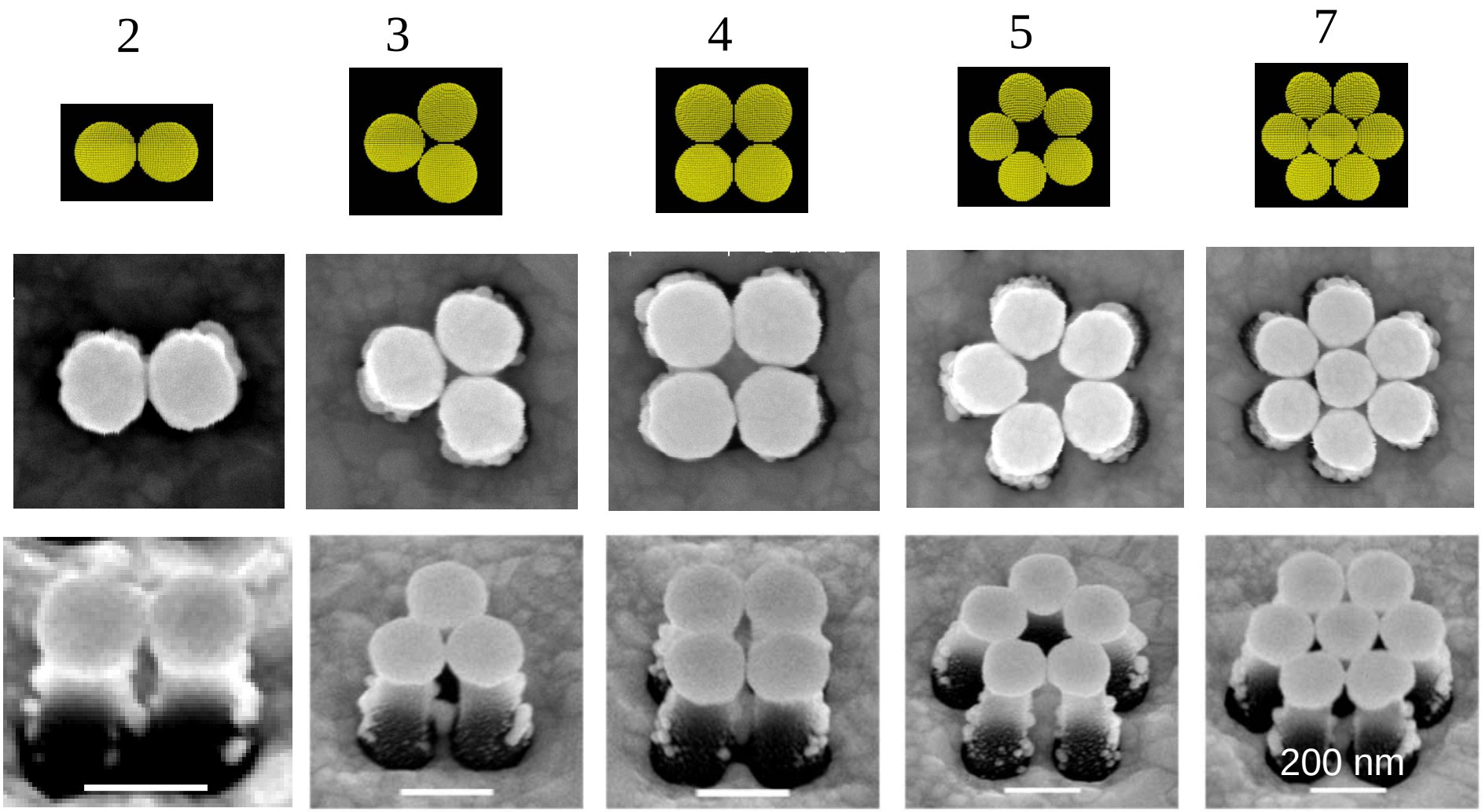
Top-down meets self-assembly

— 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.

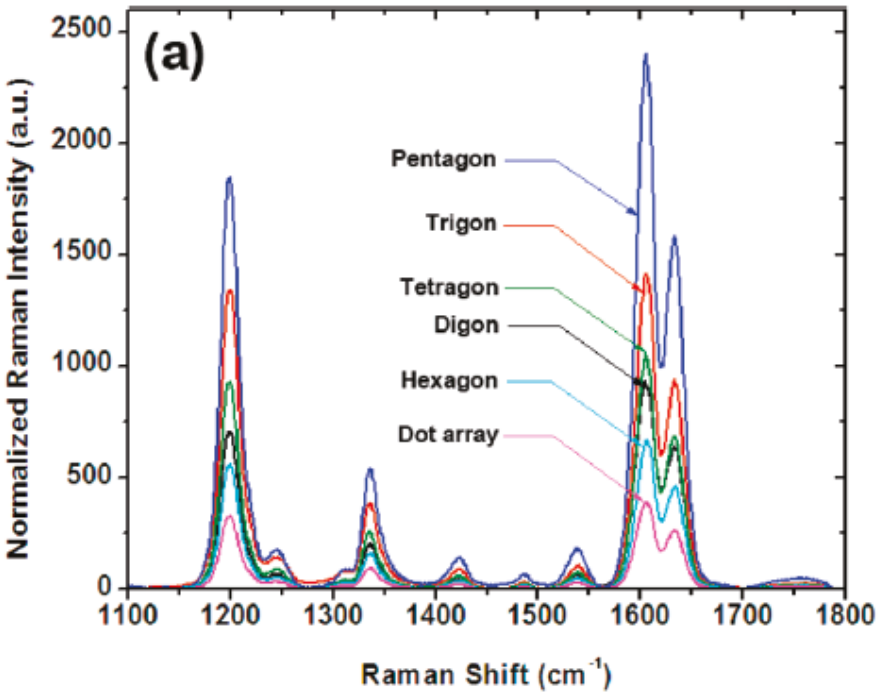
CAN WE DESIGN FINGER SYMMETRY?

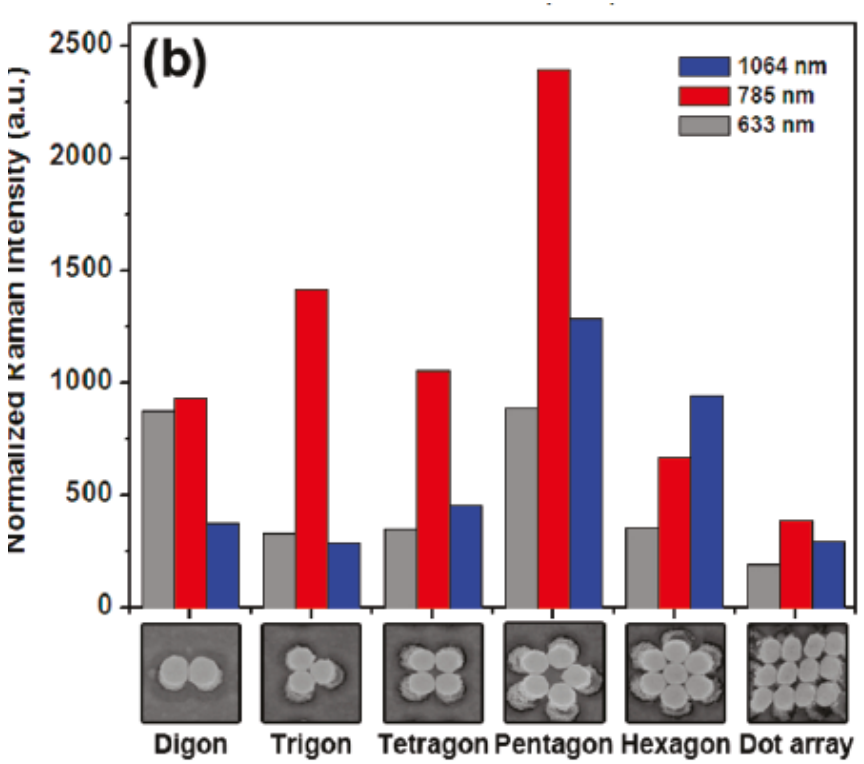


Ou, F. S. et. al. Nano Letters, 2011, *11*, 2538–2542.

SERS of nanofinger of different symmetry

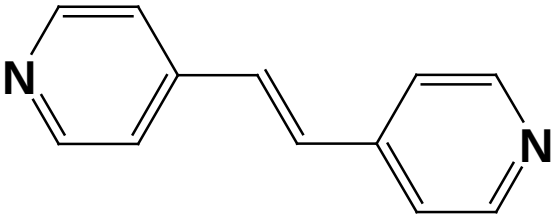
BPE





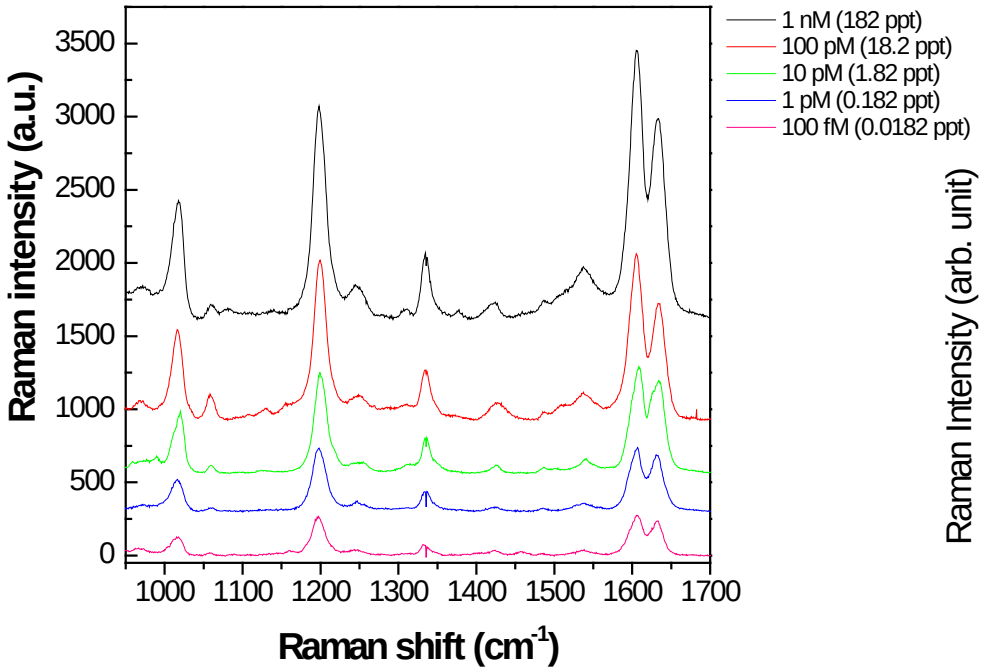
Ou, F. S. et. al. Nano Letters, 2011, *11*, 2538–2542.

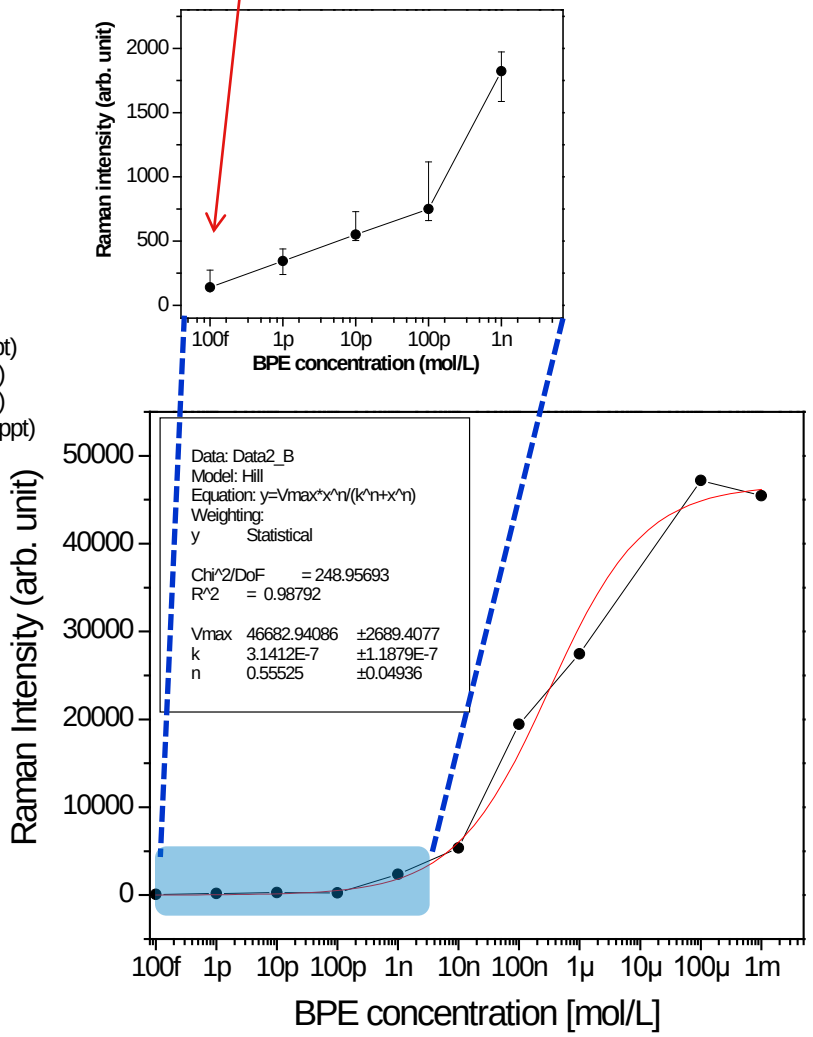
BPE sensing



Ethanol solution

Detection limit of
0.02 parts per trillion

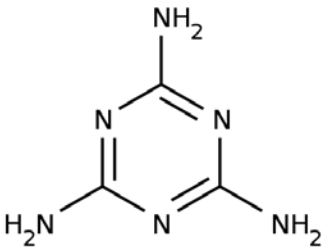




Demonstration A:

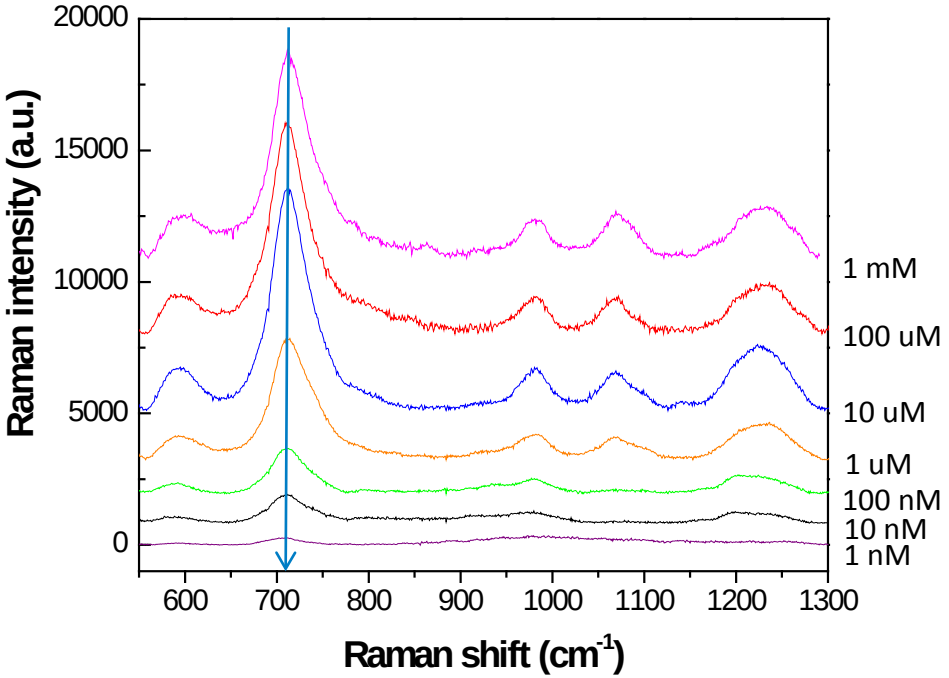
Melamine sensing with HP nanofinger SERS: >10,000× better than competitors

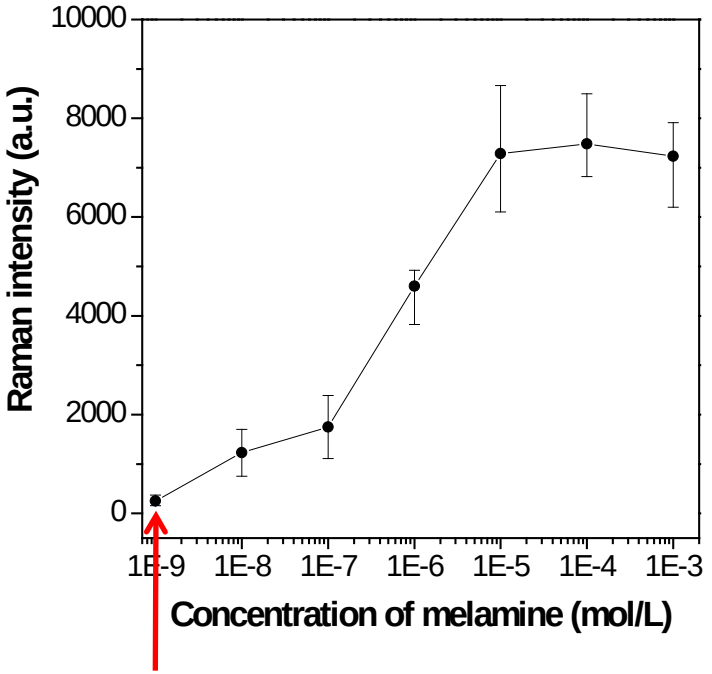
Melamine contamination in milk, 300,000 victims in China 2008



max. amount in infant formula (FDA):

1 mg/kg (1part per million)



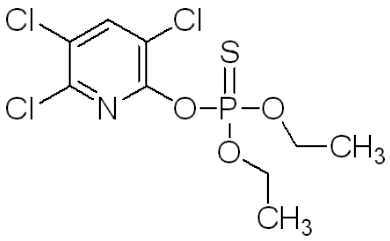


Detection limit of
100 parts per trillion

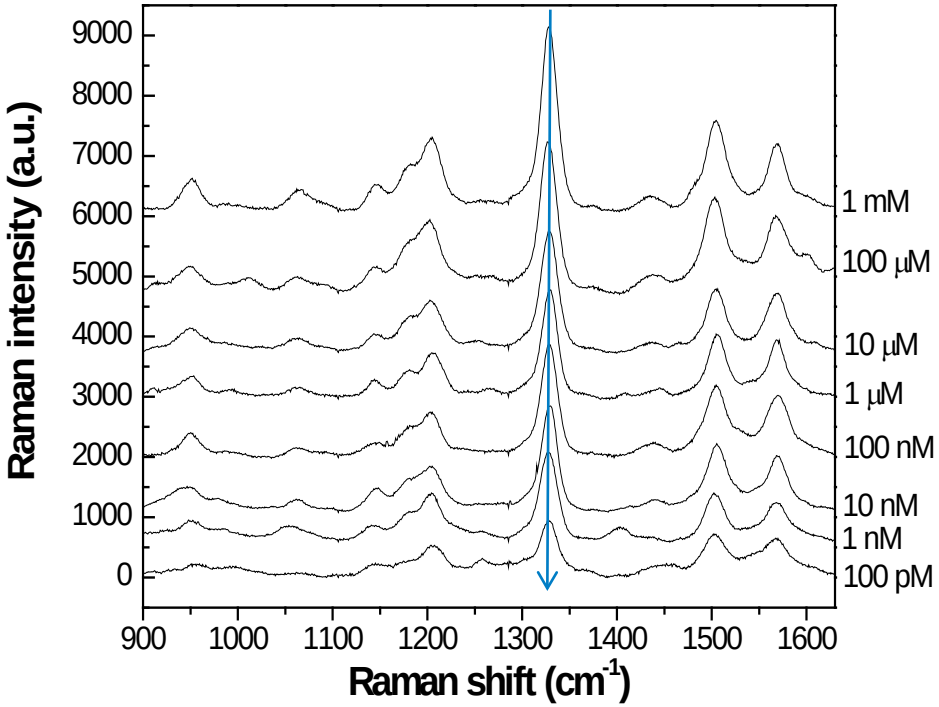
Demonstration B:

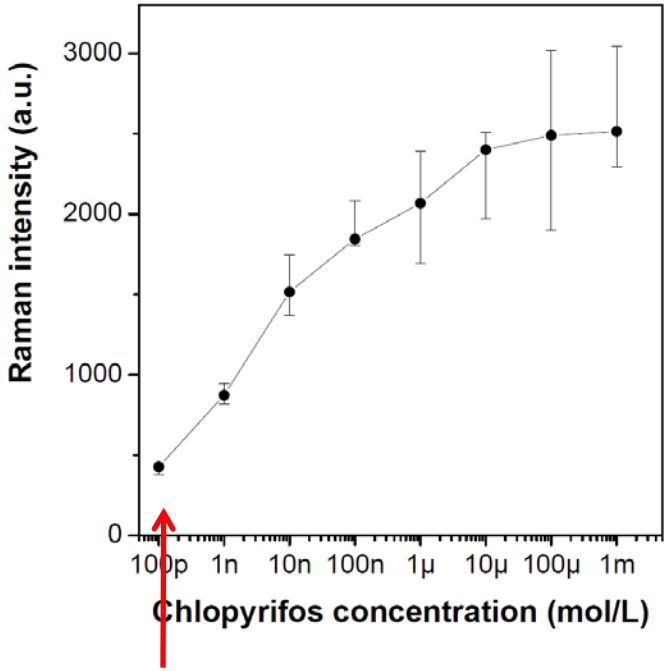
Chlropyrifos sensing with HP nanofinger SERS: >1,000× lower than EPA regulation

Chlropyrifos, 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