

# Hollow Plasmonic nanostructures for multifunctional microfluidics biodevices



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<http://neuroplasmonics.eu>

Francesco De Angelis



**ISTITUTO ITALIANO  
DI TECNOLOGIA**

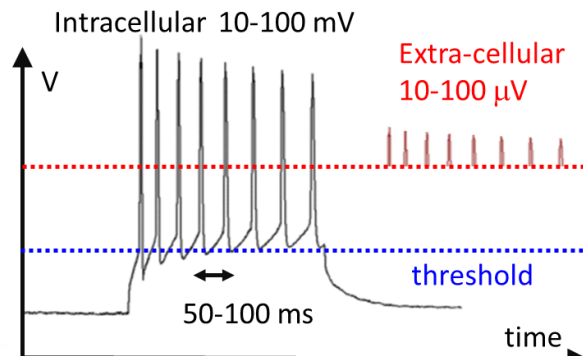
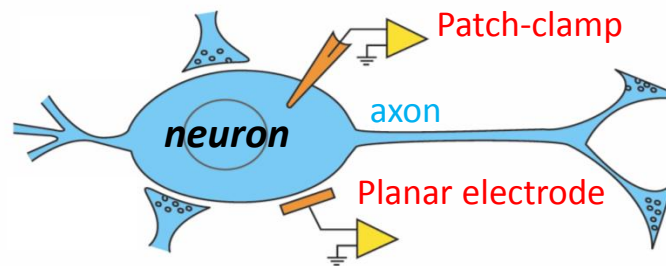
Michele Dipalo

*Plasmon Nanotechnologies*

[Michele.dipalo@iit.it](mailto:Michele.dipalo@iit.it)

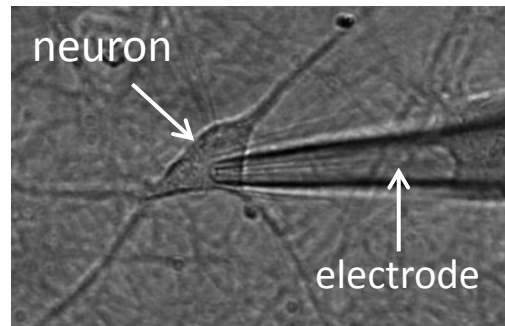
[www.iit.it](http://www.iit.it)

**Basic principles: action potentials**



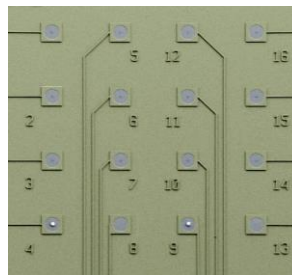
**Patch Clamp (in cell).**

Single sharp electrode: detailed investigation of electric action potentials but **just few cells, possible cell damage, difficulties in long term observations and automation.**

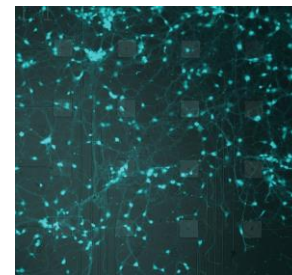


**Micro-Electrode-Arrays (MEA) (extra-cellular)**

Network investigation, long term, no damage, full automation, **but poor electrical sensitivity (NO subthreshold!!) due to contact resistance between membrane and electrode.**

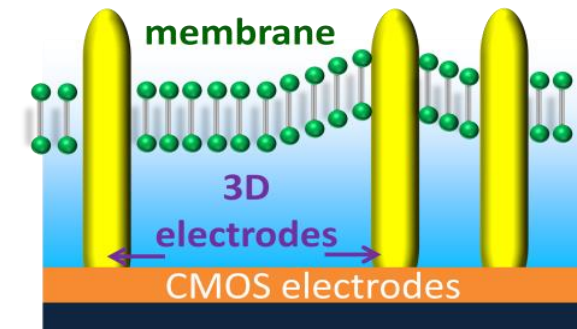


MEA



Cultured MEA

**MEA + 3D micro-nano-electrodes. Network investigation with low contact resistance!**



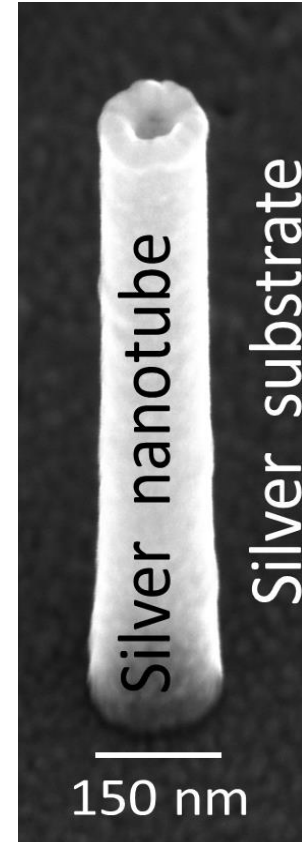
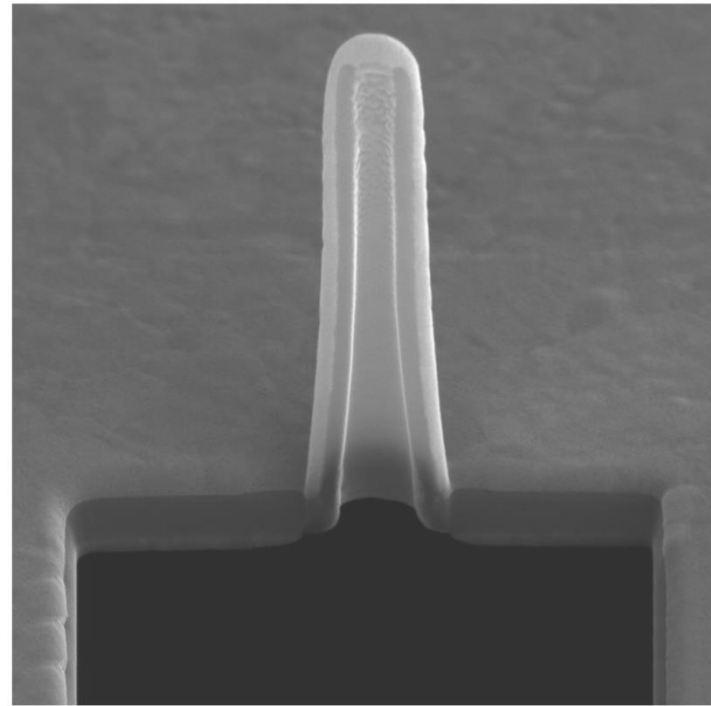
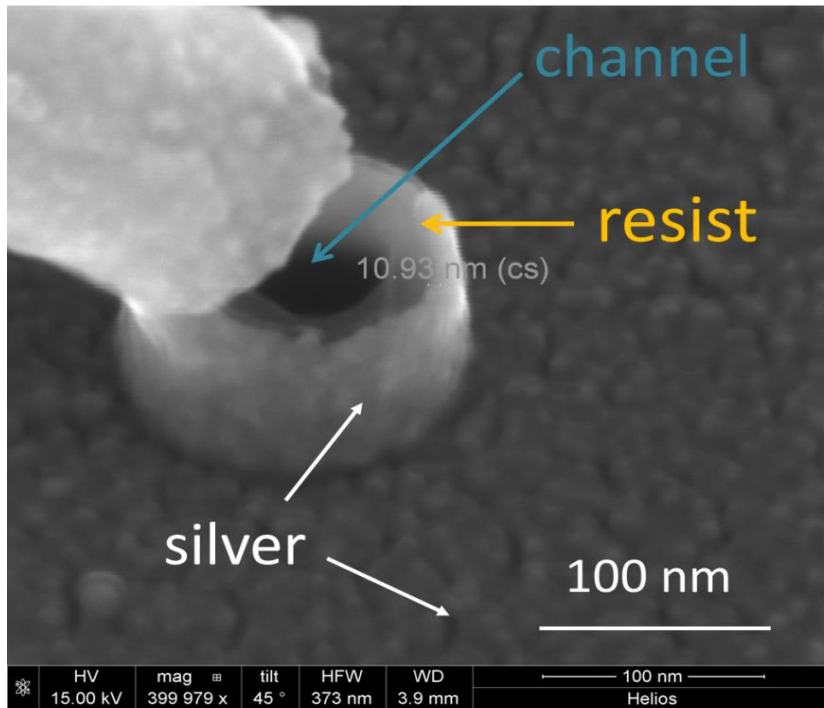
**Challenges??**

- 3D nanofabbrication
- electrode penetration
- membrane damage
- membrane reforming
- Chemical Signaling???**
- Neurotransmitters??**



**Investigations at molecular level by Plasmonics and Advanced Spectroscopies**

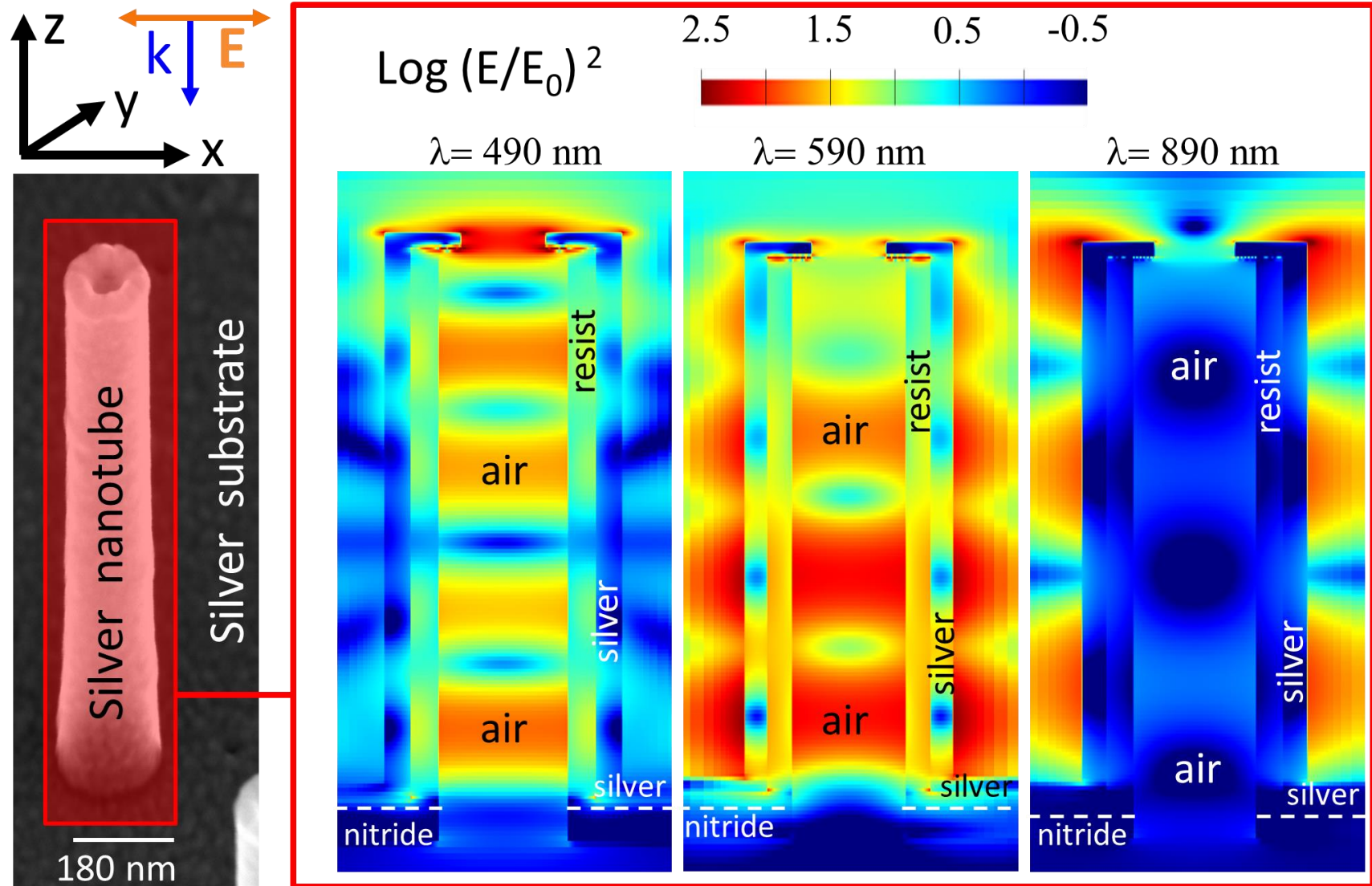
3D plasmonic hollow nanostructures for multifunctional plasmonics, F. De Angelis et al., Nano letters 13 (8), 3553-3558.



**Remark 1:** All devices are hollow and the channel passes through the whole structure up to the backside of the supporting membrane → **Microfluidic & Optofluidic!**

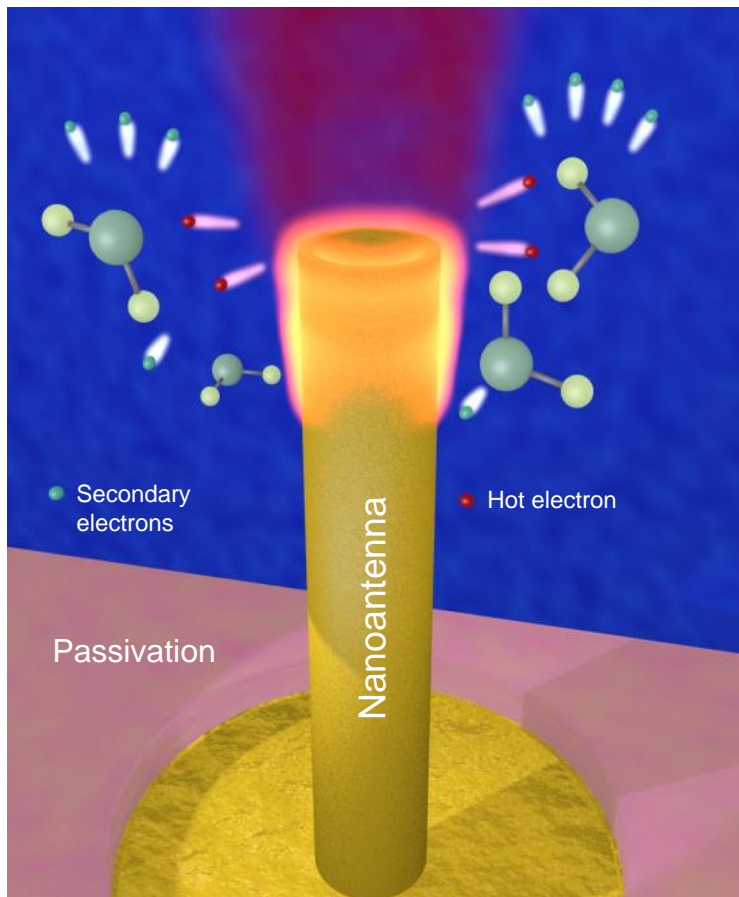
**Remark 2:** there is a uninterrupted metal layer that short-circuits the antennas → **Optoelectronics, electrically driven optical properties, electrolytic cells, Photovoltaics, electro-photochemical catalysis.**

# Optical properties: nanochannel in the visible region



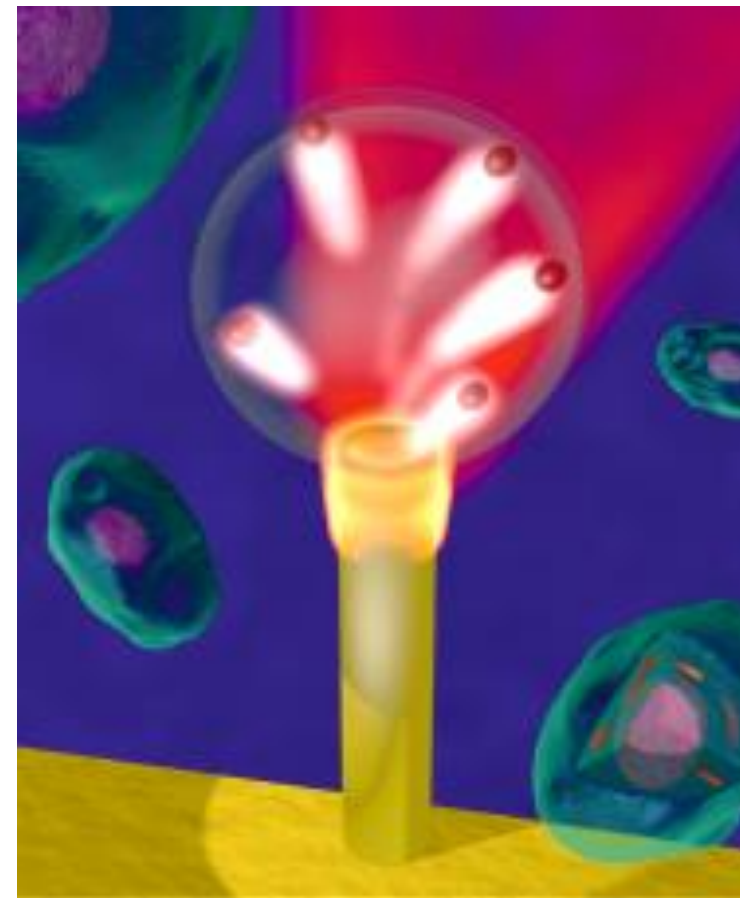
*3D plasmonic hollow nanostructures for multifunctional plasmonics, F. De Angelis et al., Nano letters 13 (8), 3553-3558.*

## Hot electrons generated in water

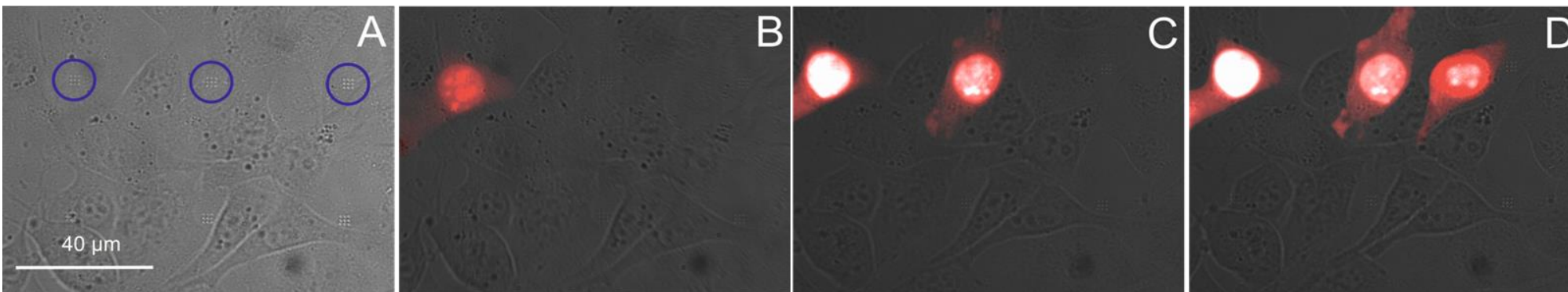
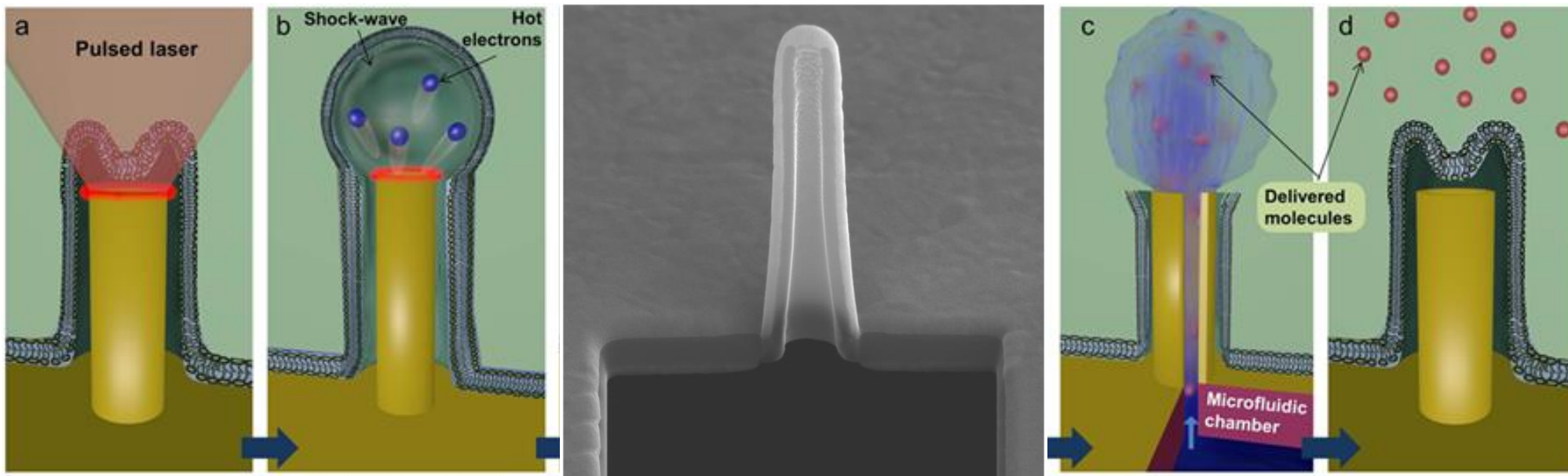


1064 nm  
 $10^9$  W/cm<sup>2</sup>  
8 ps pulse  
80 Mhz

## Cavitation nano-bubble

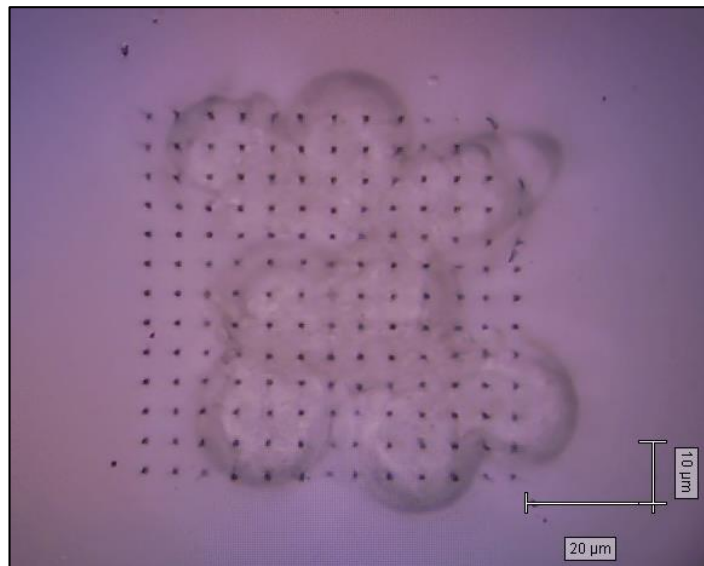


G.C. Messina, M. Dipalo, et al., *Advanced Materials* 2015

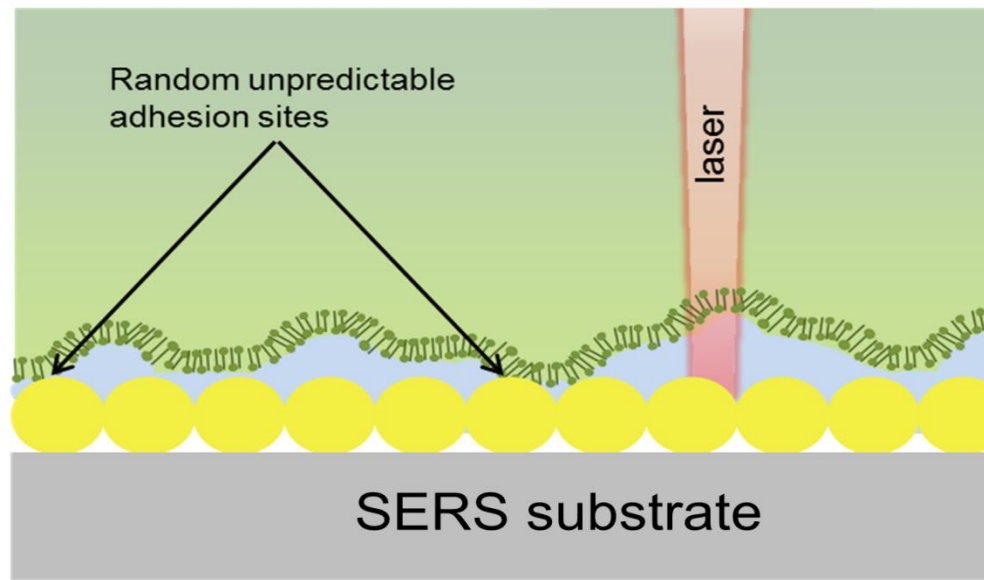
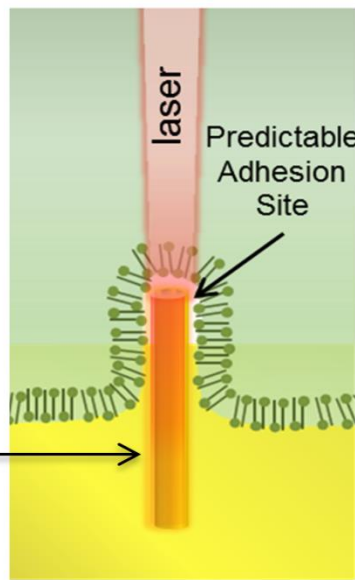
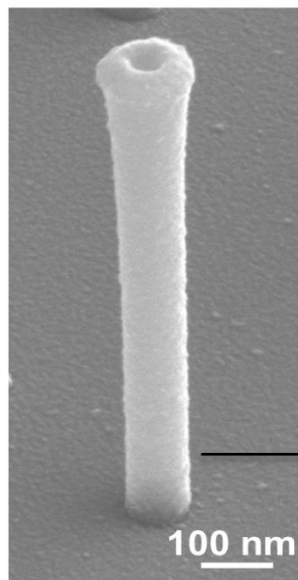


Real time, quantitative, broad range of molecules delivered, cell selective....

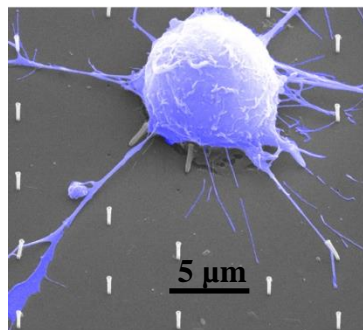
G.C. Messina, M. Dipalo, et al., *Advanced Materials* 2015



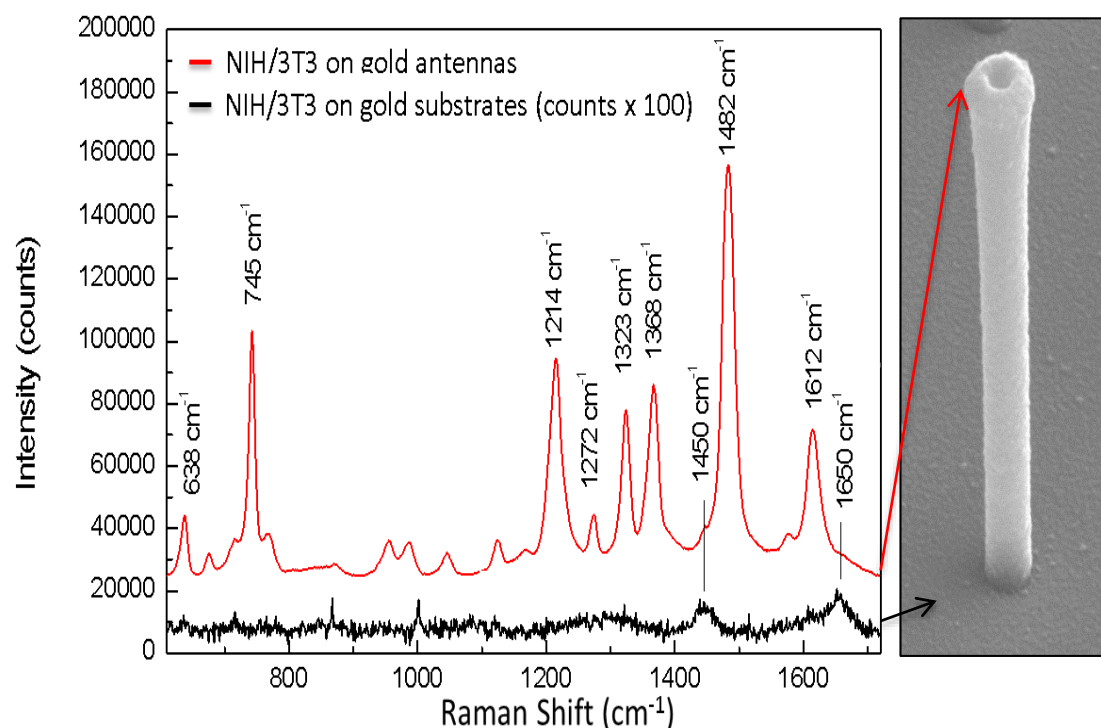
- N2A cell line
- strong spontaneous adhesion
- Predictable adhesion sites



Out-of-Plane Plasmonic Antennas for Raman Analysis in Living Cells.  
 R. La Rocca, M. Dipalo et al. Small 2015



*In-vitro* Raman characterization of cell membrane  
 $\lambda=785$  nm, acquisition time 10 seconds  
 Future perspective: membrane receptor investigations



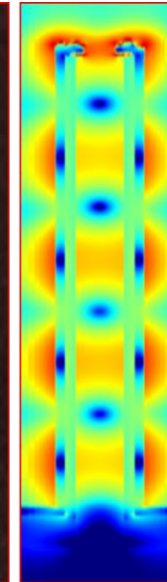
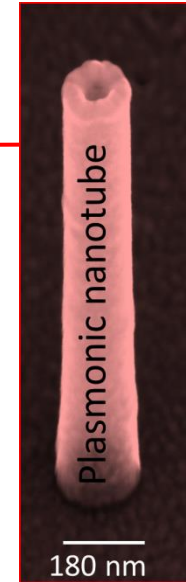
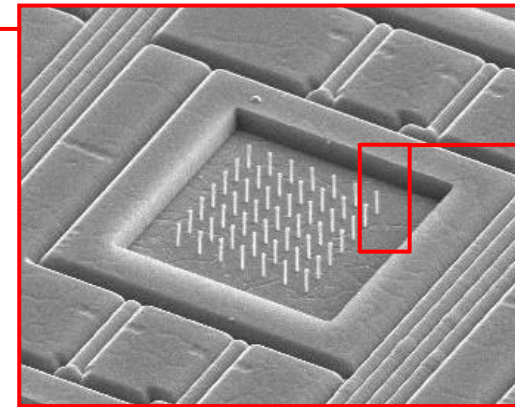
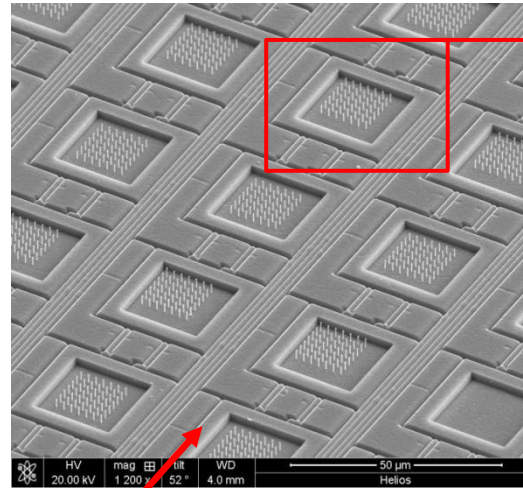
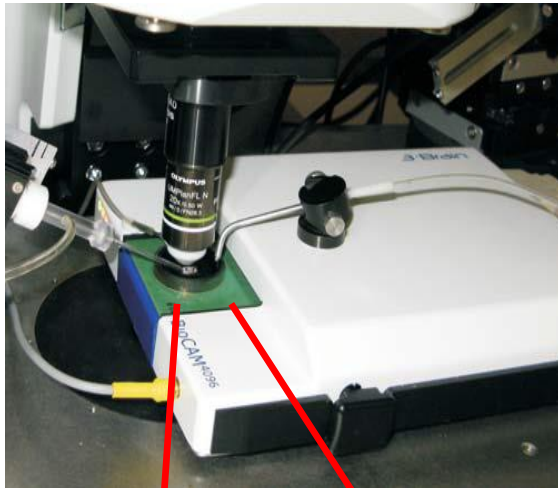
Peak position (cm <sup>-1</sup> )	Possible attribution
638	C-C twist Phenylalanine, Tyrosine
677	
726	C-S protein, twist CH <sub>2</sub> , rocking A (Adenine)
745	Ring Tryptophan
768	Ring Tryptophan
871	C-C-N sym. stretching of lipids, C-O-C carbohydrates
954	Hydroxyapatite, carotenoid, cholesterol
988	C-C BK stretching
1044	Phenylalanine
1123	O-P-O DNA backbone
1154	Tyrosine
1214	C-C <sub>6</sub> H <sub>5</sub> , Tyrosine, Tryptophan, Phenylalanine
1272	Saccharides, proteins
1323	Amide III alpha helix
1368	CH <sub>3</sub> symmetric stretching of lipids
1450	CH <sub>2</sub> , CH <sub>3</sub> deformation, phospholipids
1482	Amide II
1572	G, A (Guanine, Adenine)
1612	C=C Tyrosine, Tryptophan
1650	Amide I

How we can integrate them with electrical sensors??

Out-of-Plane Plasmonic Antennas for Raman Analysis in Living Cells.  
 R. La Rocca, M. Dipalo et al. Small 2015

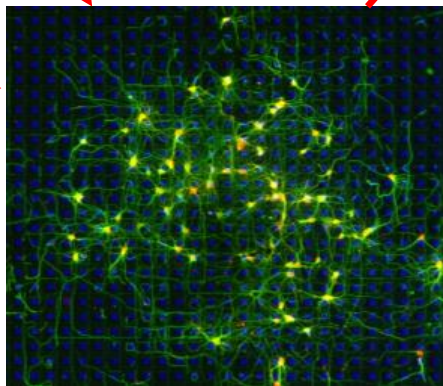
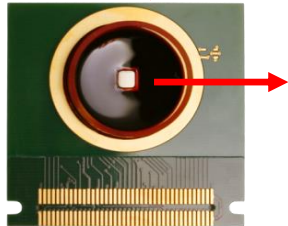


3Brain commercial chipset with 4096 recording electrodes ([www.3brain.com](http://www.3brain.com))



Our 3D plasmonic nanoelectrodes

- Large scale and fast processes
- High plasmonic performances thanks to the 3D structures
- Direct integration with commercial electronic chip
- Direct access to the market



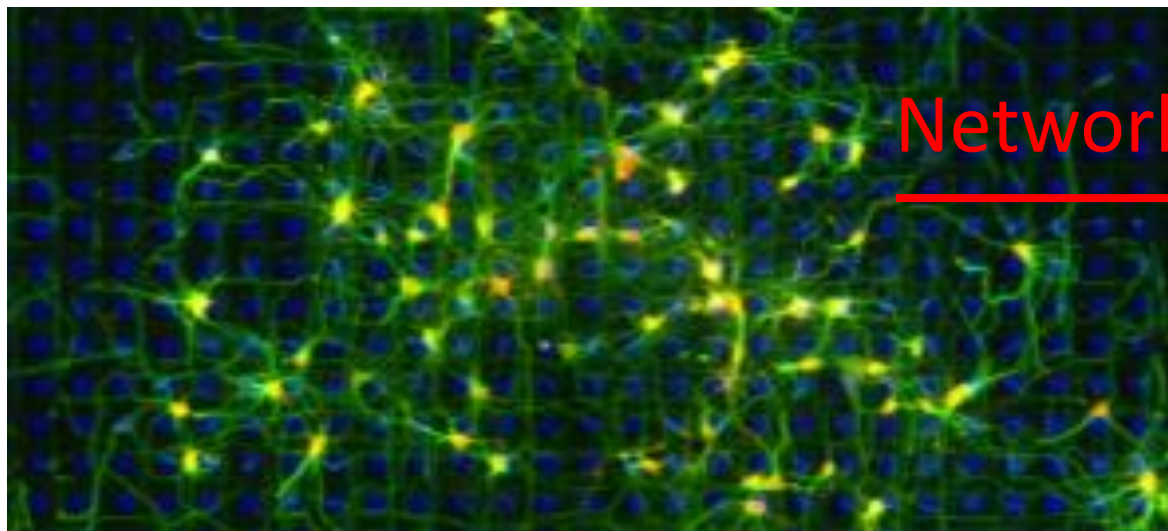
Plug&Play  
Commercial  
chip

Rat-hippocampal neurons

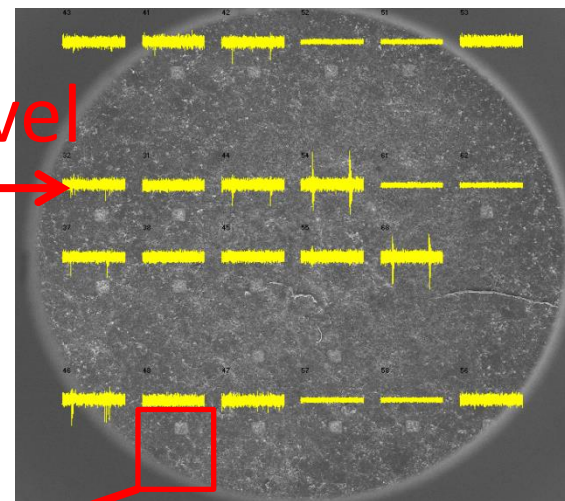
Direct integration with confocal microscopes and spectroscopic tools (including Fluorescence and Raman)

3D plasmonic nanoantennas integrated with MEA biosensors. M. Dipalo et al. *Nanoscale* 2015

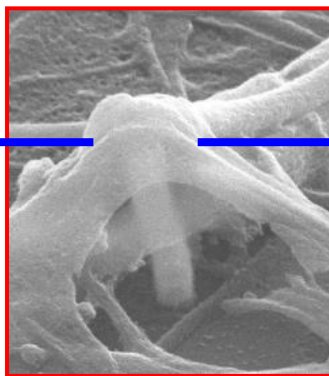
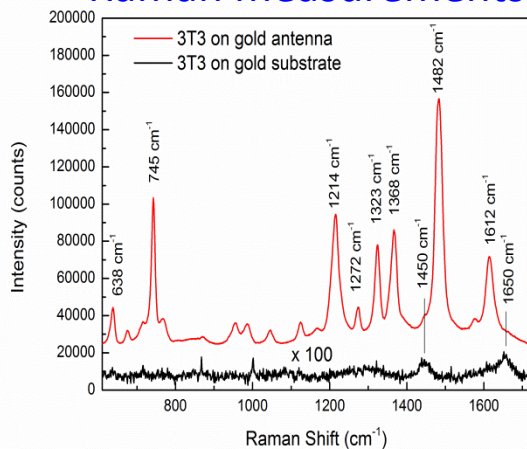
- hippocampal neurons from rat, 21 days in vitro



Network level

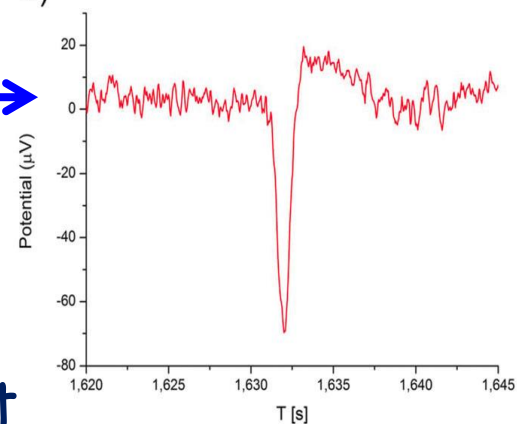


Raman measurements



extracellular contact

d) Electrical measurements



3D plasmonic nanoantennas integrated with MEA biosensors. M. Dipalo et al. Nanoscale 2015

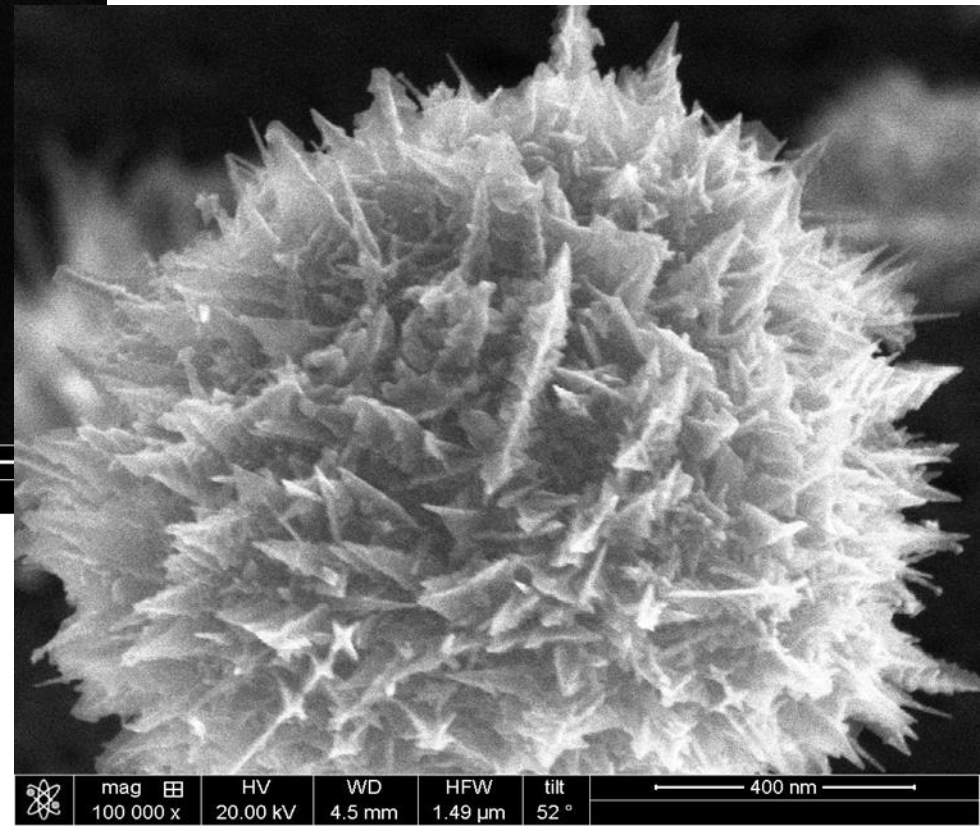
tip radius  $\approx 1-2$  nm

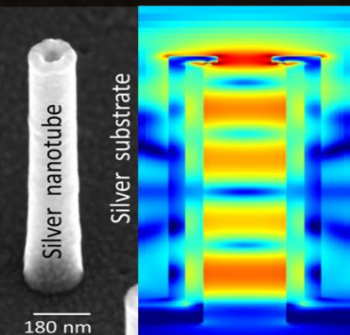
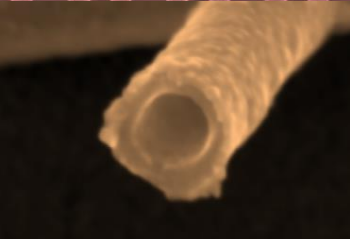
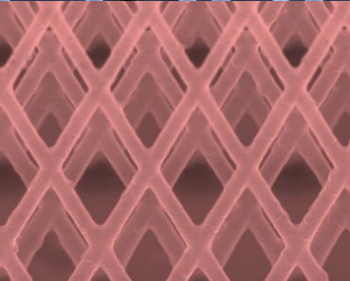
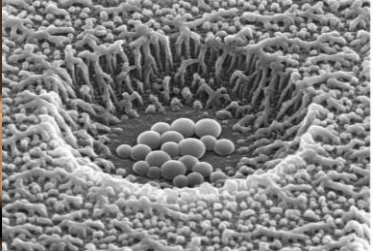
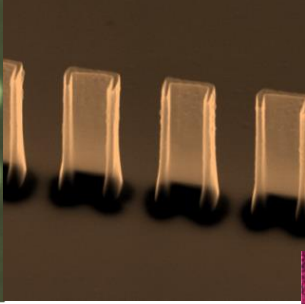
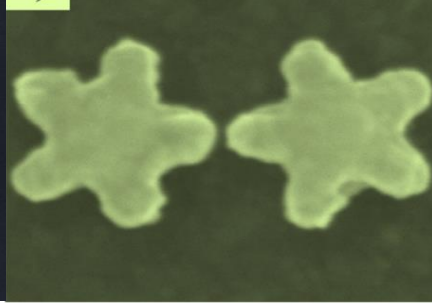
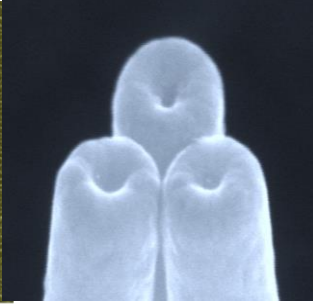
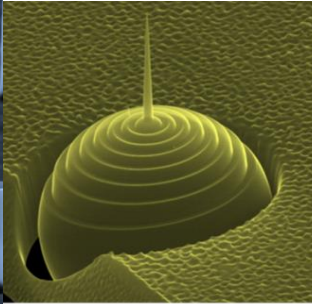
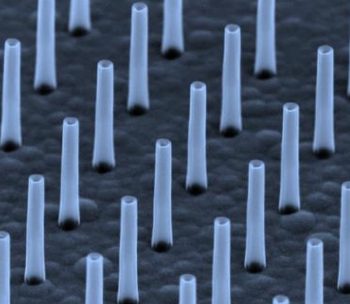
- Spontaneous penetration
- Large contact area (low resistivity)
- Strong Raman enhancement

Lack of reproducibility



*Better reproducibility  
but still insufficient* →





# Neuro-Plasmonics



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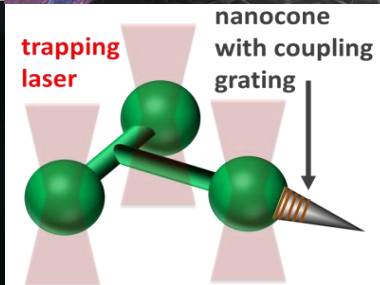
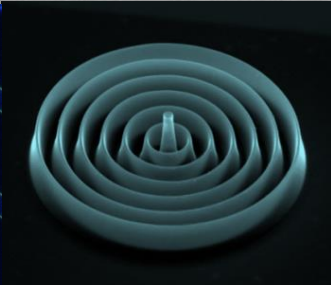
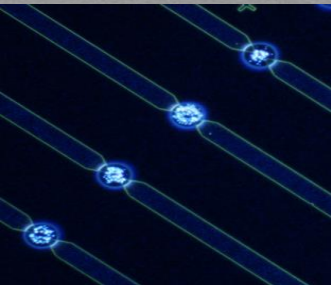
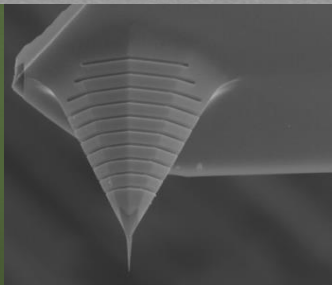
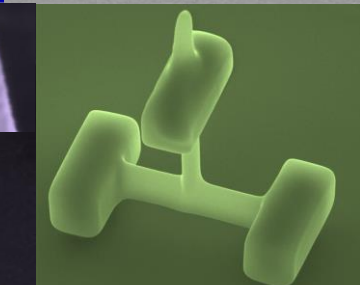
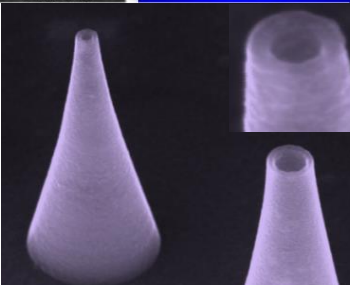
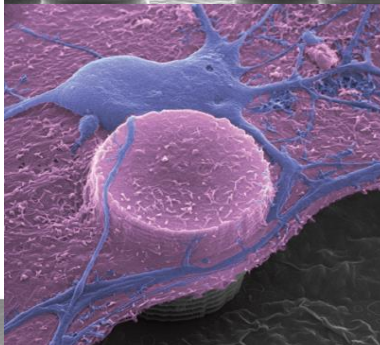
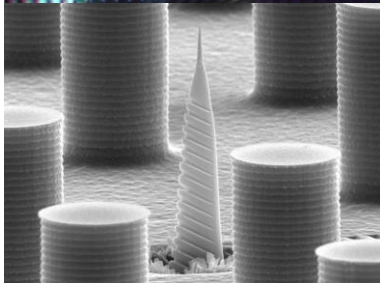
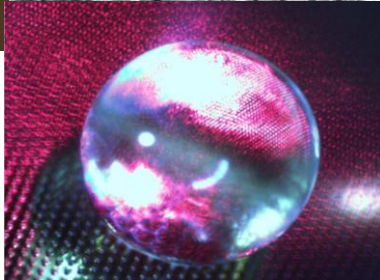


*Thanks for your attention!!*



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DI TECNOLOGIA

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**Laser Pulse:**

Duration = 1 ps

 $\lambda = 830 \text{ nm}$  $E_{\text{TOT}} \approx 100 \text{ pJ}$ 

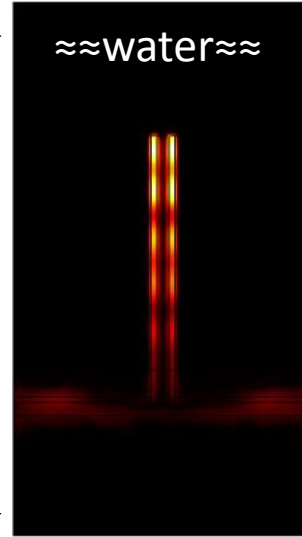
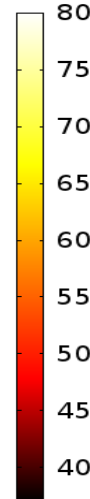
Ambient: water

Intensity =

 $30 \text{ W}/\mu\text{m}^2$ 

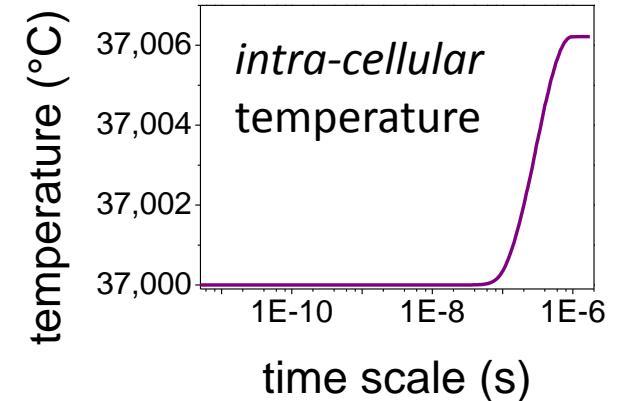
Temperature distribution

@ 10 ps

4  $\mu\text{m}$  $T(^{\circ}\text{C})$ 

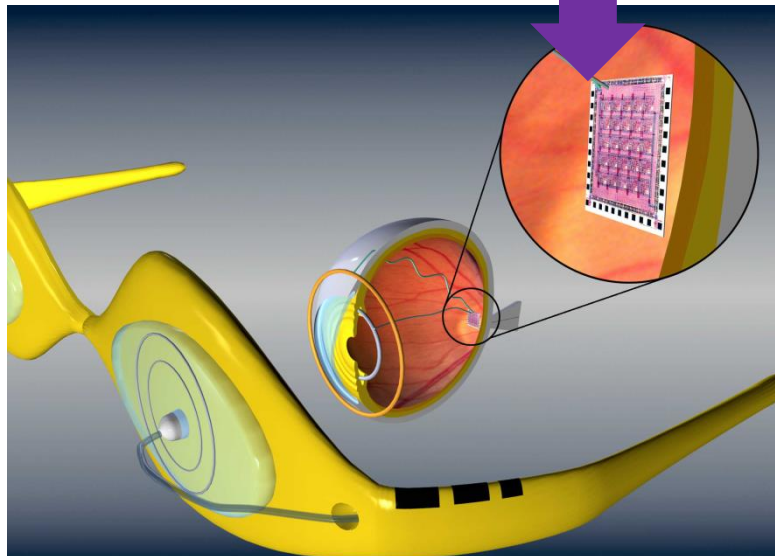
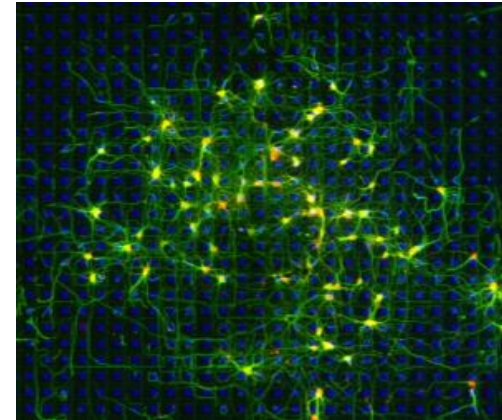
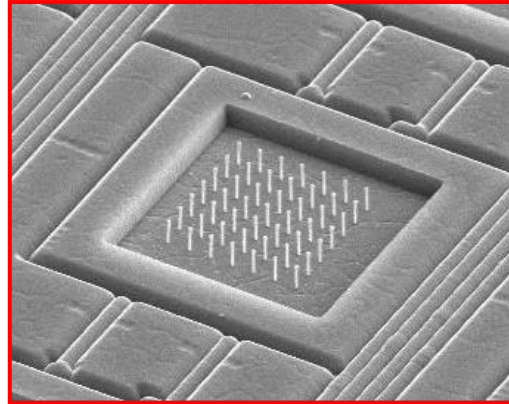
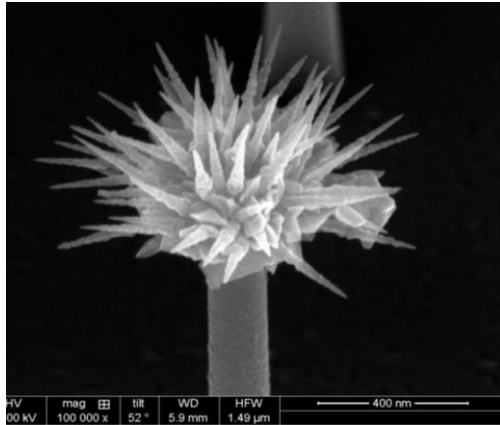
What happen  
to neurons??

Temperature vs Time @  
500 nm above the antennas tip  
(*intra-cellular* temperature)

**Remark:**

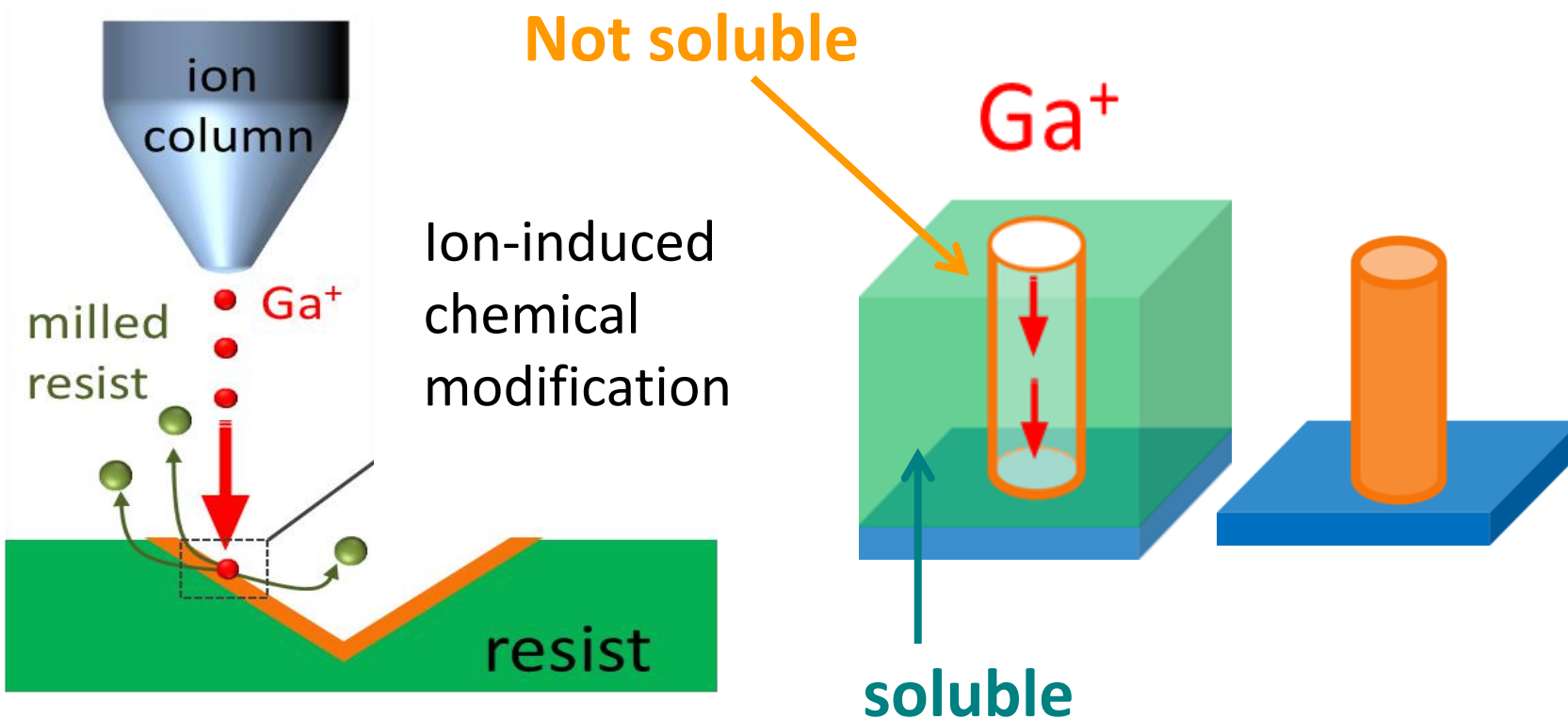
we can locally control the antennas temperature in space and time without affecting the the neuron cells → spectroscopy and thermoporation enabled!

See also, High Temperature Nanoplasmonics: The Key Role of Nonlinear Effects  
A. Alabastri et al., ACS Photonics 2015, 2, 115–120



*Potential impact on  
Artificial retinas  
Artificial synaptic junctions*

Combination of Focused Ion Beam (FIB) and ion-induced chemical modification on a proper polymer film that works as lithographic resist.



*3D plasmonic hollow nanostructures for multifunctional plasmonics,*  
 F. De Angelis et al., Nano letters 13 (8), 3553-3558.