



# SOME THOUGHTS ON NANOTECHNOLOGY

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EURONANO, 01.06.2011

# “There’s Plenty of Room at the Bottom”

R.Feynman

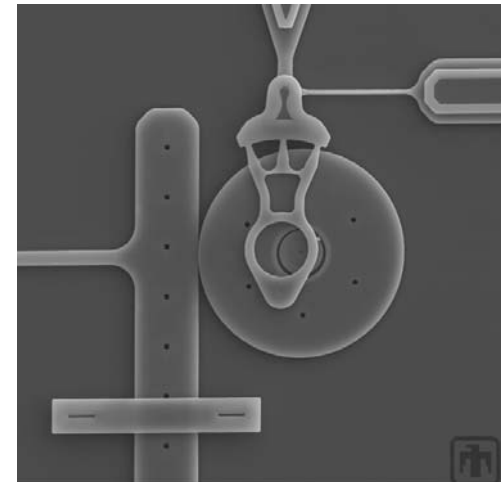
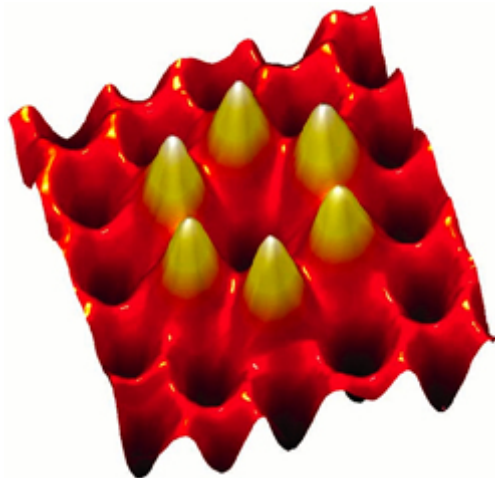
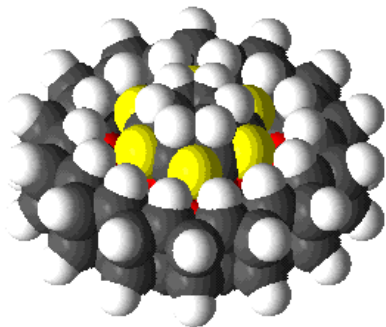


**The stability of nanostructures questioned for some time**



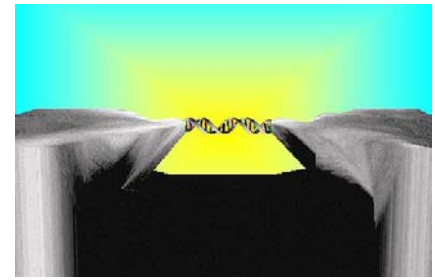
# PRINCIPAL LIMITS (1)

- \*ONE ATOM = ONE BIT IN A MASS-MEMORY
- \*ONE IMPURITY ATOM IN A TRANSISTOR (probably a few atoms, due to physical principles)
- \*THE RESOLUTION OF THE FINEST MACHINING TECHNOLOGIES APPROACH THE DIAMETER OF ATOMS (see the AFM and STM technologies)





## PRINCIPAL LIMITS (2)



INFORMATION(transfer): PHYSICAL QUANTITY

THEREFORE IT HAS ENERGY CONTENT

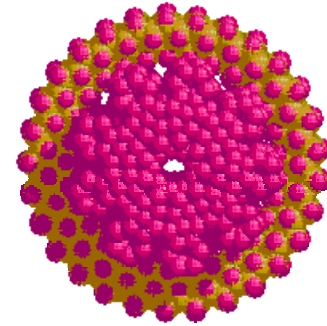
R. Feynman: To transfer 1 bit information irreversibly in a computational network (at  $T$  temperature with  $\nu$  frequency on  $d$  distance, based on thermodynamical consideration, this energy is

$$E = kT d \nu / c$$

(in 1sec , with 1W power, at room temperature,  $10^{18}$  bit information can be transferred to 50nm distance)



# FUNDAMENTAL GOALS IN NANORESEARCH



- **THE MANIPULATION OF INDIVIDUAL ATOMS**
- **THE DEVELOPMENT OF „ASSEMBLERS”**  
programmed nanoscopic machines to manipulate  
single atoms or molecules
- **THE DEVELOPMENT OF „REPLICATORS”**  
programmed nanoscopic machines to build  
assemblers

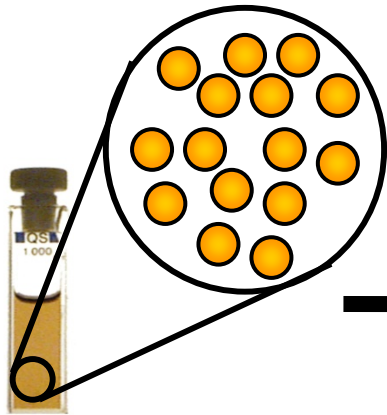
**NEW TYPE OF DIAGNOSTIC TOOLS NEEDED!**

**(scattering experiments, EM, STM, AFM,...)**

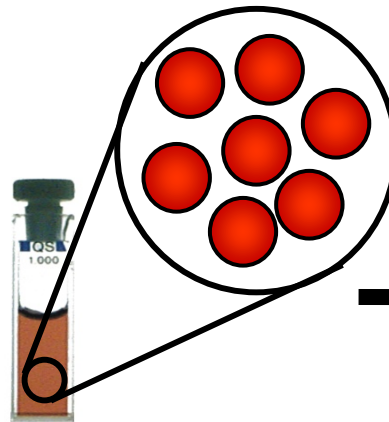
# Why Is nanotechnology so interesting?



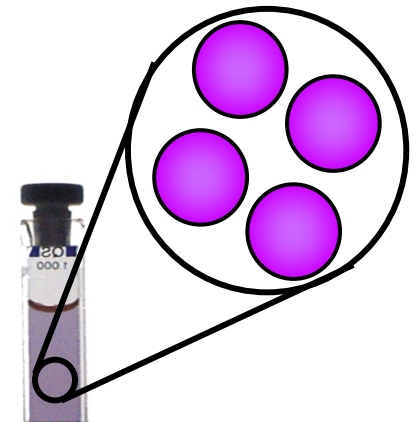
Bulk Gold  
mp = 1064° C  
Color = gold



1 nm gold particles  
mp = 700 °C  
 $\lambda_{\max} = 420 \text{ nm}$   
Color = brown-yellow

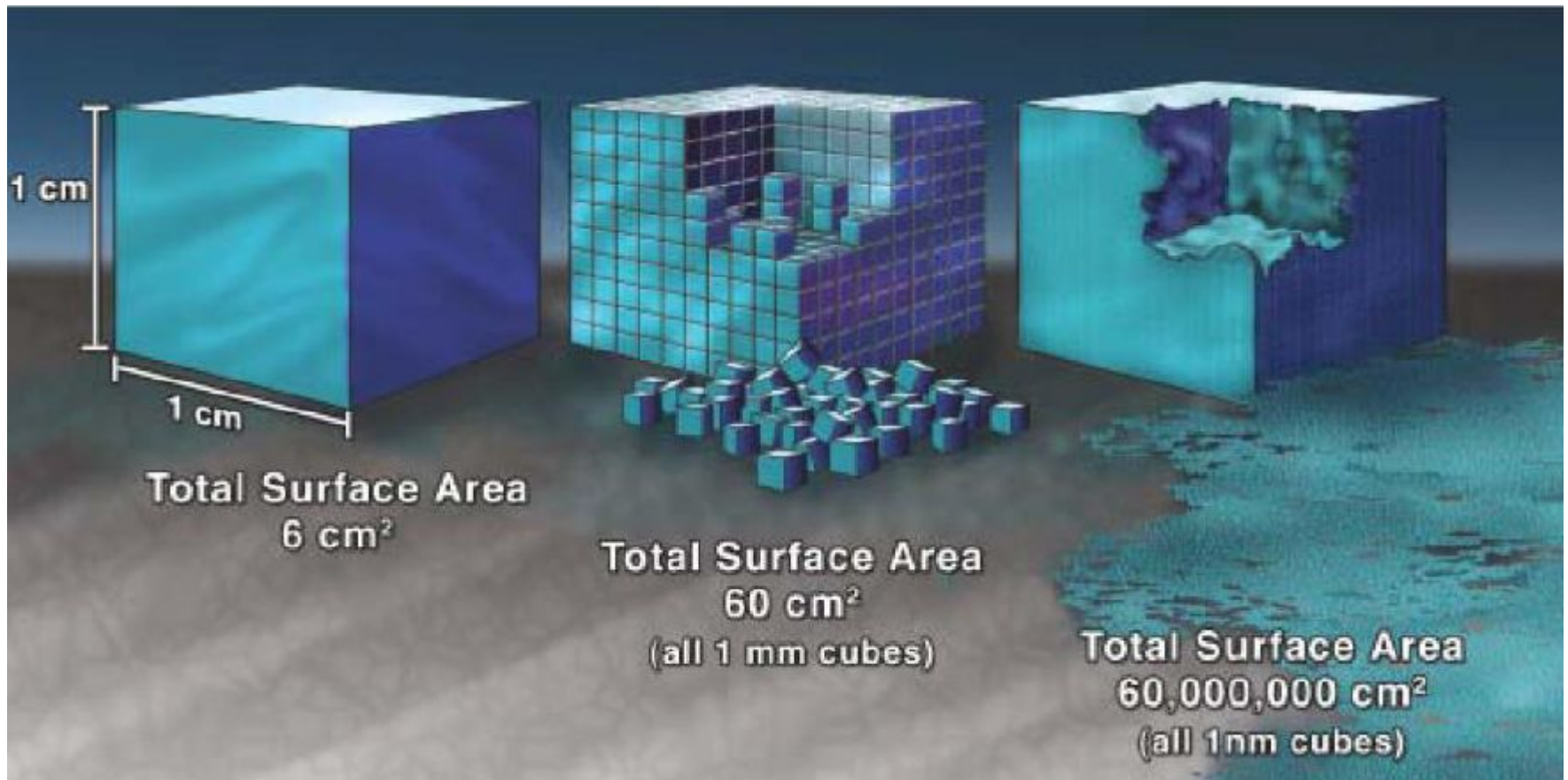


20 nm gold particles  
mp = ~1000 °C  
 $\lambda_{\max} = 521 \text{ nm}$   
Color = red



100 nm gold particles  
mp = ~1000 °C  
 $\lambda_{\max} = 575 \text{ nm}$   
Color = purple-pink





**Large surface/volume ratio  $\Rightarrow$   
enhanced surface effects**





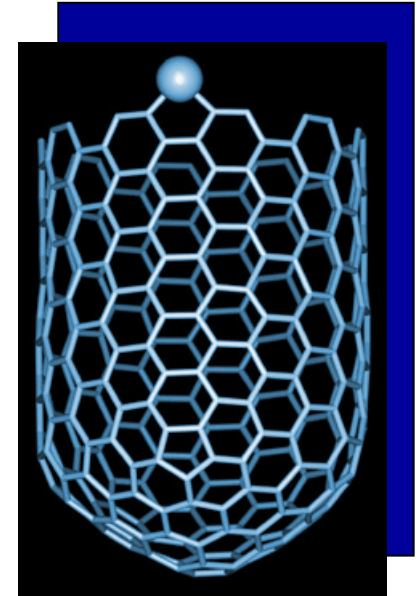
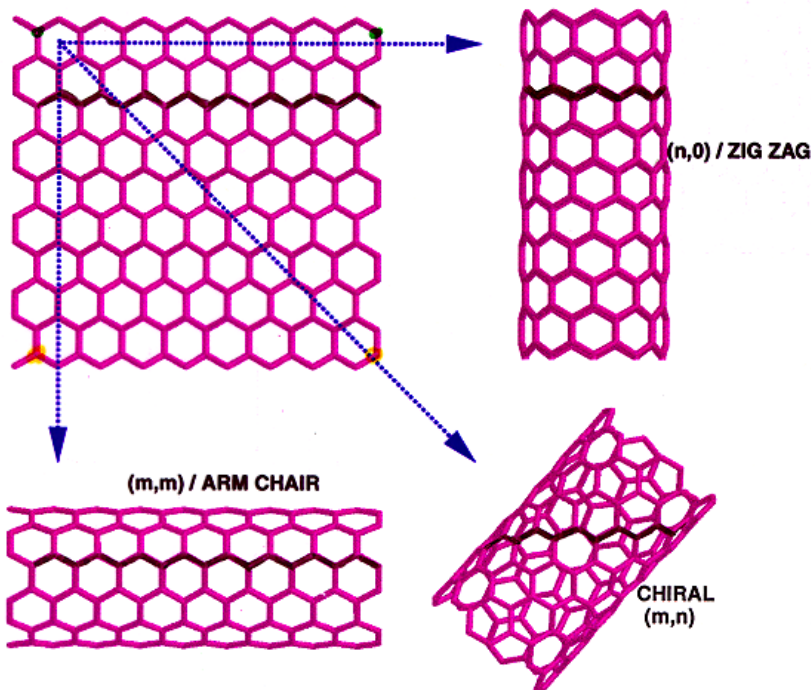
# CARBON NANOTUBES

# AND GRAPHENE!!!

CNT is a tubular form of carbon with diameter as small as 1 nm.  
Length: few nm to microns.

CNT is configurationally equivalent to a two dimensional graphene sheet rolled into a tube.

- STRIP OF A GRAPHENE SHEET ROLLED INTO A TUBE



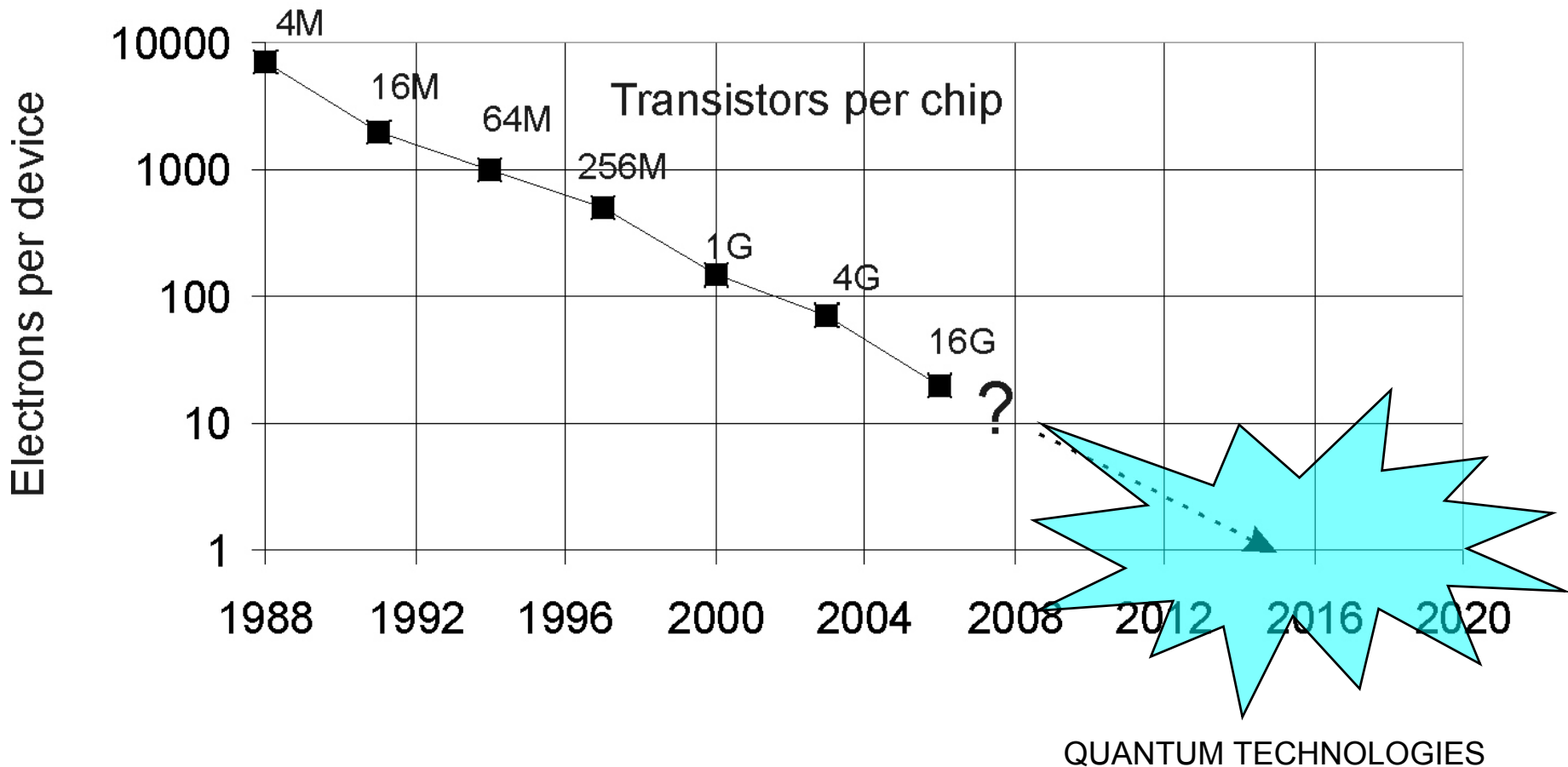
CNT exhibits extraordinary mechanical properties: Young's modulus over 1 Tera Pascal, as stiff as diamond, and tensile strength ~ 200 GPa.

CNT can be metallic or semiconducting, depending on chirality.





# TOWARDS THE QUANTUM LIMIT



# The Lycurgus Cup (glass; British Museum; 4<sup>th</sup> Century A. D.)

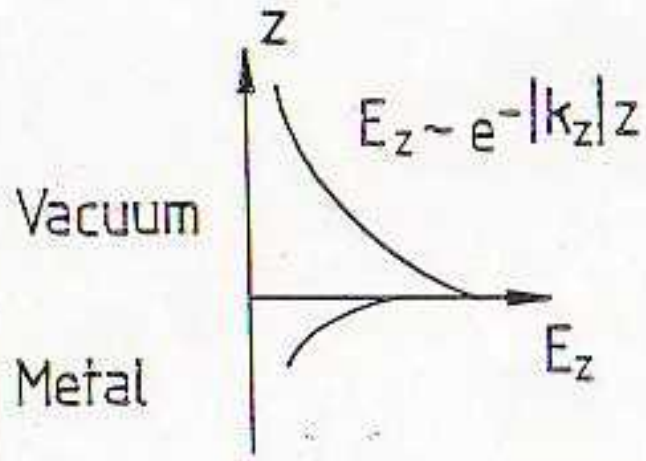
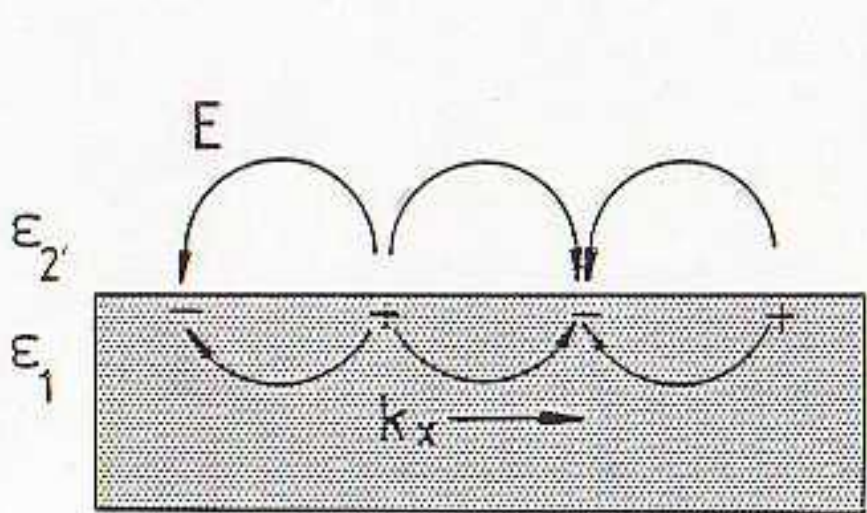
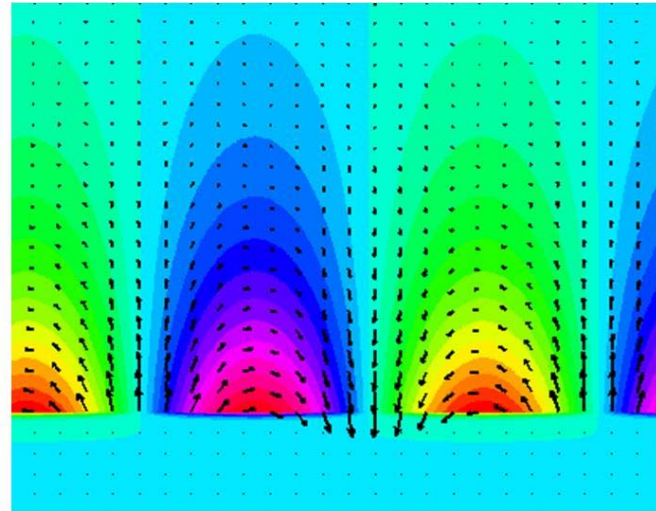


When illuminated from outside, it appears green. However, when illuminated from within the cup, it glows red. Red color is due to very small amounts of gold powder (about 40 parts per million) in glass.



# ELECTRIC FIELD OF SURFACE PLASMONS

Surface plasmons



From Maxwell's equations



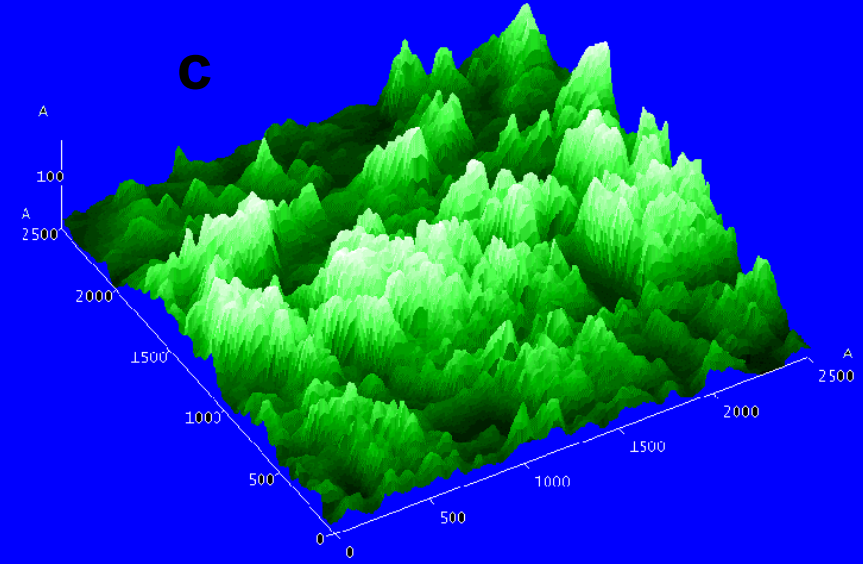
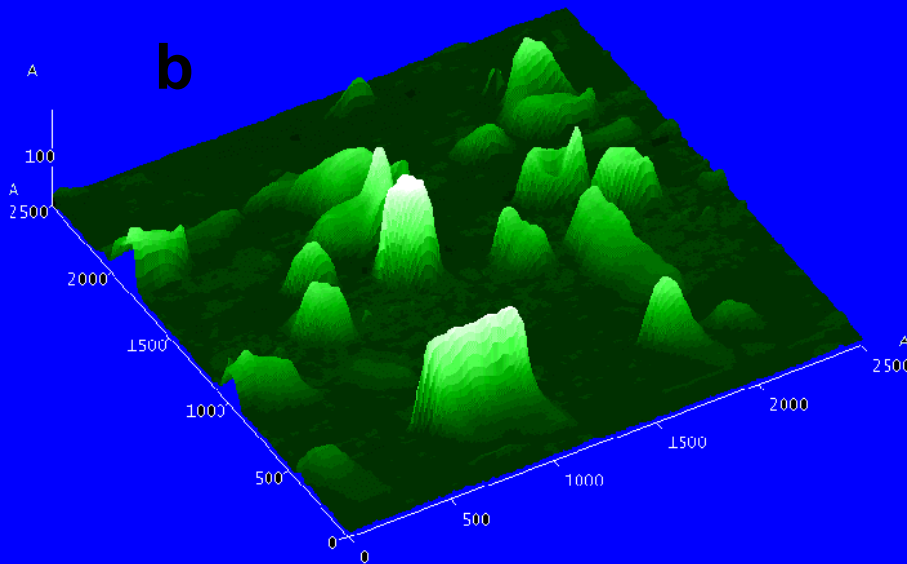
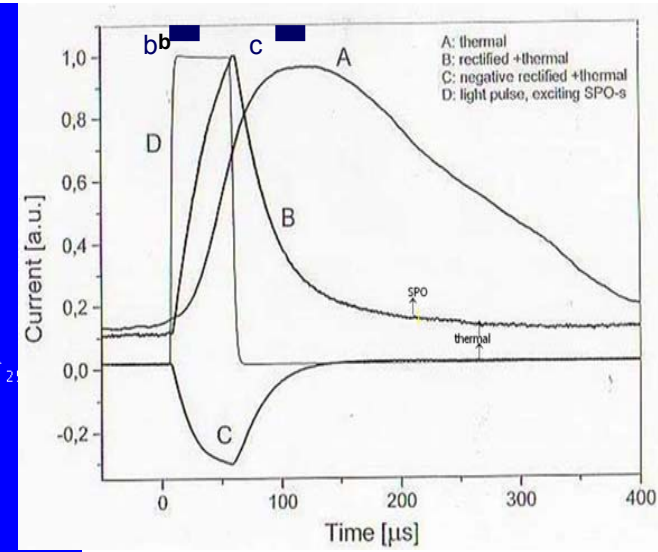
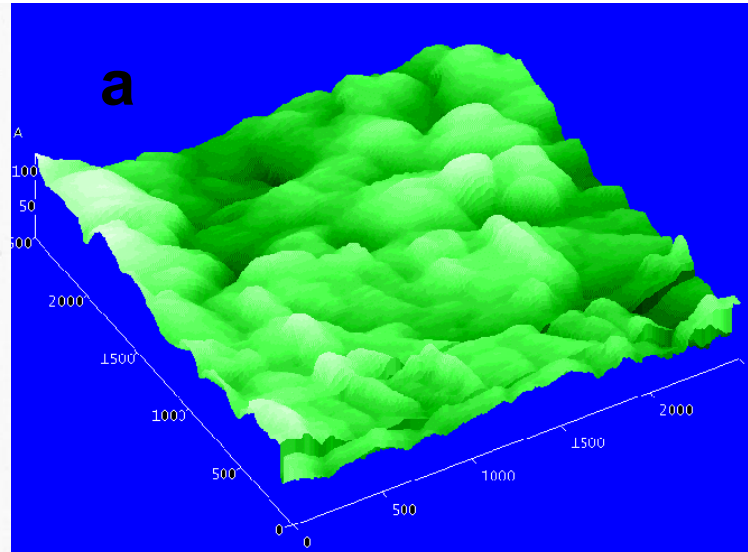
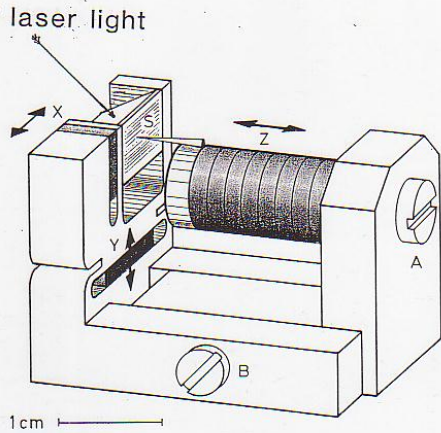


# ***SURFACE PLASMON POLARITONS are a „NEW TYPE OF LIGHT“, they are***

- 1. BOUND TO THE (METAL) SURFACE;**
- 2. HAVE SPECIFIC DISPERSION PROPERTIES;**
- 3. THE DIFFRACTION LIMIT DOES NOT APPLY;**
- 4. MAY BE GUIDED ON THE SURFACE;**
- 5. REPRESENT VERY HIGH ELECTRIC FIELDS;**
- 6. MAY BE LOCALIZED (e.g. to nanospheres or surface irregularities);**
- 7. MAY HAVE A BANDGAP;**
- 8. MAY BE THE SUBJECT OF NONLINEAR PROCESSES;**
- 9. SHOW NON-CLASSICAL PROPERTIES.**

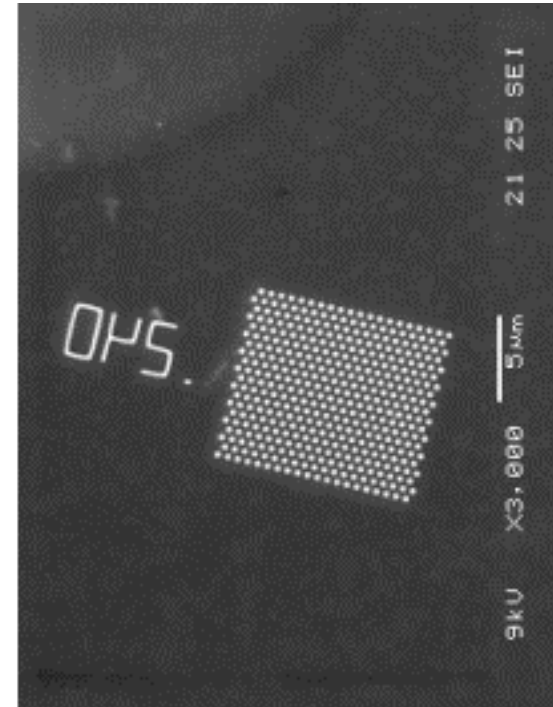
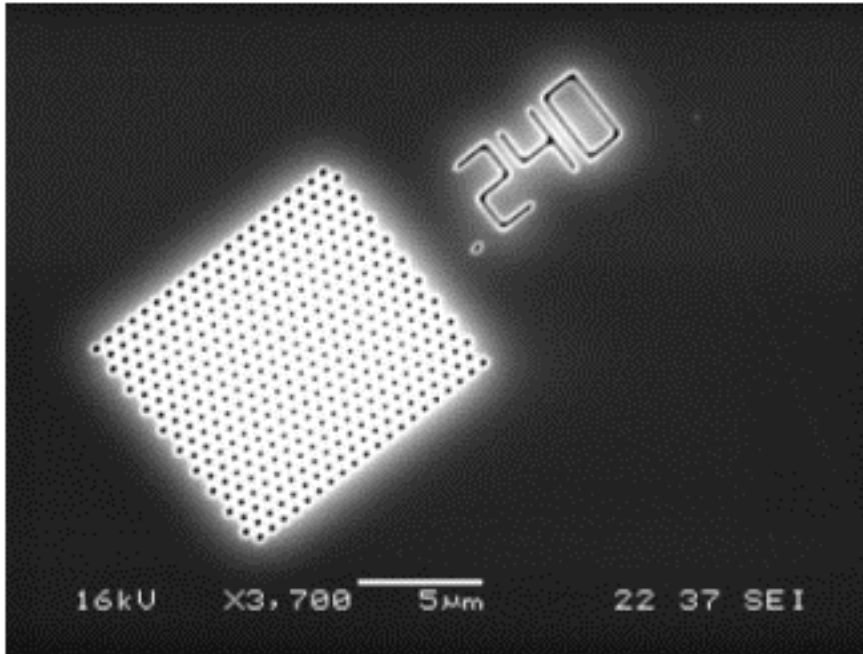
**A POTENTIAL BASIS OF FUTURE PLASMONICS (applications)  
NONLINEAR EFFECTS AT LOWER LASER POWERS THAN IN  
NONLINEAR OPTICS!**

# NEAR FIELD STM [with topographic(a), SPO(b) and thermal(c) images]



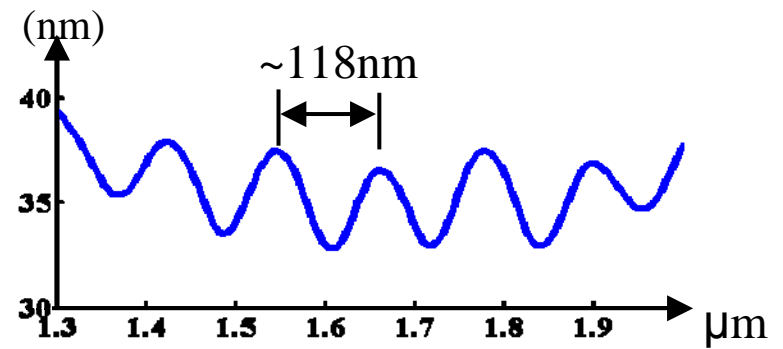
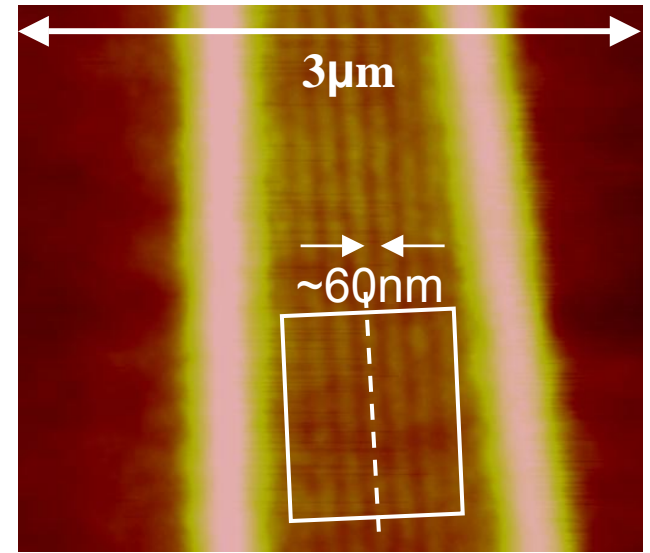
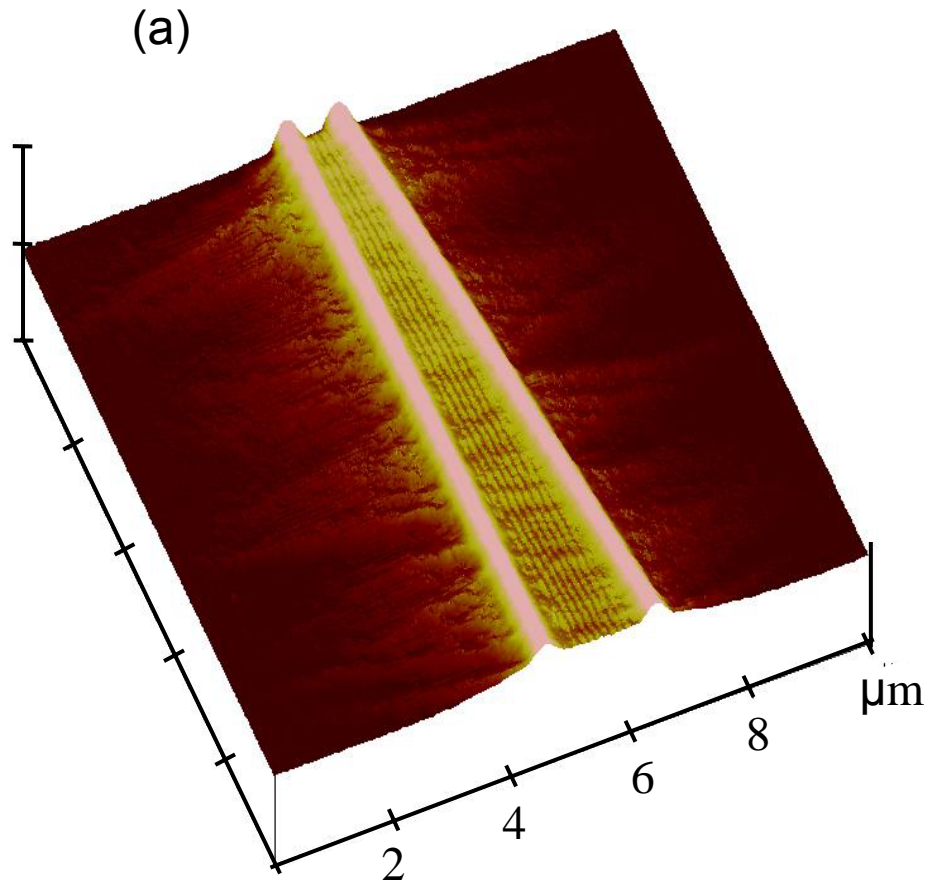


# TRANSPARENCY WITH VERY SMALL HOLES



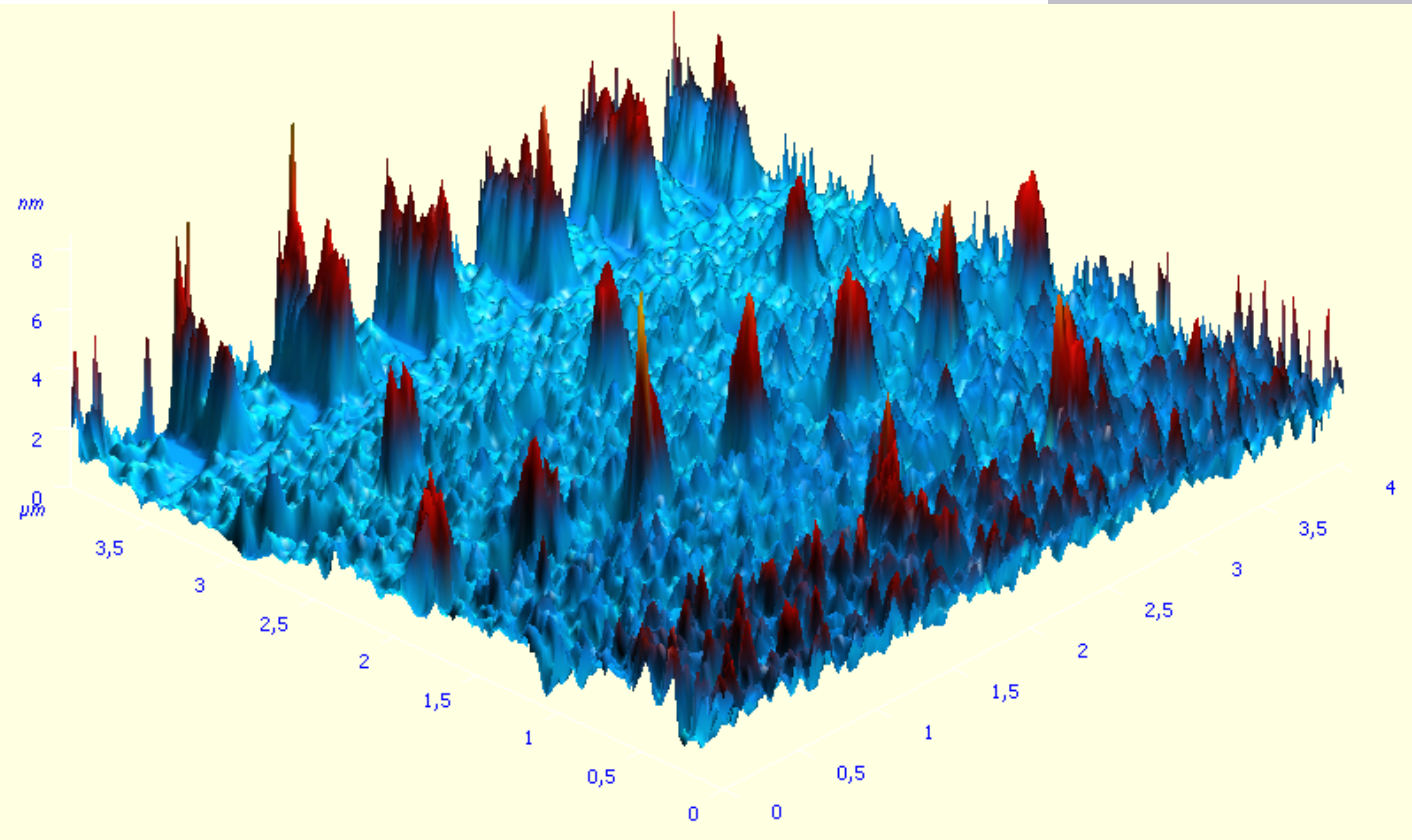
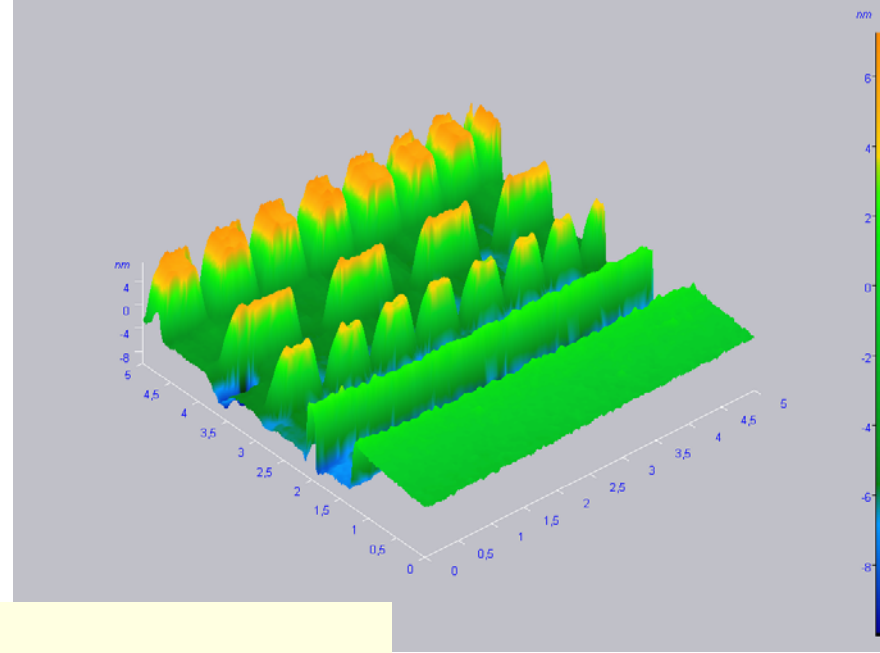
PARADIGM SHIFT SIMILAR TO THE SHIFT FROM SHIPS TO AIRPLANES IN TRANSPORT OR FROM VACUUM TUBES TO TRANSISTORS IN ELECTRONICS

# Litography





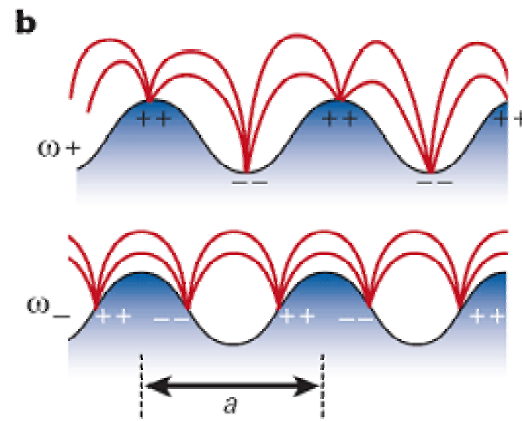
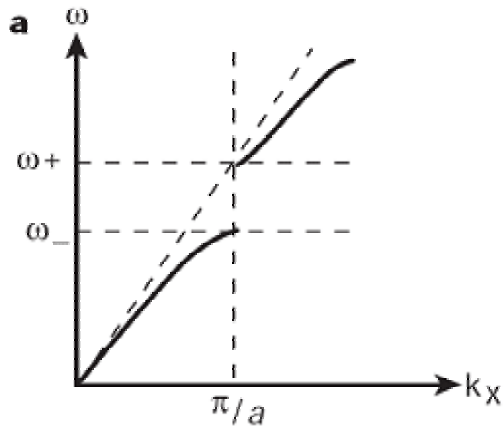
# SURFACE PLASMON LIGHTGUIDE



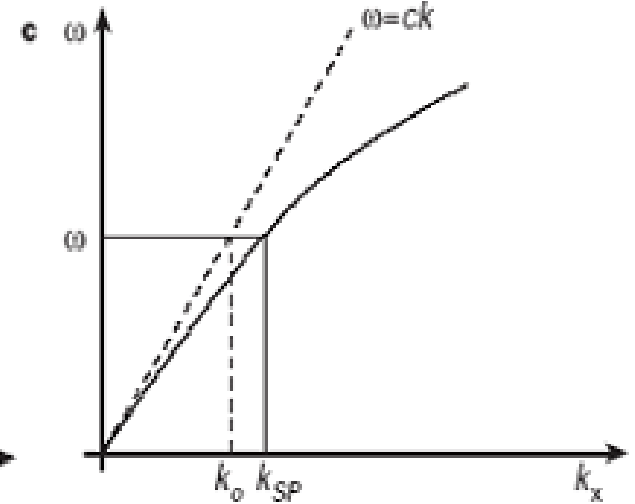
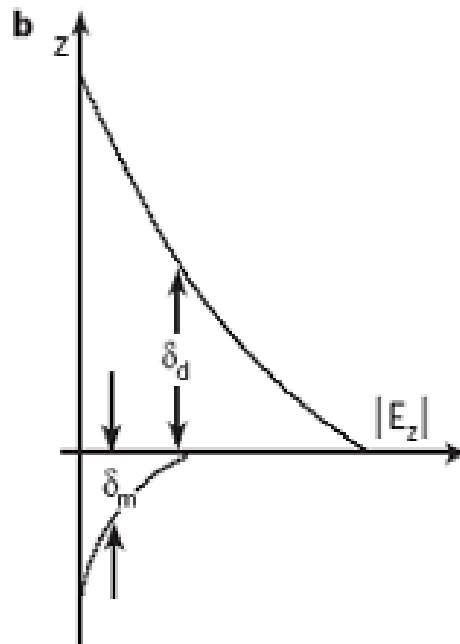
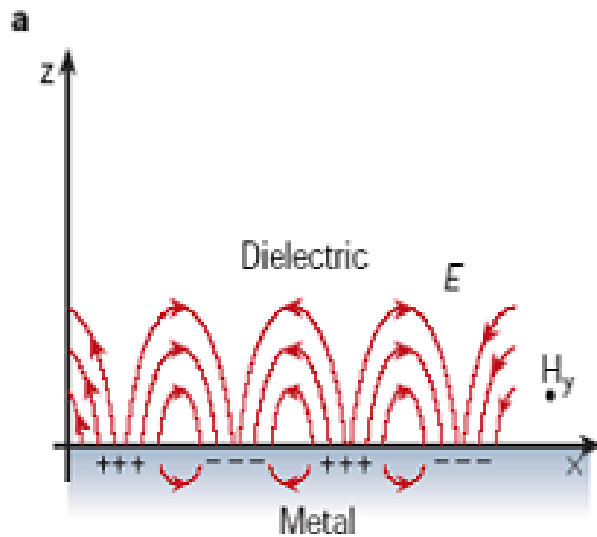
38590+92  
4000x4000nm  
Gold images  
Cut from  
5000x5000nm images



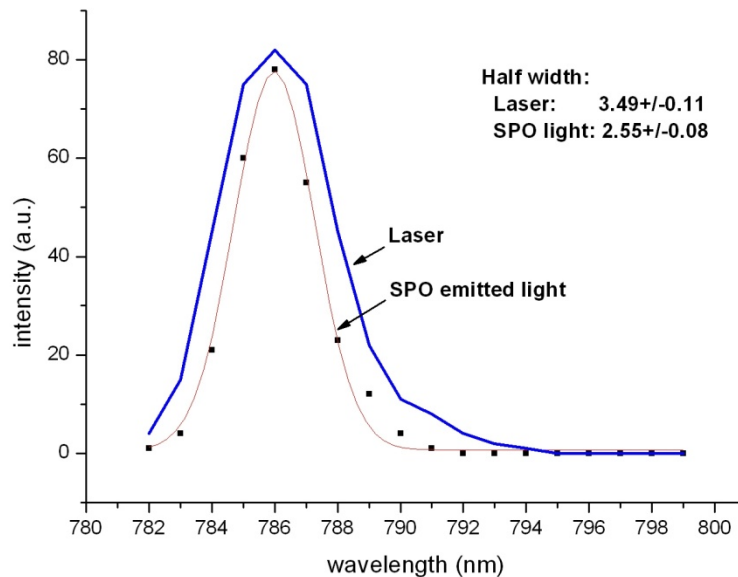
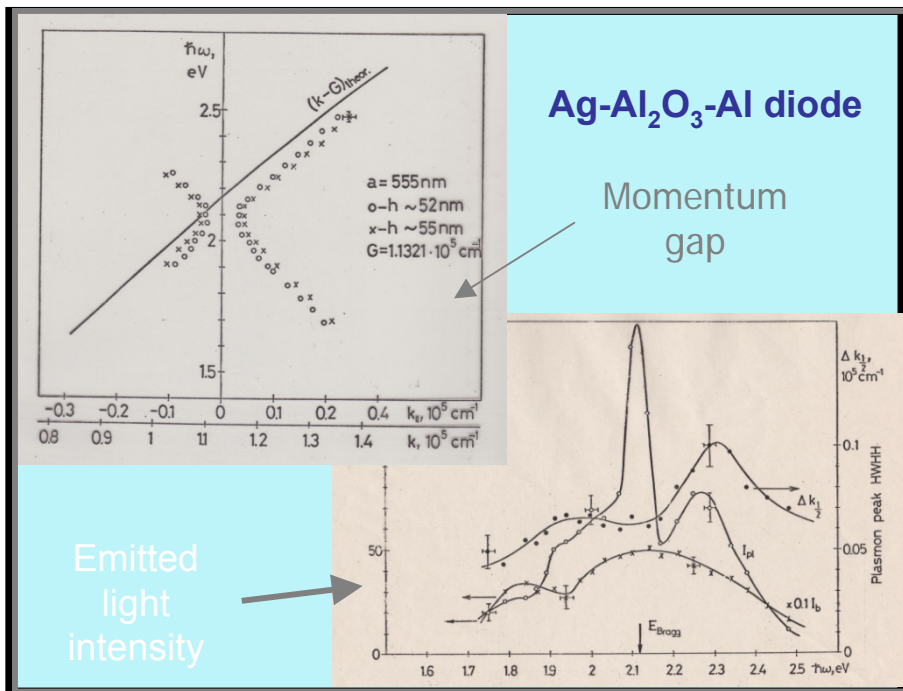
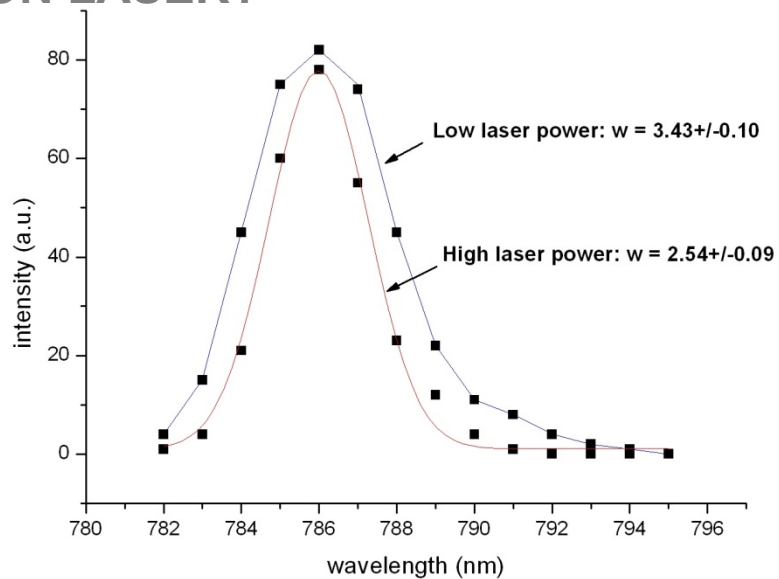
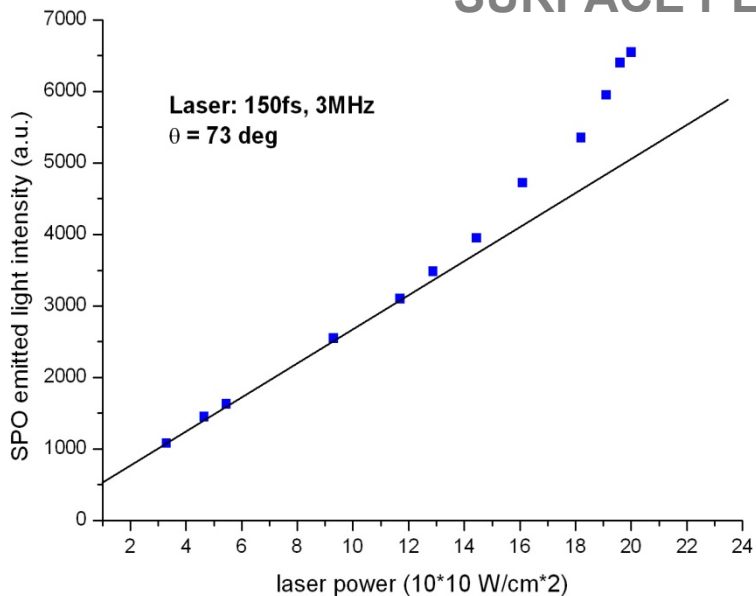
# ENERGY GAP OF SURFACE PLASMONS



OptiCAL transistors  
might be built

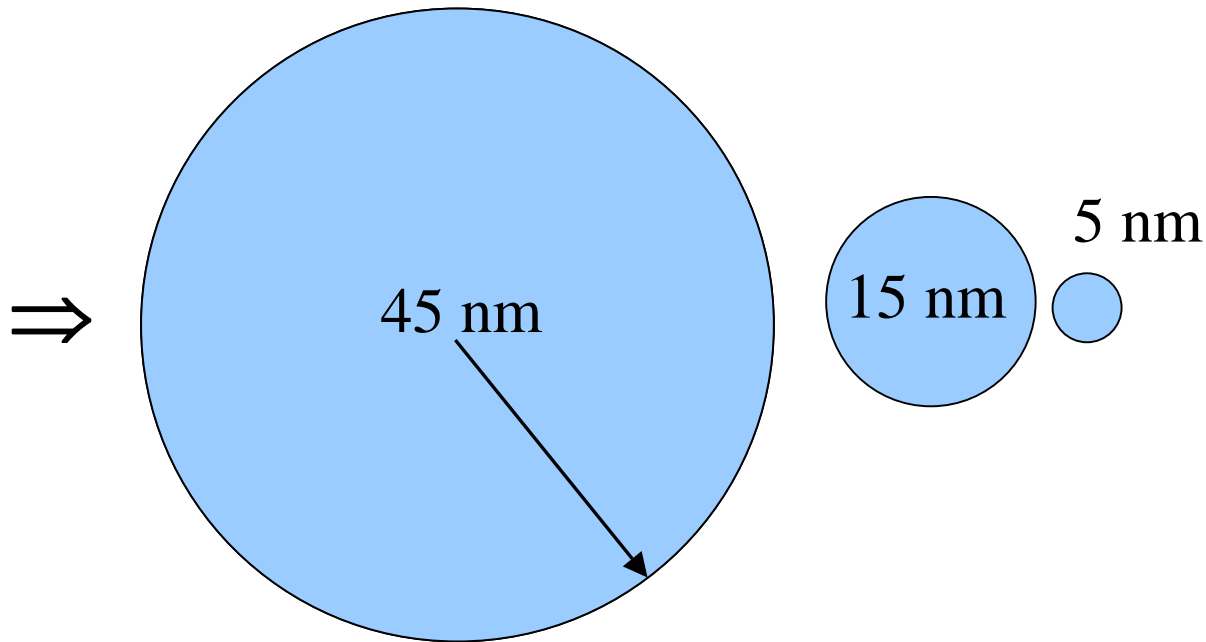


# SURFACE PLASMON LASER?





# Efficient Self-Similar Nanolens of Nanospheres

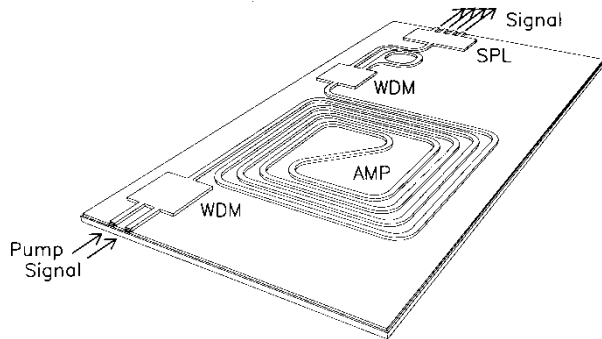


Silver Nanospheres

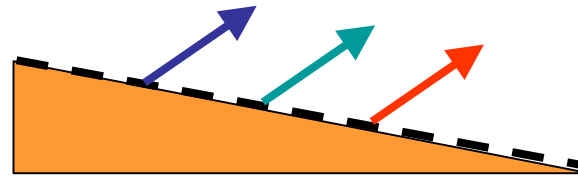
**HOLES BEHAVE SIMILARLY !**

# Plasmonic toolbox: $\omega$ , $\epsilon(\omega)$ , $d$ - Engineer $\lambda(\omega)$

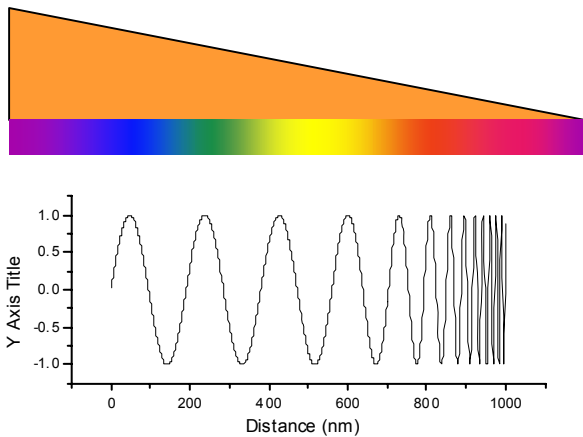
## Plasmonic integrated circuits



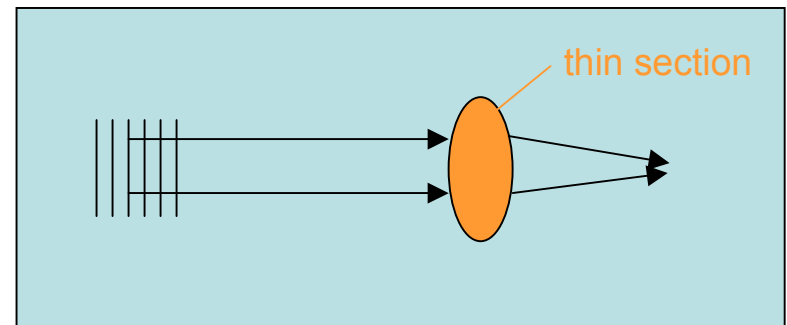
## Plasmonic multiplexer



## Plasmonic concentrator



## Plasmonic lens



And much more .....



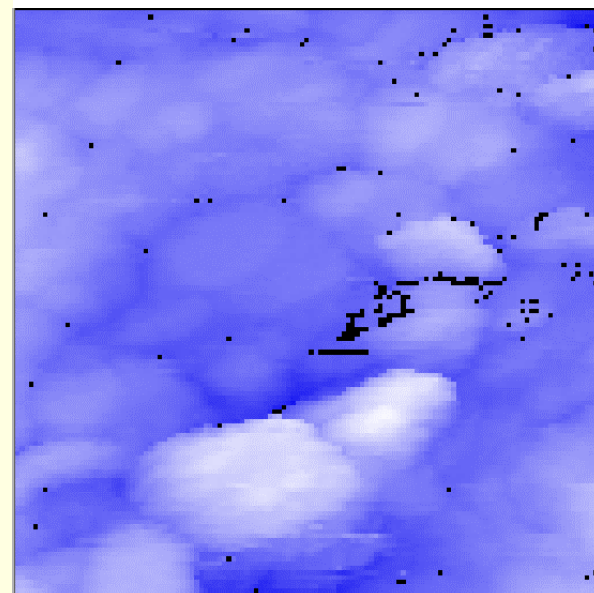
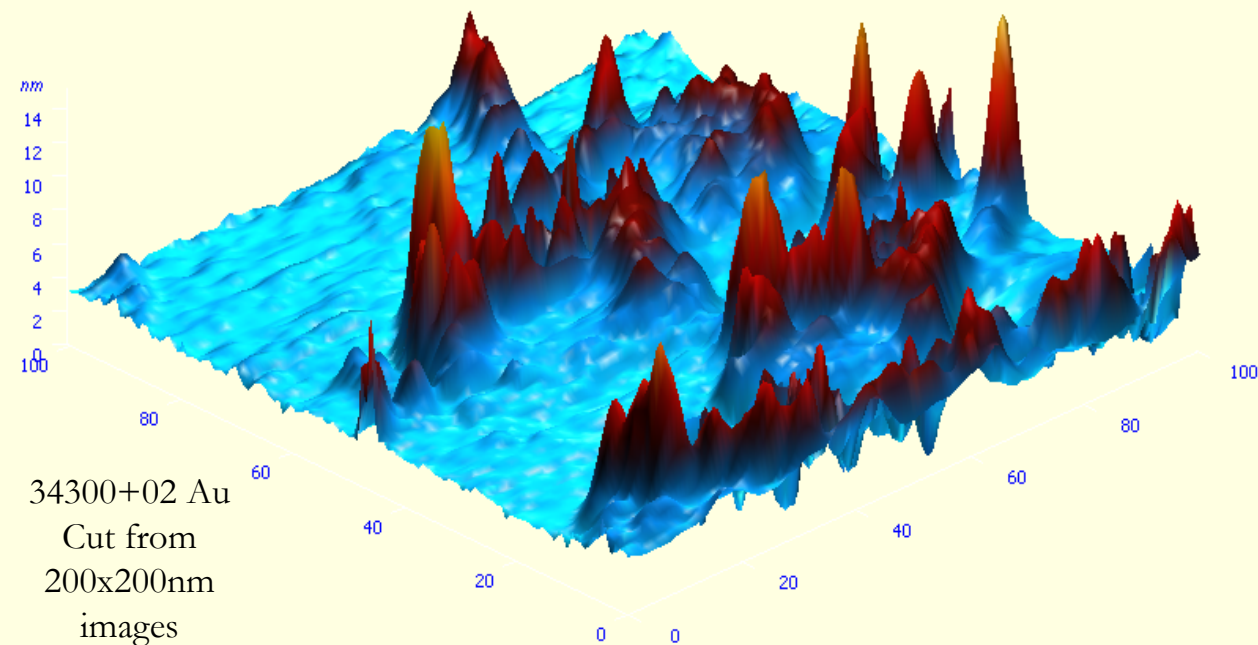
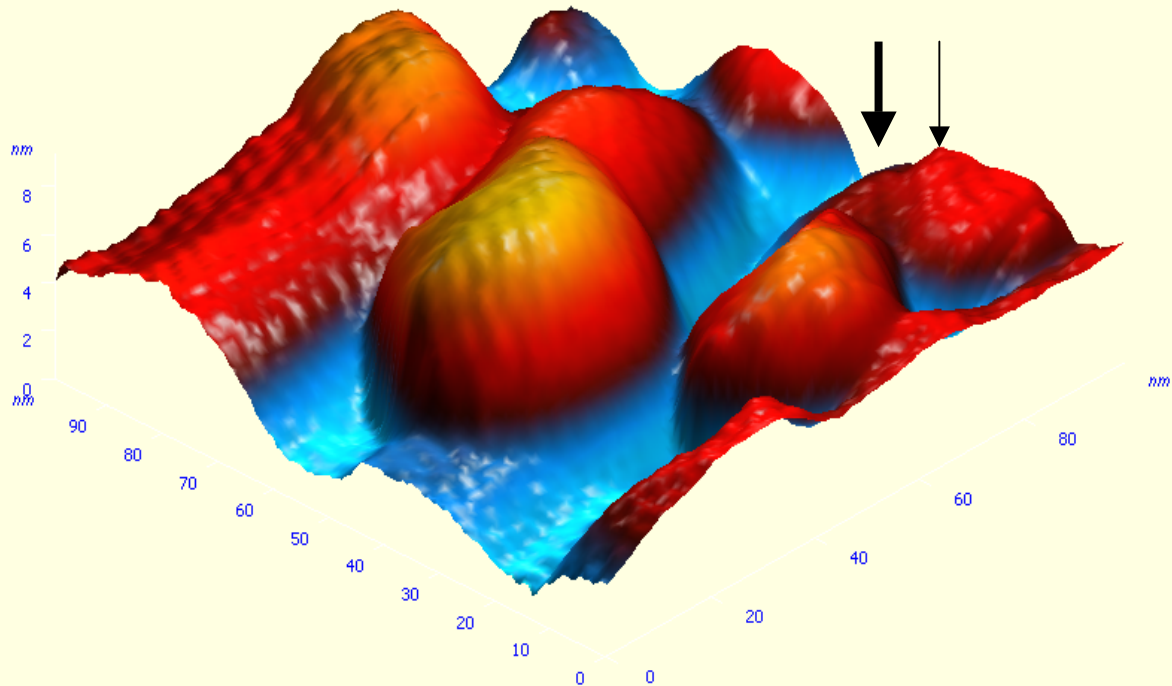
100x100nm

**Au+Au STM tip**

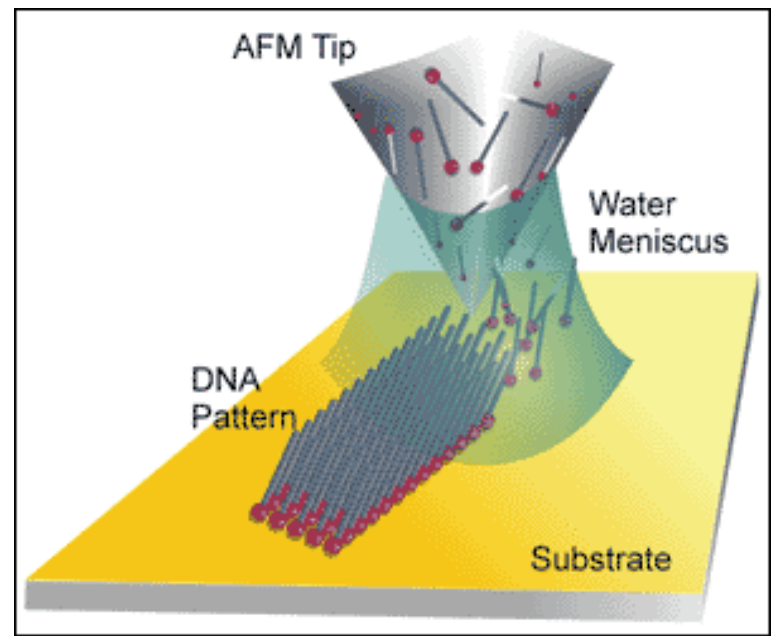
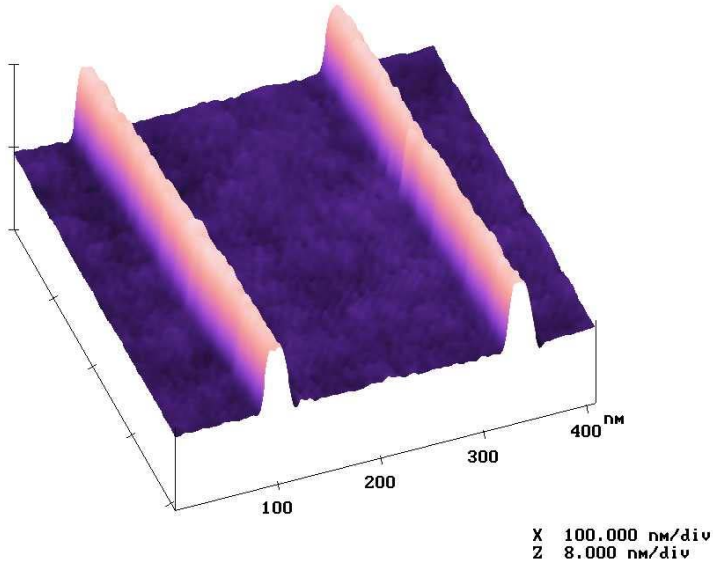
**Topography and**

**SPO near field**

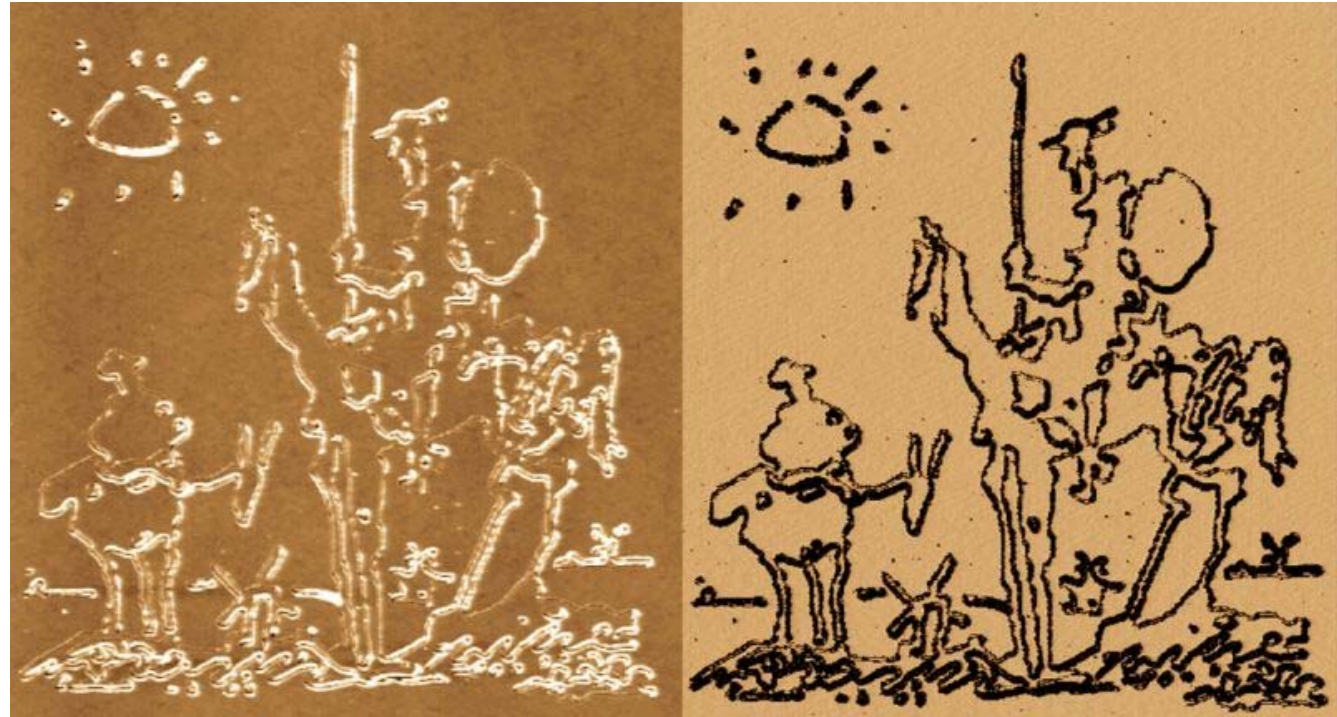
**STM image**



**NEGATIVE SIGNALS!**



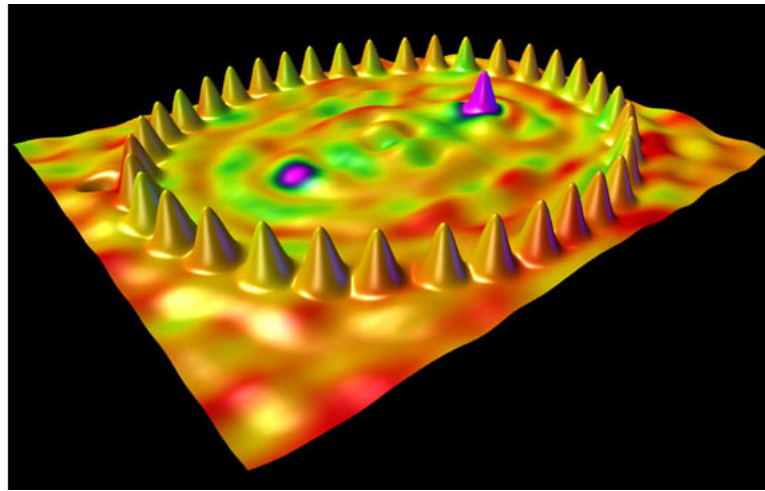
# NANO- STRUC- TURES



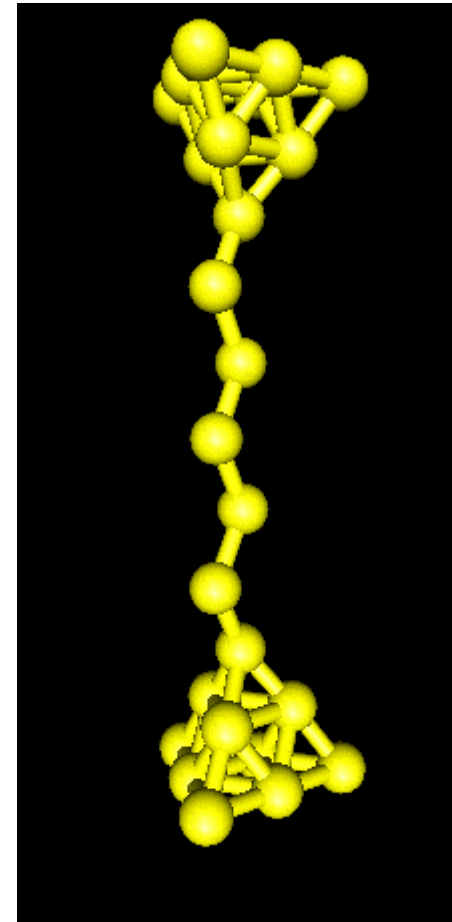
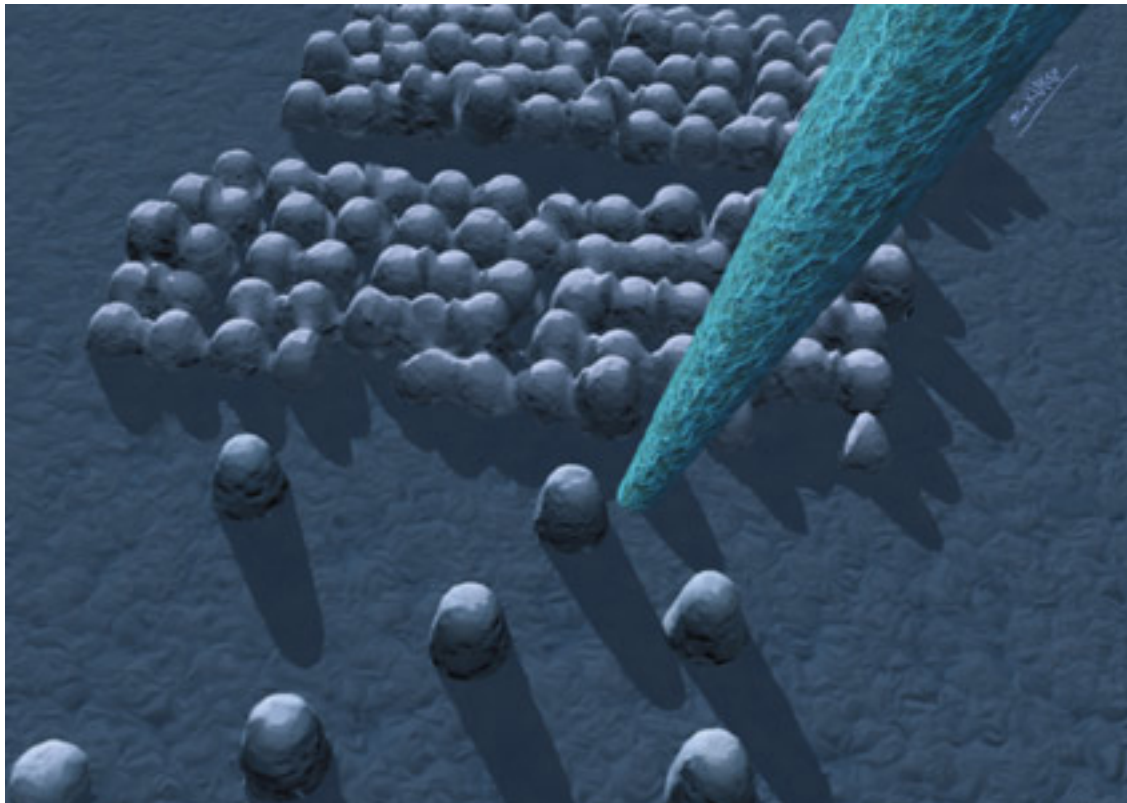




# MANIPULATION OF ATOMS



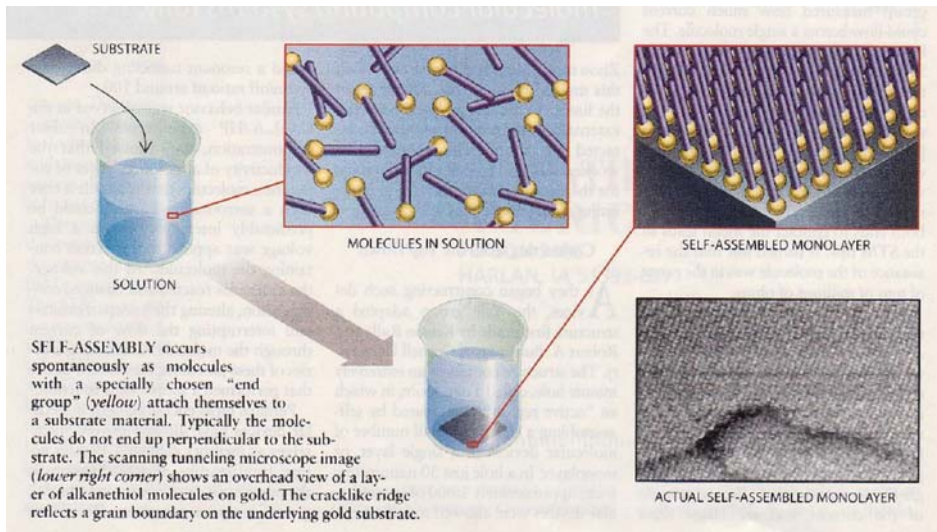
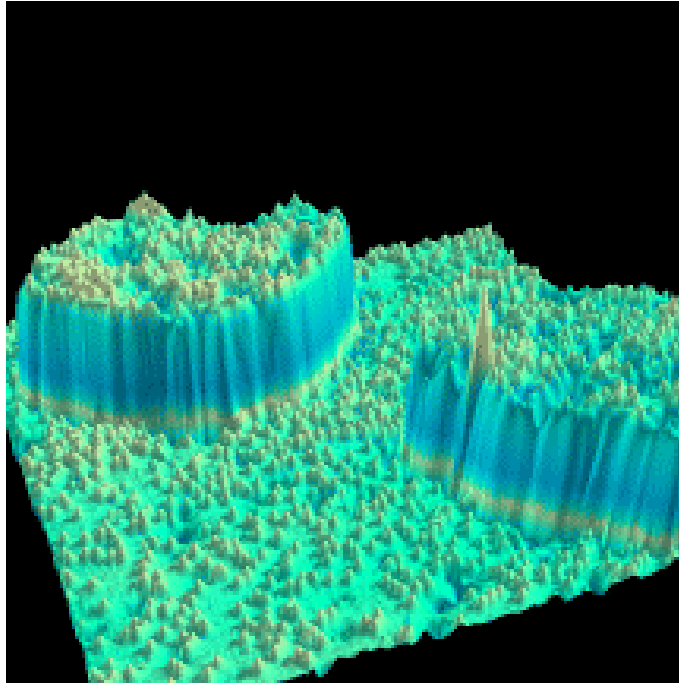
**BOTTOM  
UP!**

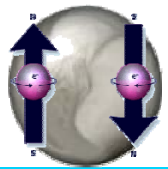




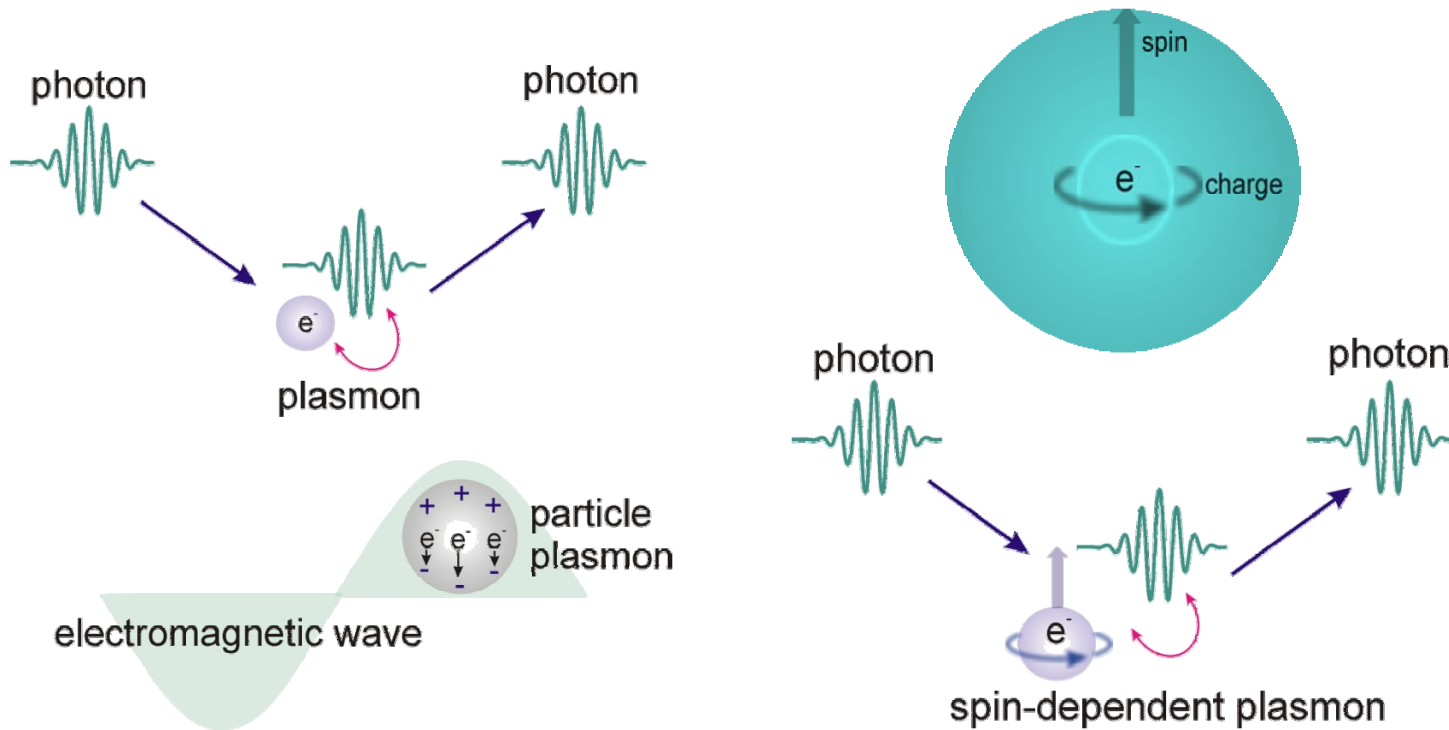


# CHEMICAL SELF-ORGANISATION





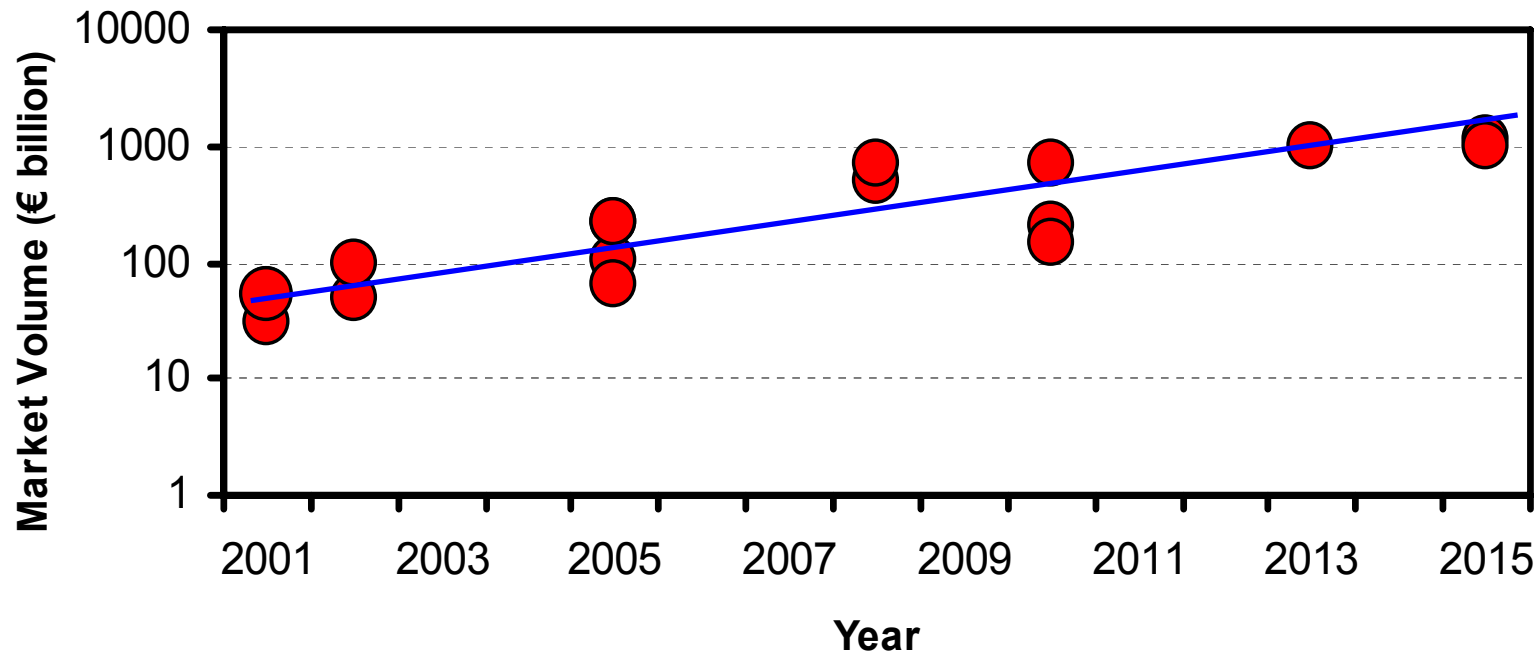
- **Plasmonics:** convert optical energy into electronic oscillations
- **Spintronics:** devices that exploit electron spin rather than charge



- Can we merge the advantages of both fields?

# *Why is nanotechnology important for industry?*

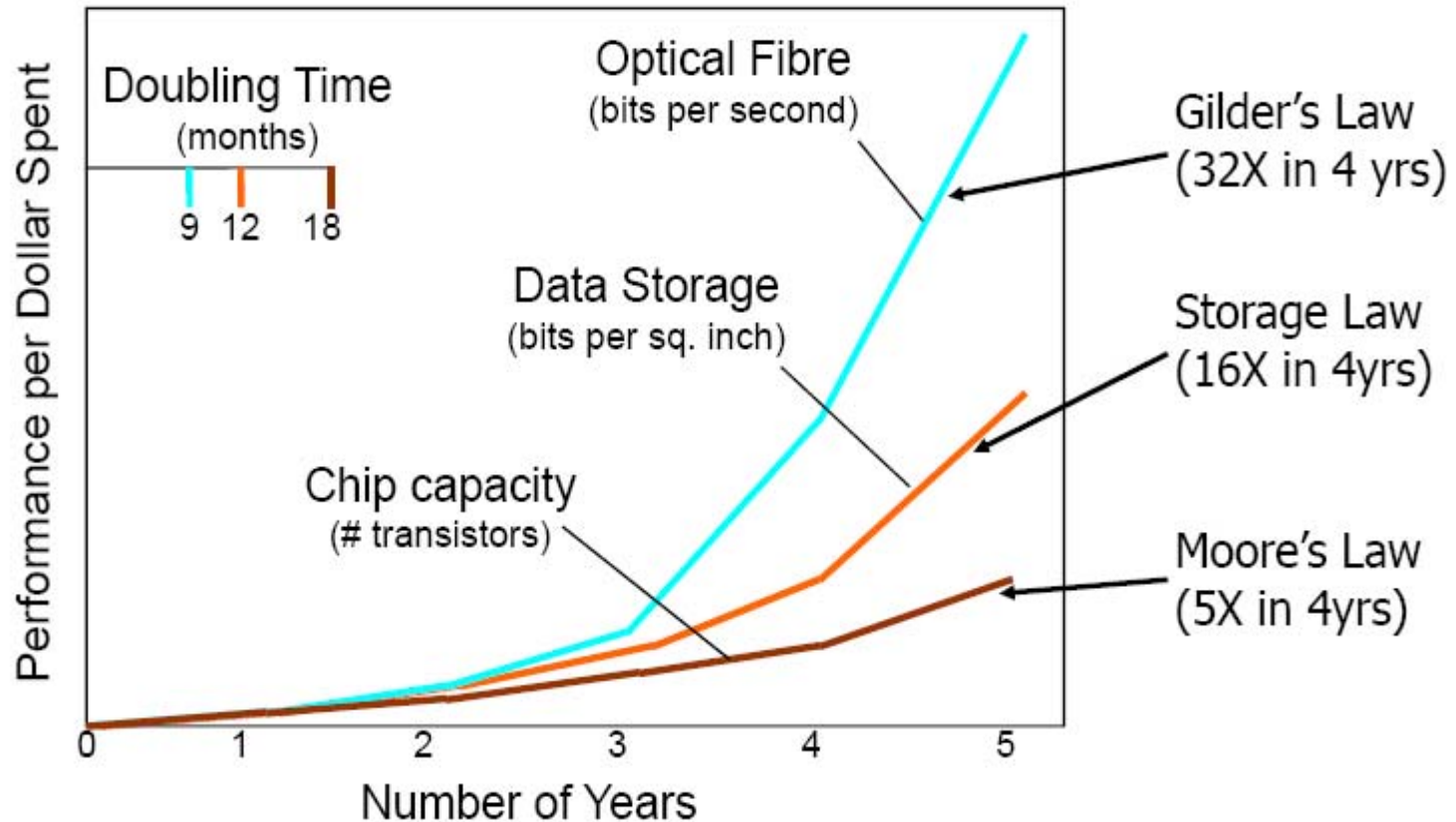
- 1 **Analysts estimate that the market for products based on nanotechnology could rise to hundreds of billions by 2010 and exceed one trillion after**





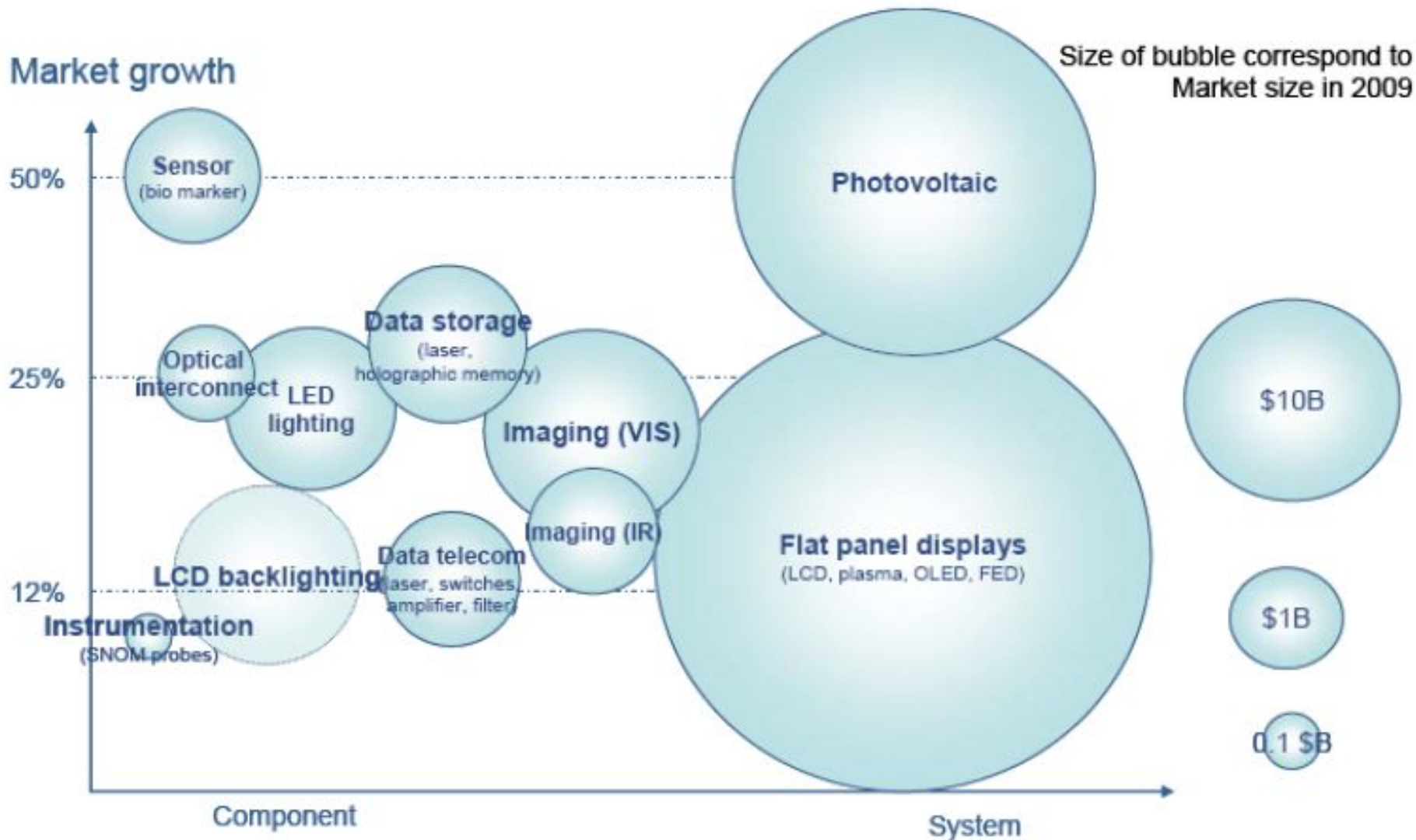
# Technological evolution

## Exponential Growth



Triumph of Light – *Scientific American*. George Stix, January 2001

# Market size for application



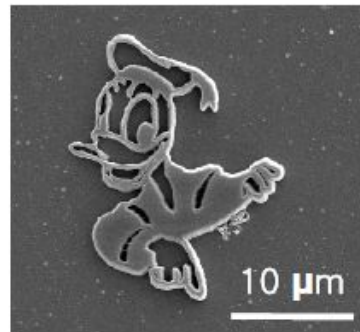


**THANK YOU FOR YOUR  
ATTENTION**

**HUNGARIAN ACADEMY OF  
SCIENCES**

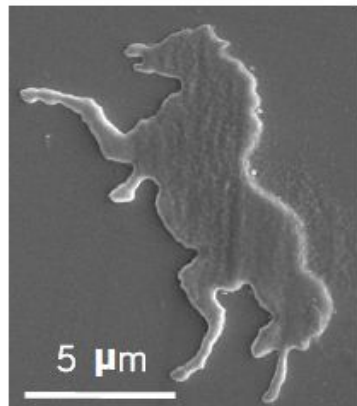


## Nano Replication Process



Bit map image  
of Donald

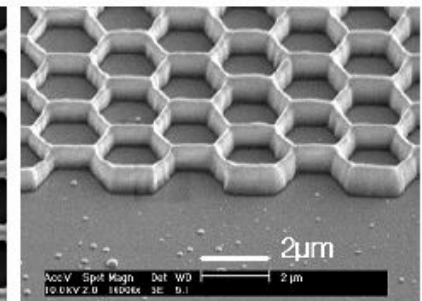
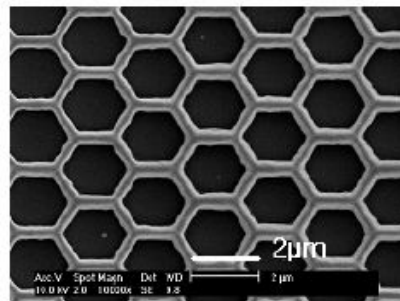
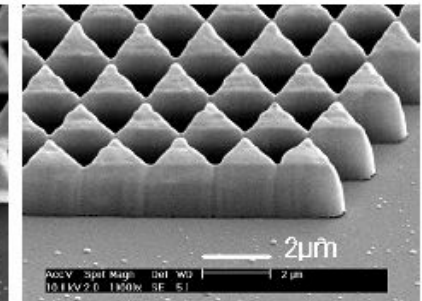
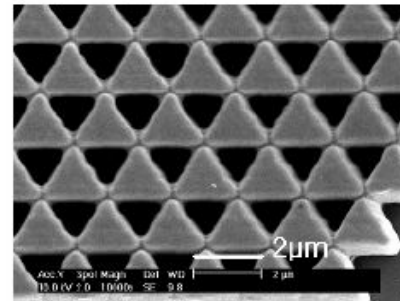
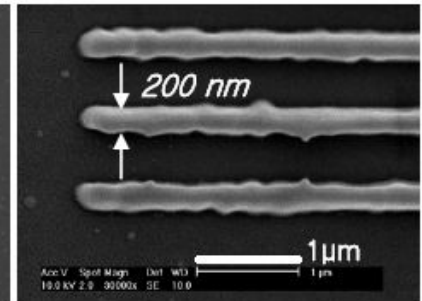
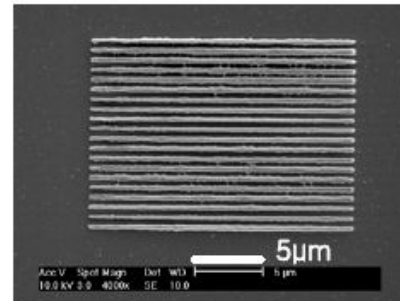
Replicated  
image



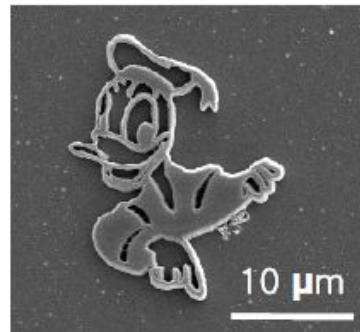
Bit map image  
of a horse

Replicated  
image

## 2D Patterning

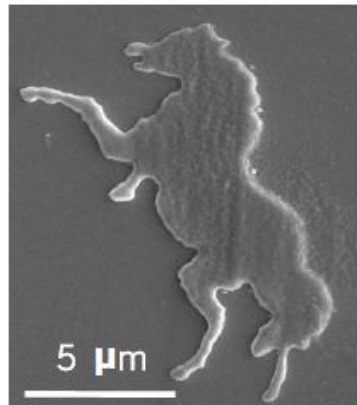


## Nano Replication Process



Bit map image  
of Donald

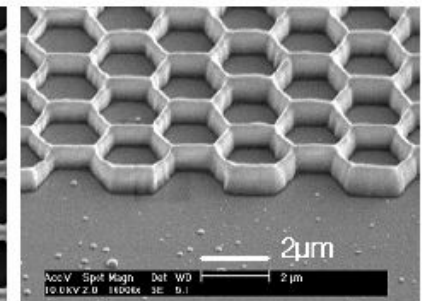
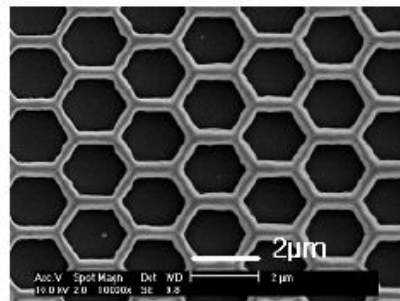
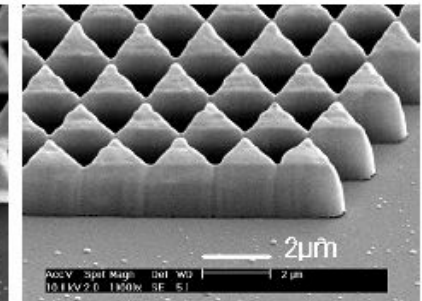
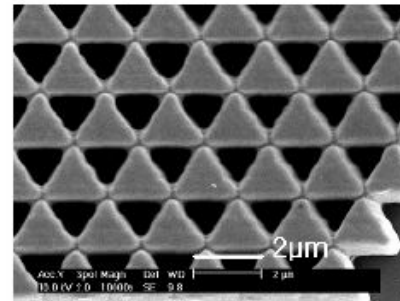
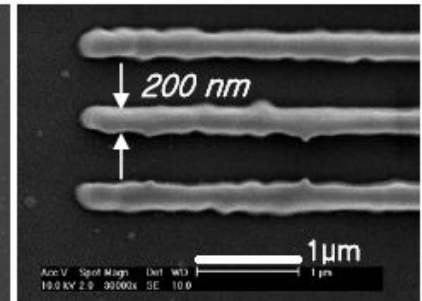
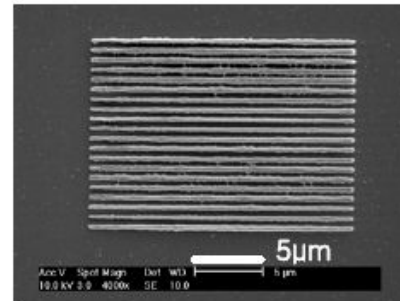
Replicated  
image



Bit map image  
of a horse

Replicated  
image

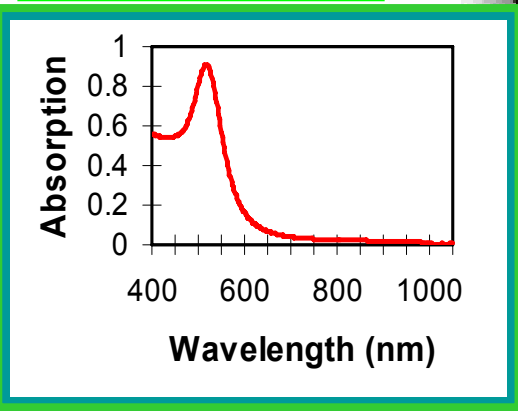
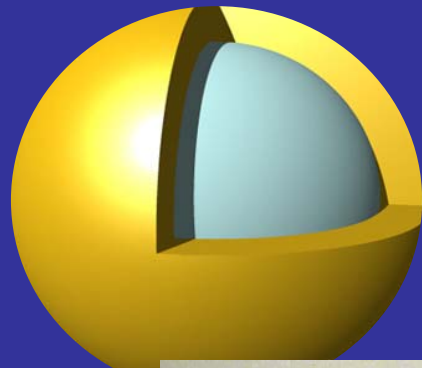
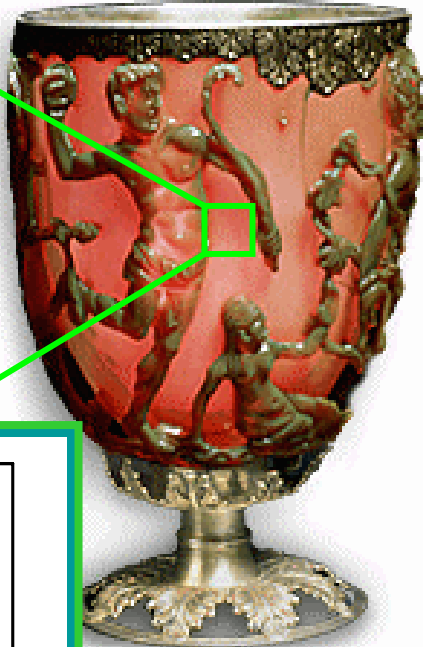
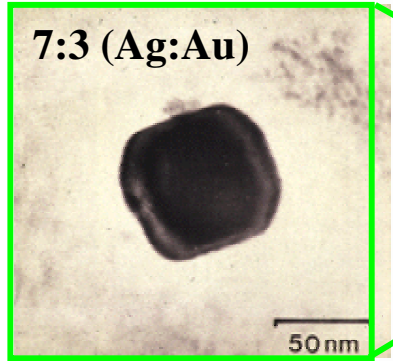
## 2D Patterning

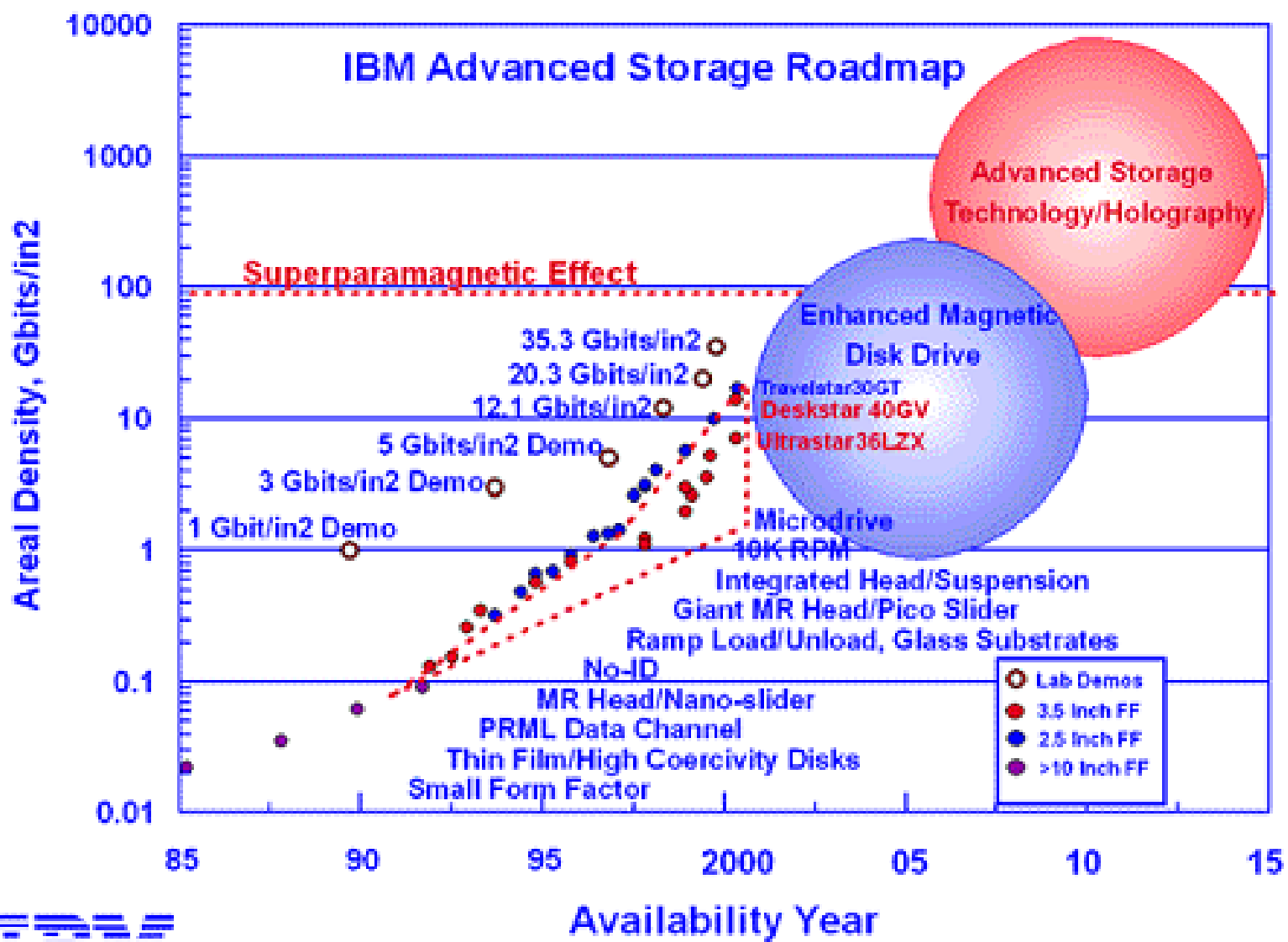




# Nanospheres → Nanoshells

Lycurgus Cup  
4th Century A.D., Roman





advr.dmp00a.prz



ED GROCHOWSKI at ALMADEN