2. mezinárodní podzimní škola povrchového inženýrství , Plzen 14-18.X.2013

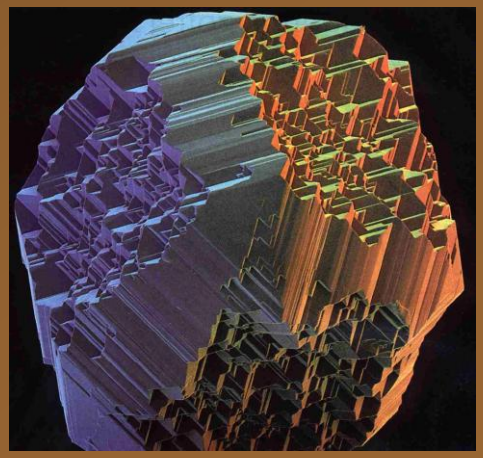
Bioaktivita nanodiamantu

Stanislaw F. Mitura

Katarzyna Mitura

KOSZALIN University of Technology, Poland

Technical University of Liberec, Czech Republik



e-mail: stanislaw.mitura@gmail.com

CENTRE OF EXCELLENCE NANODIAM

Stefanowskiego 1, 90-924 Lodz, Poland

Technical University of Lodz
Faculty of Mechanical Engineering
Institute of Materials Science and Engineering

"New technologies for medical applications: studying and production of carbon surfaces allowing for controllable bioactivity"

Phone: **+48 42 631 32 63** Fax: **+48 42 636 92 43**

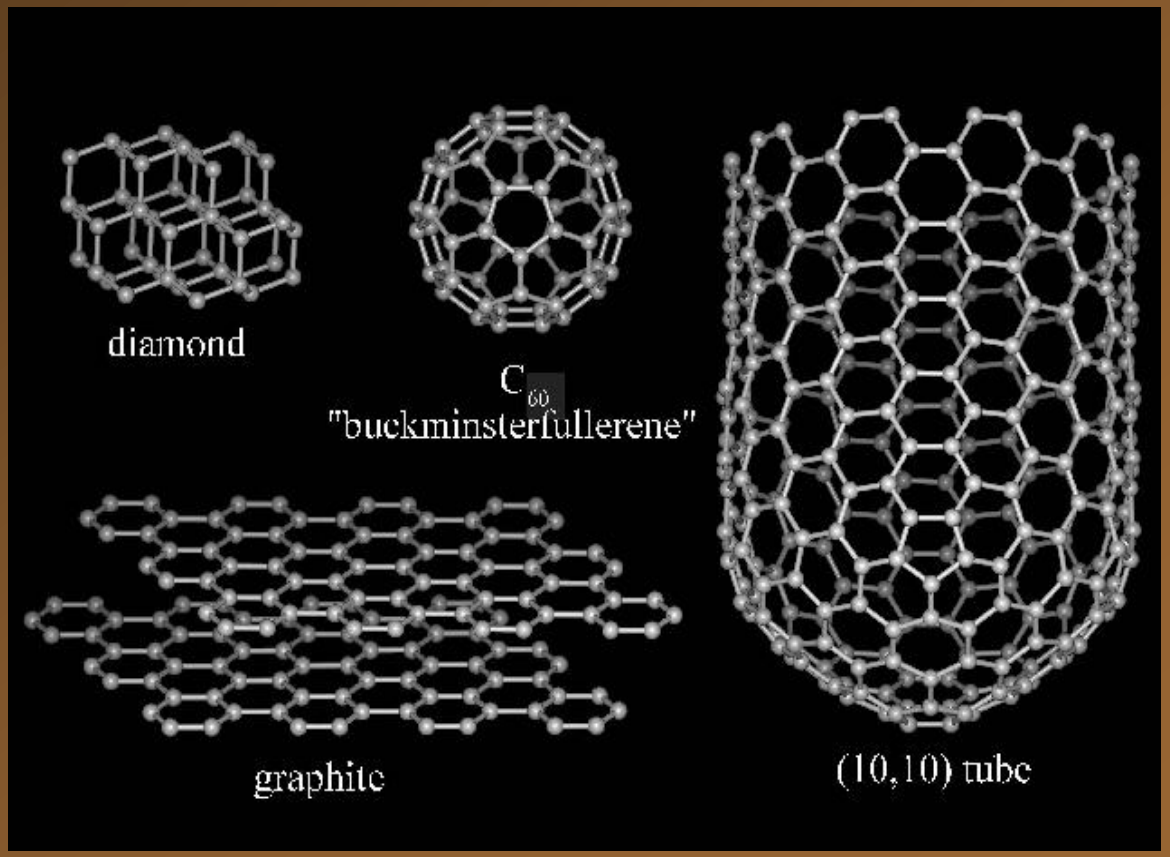
CENTRE OF EXCELLENCE NANODIAM

Carbon Allotropy

Allotropy?
What is this…

Forms of Carbon

Diamond
Graphite
Carbines
...???...
Fullerens
Nanotubes
Foams
.....



Electron Configuration: $[1s^2]\ 2s^2\ 2p^2$

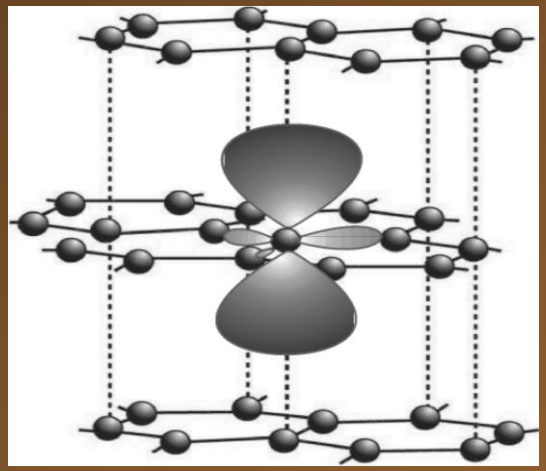
Allotropic Forms of Carbon

Carbon: $^{12}C_6$

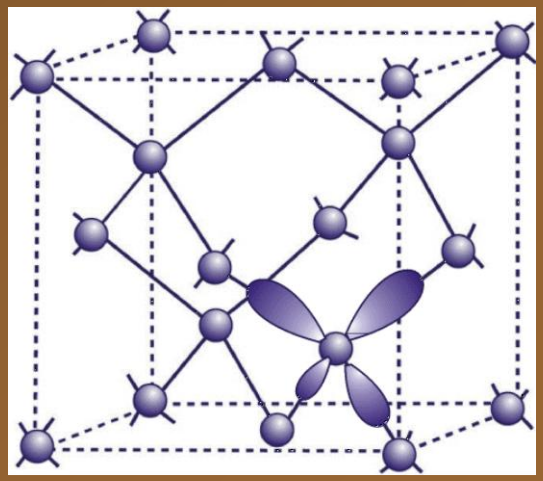
Electron Configuration: $[1s^2]\ 2s^2\ 2p^2$

$2s^2\ 2p^2$ ⇒

- $\sigma\ sp + \Pi p^2$
- $\sigma\ sp^2 + \Pi p$
- σsp^3

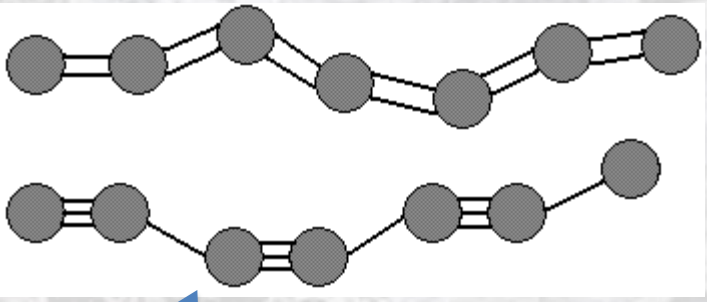


- Graphite
- Diamond



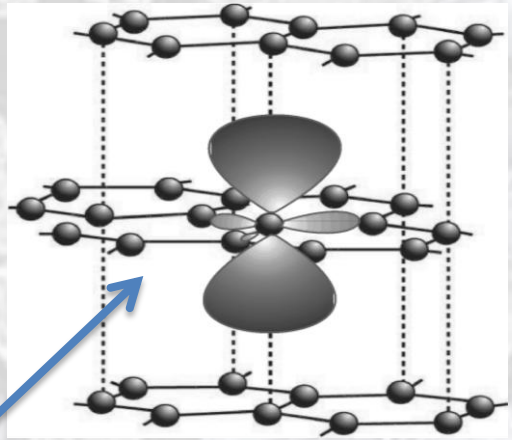
Allotropic Forms of Carbon

electron configuration



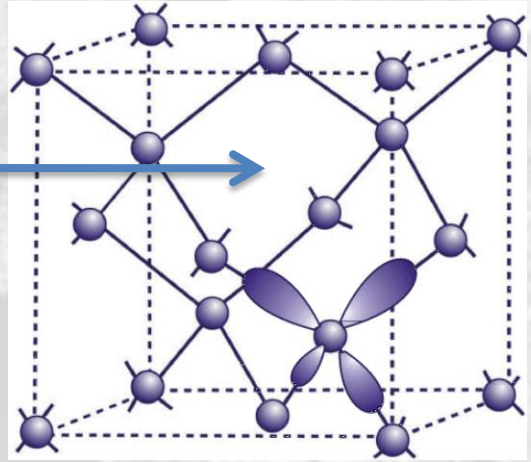
Carbon: $^{12}C_6$

Electron configuration: $[1s^2]\ 2s^2\ 2p^2$



$2s^2\ 2p^2$ ⇒

- » $\sigma\ sp + \Pi p^2$ ◆ Carbine
- » $\sigma\ sp^2 + \Pi p$ ◆ Graphite
- » σsp^3 ◆ Diamond



Allotropic Forms of Carbon

Carbon: $^{12}C_6$

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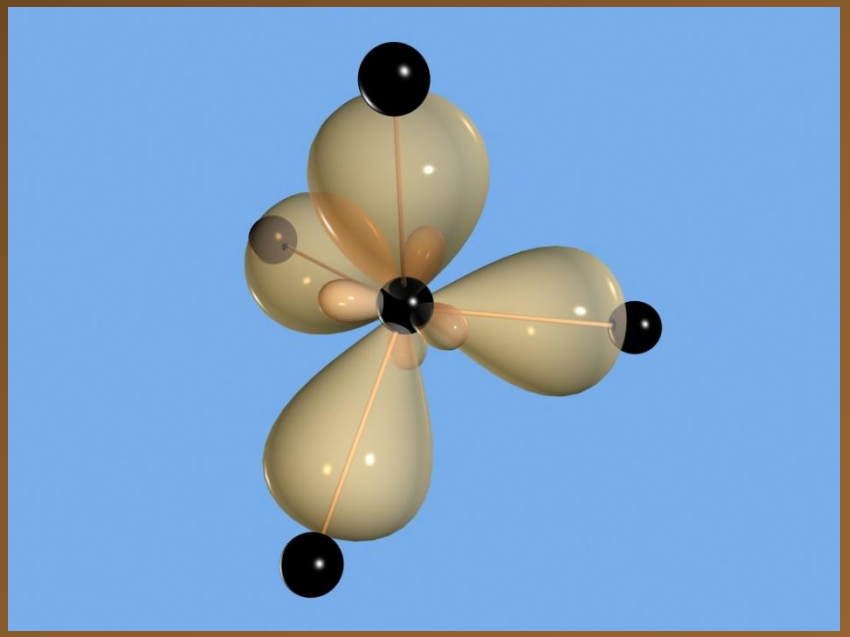
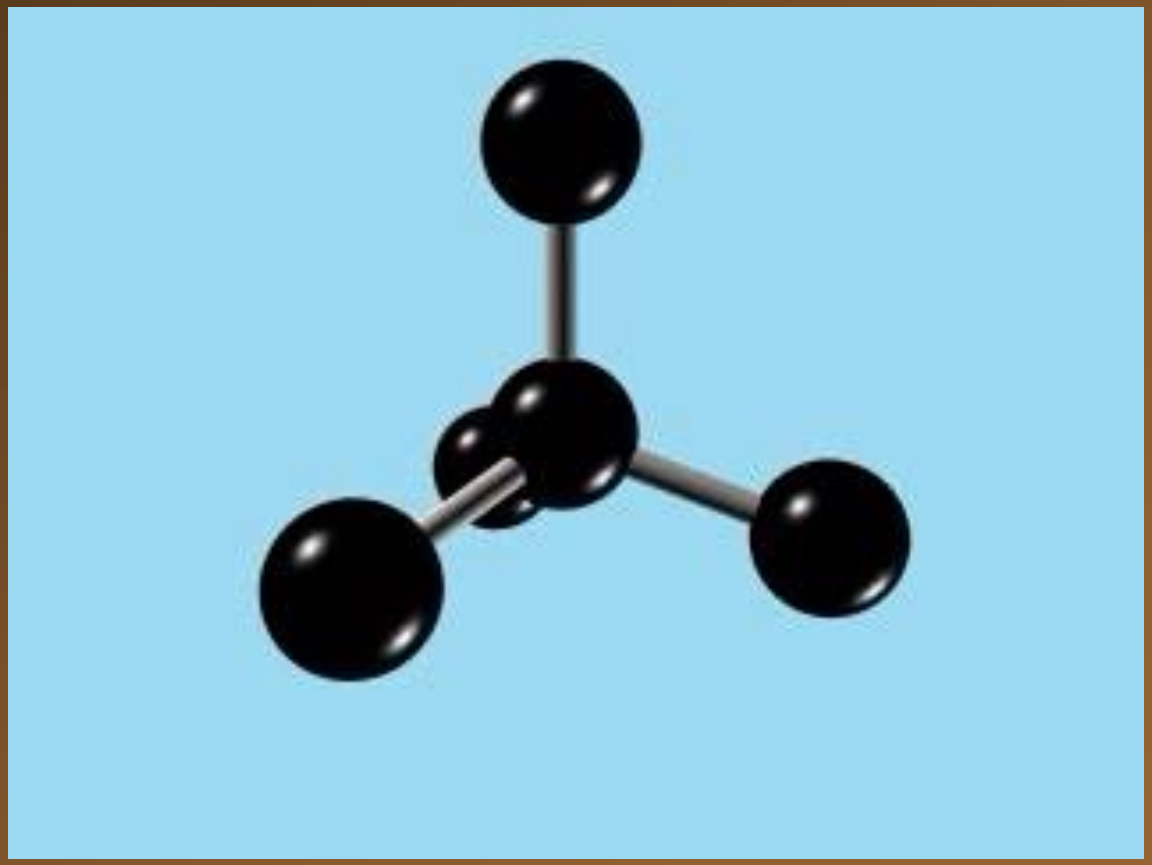
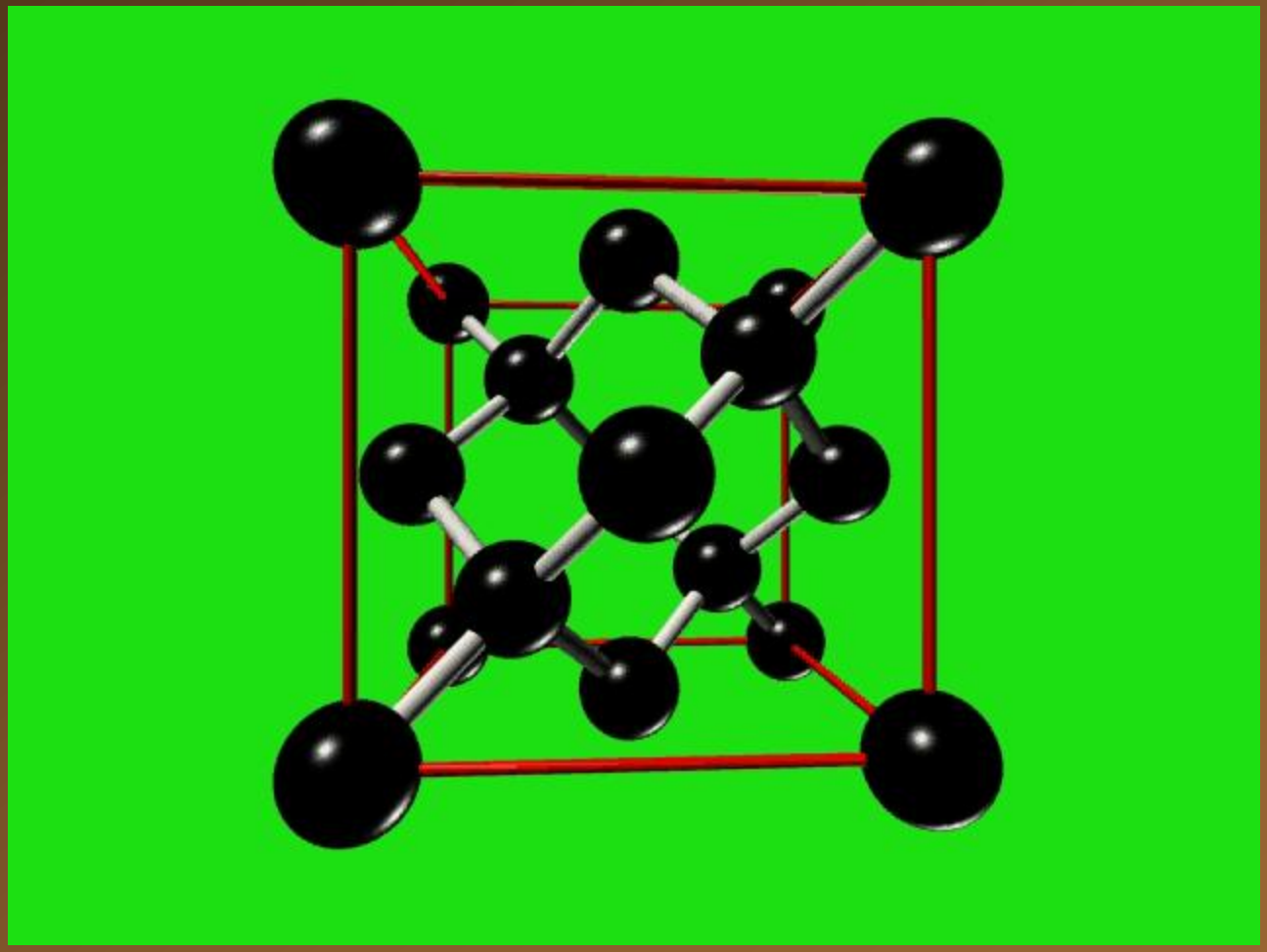


Diamond

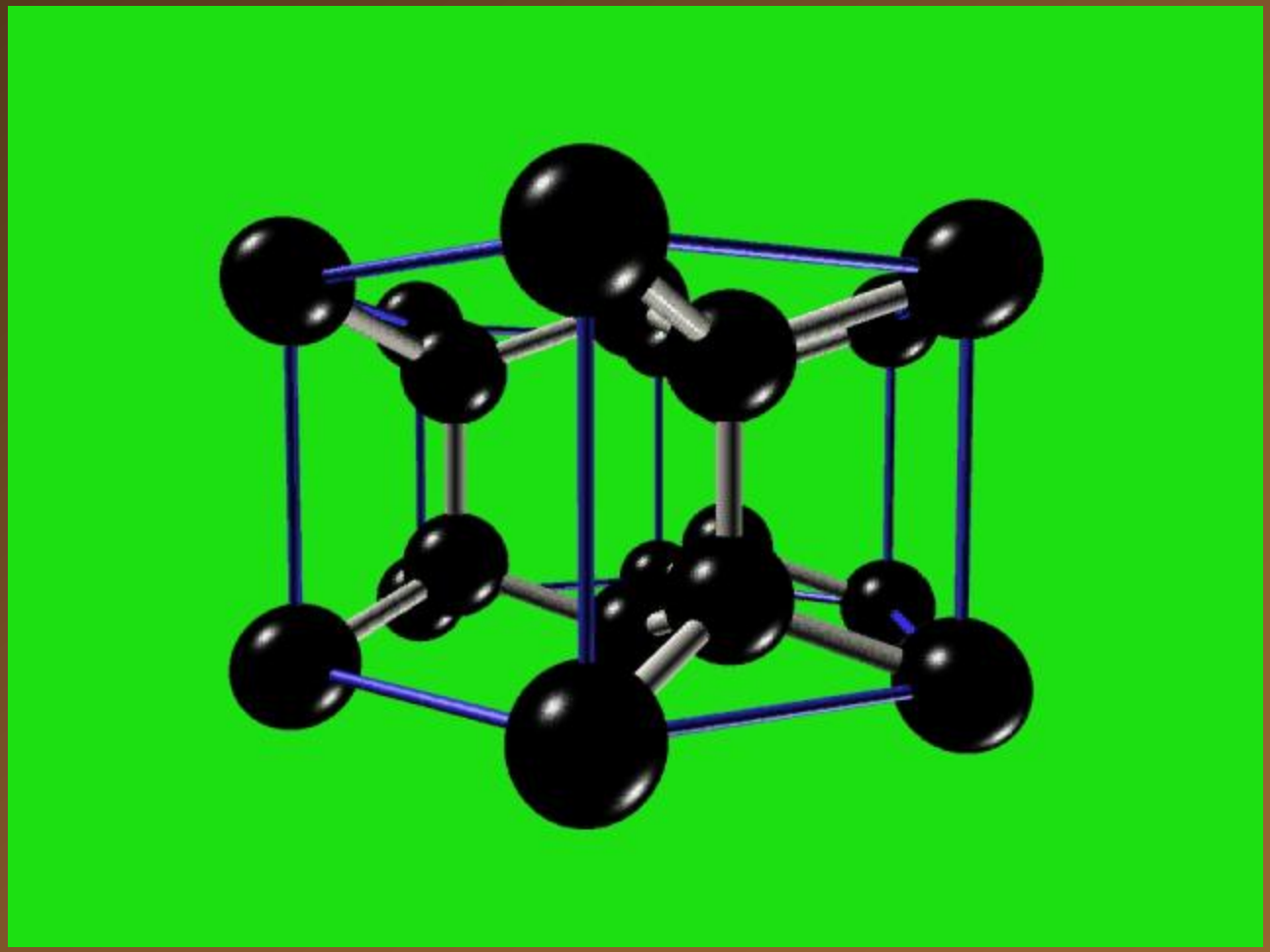
The smallest unit of diamond



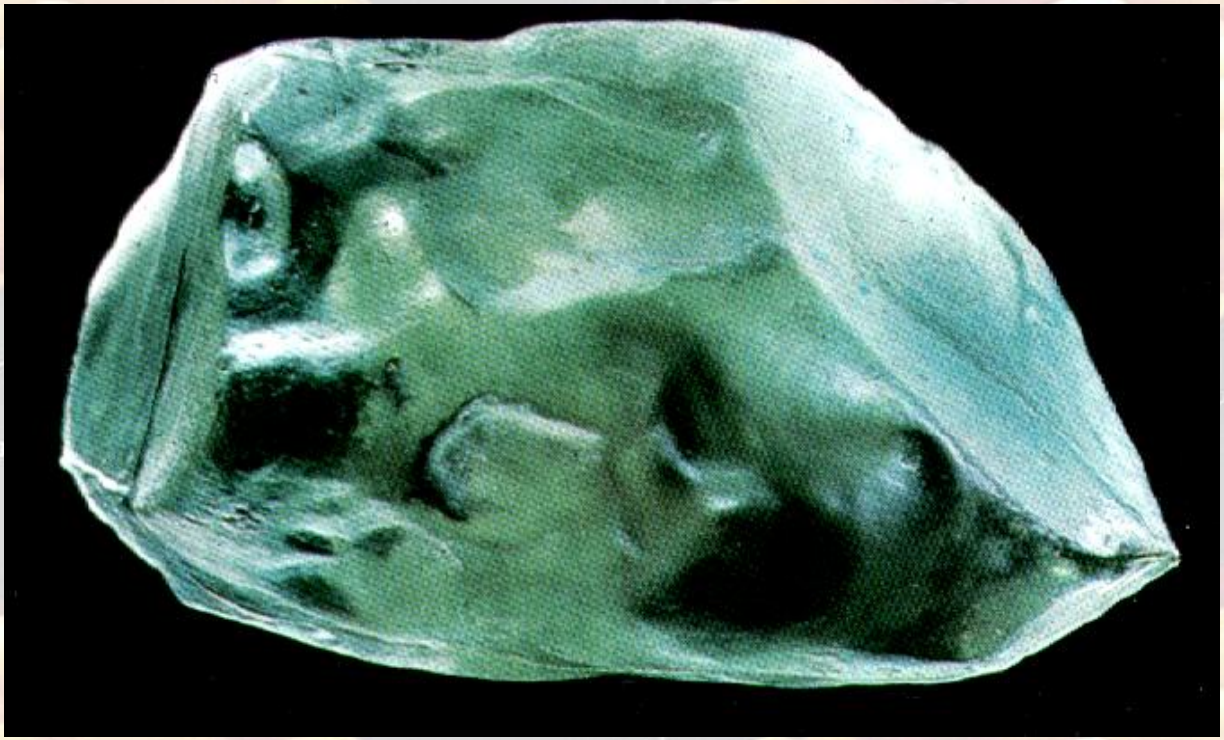
Cubic Diamond



Hexagonal Diamond (Lonsdeilit)



Diamonds



Cullinan

3106 ct (621 g)

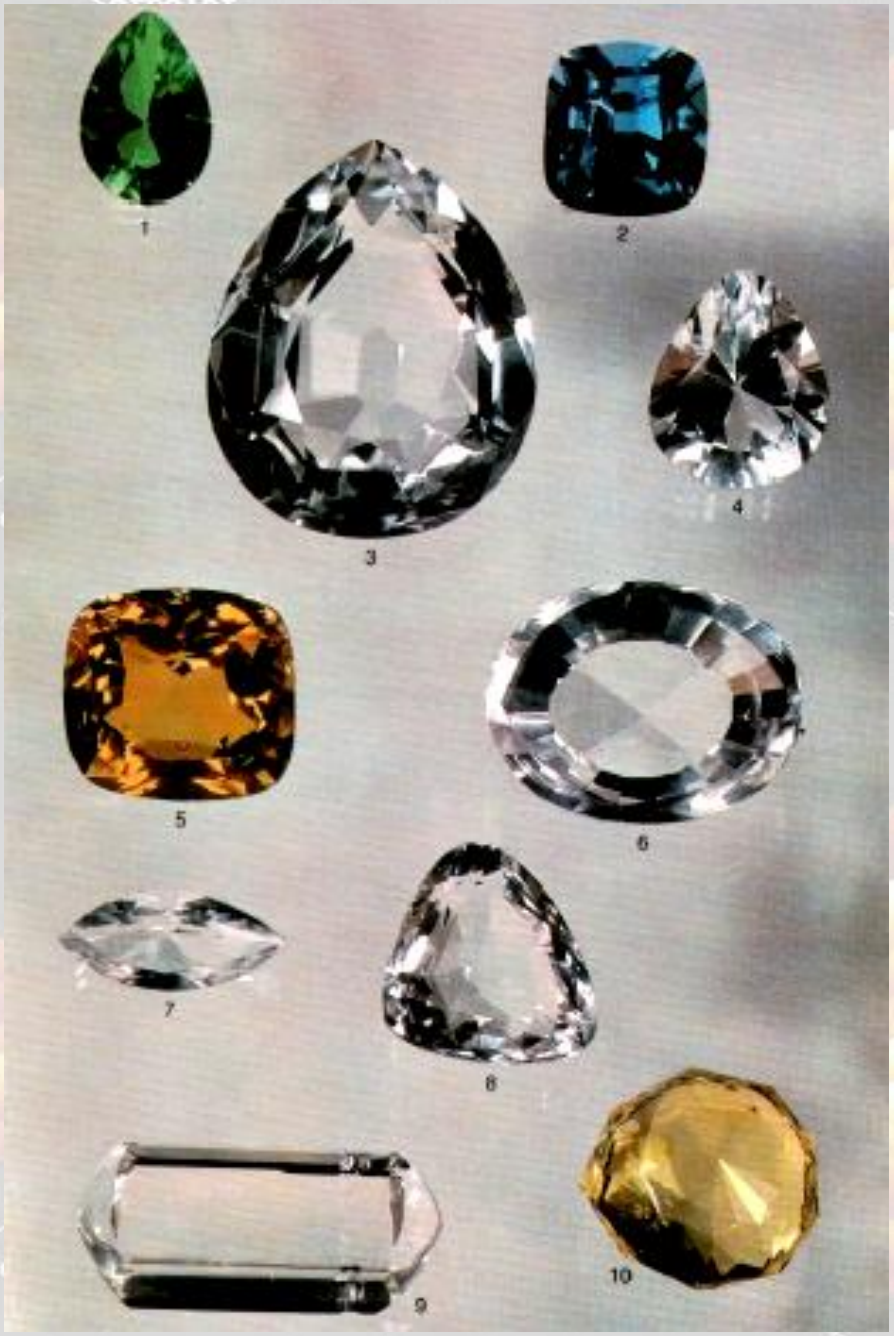
» 106 Brilliants

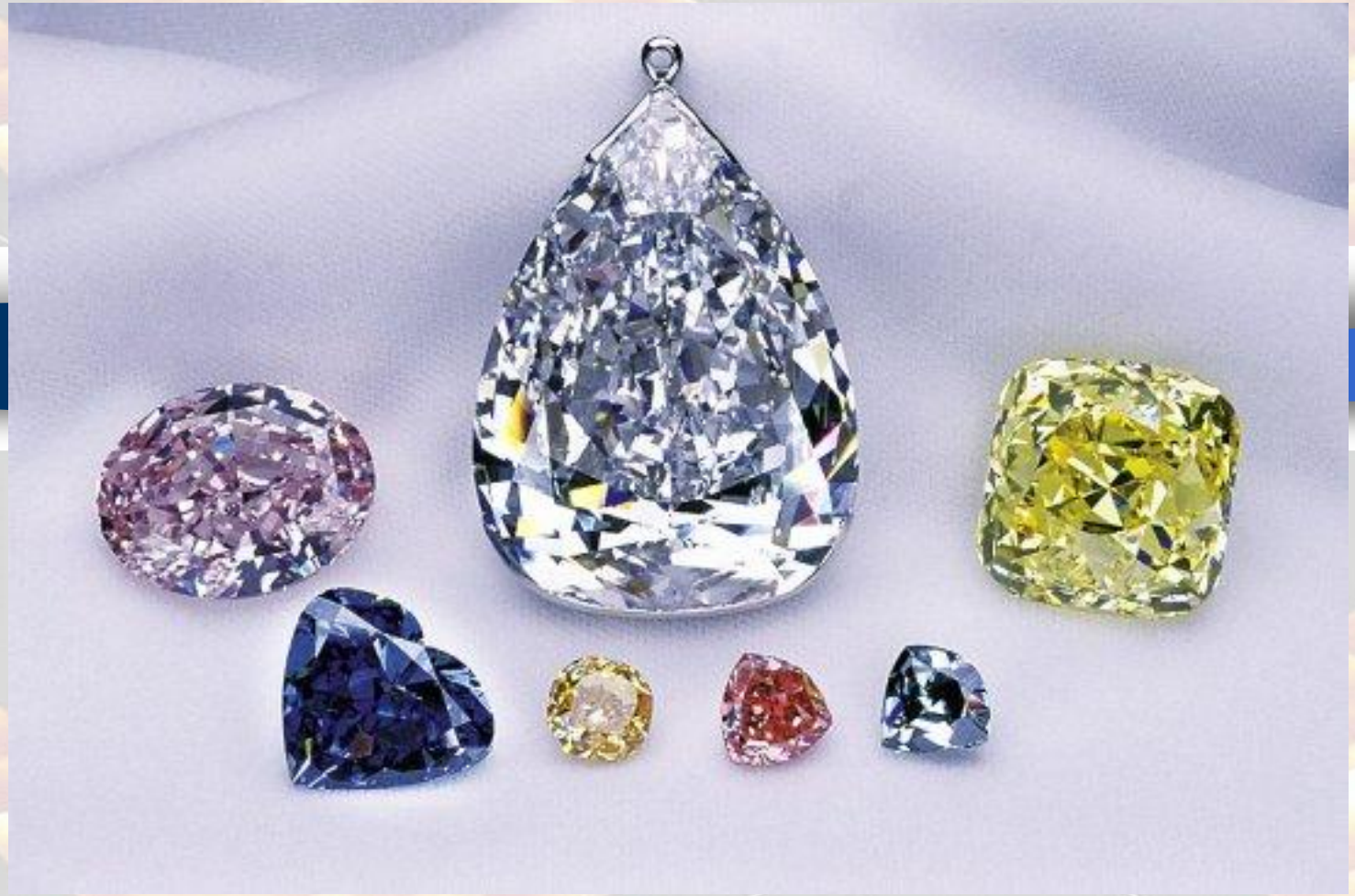
Cullinan I (530 ct)

Cullinan II (317 ct)

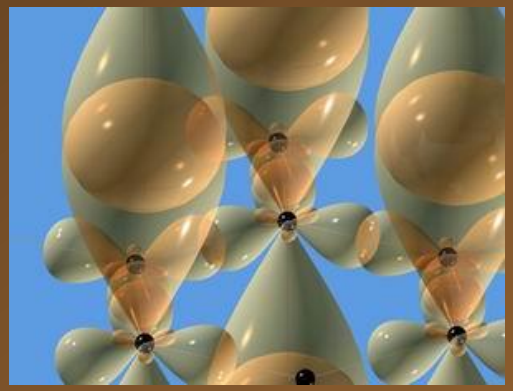
Diamonds
brillants

Different type
of diamond stones;
it means...





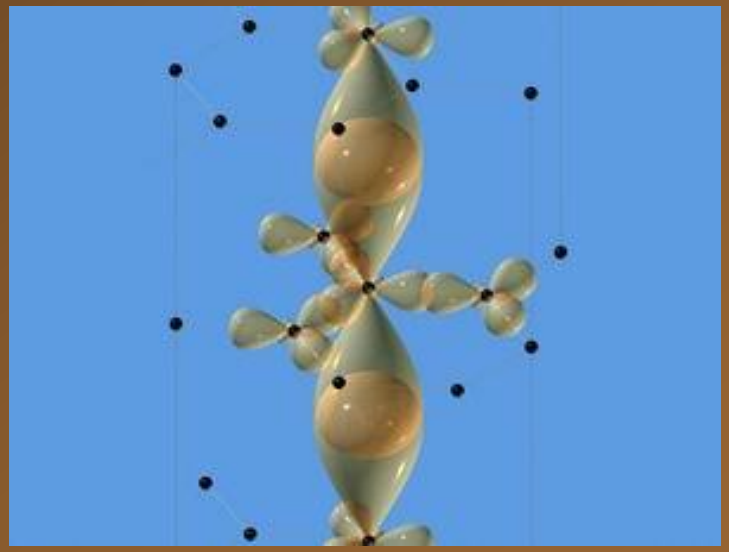
Allotropic Forms of Carbon



Carbon: $^{12}C_6$

Electron Configuration: $[1s^2]$ $2s^2\ 2p^2$

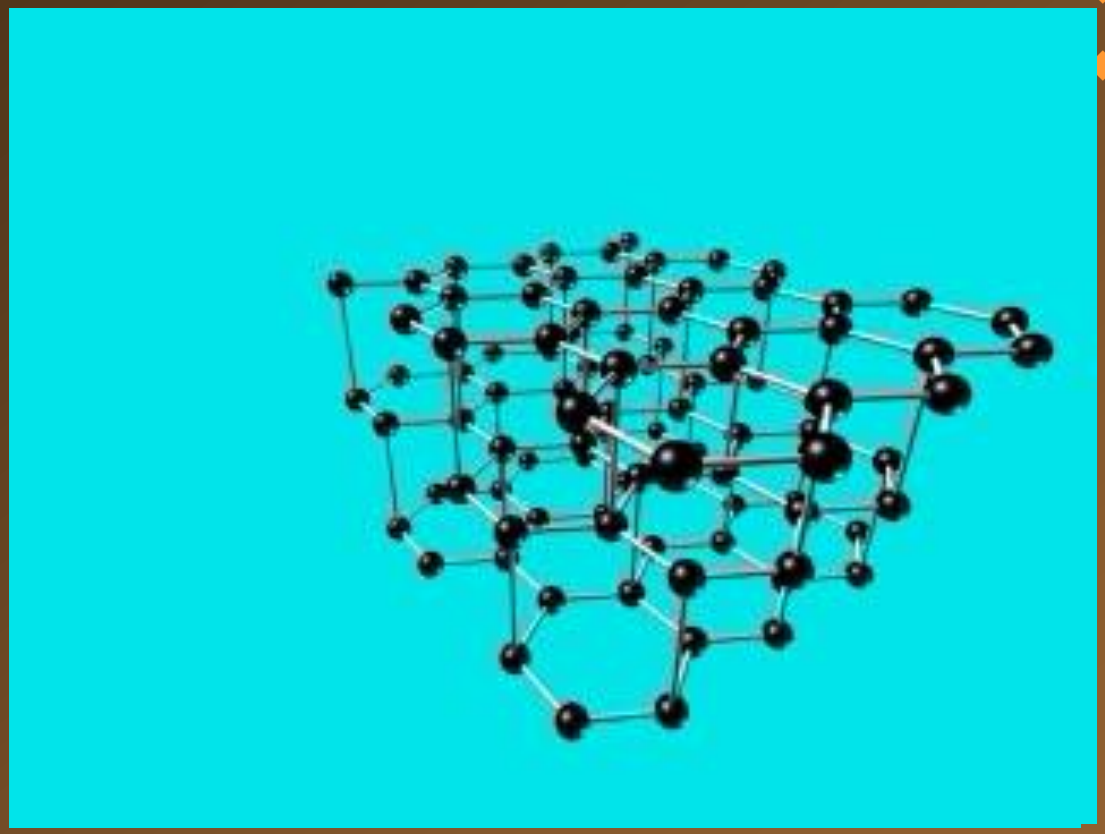
$2s^2\ 2p^2$ ⇒ ◆ $\sigma\ sp^2 + \Pi p$

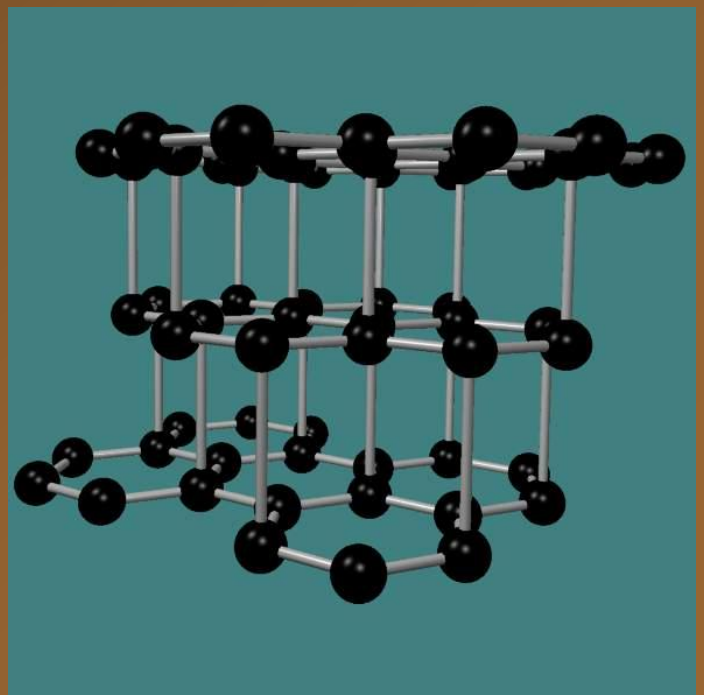


Graphite

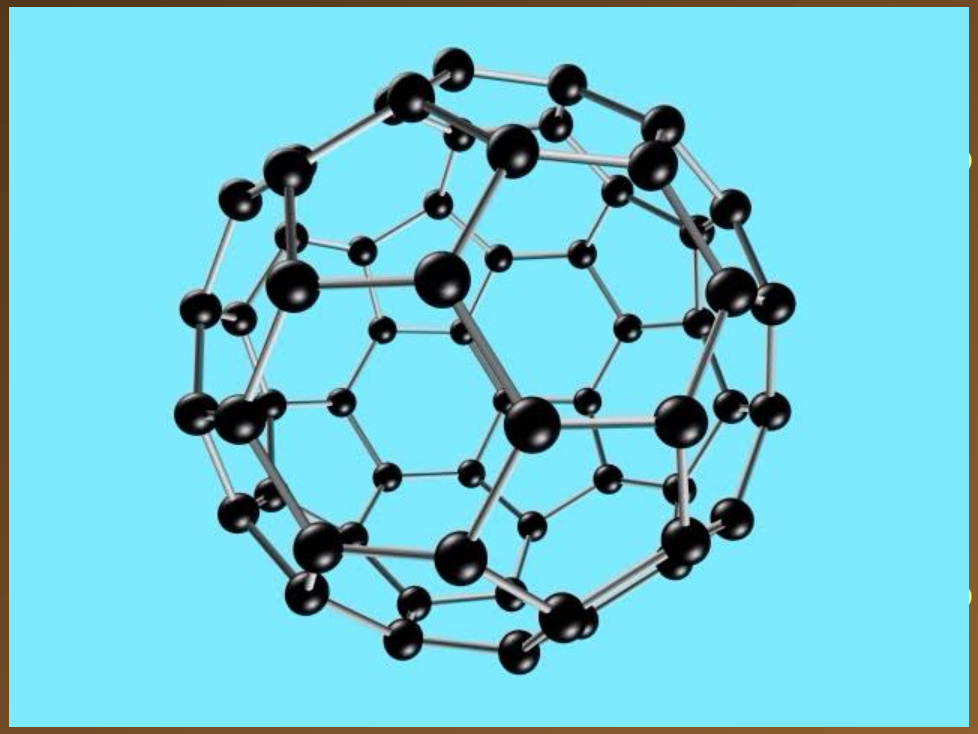
Graphite

- Hardness very low
- Electrical conductivity high
- Density 2.25 g/cm^3



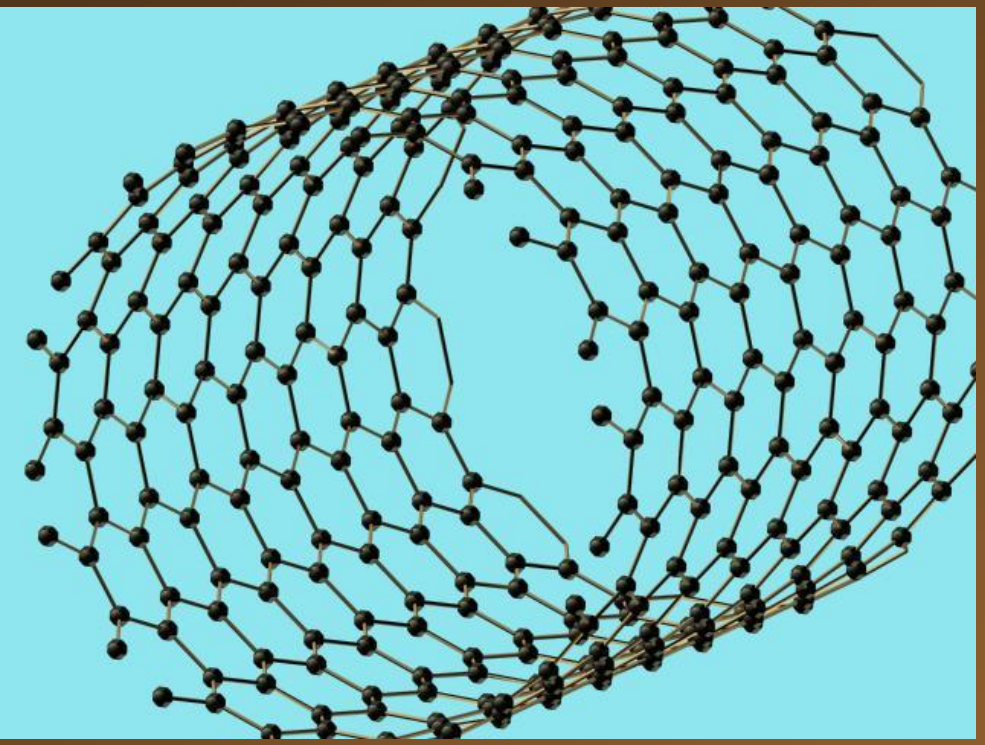


Fullerene C_{60}



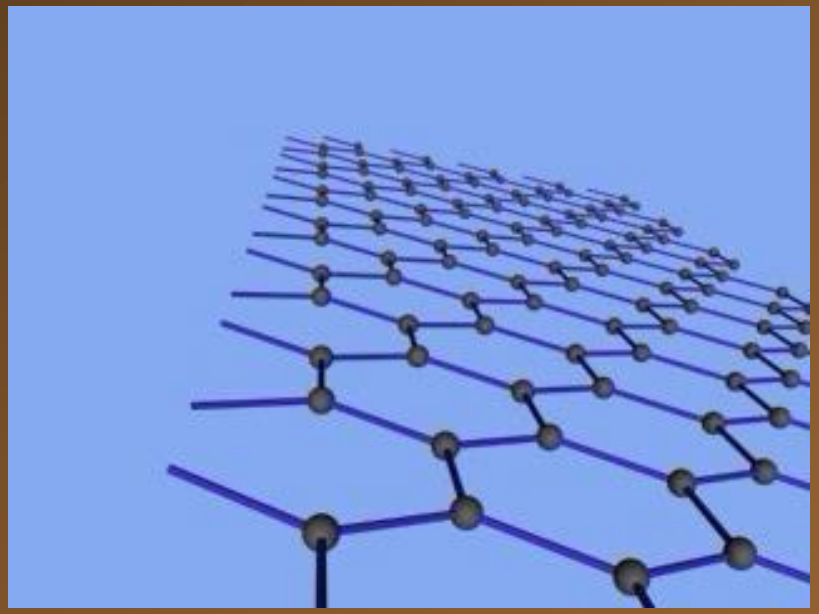
- A C_{60} molecule consists of 60 carbon atoms bonded in the nearly spherical configuration
- A C_{60} molecule or "buckyball" is about 7 angstroms in diameter (4.5 times as large as a hydrogen atom, or a bit less than a billionth of a meter)
- Visually, it is quite different from both graphite and diamond - it is a yellow powder

Nanotubes



Carbon nanotubes exist as a macro-molecule of carbon, analogous to a sheet of graphite rolled into a cylinder

Carbon Nanotube



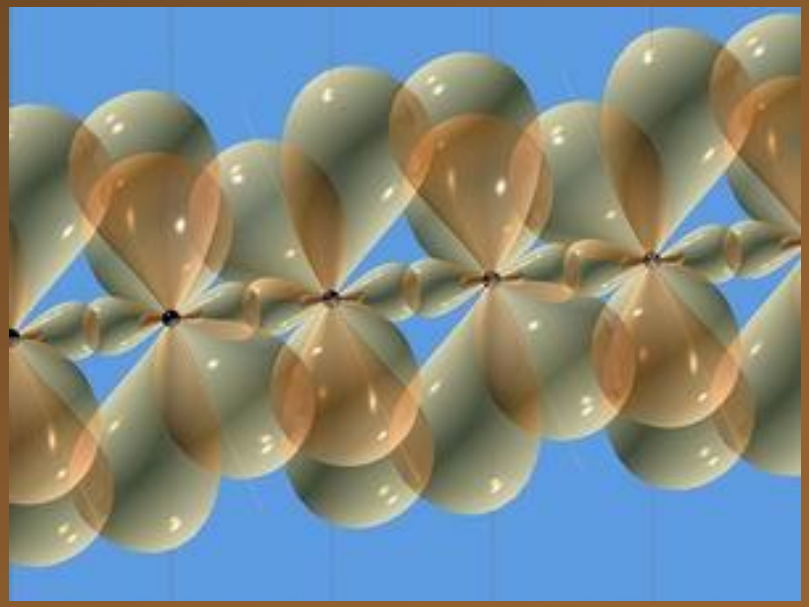
Graphite Crystallographic Plane (0001) !!!

Allotropic Forms of Carbon

Carbon: $^{12}C_6$

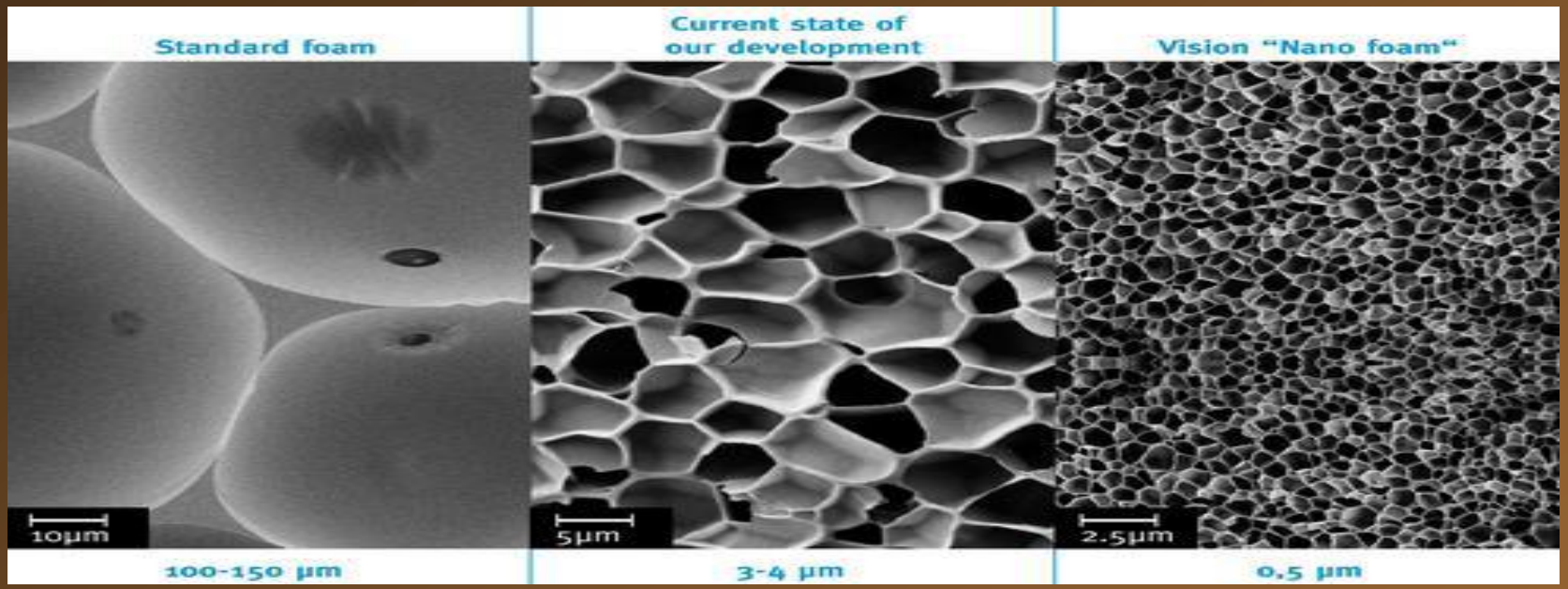
Electron Configuration: $[1s^2]$ $2s^2\ 2p^2$

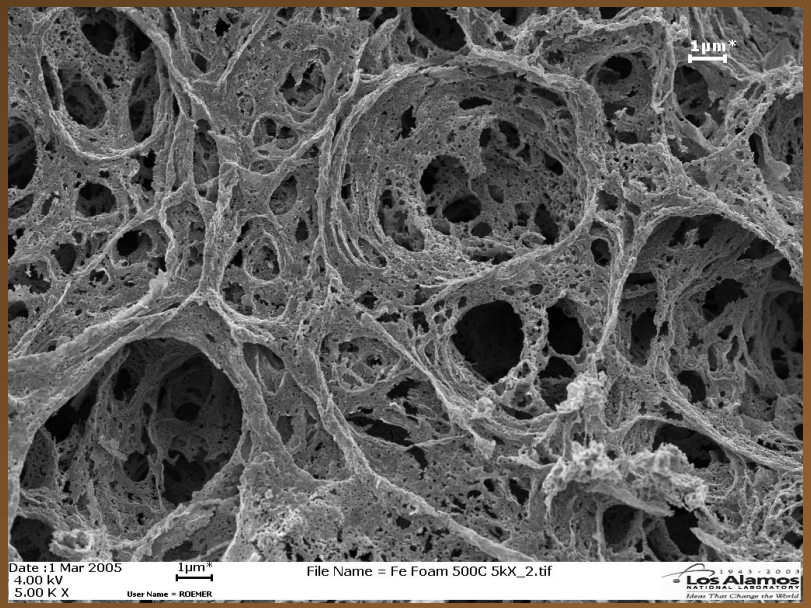
$2s^2\ 2p^2$ ⇒ $\sigma\ sp + \Pi p^2$

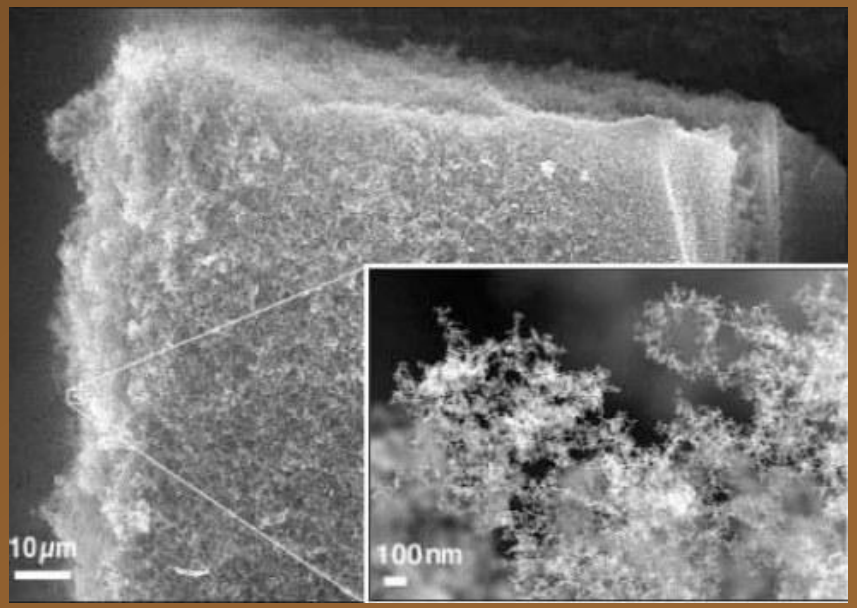


Carbyne
Carbine

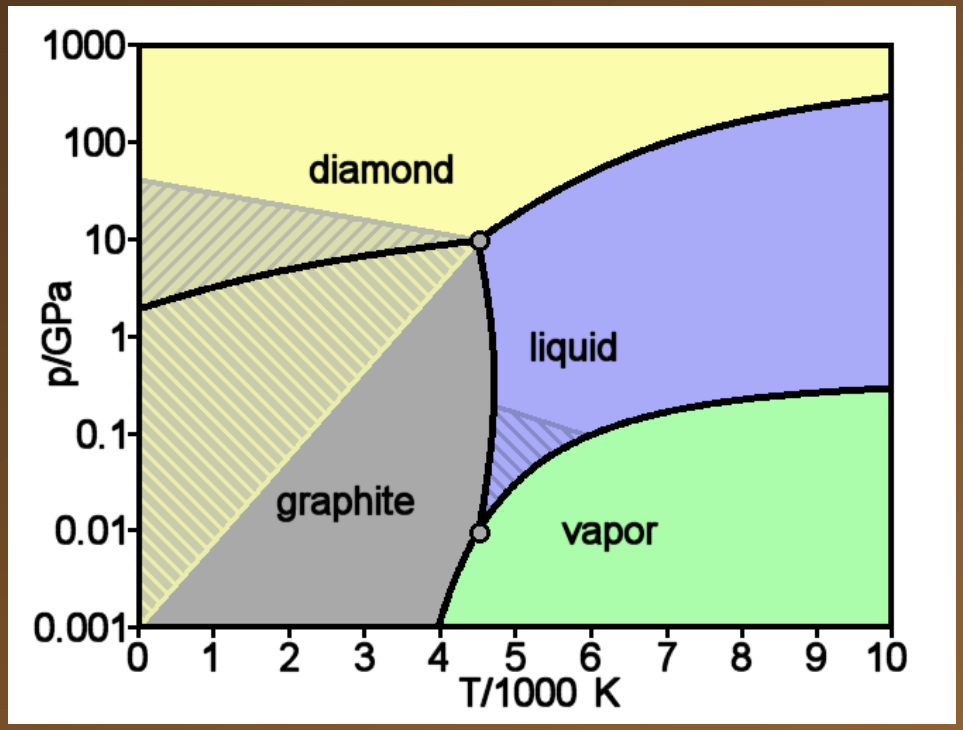
nanofoam


Standard foam
Current state of our development
Vision "Nano foam"
10µm
5µm
2.5µm
100-150 µm
3-4 µm
0.5 µm


1µm*
Date :1 Mar 2005
4.00 kV
5.00 K X
1µm*
User Name = ROEMER
File Name = Fe Foam 500C 5kX_2.tif
Los Alamos
NATIONAL LABORATORY
Ideas That Change the World


10µm
100nm

Theoretical phase diagram of carbon, which shows the state of matter for varying temperatures and pressures. The hatched regions indicate conditions under which one phase is metastable, so that two phases can coexist.

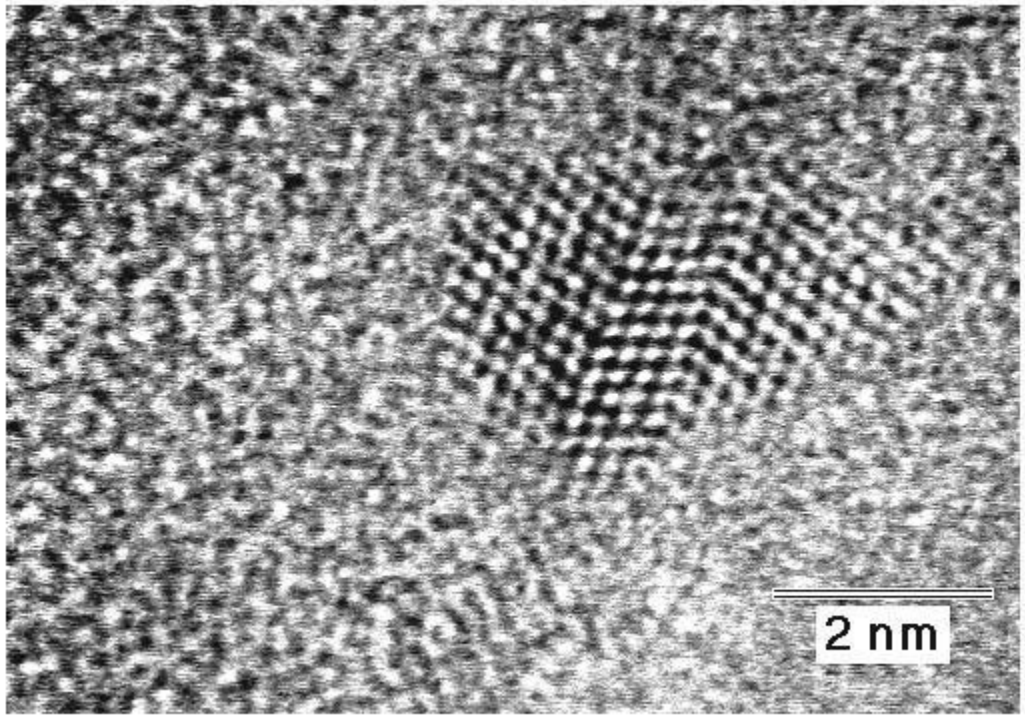


Jan M. Zazula, On Graphite Transformations at High Temperature and Pressure Induced by Absorption of the LHC Beam, 1997

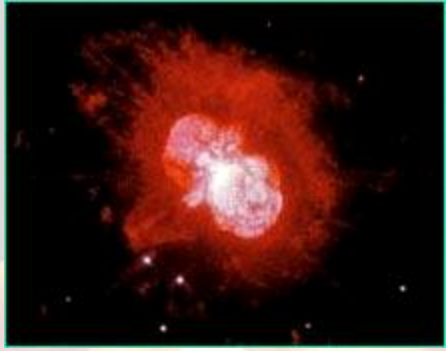
http://lbruno.home.cern.ch/lbruno/documents/Bibliography/LHC_Note_78.pdf

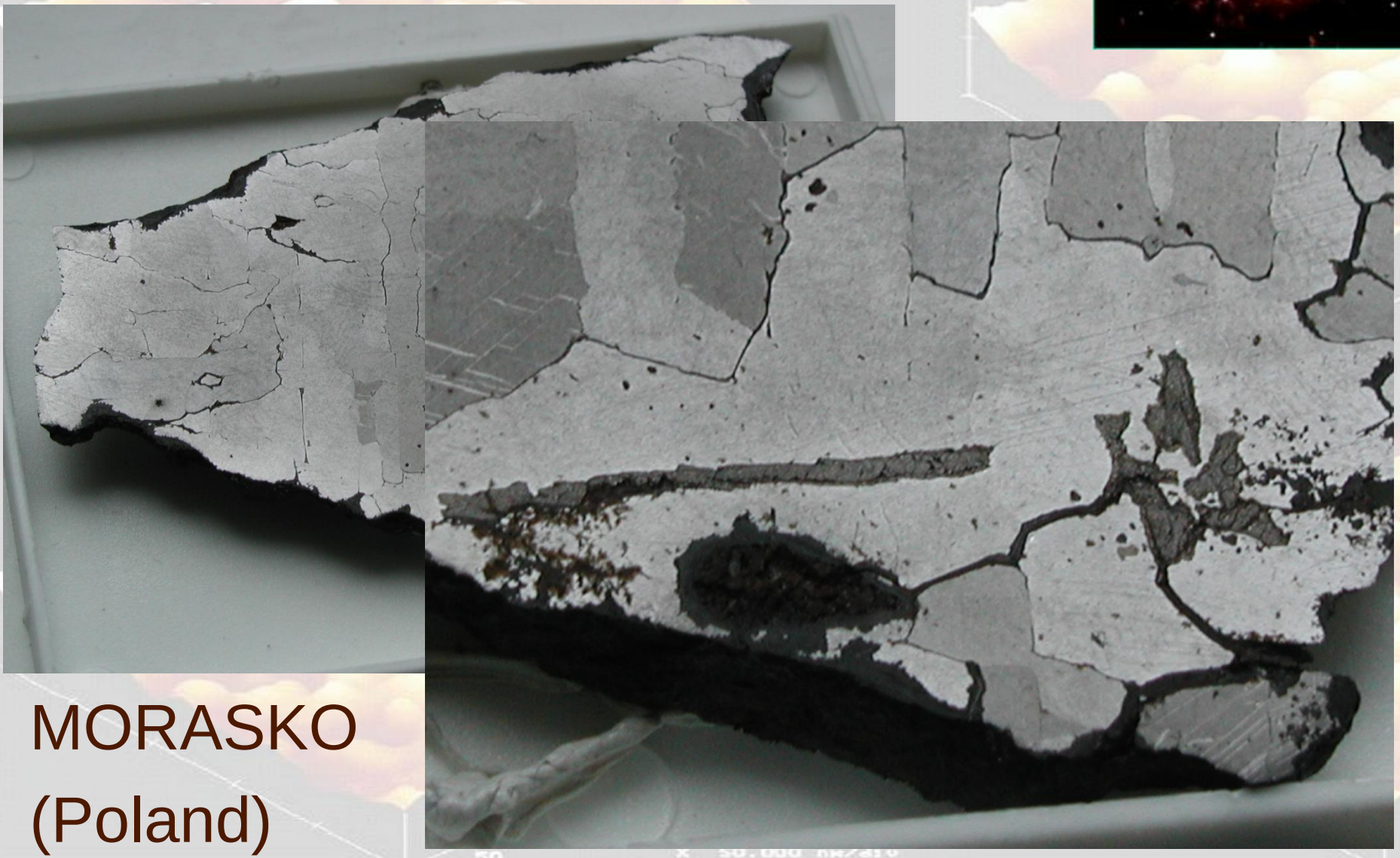
Carbon Synthesis

The SEM micrograph of Diamond Powder from the Space



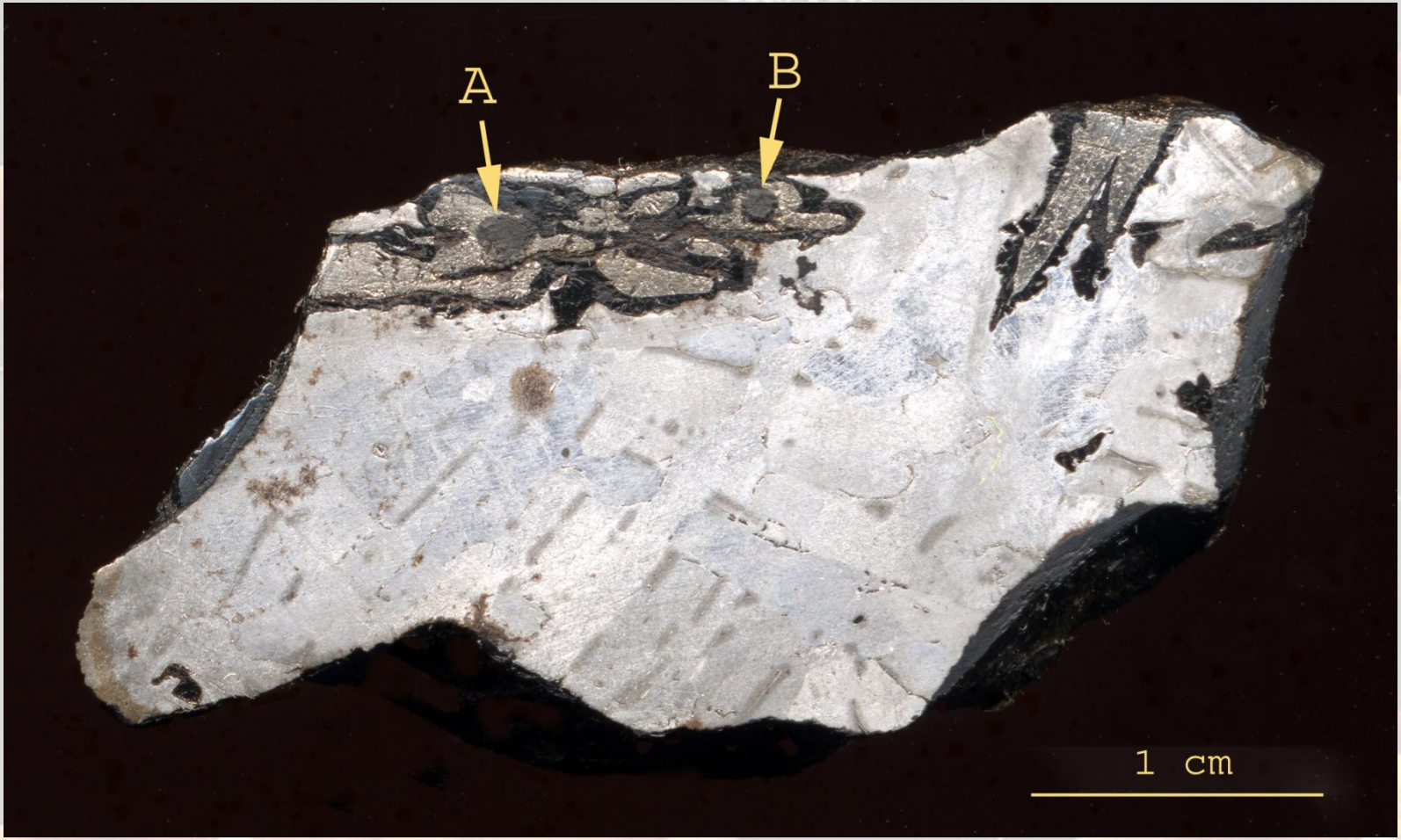
Diamonds from the space





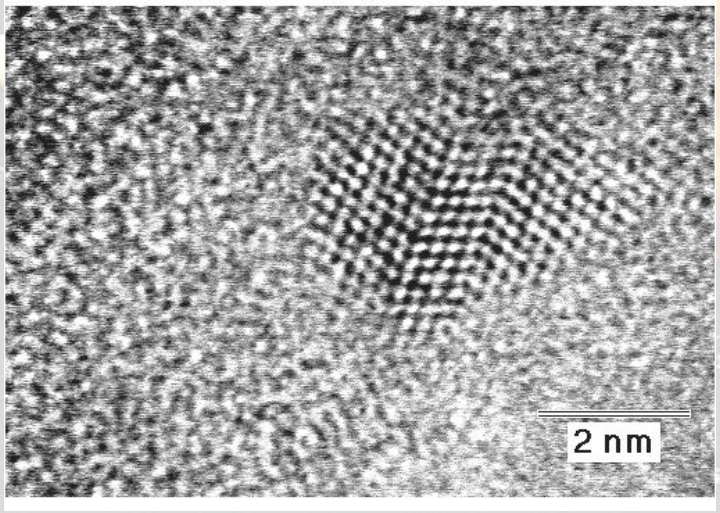
MORASKO

(Poland)

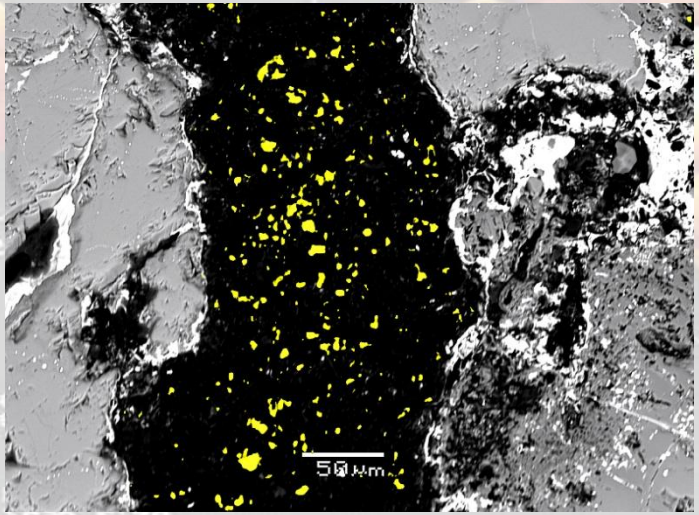


Canyon Diablo with diamonds

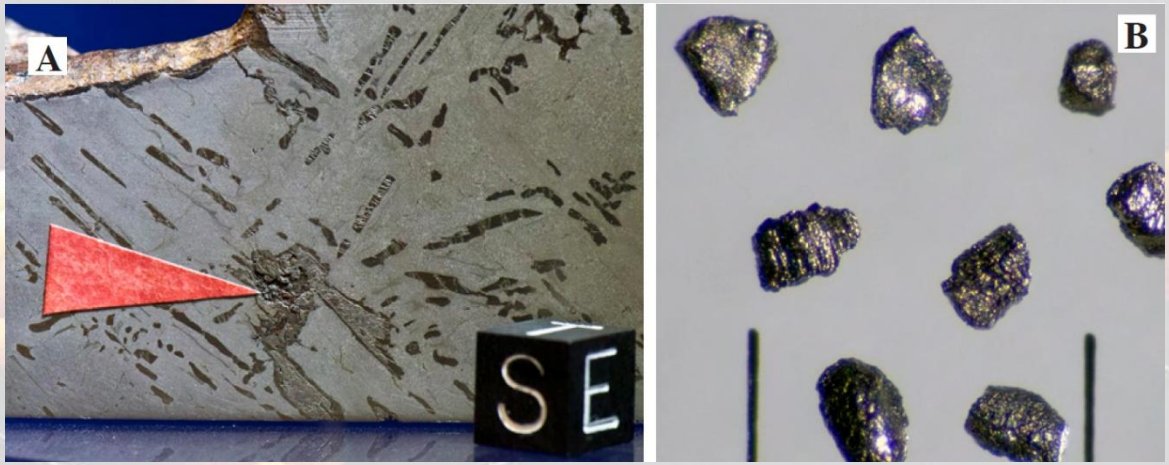
Diamonds from the Space



Nanodiamond from Allende



Micro-diamonds from Ureilit

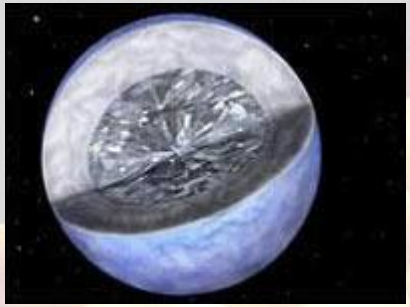


Diamonds from Canyon Diablo

Lucy

- At a distance of 50 light years from Earth in the constellation Centaurus is a star of astronomical weighing 10 carats quadrillion. It is a giant lump of crystallized carbon (diamond) with a diameter of 1500 km.

BPM 37093 cool white dwarf



According to American astronomers at the Harvard-Smithsonian Centre for Astrophysics, a white dwarf star in the constellation of Centaurus, next to the Southern Cross, has been found to have a 3000-kilometre-wide core of crystallised carbon, or diamond.

It weighs 2.27 thousand trillion trillion tonnes - that's 10 billion trillion trillion carats, or a 1 followed by 34 zeroes. The biggest earthly jewel is one of the British crown jewels, the 530-carat Star of Africa.

However, this cosmic jewel is hidden beneath a layer of hydrogen and helium gases, with the diamond core making up between 50 and 90 per cent of its mass. "It's the mother of all diamonds," said astronomer Travis Metcalfe, who led the team of researchers that studied the star.

"Some people refer to it as Lucy, in a tribute to the Beatles song *Lucy in the Sky with Diamonds*."

Known officially as BPM 37093, the star confirms a theory, first raised in the early 1960s, that cool white dwarfs should have a diamond core.

A white dwarf is what small stars, those up to about the size of the sun, turn into when they run out of nuclear fuel and die.

The intense pressures at the heart of such dead stars compress the carbon into diamond.

But confirming this theory has only been possible recently.

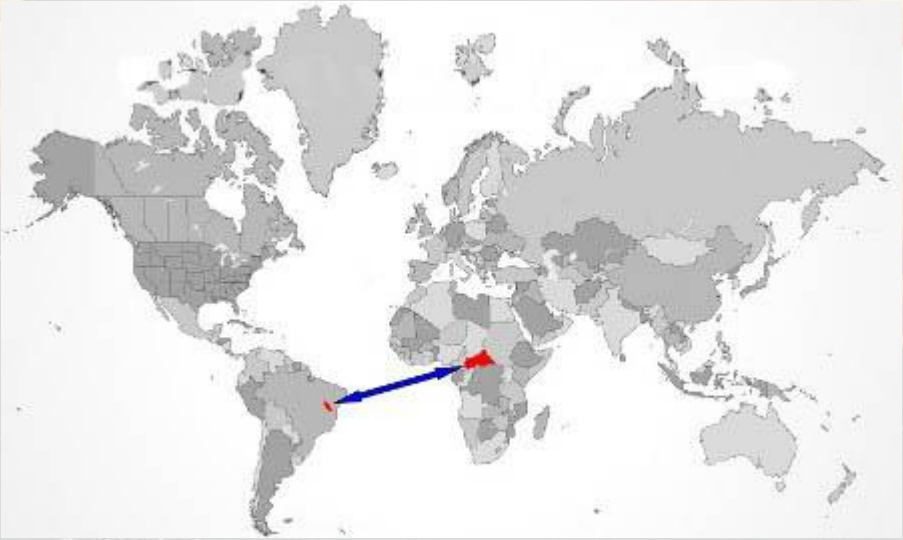
Lucy "pulsates", which means its light fluctuates at regular intervals. "By measuring these pulsations, we were able to study the hidden interior of the white dwarf, just like seismograph measurements of earthquakes allow geologists to study the interior of the Earth," Dr Metcalfe said.

"We figured that the carbon interior of this white dwarf has solidified to form the galaxy's largest diamond.„

http://www.theage.com.au/articles/2004/02/17/1076779973101.html

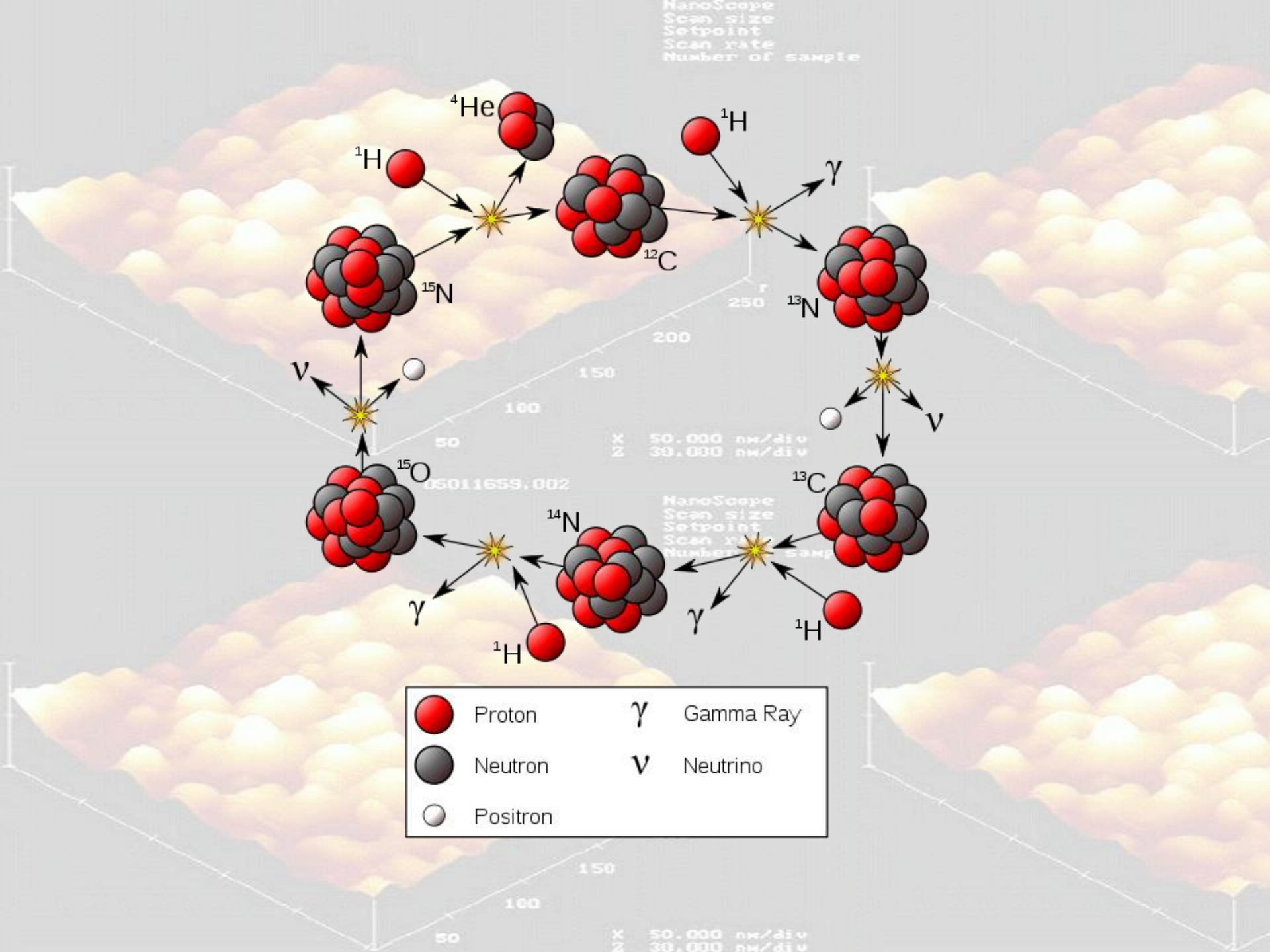
Diamonds from the Space

Black Diamonds Carbonado

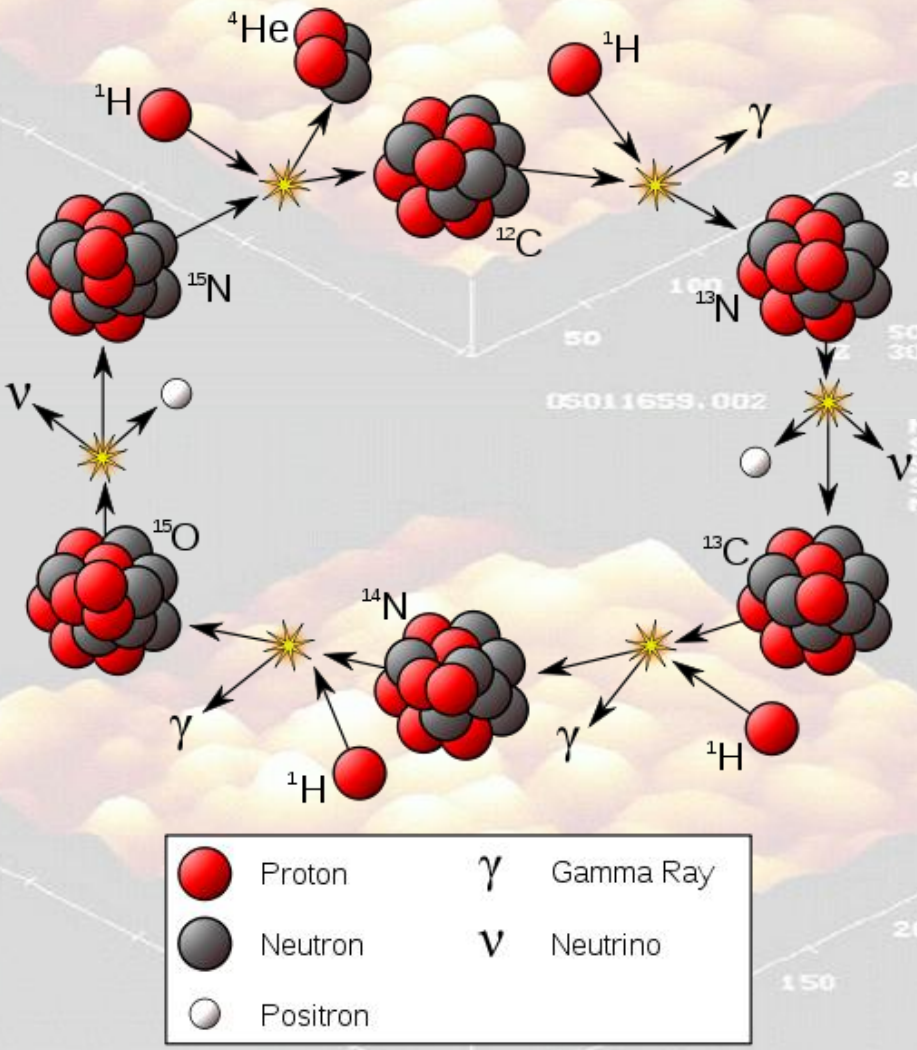


The occurence of CARBONADO

Carbonado - black diamonds, occurring in only two regions on earth in alluvial deposits (Africa and South America). Age them date back to the 3 billion years. Were probably the result of the supernova explosion (Cool White Dwarf???) and its chemical composition reveals similarity to cosmic dust.


^{4}He
^{1}H
^{1}H
^{12}C
γ
^{15}N
^{13}N
ν
ν
^{15}O
^{13}C
^{14}N
γ
γ
^{1}H
^{1}H
Proton
Neutron
Positron
γ Gamma Ray
ν Neutrino

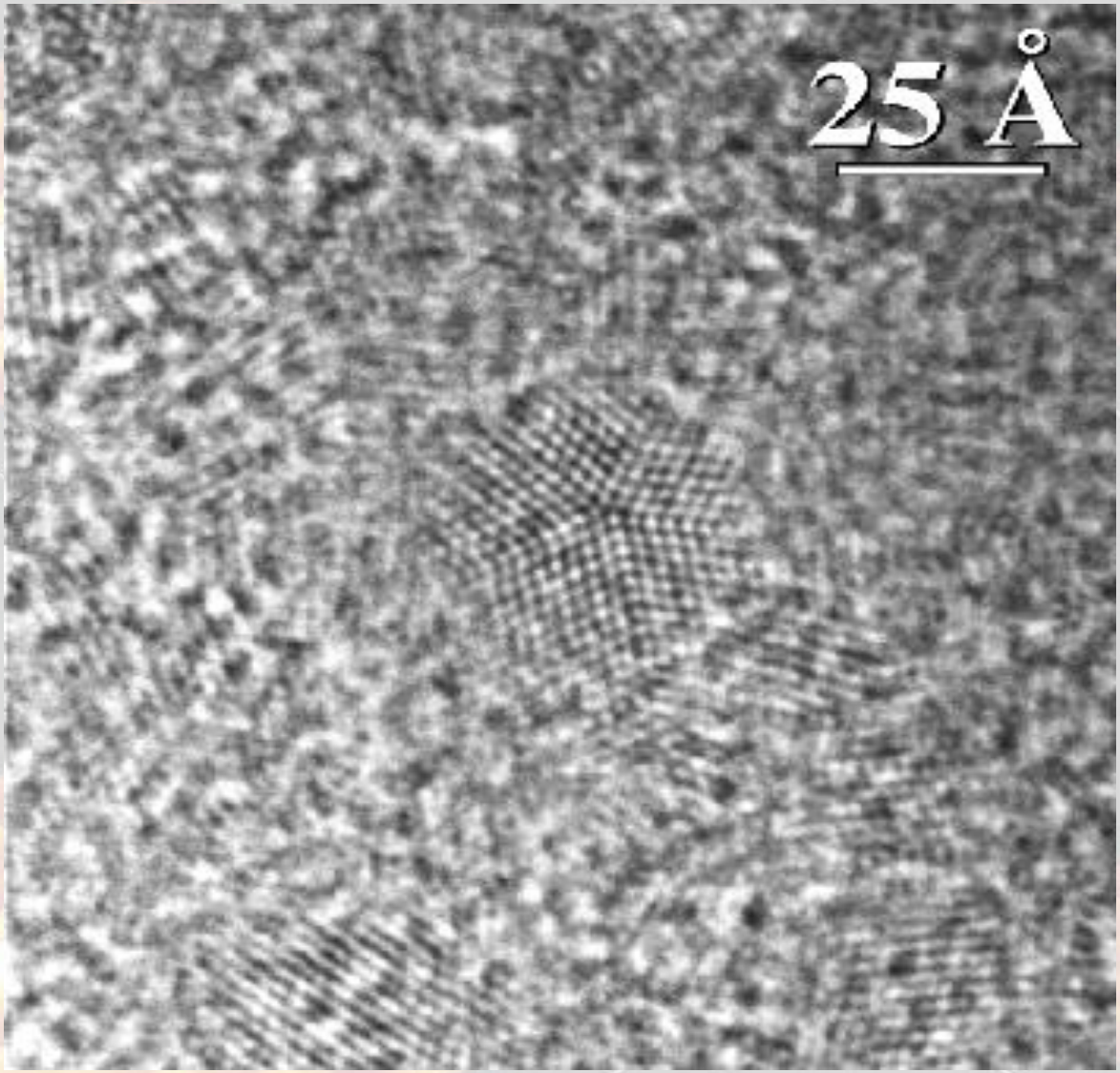
CNO cycle



The CNO cycle (for carbon–nitrogen–oxygen) is one of two sets of fusion reactions by which stars convert hydrogen to helium, the other being the proton–proton chain. Theoretical models show that the CNO cycle is the dominant source of energy in stars more massive than about 1.3 times the mass of the Sun.

The CNO process was independently proposed by Carl von Weizsäcker and Hans Bethe in 1938 and 1939, respectively.

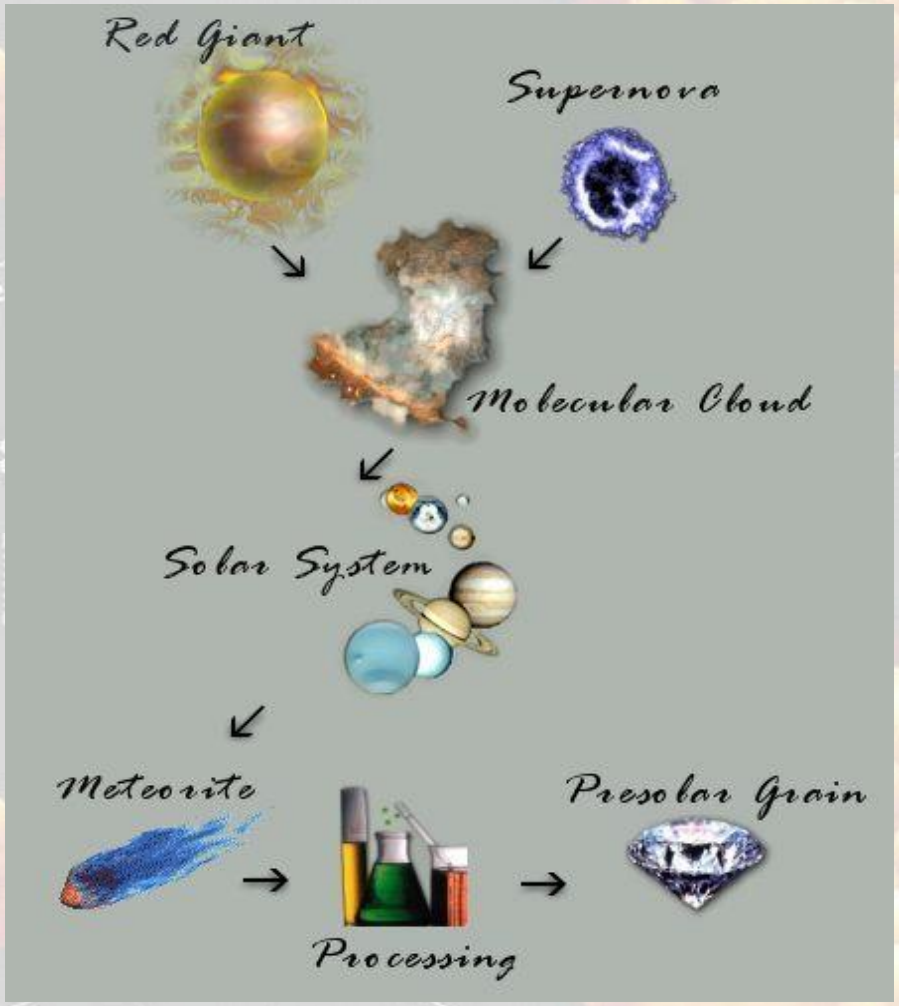
http://en.wikipedia.org/wiki/CNO_cycle



Presolar diamonds

A. Karczemska: NANODIAM, PWN, 2006

Diamonds from the Space

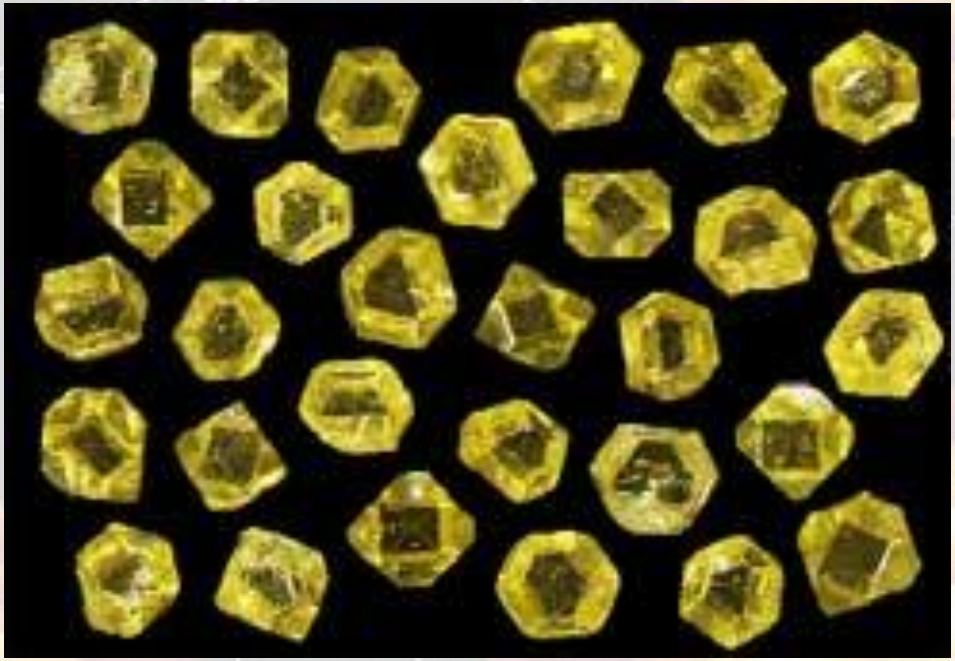


Supernova
Cool White Dwarf
Red Giant

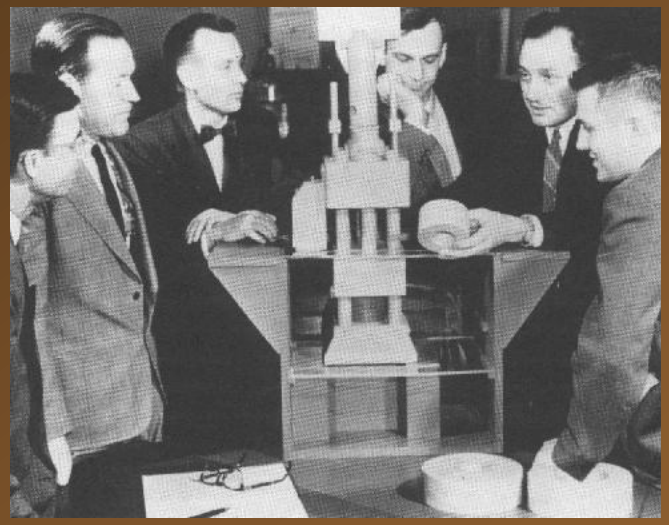
Diamond Crystals

from Erth

from Laboratory



The original photo of
General Electric Diamond Team:
F.P.Bundy, H.M.Strong, H.T.Hall,
R.H.Wentorf, A.J.Nerad, J.E.Cheney

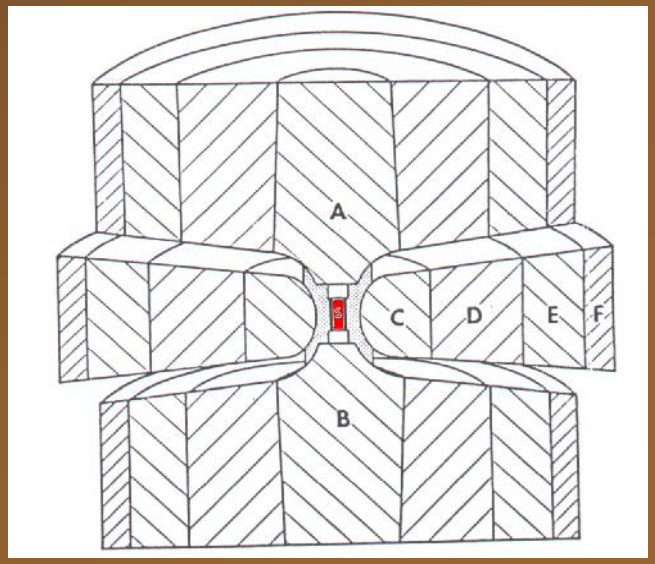


Diamond Synthesis

- High Temperature & High Pressure Conditions

The Hall Belt;

the dotted region surrounding the sample S (red) is the pyrolitic gasket



Diamond wafers

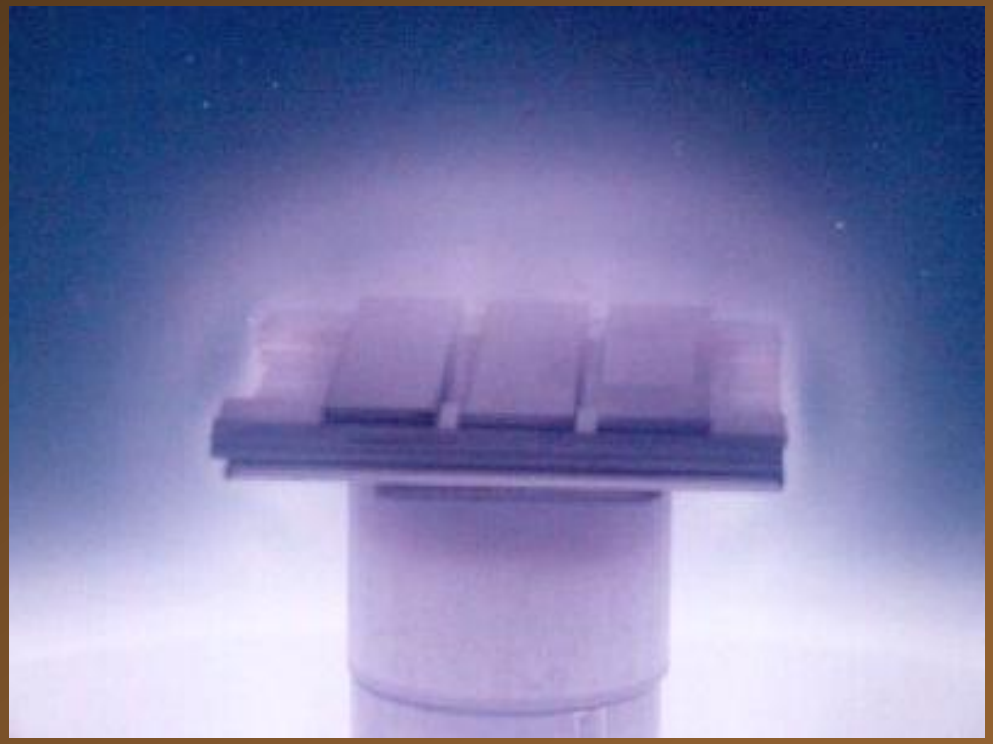
- DIAFILM

Artificial diamond wafers

- **Crystals of diameters about 1 cm**
- **Very high termal conductivity!**
- **Small internal stressess**

De Beers Industrial Diamonds Group

Diamond Synthesis



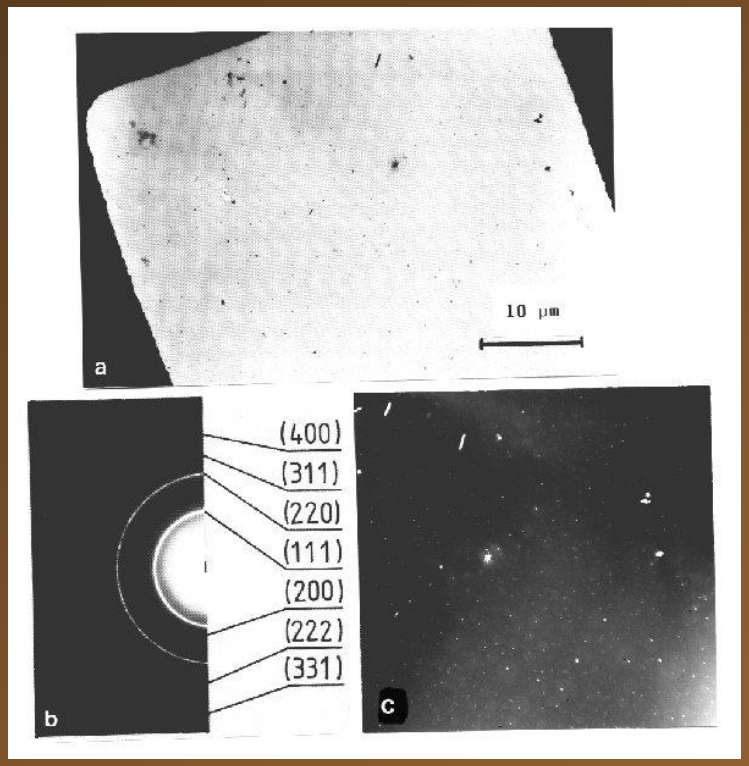
- Special Conditions under Reduced Pressure:

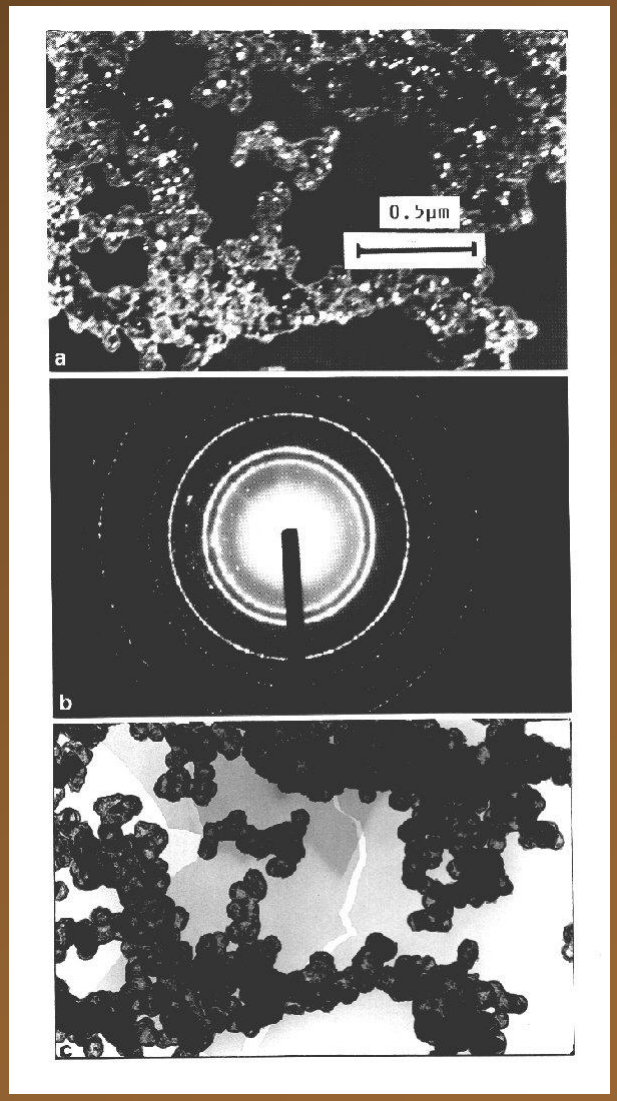
  σsp^3 hybridisation

  - Very Important Role of Electrons
  - Nucleation on Carbon Ions
  - Role of Hydrogen

The σsp^3 hybridisation in the gas phase

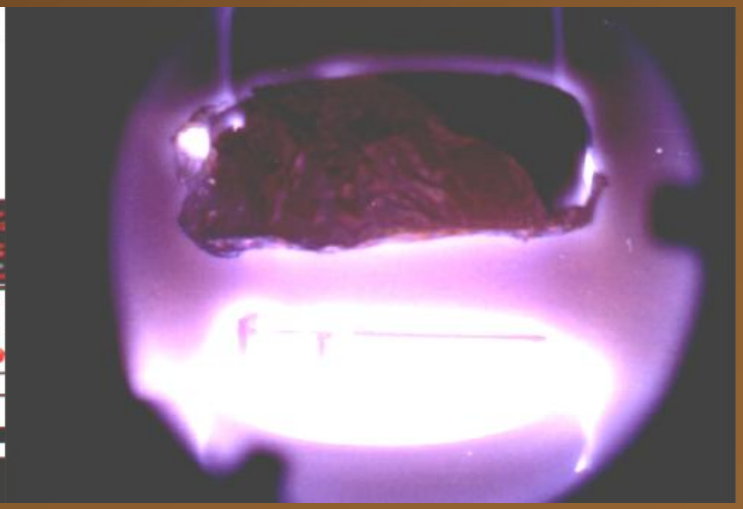
- Very Important Role of Electrons
- Nucleation on Carbon Ions
- Role of Hydrogen





Synthesis of Diamond-like Carbon & Nanocrystalline Diamond Coatings

Radio Frequency Plasma Activated Chemical Vapour Deposition
RF PA CVD



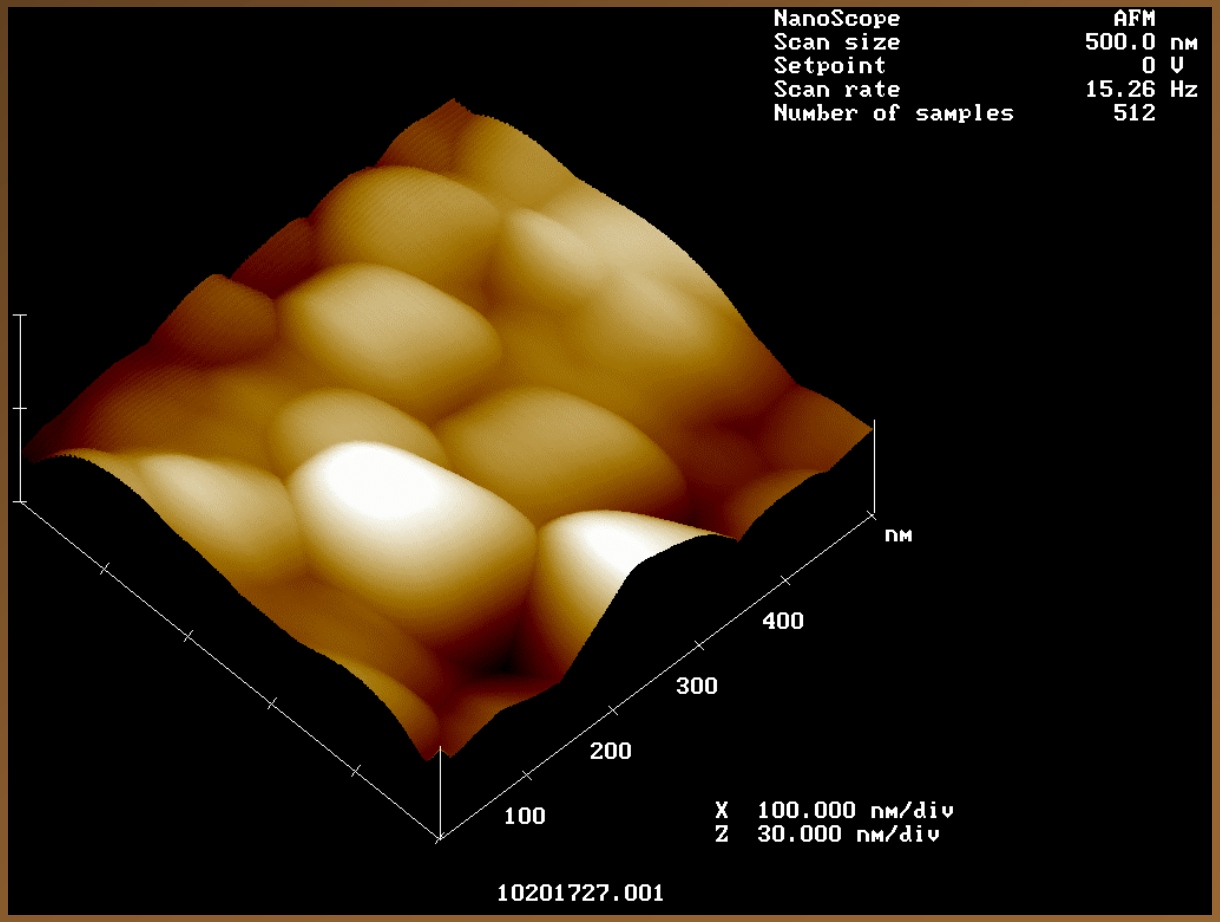
- S.Mitura, E.Mitura, A.Mitura: *"Manufacturing of amorphous carbon layers by RF dense plasma"*; **Diamond Rel. Materials, 4**(1995)302.
- S.Mitura, A.Mitura, P.Niedzielski, P.Couvrat: *„Nanocrystalline Diamond Coatings"*, **Journal of Chaos, Solitons and Fractals** (Special Issue), 10(12) (1999) 2165..

Carbon - Properties

AFM picture of DLC

DLC coating;

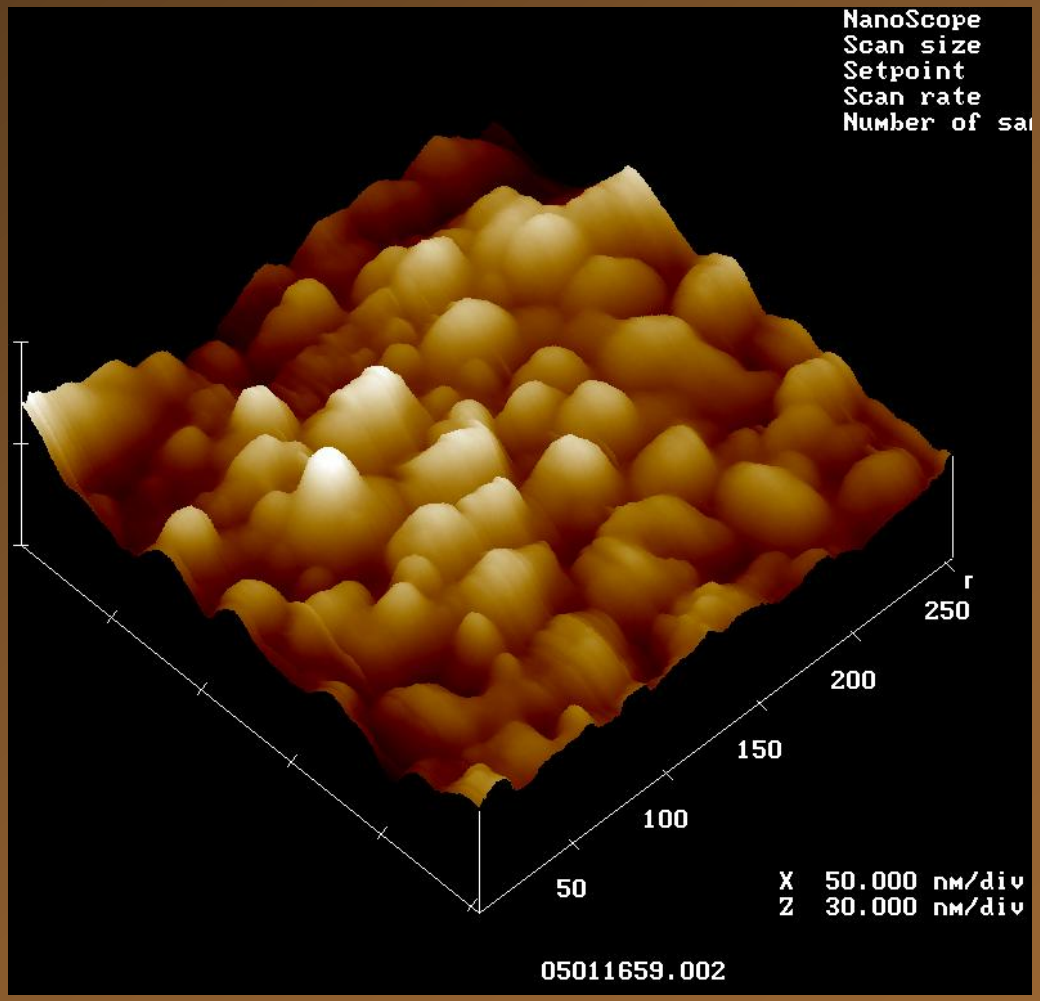
- about 3000HV
- ca 60% diamond
- ca 30% graphite
- ca 10% carbines



AFM picture of NCD

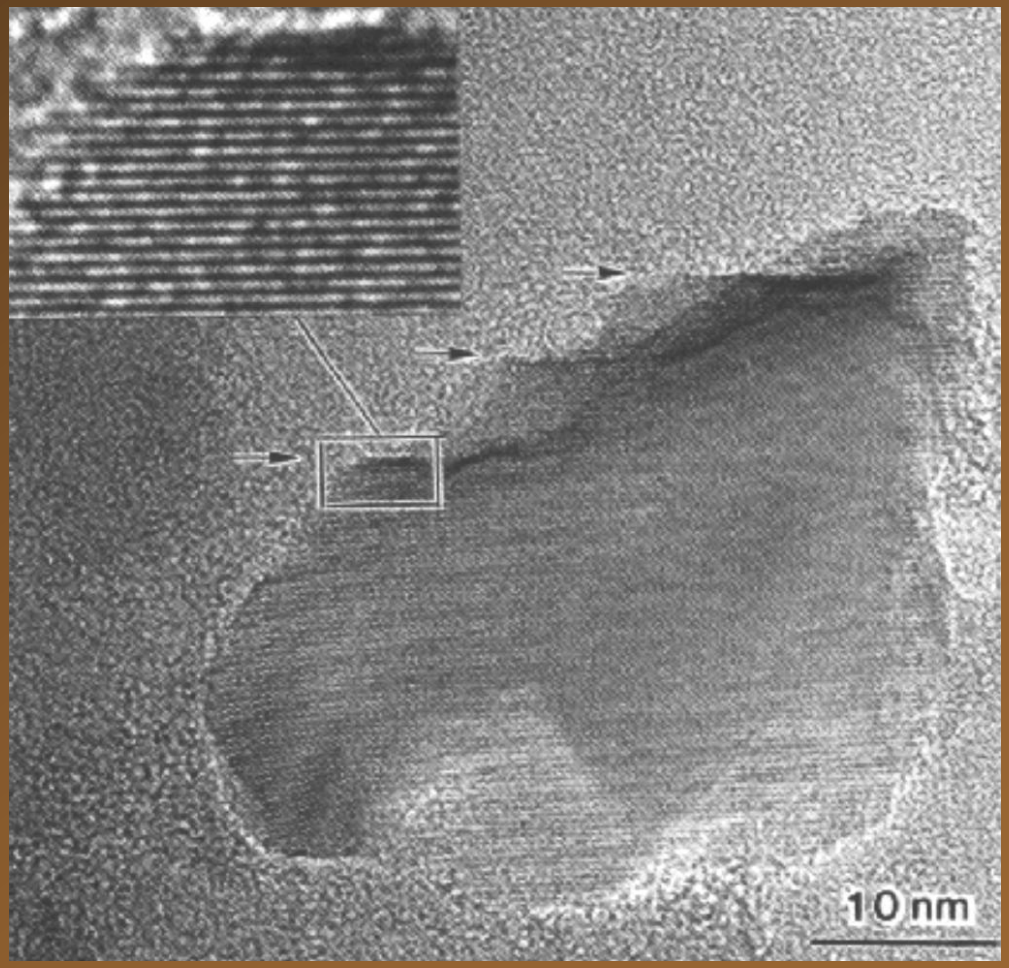
NCD coating;

- about 95 GPa
- ca 95% diamond
- ca 03% graphite
- carbines
- fullerens
- nanotubes?



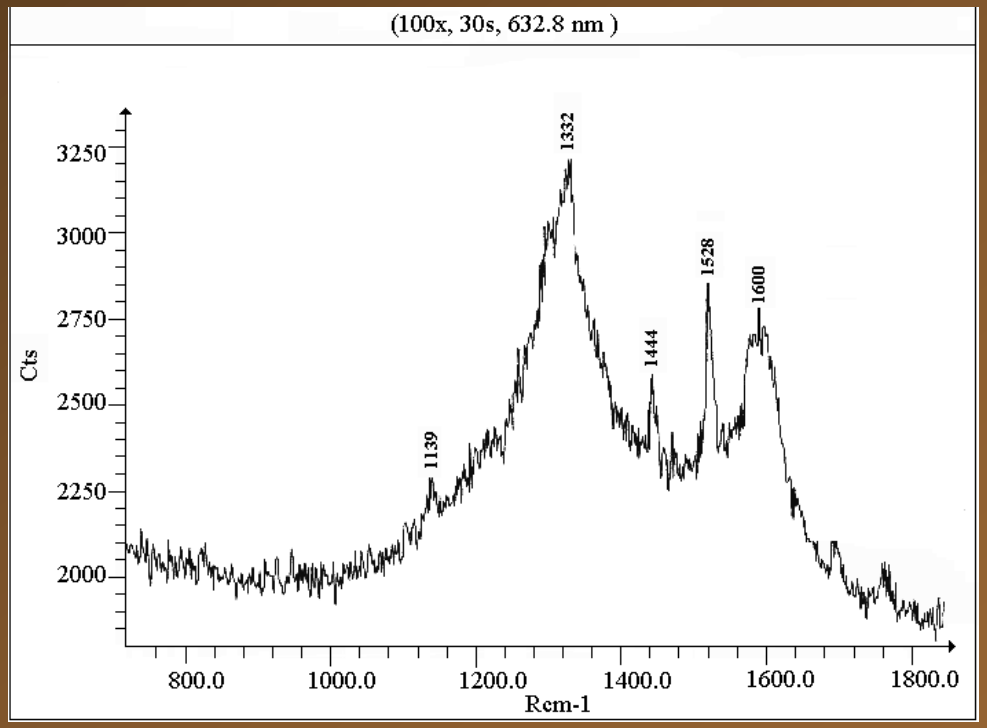
NCD

High Resolution
Transmition
Electron Micrograph
(HRTEM)
of
NANO-DIAMOND
Particle



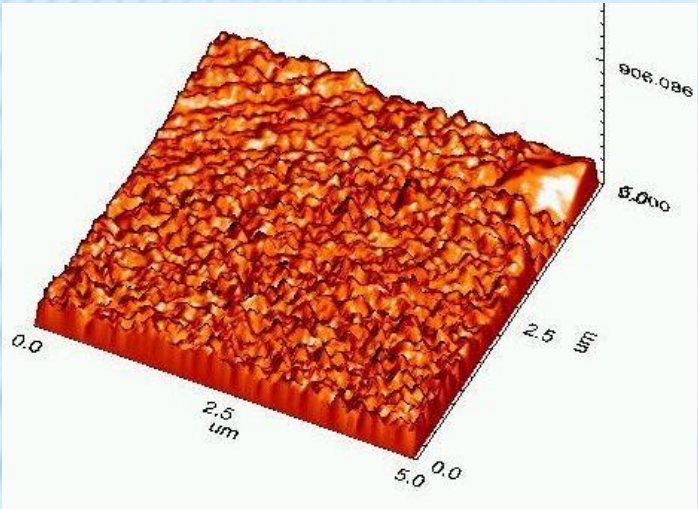
Raman Spectra of NCD

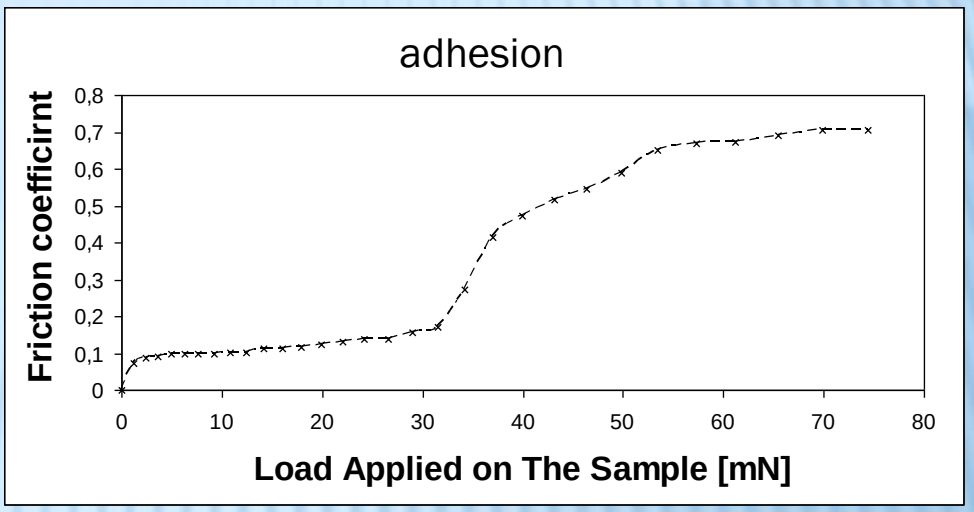
Peak [cm^{-1}]	Phase	Bond
1139	NCD	σsp^3
1332	Diamond	σsp^3
1444	NCD	σsp^3
1528	Carbine	sp^1
1600	NCG	σsp^2

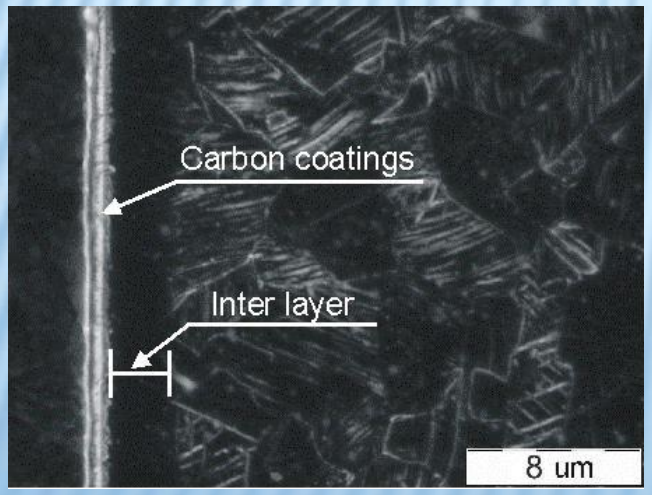


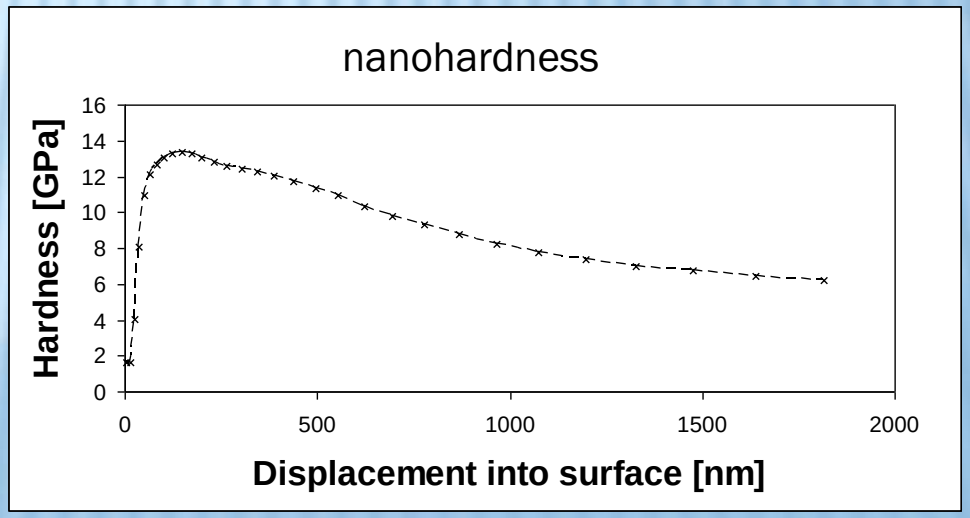
S.Mitura, A.Mitura, P.Niedzielski, P.Couvrat: *"Nanocrystalline Diamond Coatings"*, in: S.Mitura (Editor): **NANOMATERIALS**, Pergamon Press, Elsevier Science, Oxford, 2000.

WŁAŚCIWOŚCI MECHANICZNE WARSTWY







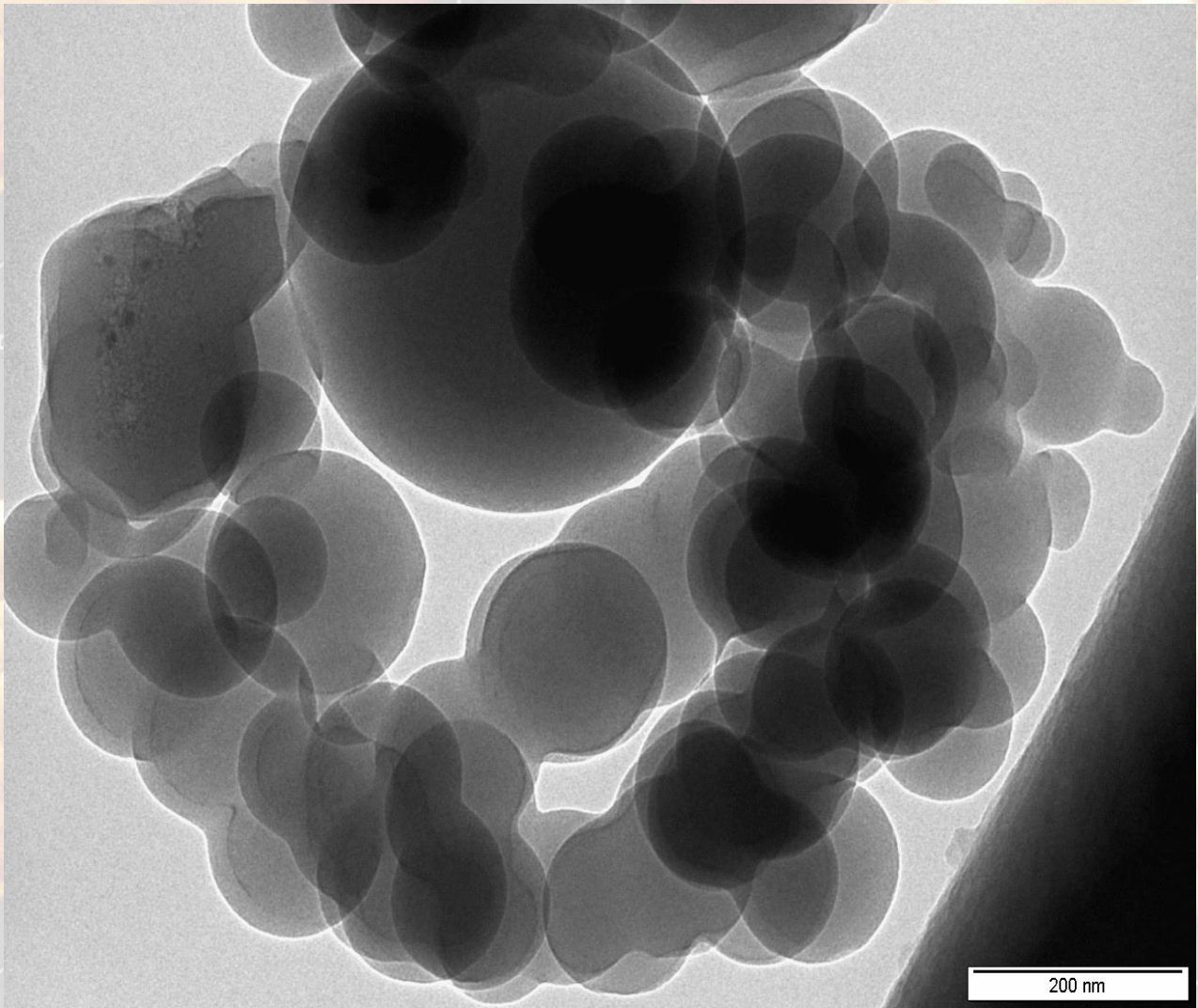


Bioactivity of diamond

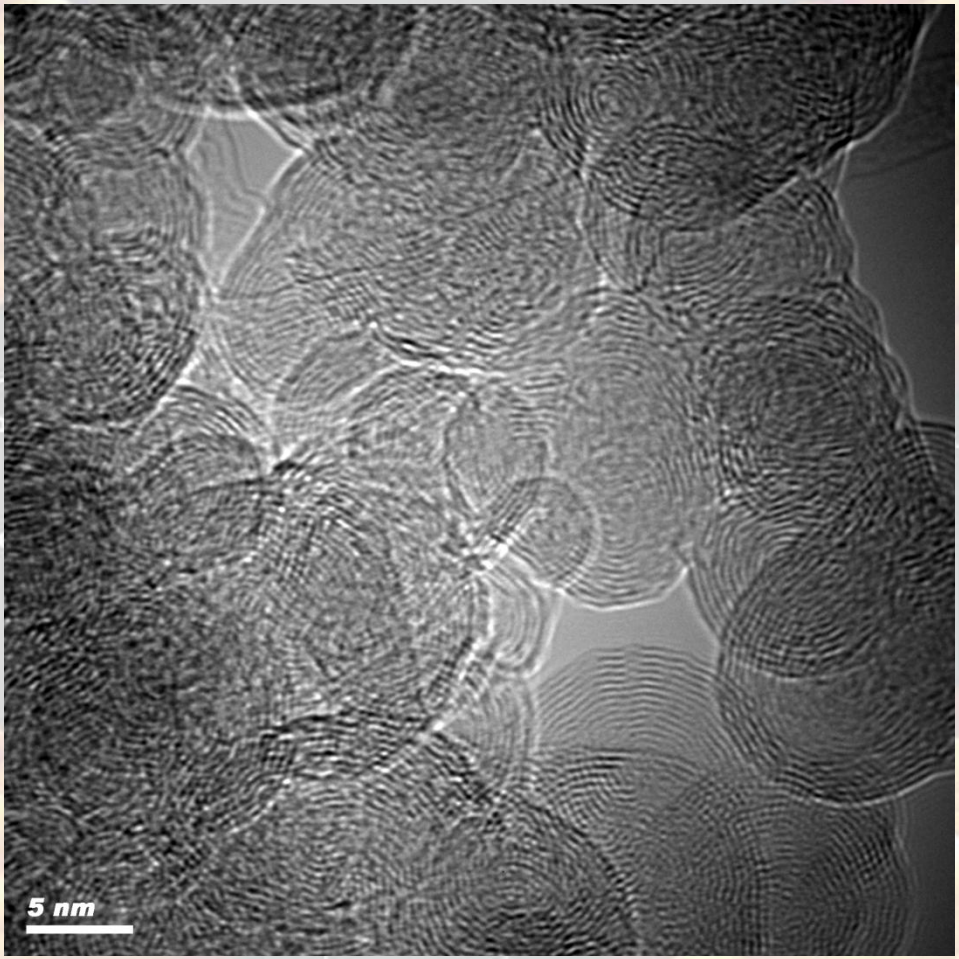
- K.Mitura, S.Mitura, *Influence of diamond powder particles on human gene expression*, in: V.Zhitomirsky and A.Raveh(eds.), Proc. The Internat. Conf. On Superhard Coatings, Kibbutz Ein-Gedi, Israel, 27 Feb.-01 March 2006, Surface Coatings Technology, 201 (2007) 6063.

NANODIAMOND PARTICLES – RF/PACVD METHOD – HR TEM

K.Mitura , HR TEM examinations of nanodiamond particles for biomedical applications, Journal of Achievements Materials and Manufacturing Engeenering, 37, (2009), 317-322.



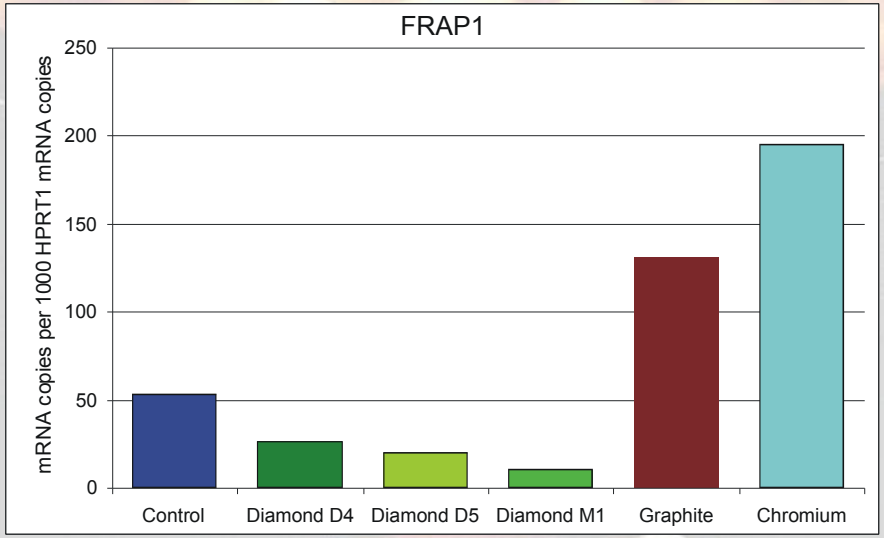
NANO-DIAMOND Particle HR TEM – detonation method

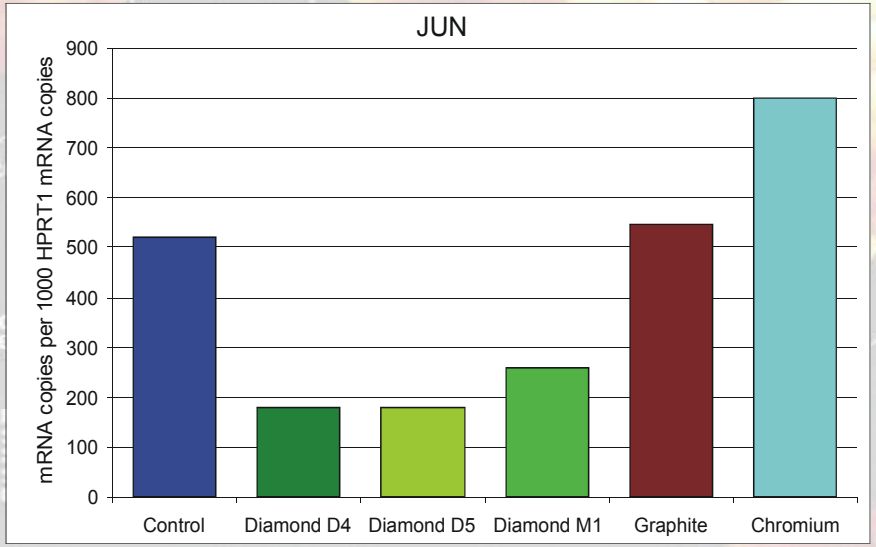


K.Mitura , HR TEM examinations of nanodiamond particles for biomedical applications, Journal of Achievements and Materials and Manufacturing Engeenering, 37, (2009), 317-322.

Molecular level

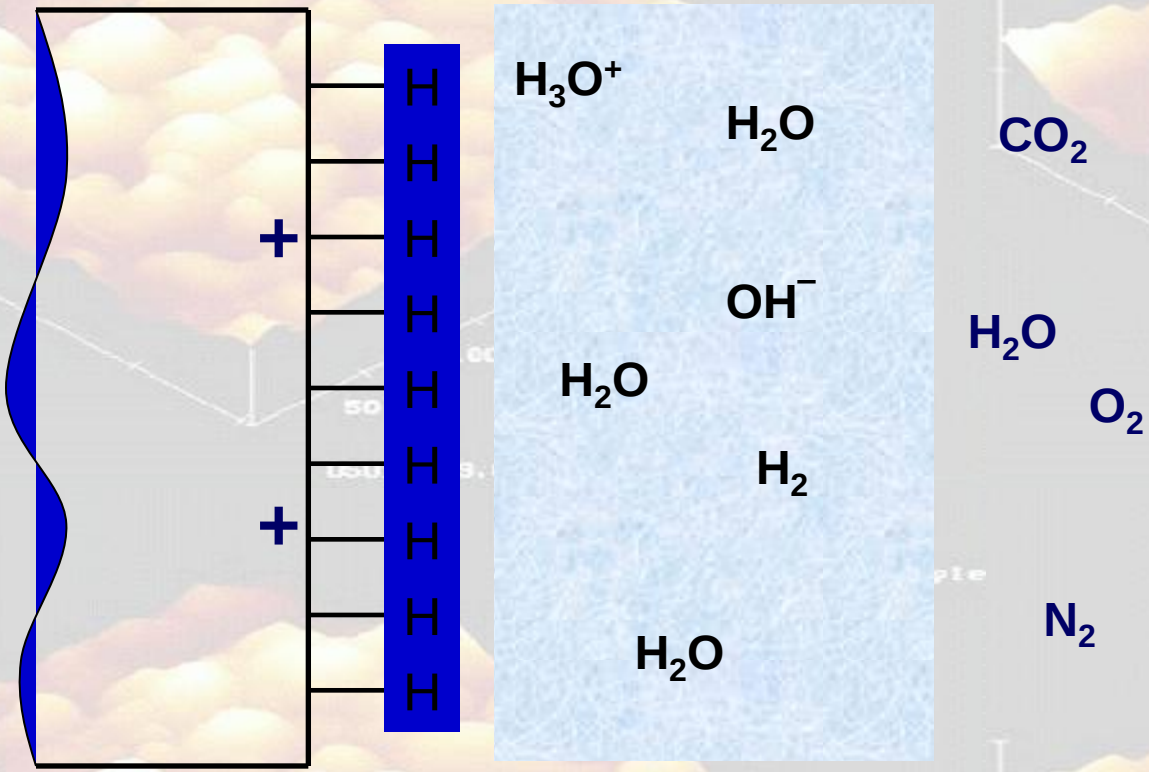
Determination of nanodiamonds bioactivity





Gene name	Encoded protein	PCR product length	Main inducing stimulus
JUN	Jun activation domain binding protein	118	Cellular stress
FRAP1	FKBP-rapamycin associated protein 1	141	Genotoxic stress

K.Mitura, S.Mitura, *Influence of diamond powder particles on human gene expression*, in: V.Zhitomirsky and A.Raveh(eds.), Proc. The Internat. Conf. On Superhard Coatings, Kibbutz Ein-Gedi, Israel, 27 Feb.-01 March 2006, Surface Coatings Technology, 201 (2007) 6063.



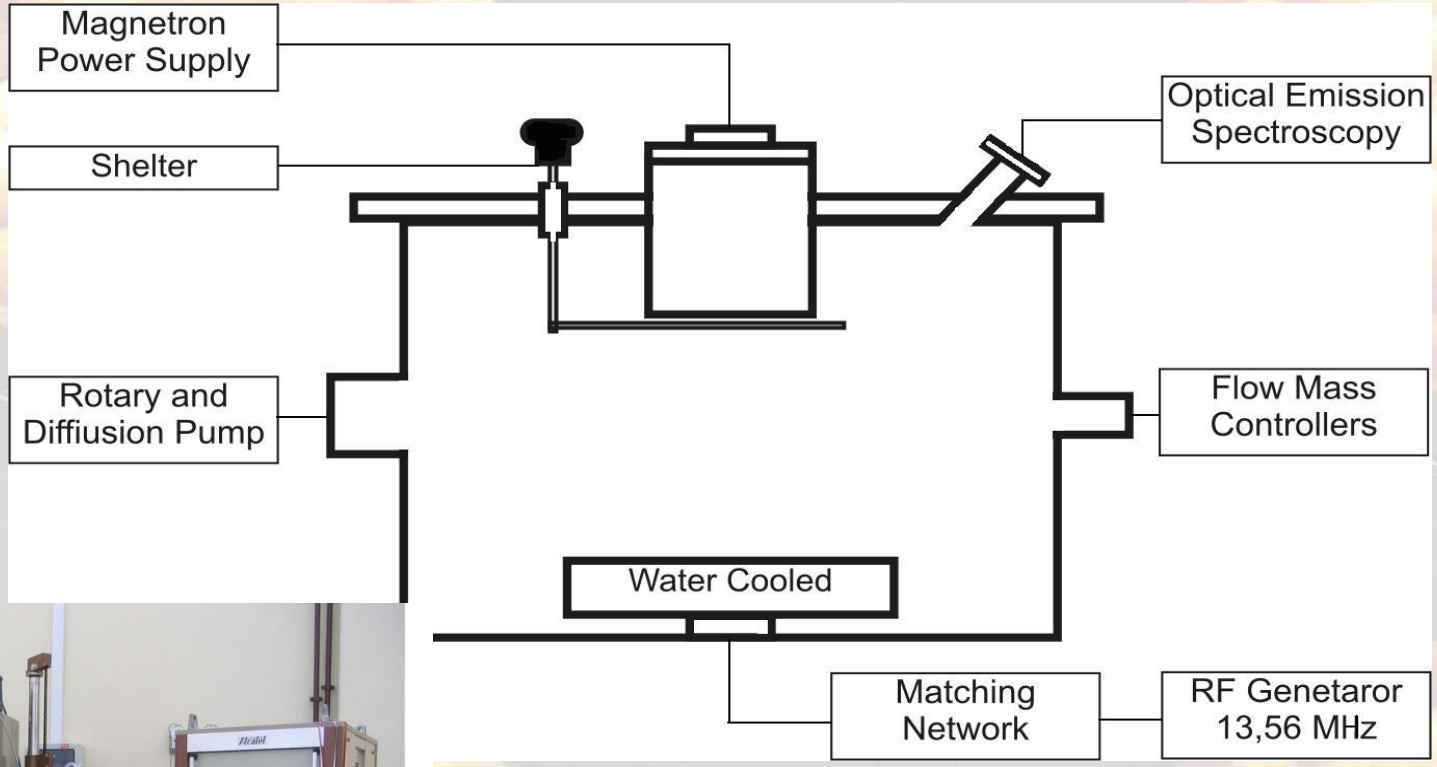
Ristein J., Riedel M., Mantel B. F., Stammler M., Ley L.: *„Surface doping: a special feature of diamond"*; **Journal of Physics: Condensed Matter**; 13(2001) 8979-8987

Allergic examinations – patch tests

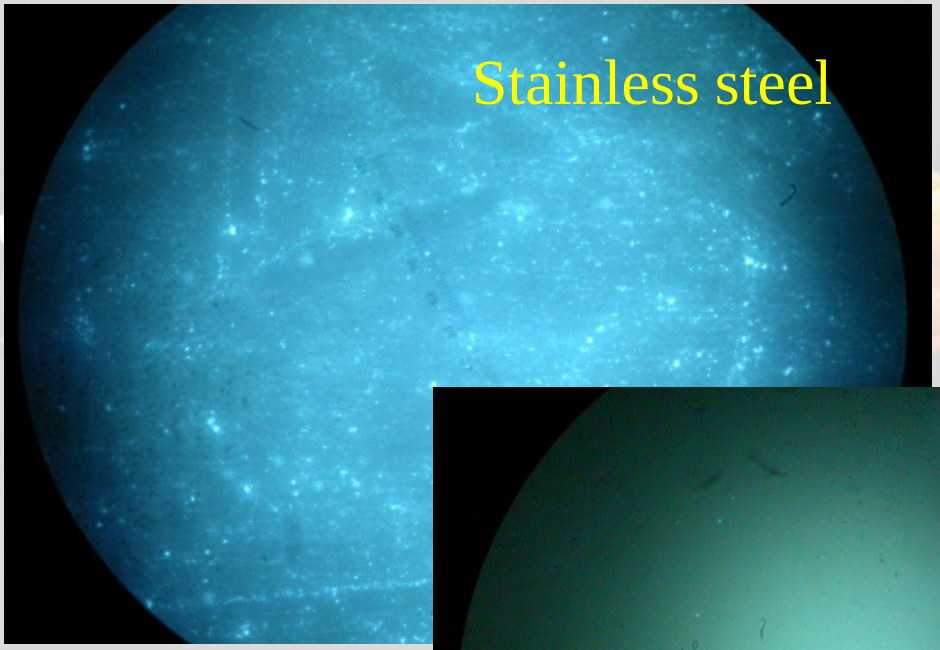
„patch test”

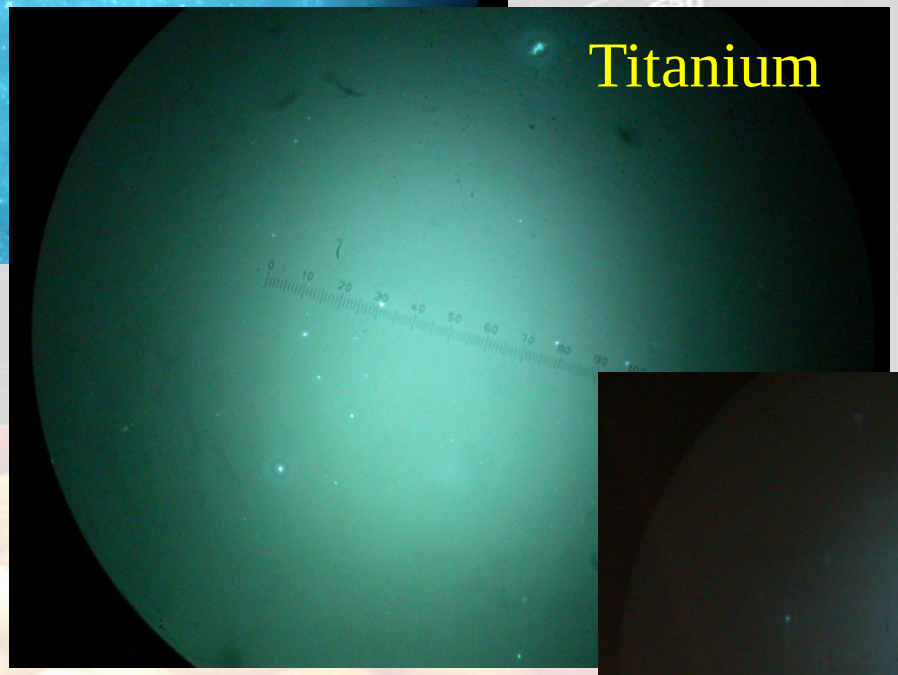
S. Mitura, P. Niedzielski, B. Walkowiak (Eds.)
NANODIAM, New technologies for medical applications: studying and production of carbon surfaces allowing for controllable bioactivity.
PWN, Warsaw 2006

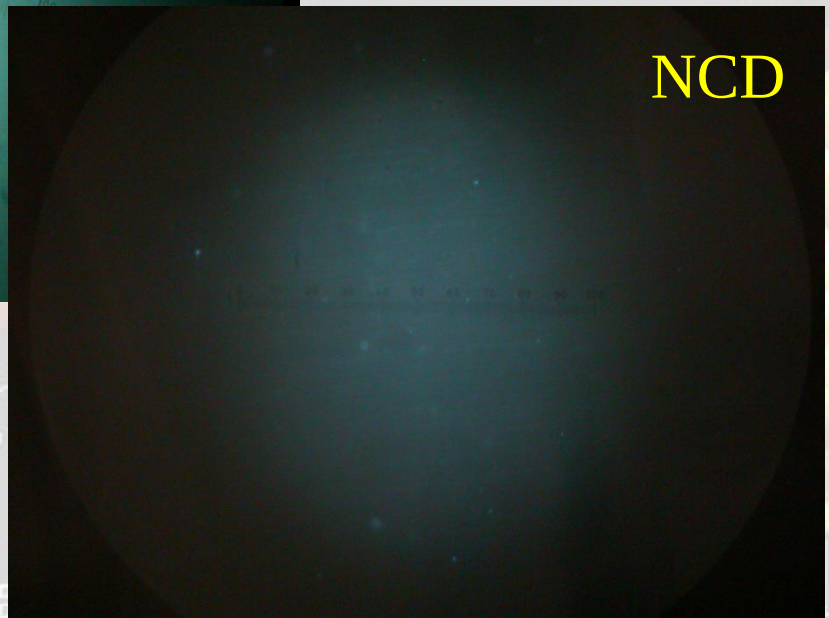
RF PACVD system with magnetron sputtering



E.coli cells found at the surfaces:







Each bright point, in this magnification, means colony of bacteria. Under higher magnification we could calculate each separate bacterium (cell).

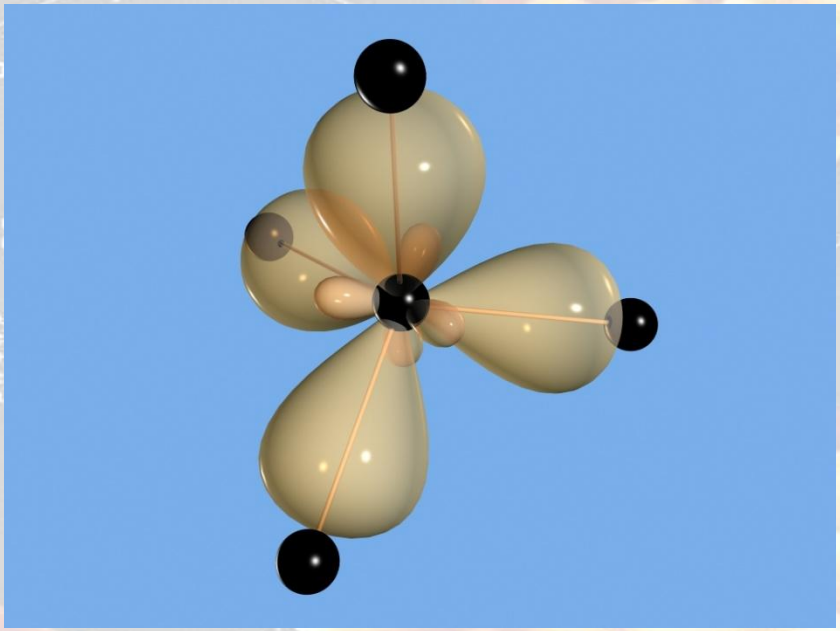
Jakubowski W., Bartosz G., Niedzielski P., Szymanski W., Walkowiak B. Nanocrystalline diamond surface is resistant to bacterial colonization. Diamond and Related Materials, 2004; 10: 1761-3.

Allotropic Forms of CCar

Carbon: $^{12}C_6$

Electron Configuration: $[1s^2]\ 2s^2\ 2p^2$

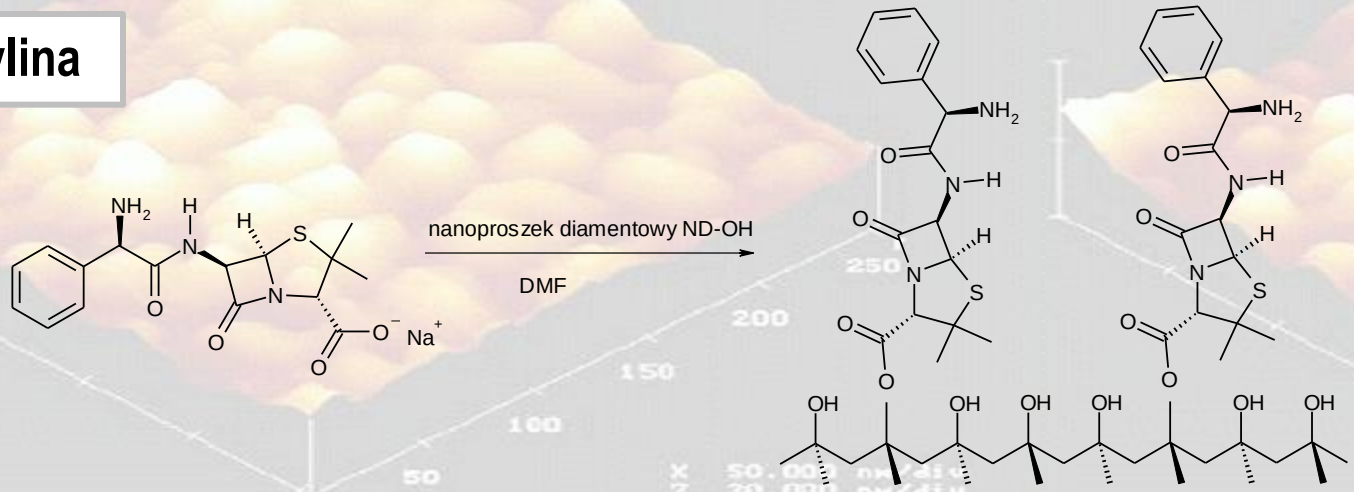
$2s^2\ 2p^2$ » σsp^3

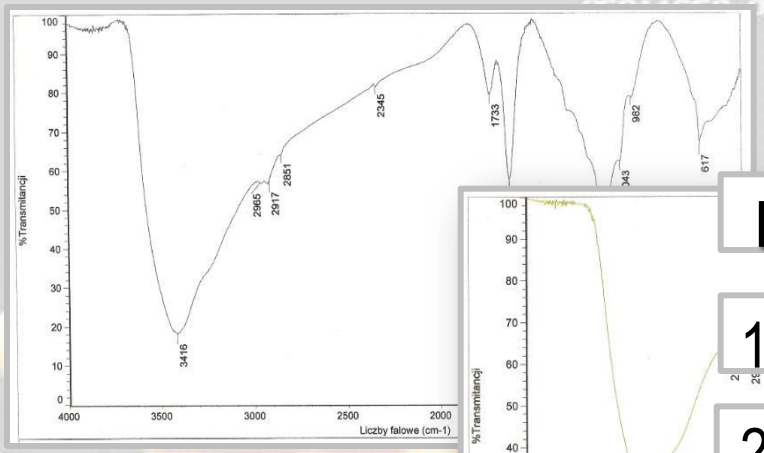


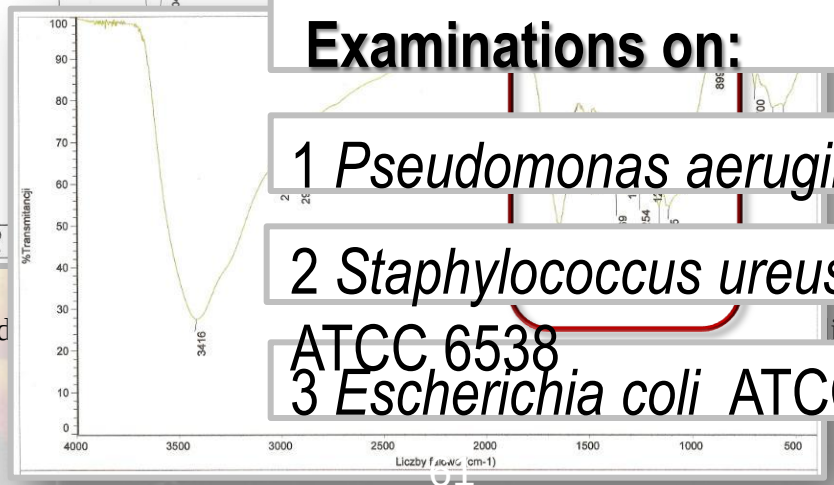
Diamond

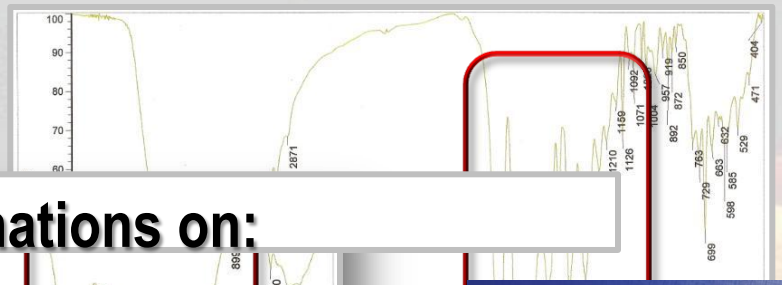
Synthesis of ampicillinum on the surfece of nanodiamond particles

Ampicylina









FT – IR from nanodiamond powd
modificated by Fenton reaction

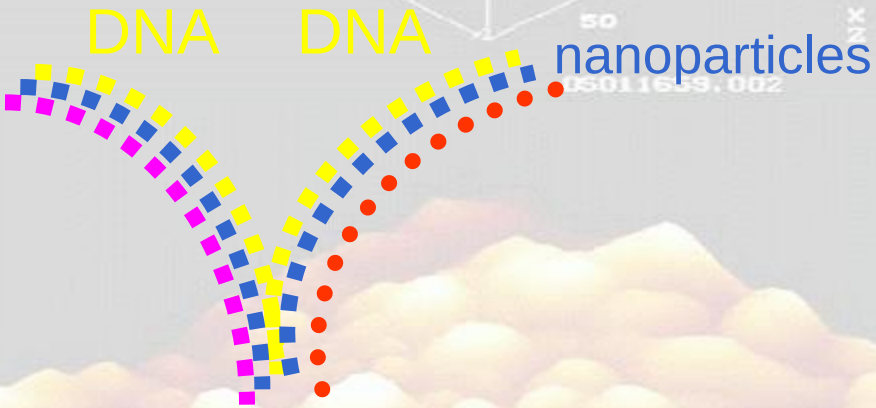
Examinations on:

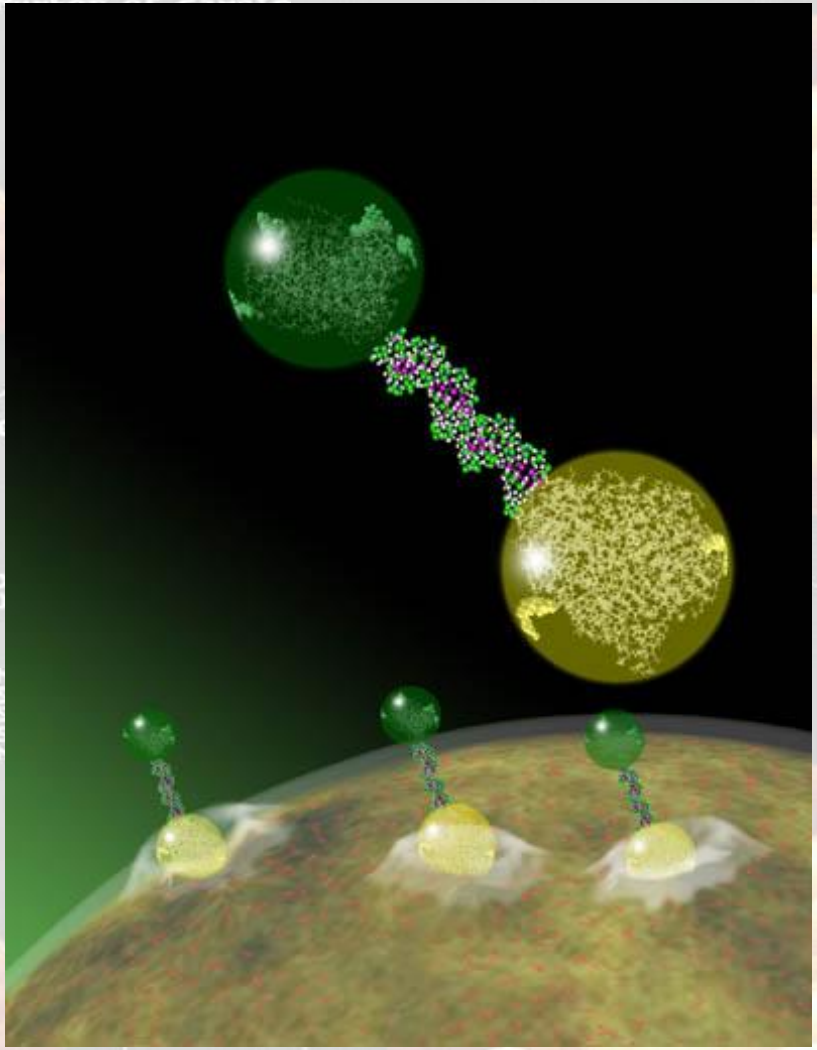
1 *Pseudomonas aeruginosa* ATCC 9027

2 *Staphylococcus ureus* ATCC 6538

3 *Escherichia coli* ATCC 8739

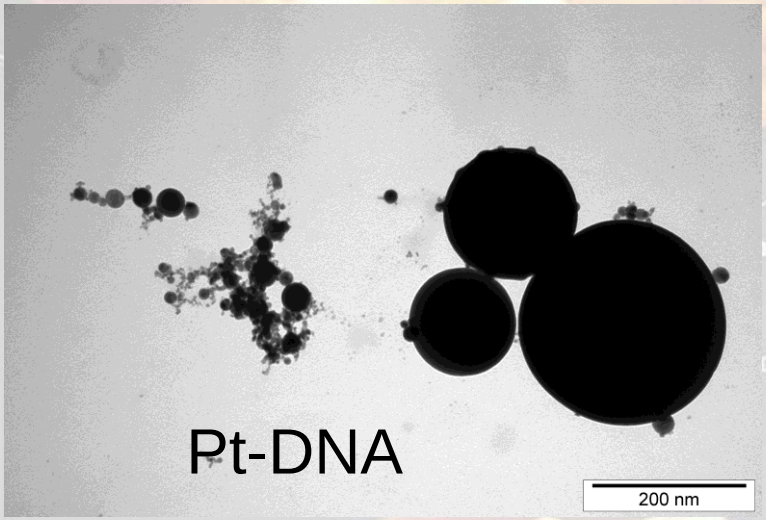
DNA - nanoparticles

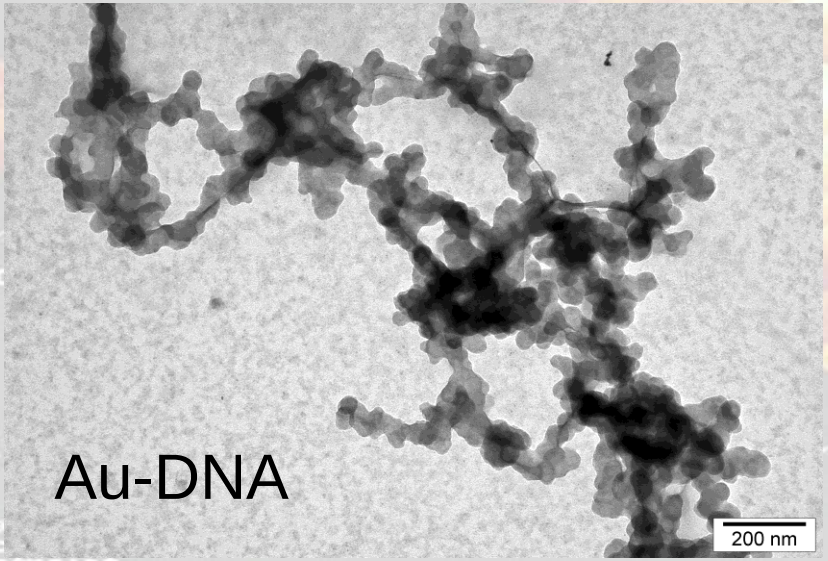


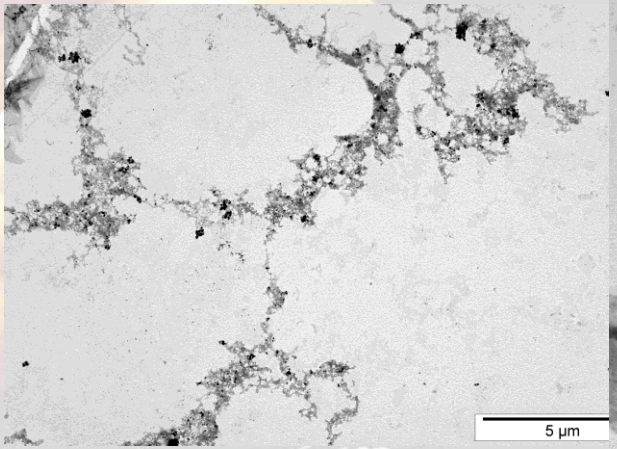


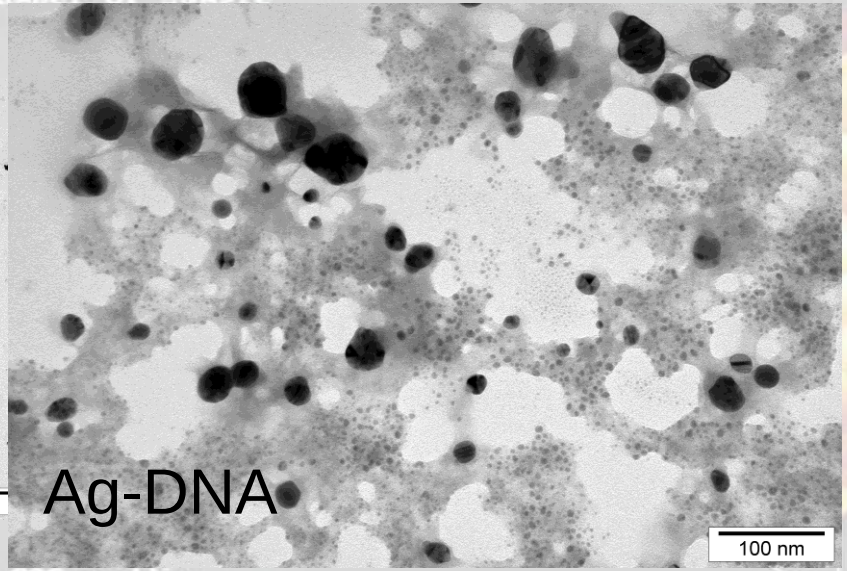
Arbor A., 2009, Proc. University of Michigan

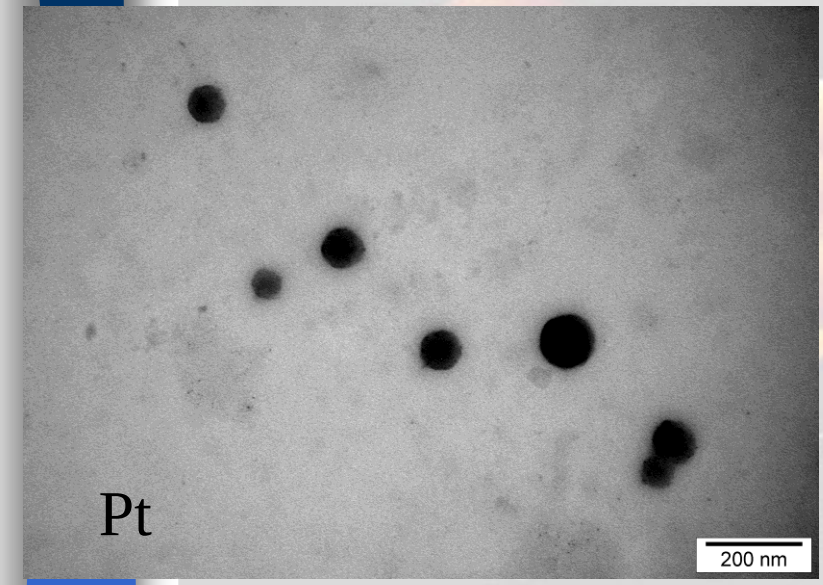
DNA
and metal nanoparticles

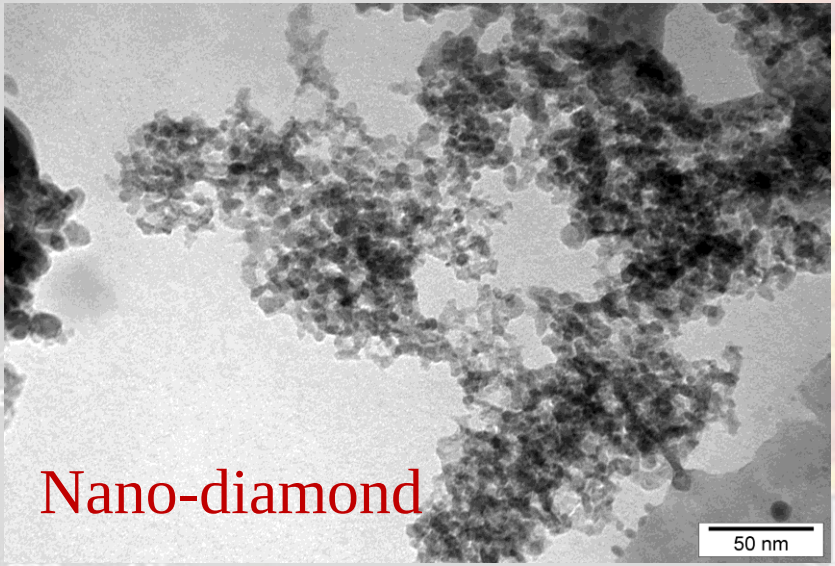


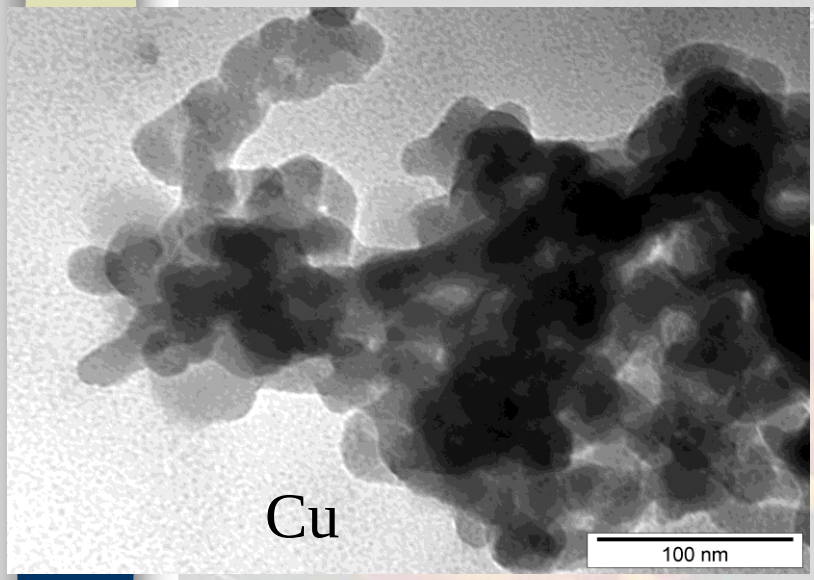


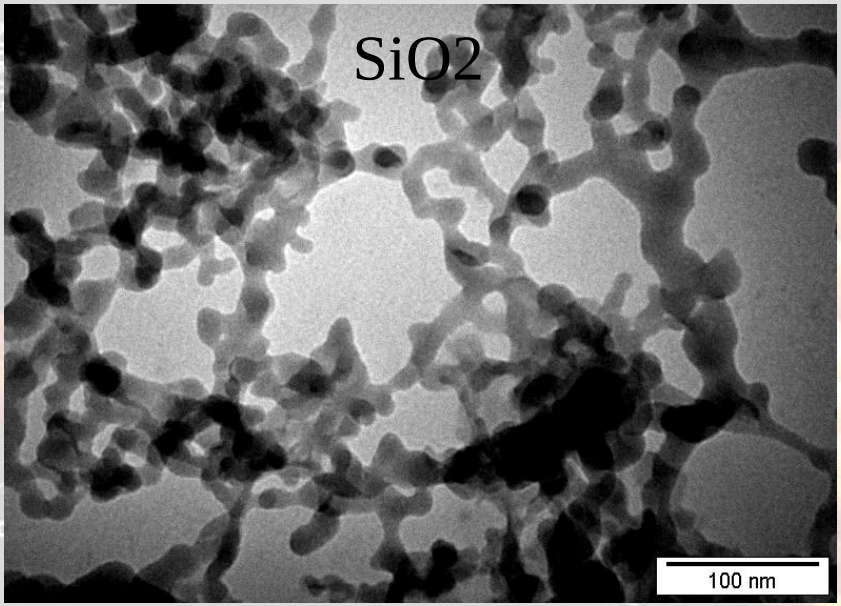




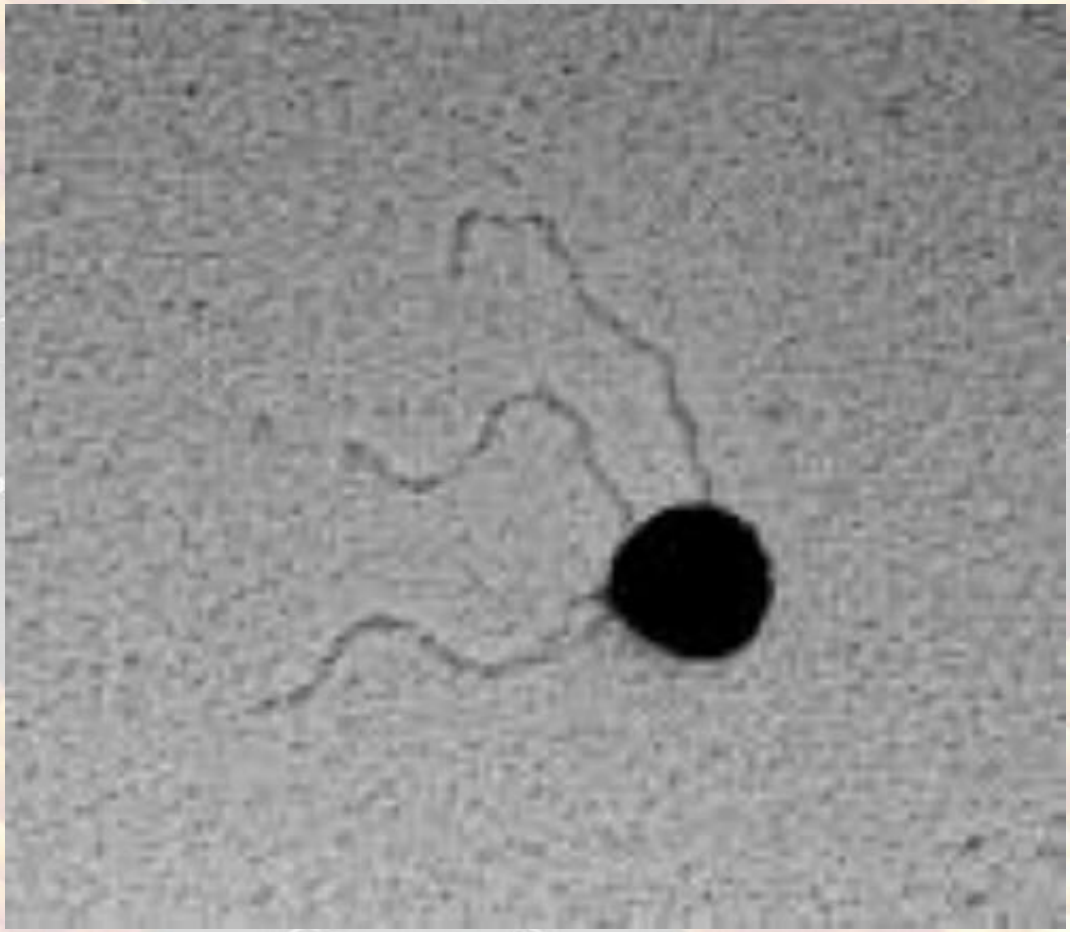

Pt
200 nm


Nano-diamond
50 nm


Cu
100 nm


SiO2
100 nm

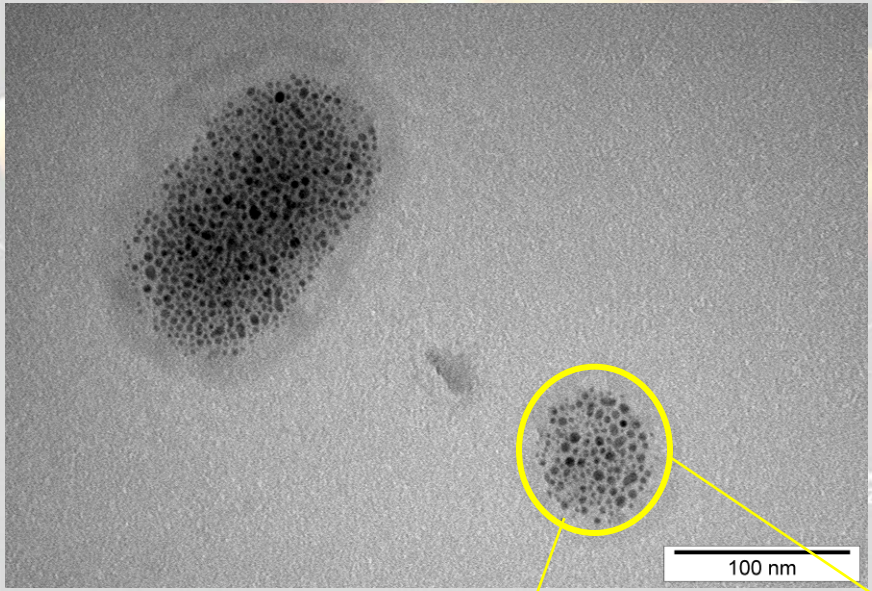
Nanocarrier of DNA

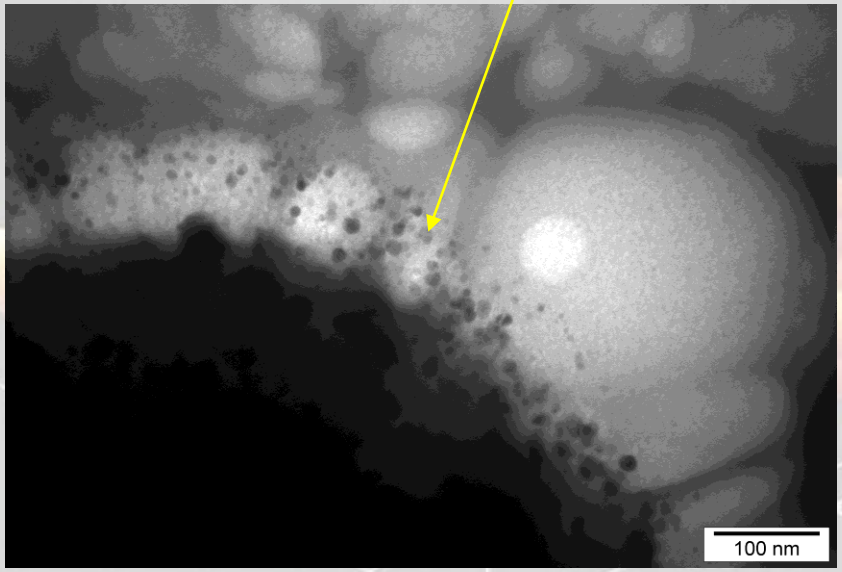


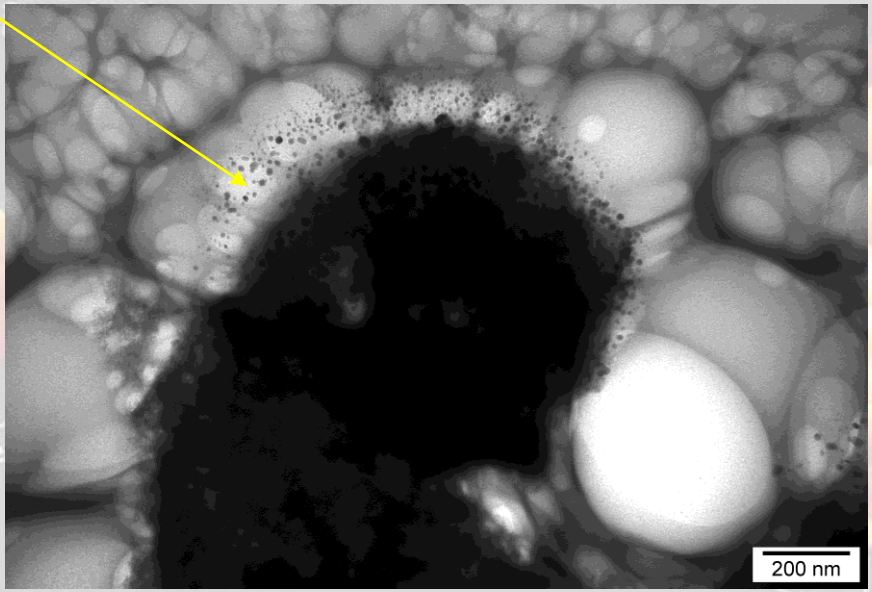
Gold nanoparticle with DNA

J. Griffith, 2009. Univ. of North Carolina

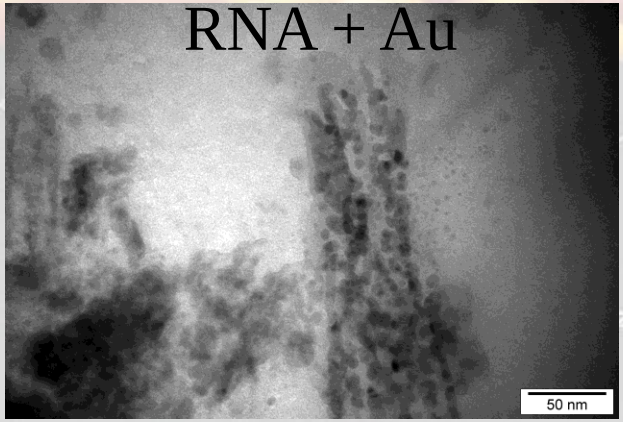
Varicella-Zoster Virus in presence of nanodiamond particles

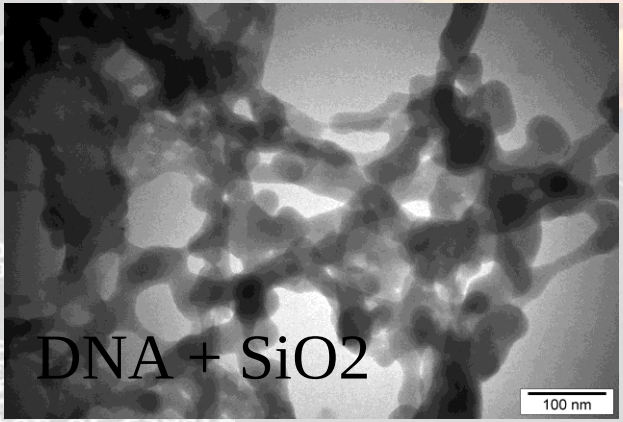


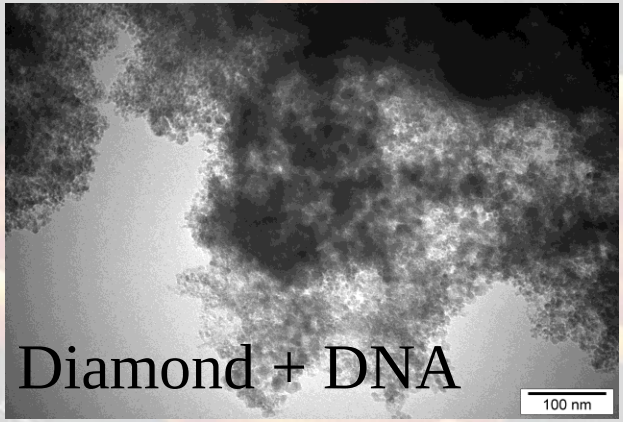


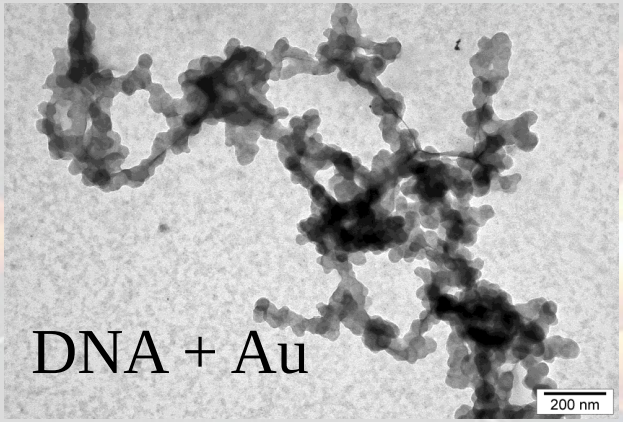


DNA and RNA and nanopowders

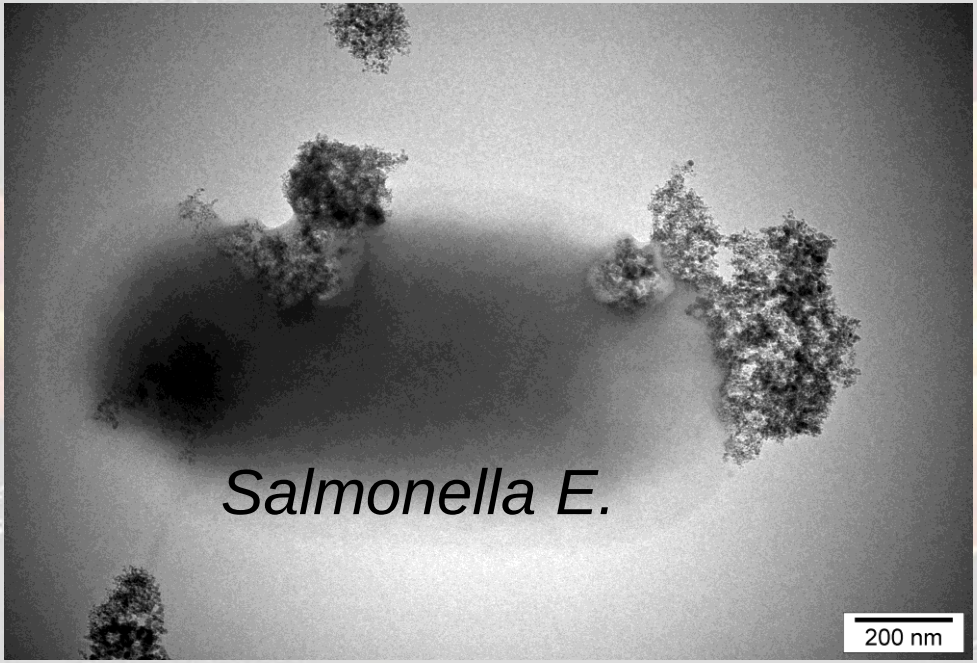


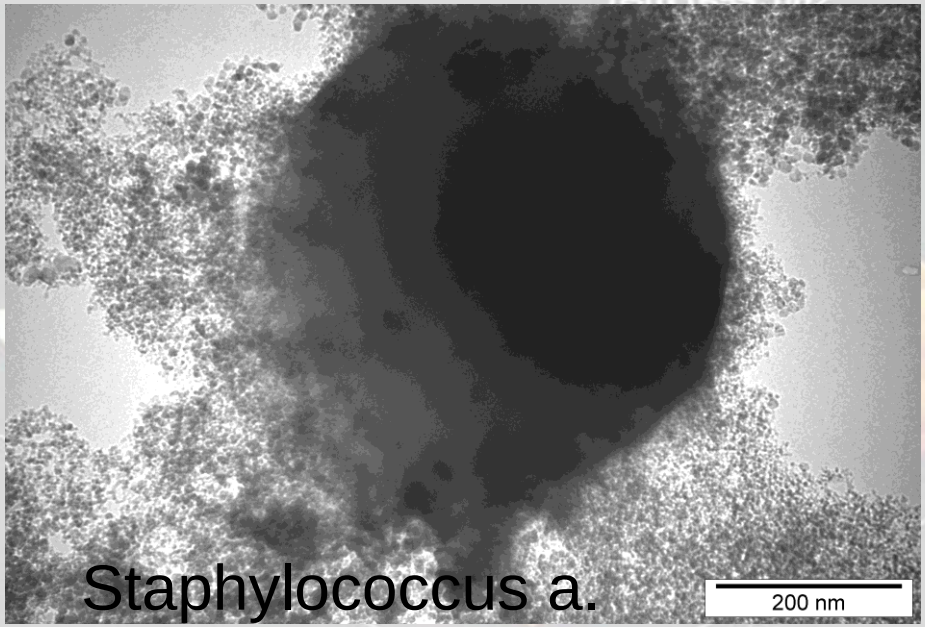


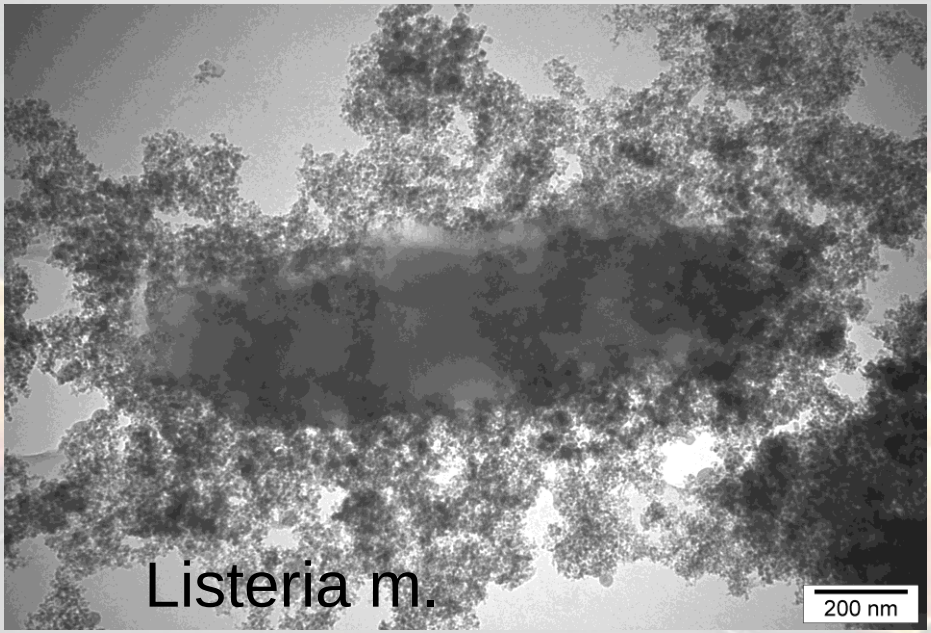


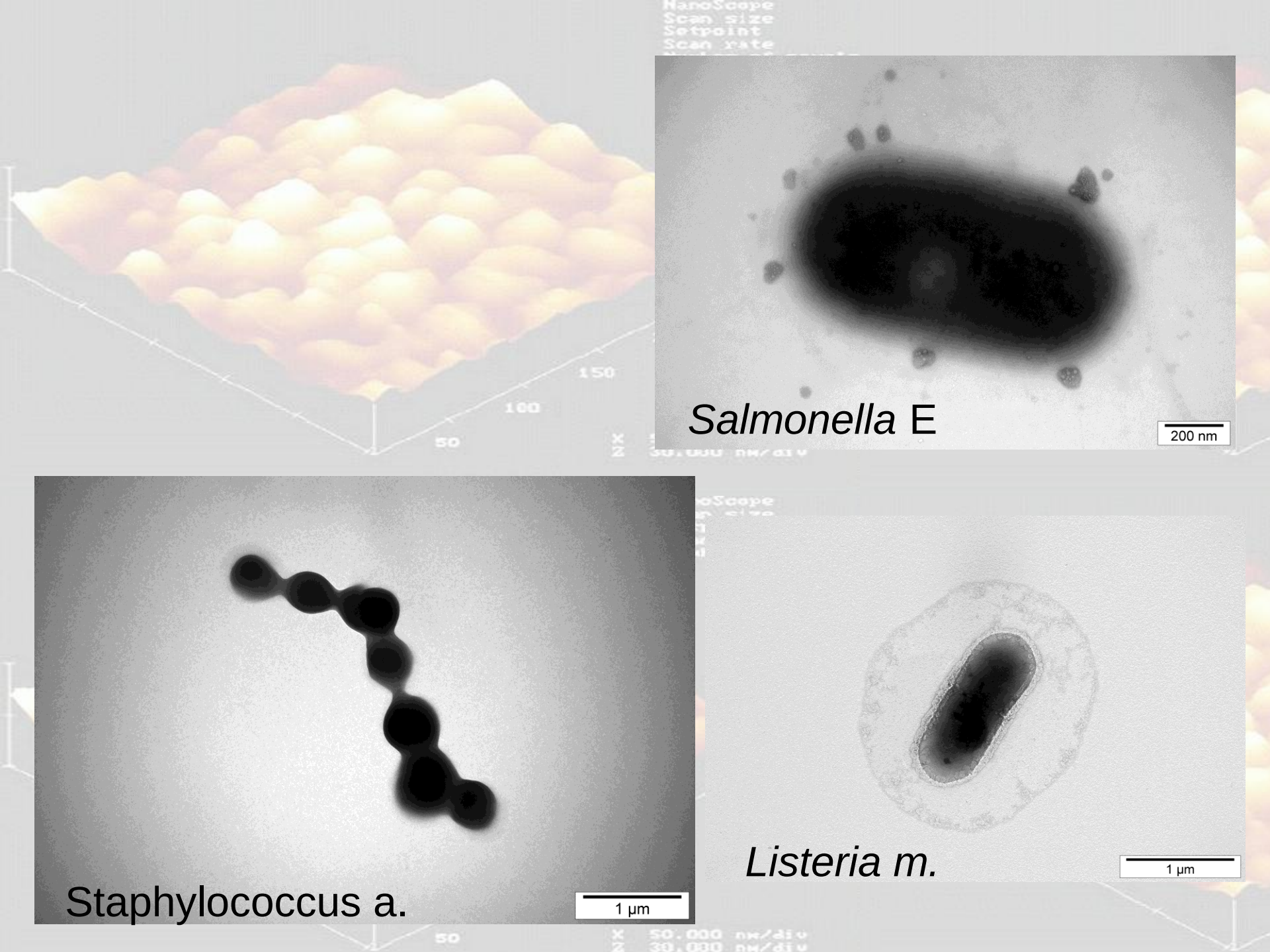


Diamond

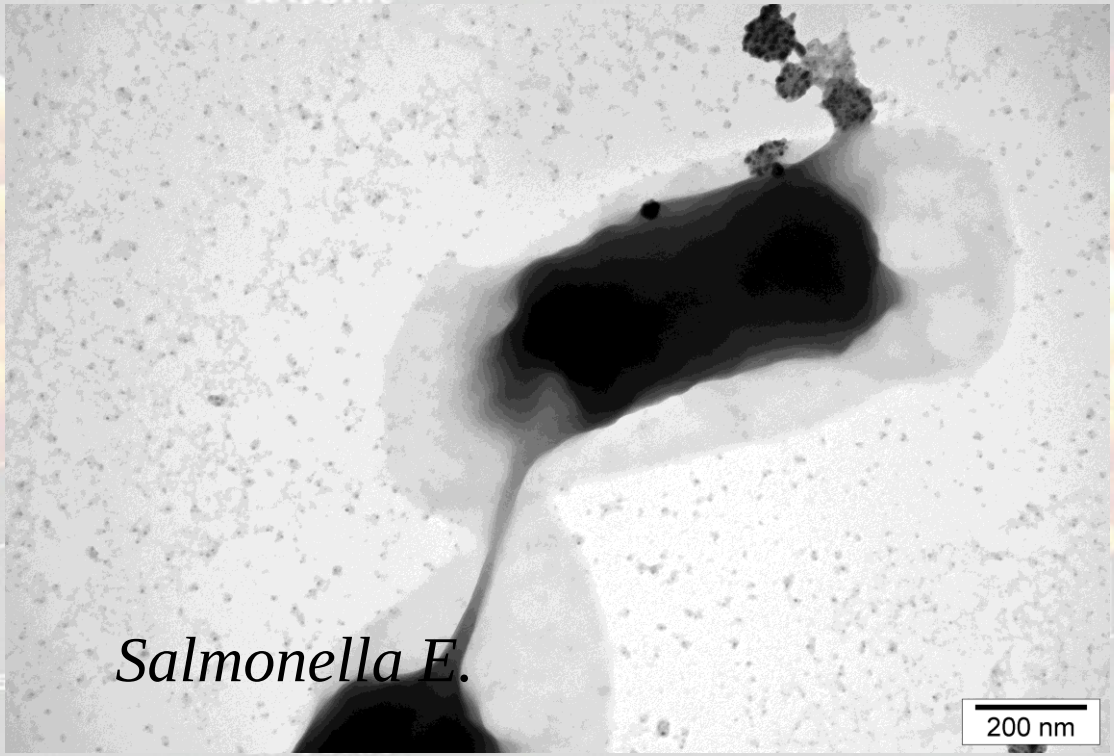

Salmonella E.
200 nm


Staphylococcus a.
200 nm

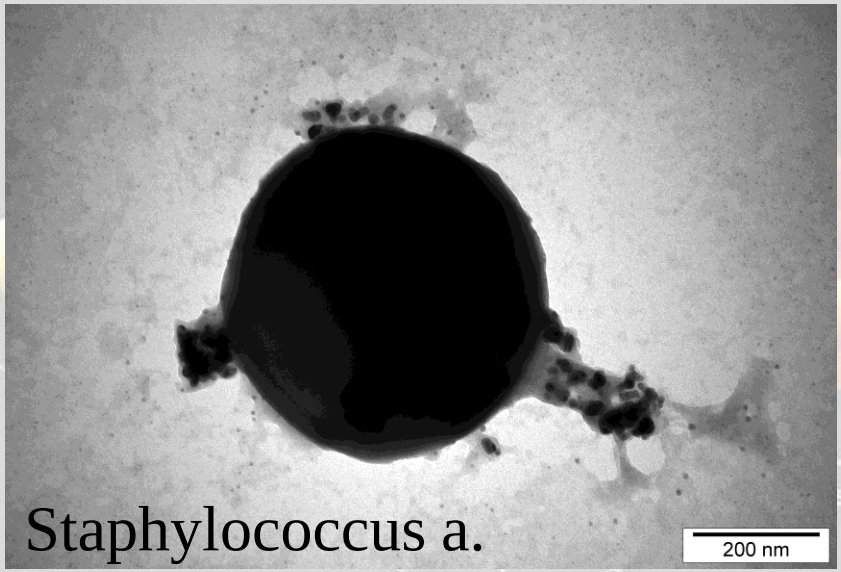

Listeria m.
200 nm


Salmonella E
200 nm
Staphylococcus a.
1 µm
Listeria m.
1 µm

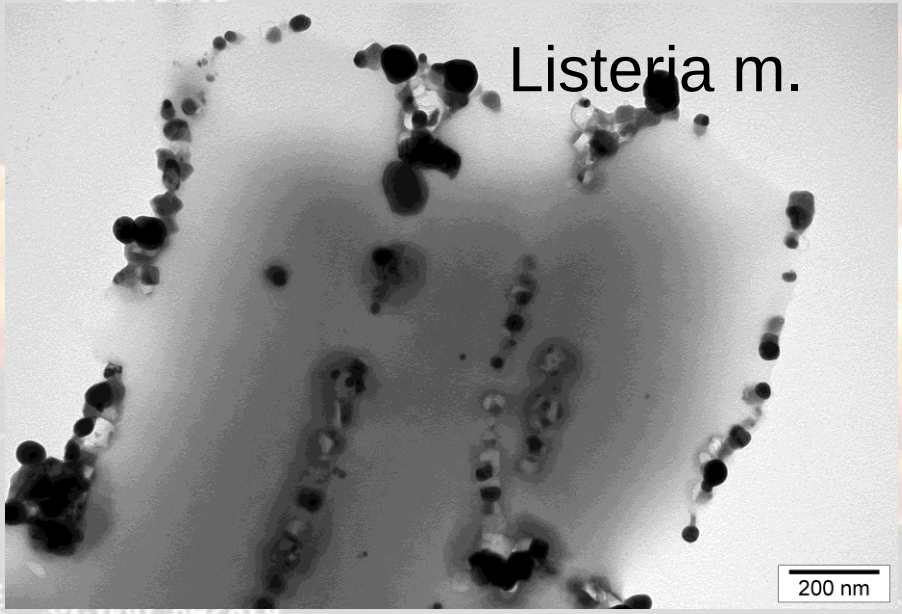
Ag



Salmonella E.

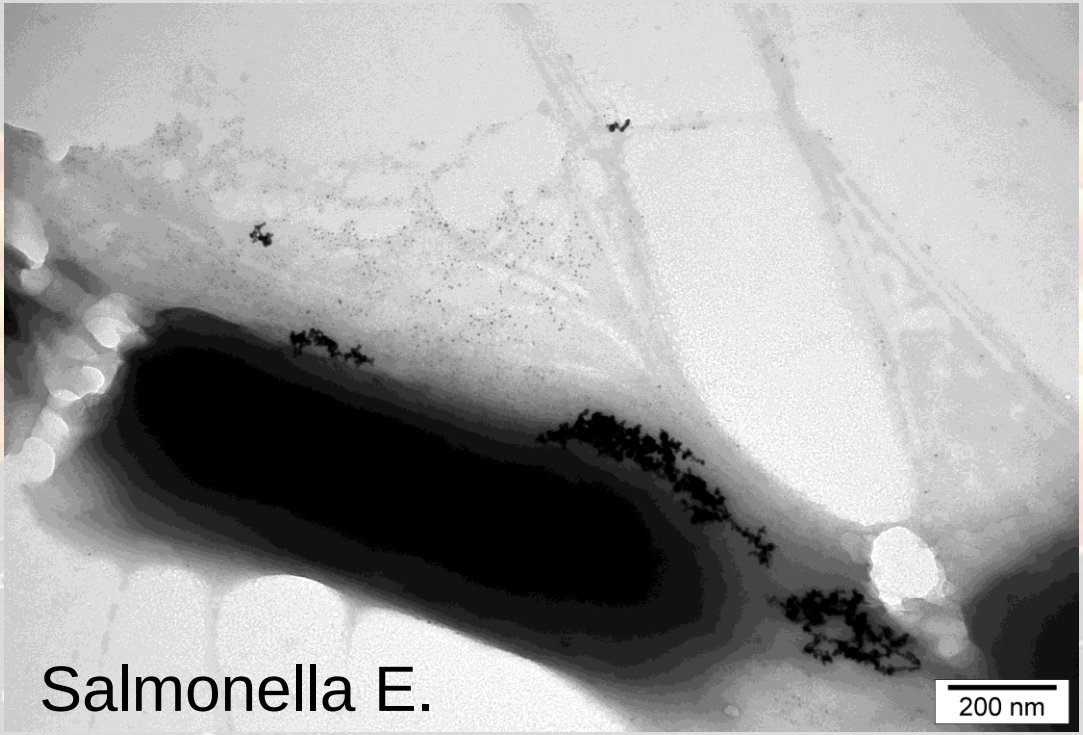


Staphylococcus a.

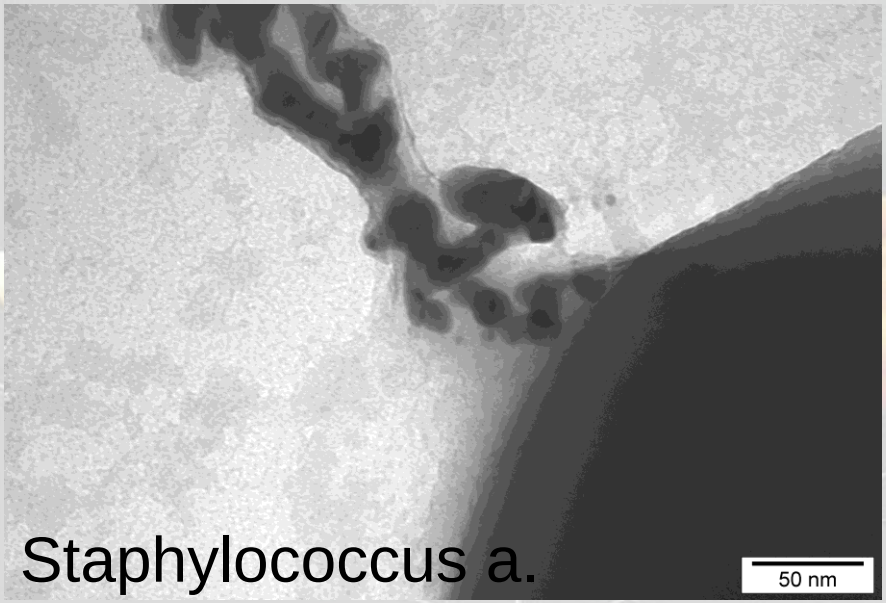


Listeria m.

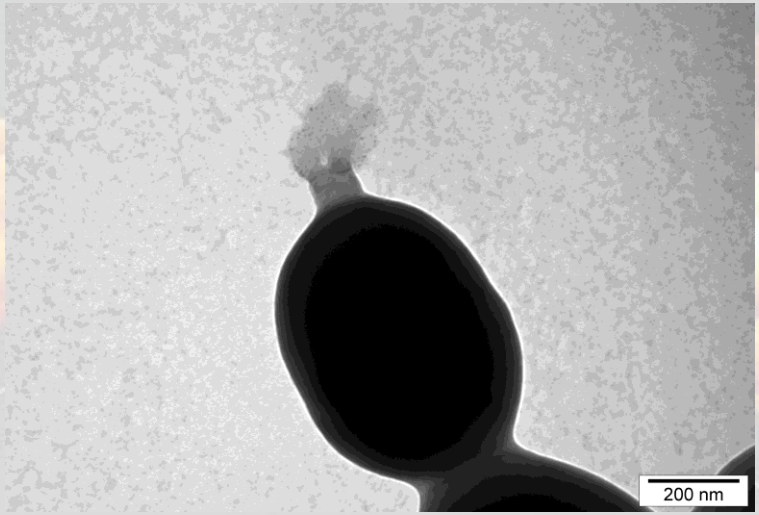
Au



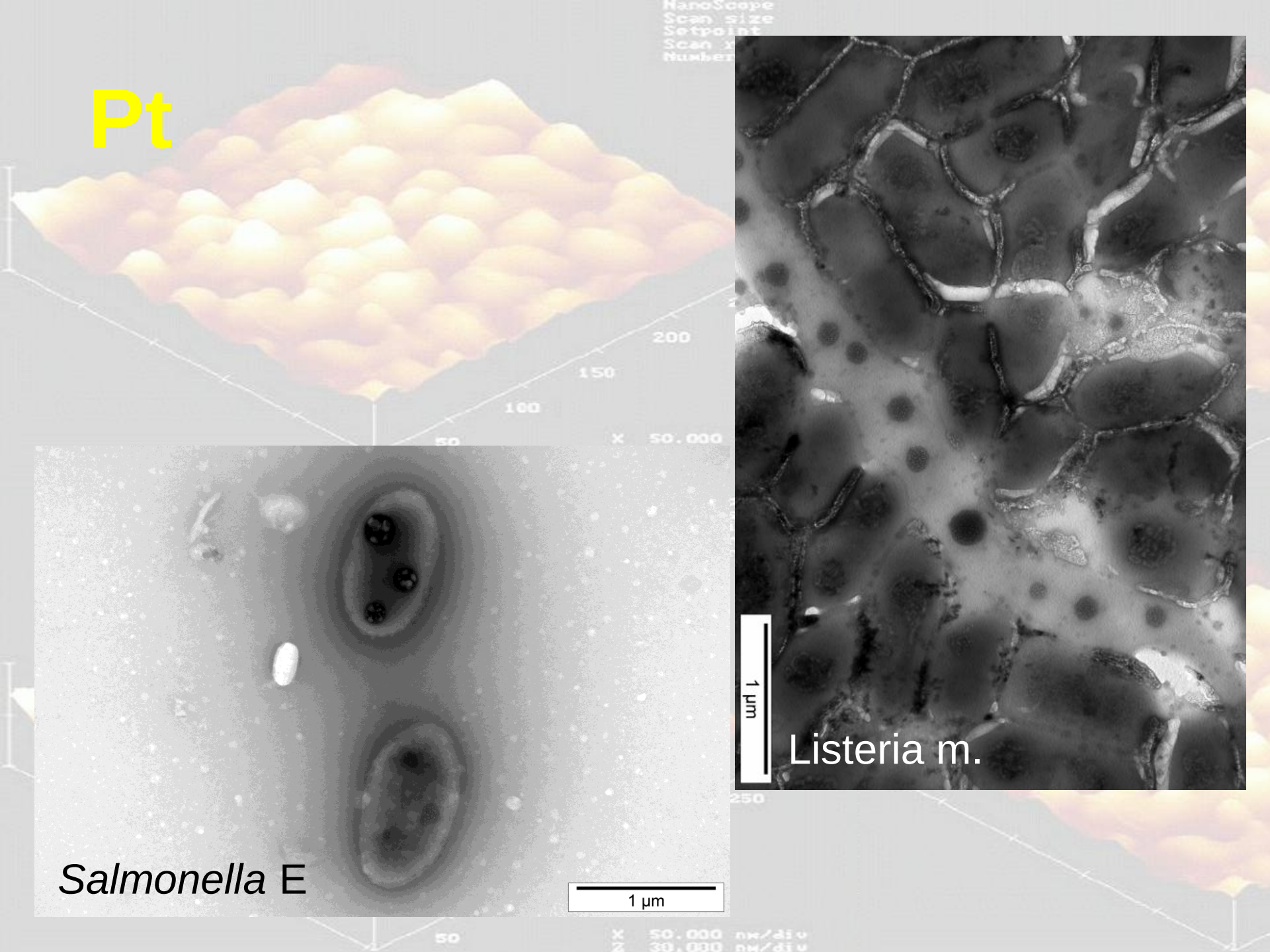
Salmonella E.



Staphylococcus a.

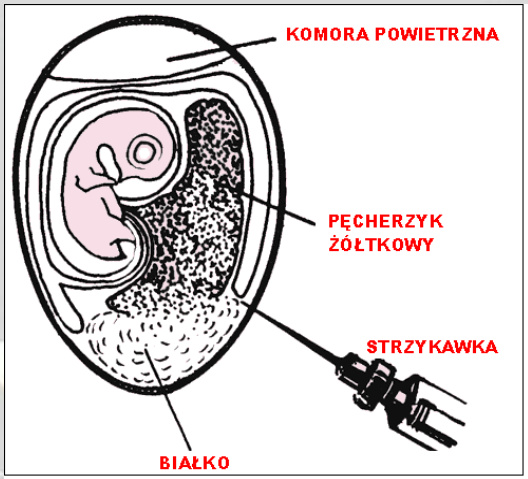


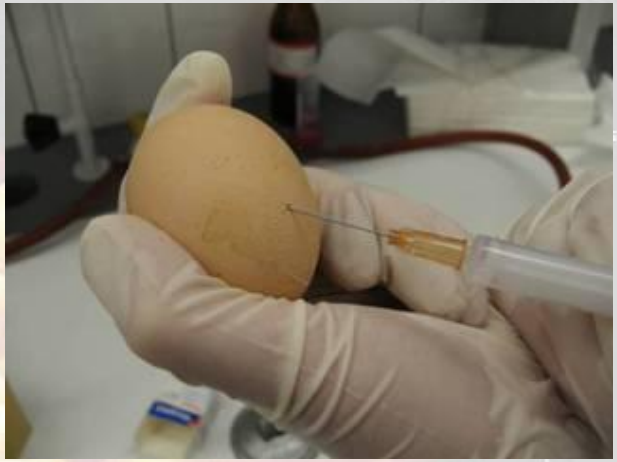
Pt



In ovo examination with nanodiamond particles

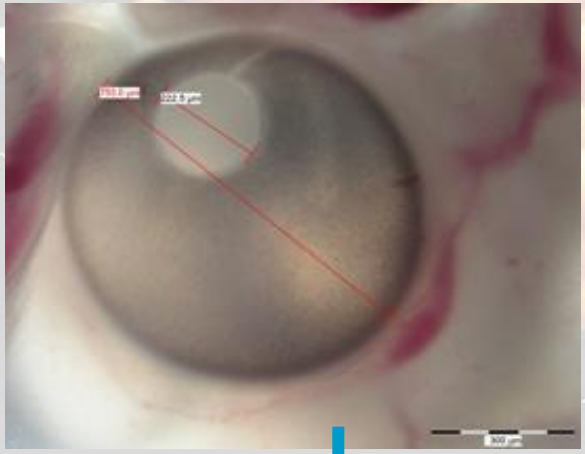
(badania modelowe na zarodkach kury, gryzoniach laboratoryjnych)





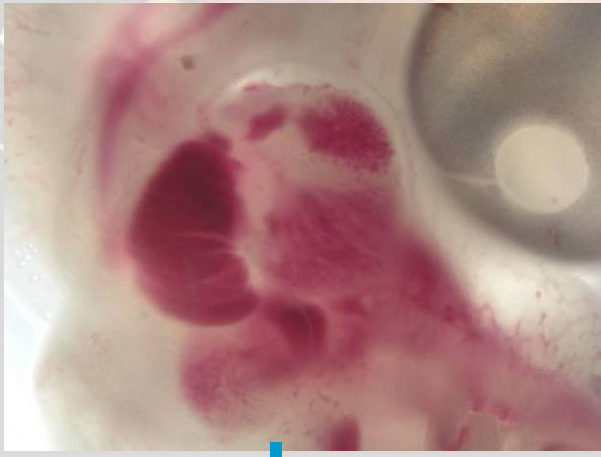
6 days

eye

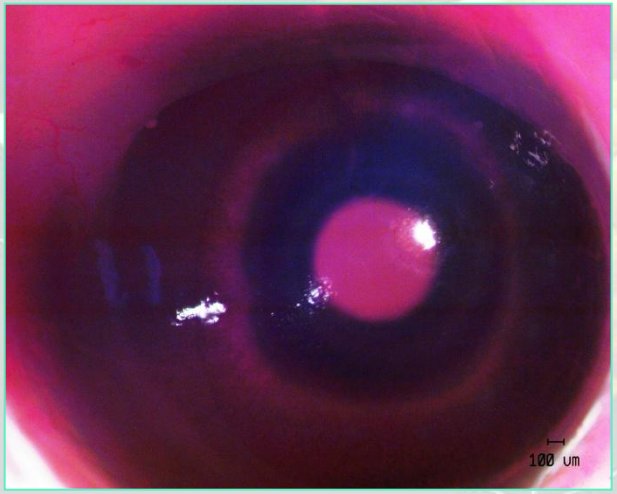


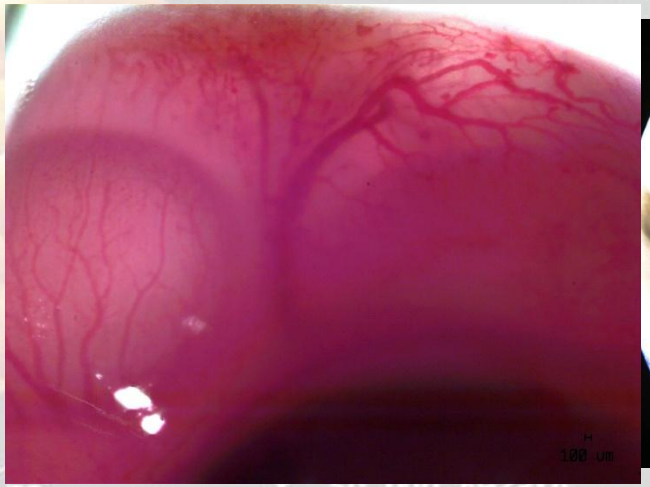
brain

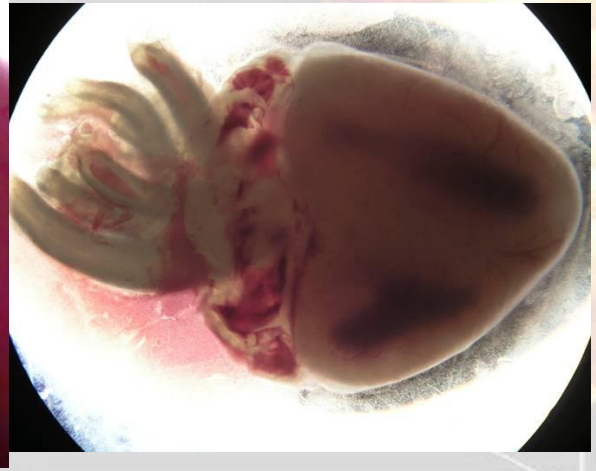
heart



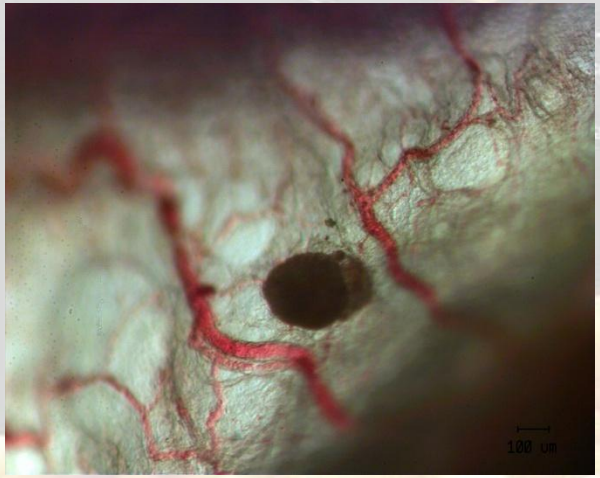
12 days

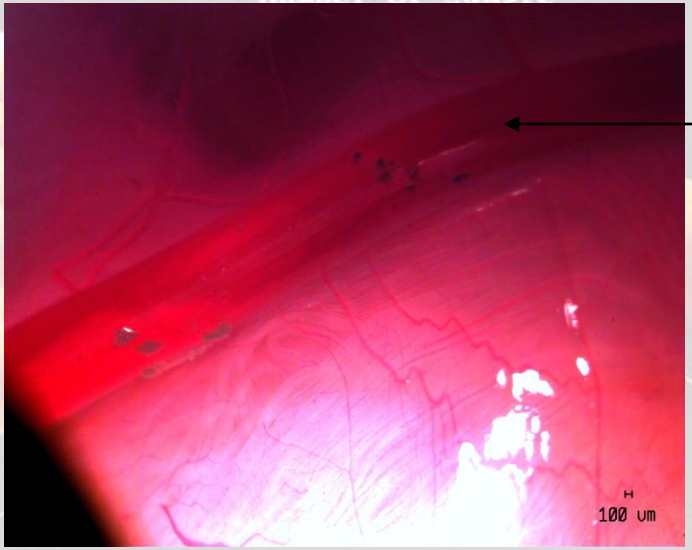






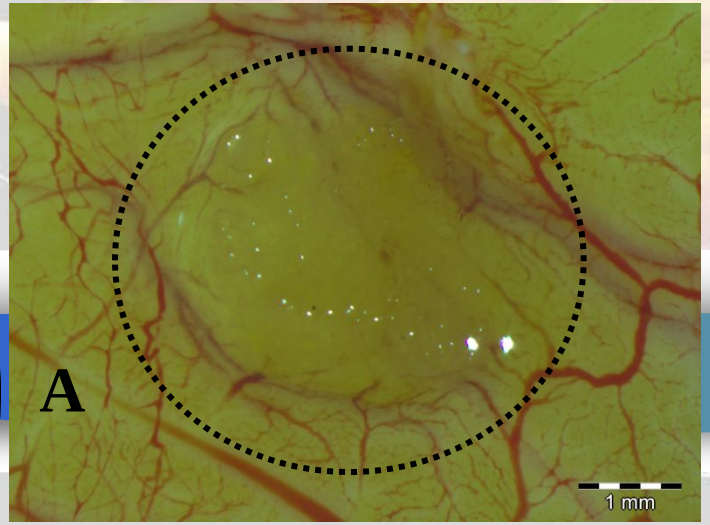
E.Sawosz, T.Niemiec, K.Mitura: Chicken embryon 12 day – vessel system nanodiamond particle introduced to embryon in the second day (300ul-50 ppm C), **NanoSMat, Rome, 2009.**

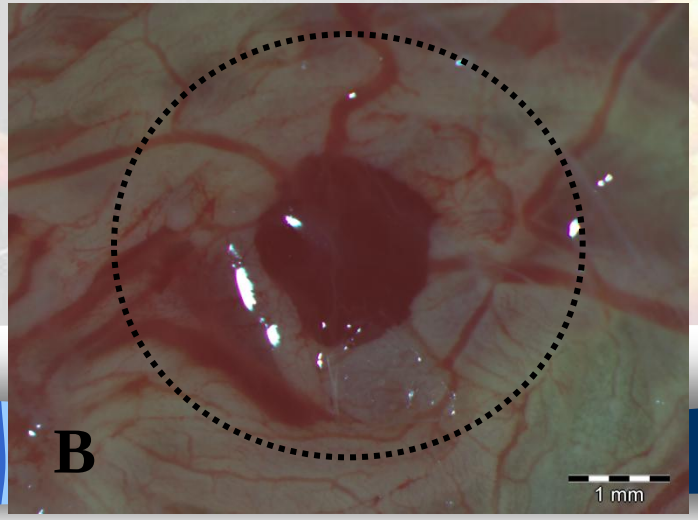


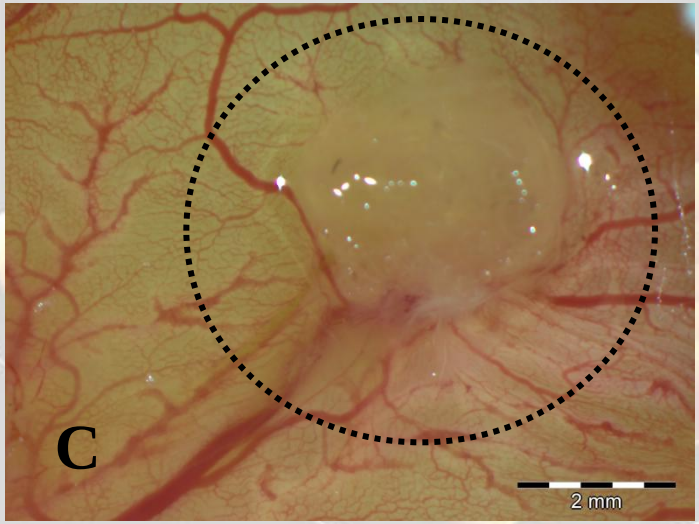


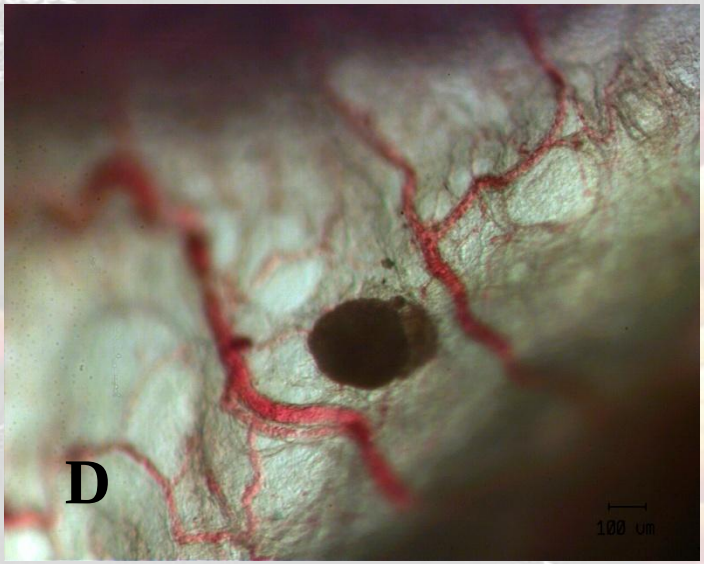
vessel

CAM of 12-day old chicken embryos implanted with a sponge loaded with; (A) PBS (control), (B) VEGF (proangiogenic control), (C) diamond nanoparticle suspended in water at a level of 50 ppm and (D) with aglomerate of nanodiamond placed onto CAM after injection of diamond nanoparticles (5000 ppm) in ovo

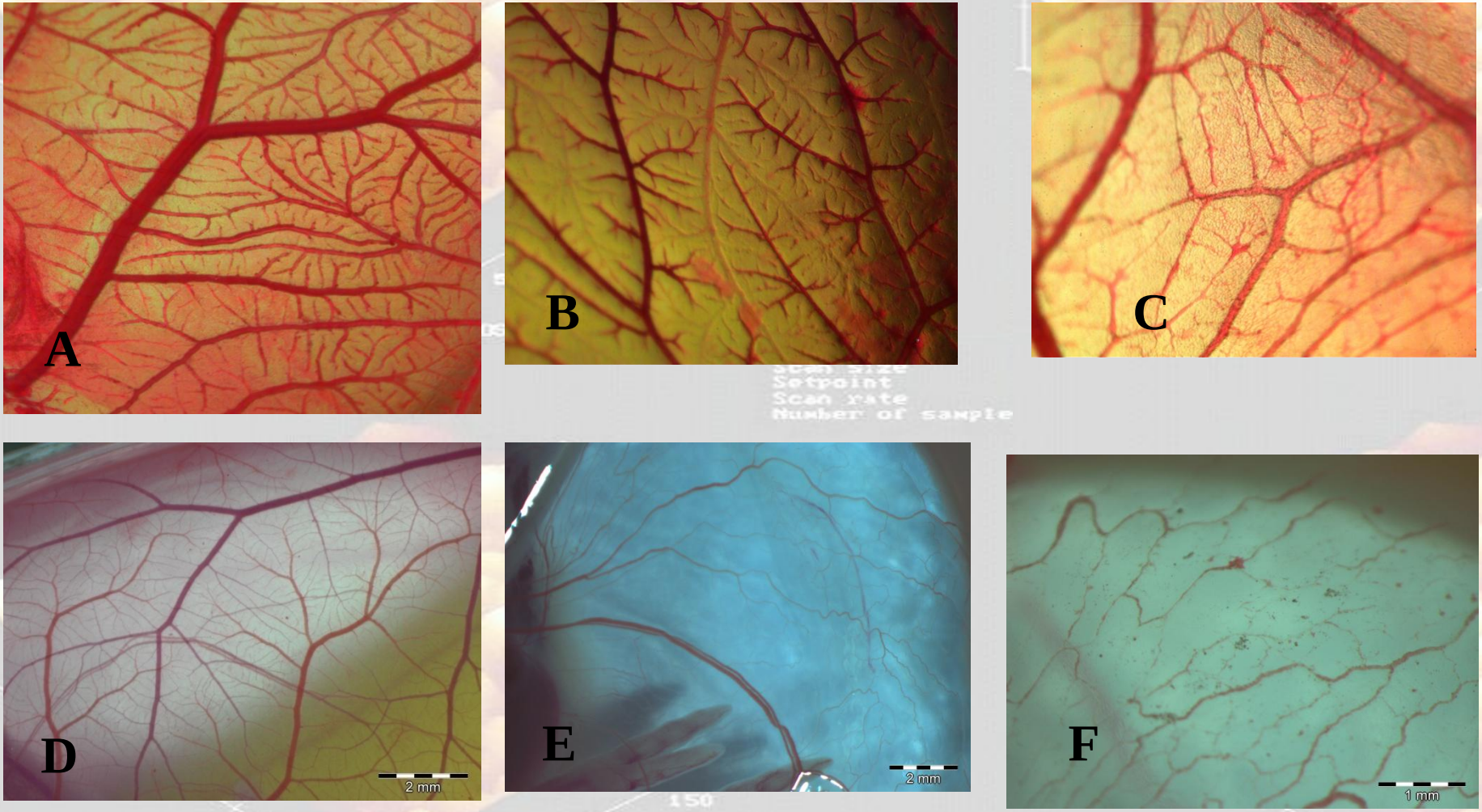




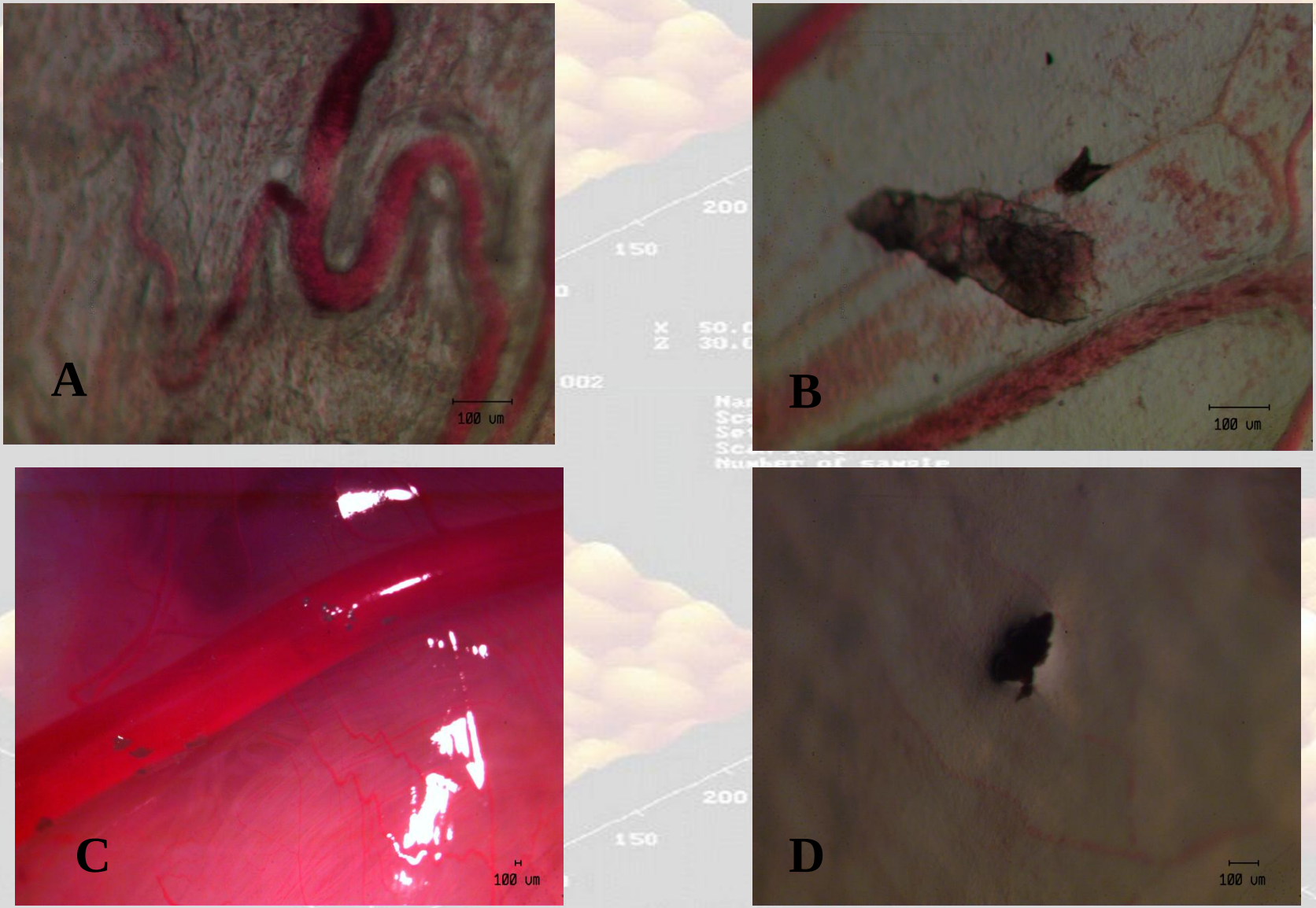




14-day old chicken embryo's chorioallantoic membrane (CAM) after treatment with; (A,D) control (PBS) and diamond nanoparticles suspended in PBS at a level: (B,E) 500 ppm, (C,F) 5000 ppm.

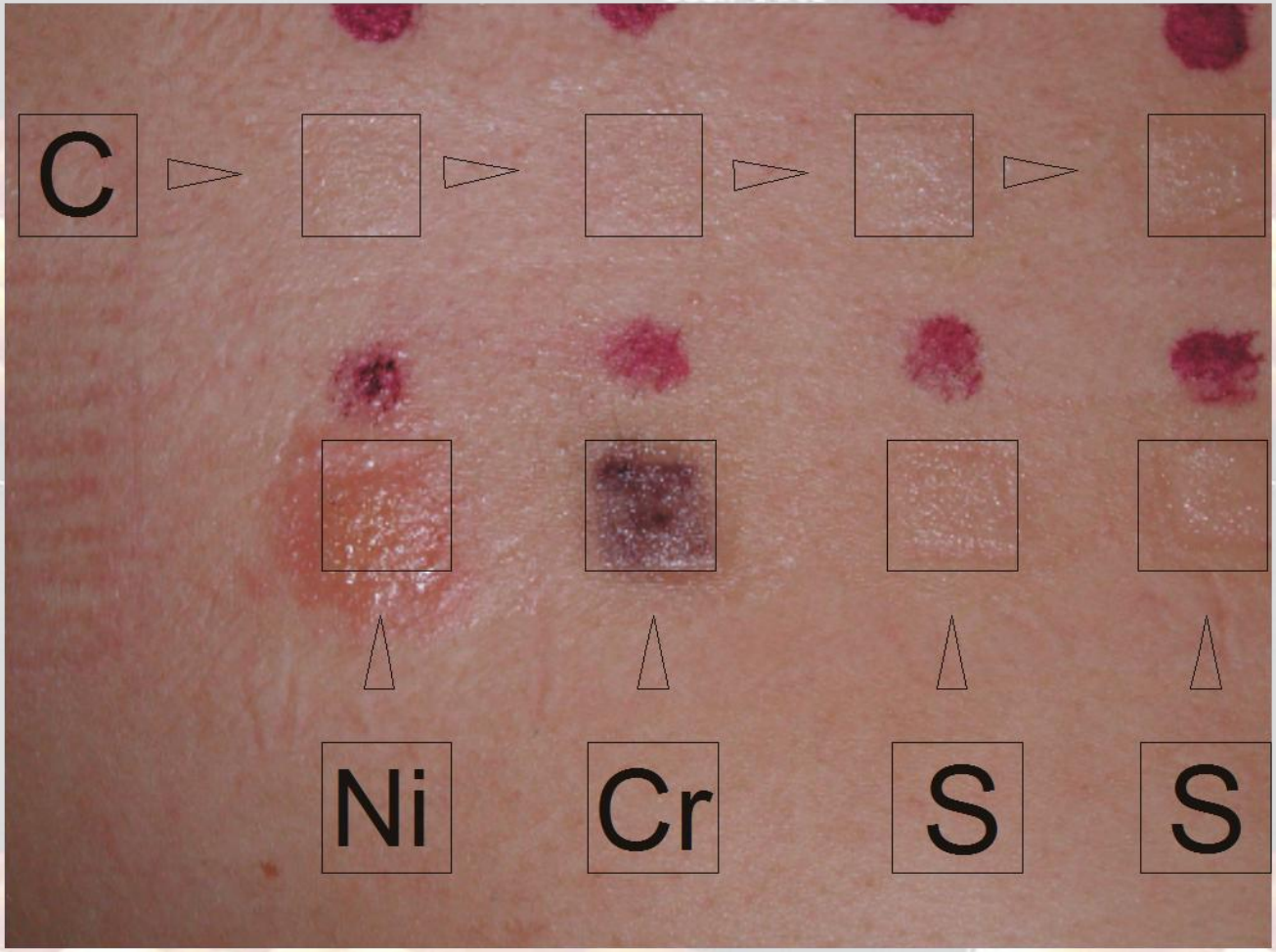


Distribution of diamond nanoparticles and their aglomeration in chicken embryo's CAM after injection of diamond nanoparticles hydrosol (5000 ppm) in ovo; (A) diamond nanoparticles flow inside blood vessels, (B) diamond nanoparticles flow inside blood vessels and aglomerates placed outside the vessels, (C) diamond nanoparticles aglomerates located arounded vessels to force them, (D) diamond nanoparticles force membrane



Contact allergy

Results of clinical research – patch test with Nanodiamond Cream



Allergic reaction on Ni and Cr (Ni - nikiel, Cr - chromium, S – standard tests).

The absence of allergic reaction on diamond powder (C – carbon)

Carbon - Applications

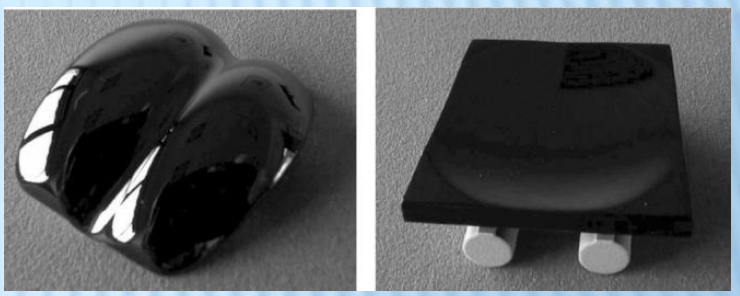
Application of Nanodiamond Cream

- **Paramedical substance in** treatment of bacterial skin diseases (staphylococcus aureus, staphylococcus epidermidis, streptococcus pneumoniae).

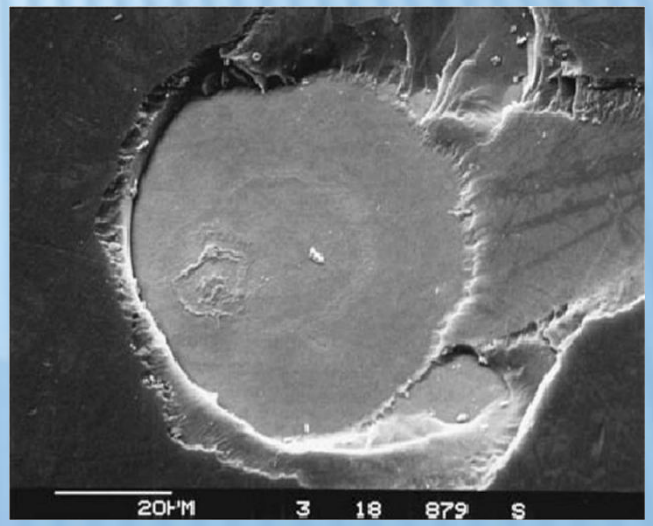
CVD CARBON COATINGS

SCIENCE TECHNOLOGY

Commercial proposition (1999):
Company M.I.L. SA (*Materiels Implants du Limousin SA*)
Proteza stawu kolanowego ze stali AISI Z5 CNMD 21 azotowanej i pokrytej warstwą DLC

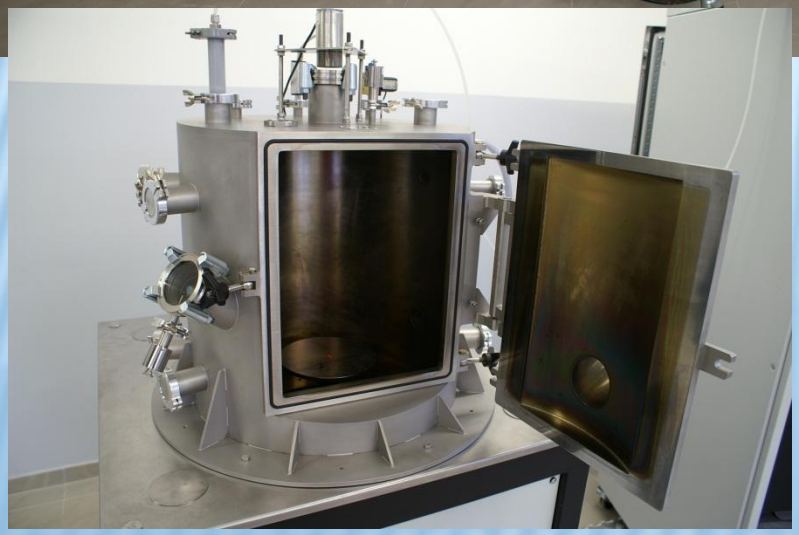


Company: *Implant Design AG* (2001)
Proteza stawu kolanowego. 190 implantations
Problems: coatings delamination
June 2001 Swiss Federal Office of Public Health (SFOPH) – forbidden of application

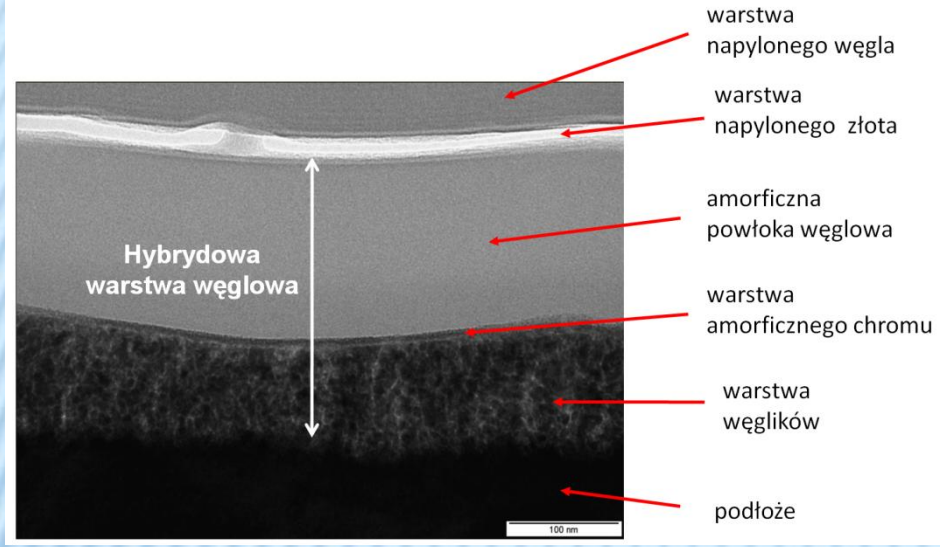


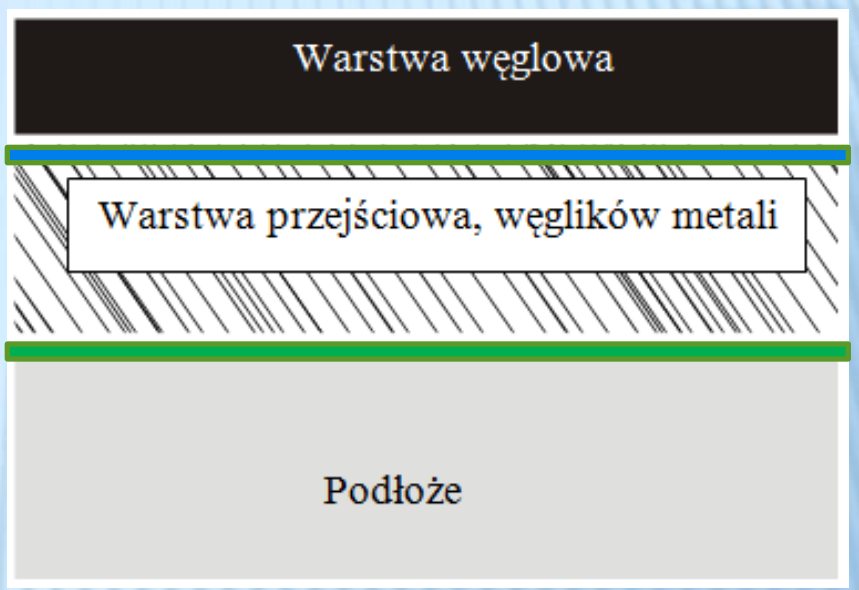
2001 company *Biomecanique*: implementation of endoprotesis from Ti6Al4V with DLC (2-3µm) named Adamante®.
After 8 years 45% reimplantations.

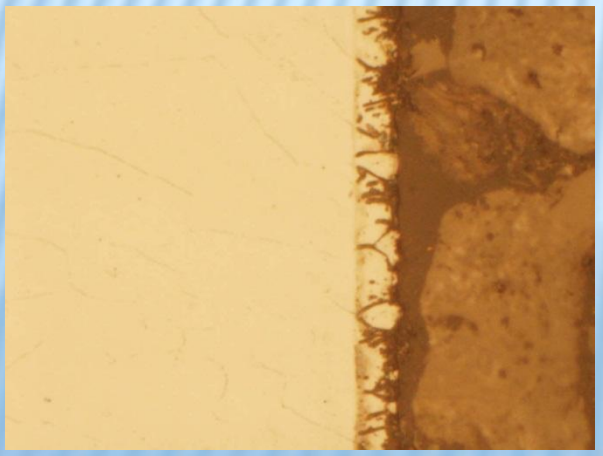
URUCHOMIENIE TECHNOLOGII U PRODUCENTA IMPLANTÓW

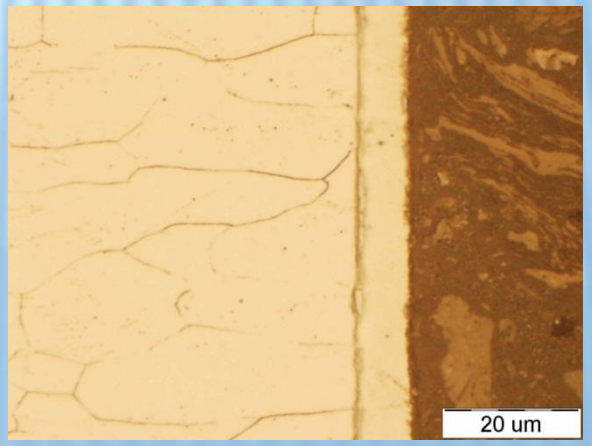


INTERFACE!!!!

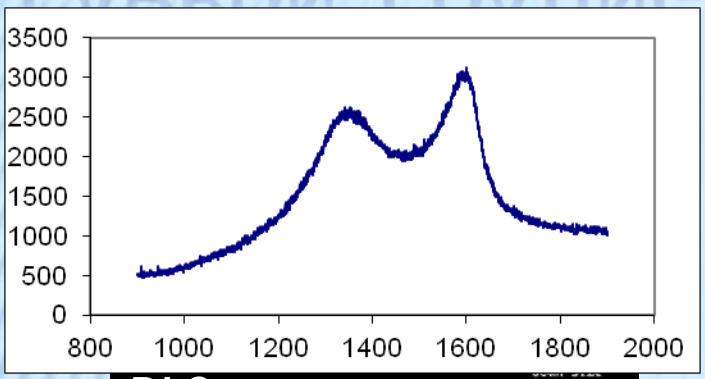

warstwa
napylonego węgla
warstwa
napylonego złota
amorficzna
powłoka węglowa
warstwa
amorficznego chromu
warstwa
węglików
podłoże
Hybrydowa
warstwa węglowa
100 nm

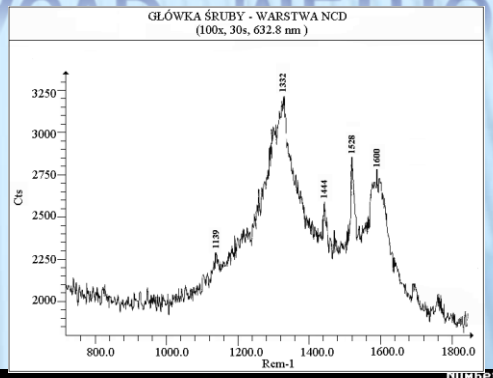

Warstwa węglowa
Warstwa przejściowa, węglików metali
Podłoże

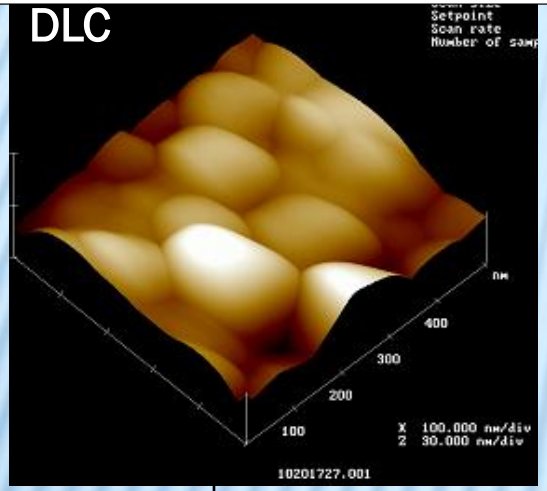



20 um

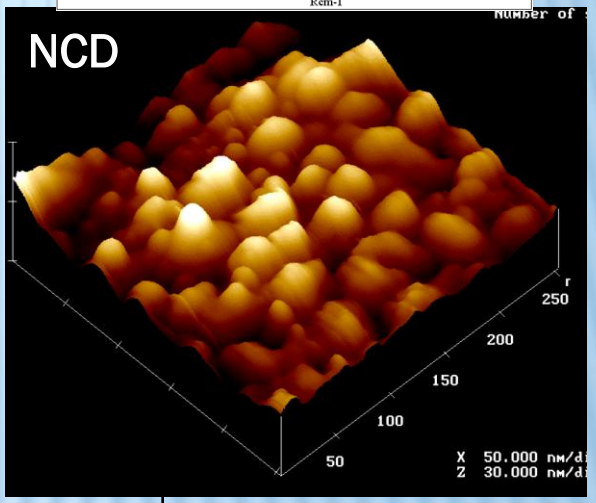
CARBON COATINGS BY RF PACVD METHODE







$\sigma sp^2 / \sigma sp^3$



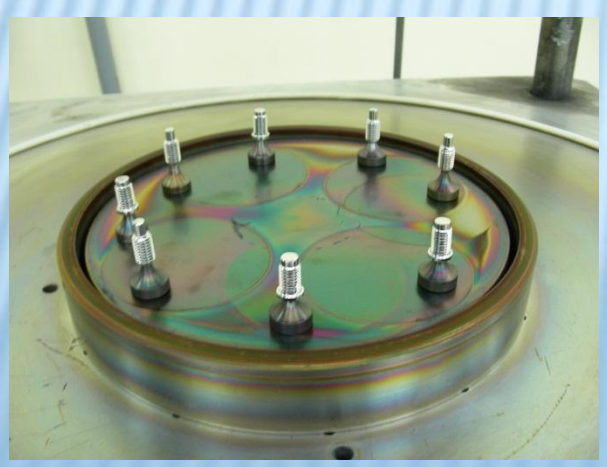
Without interface

Interface – MeC (metal carbides)

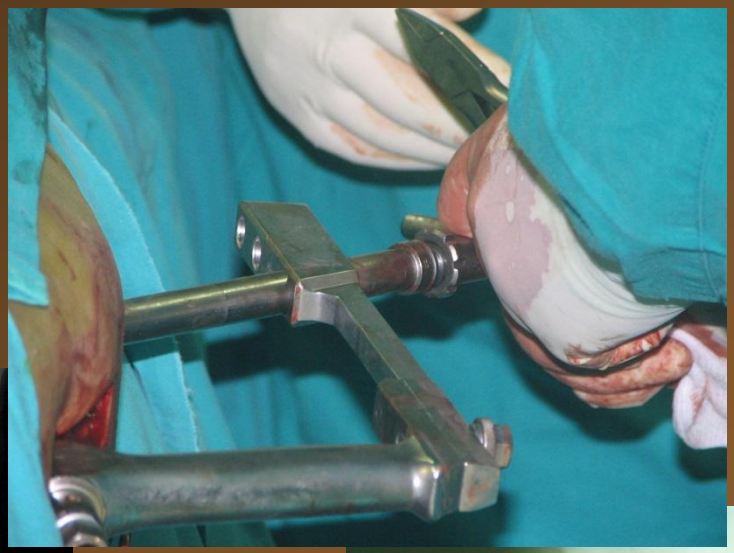
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400

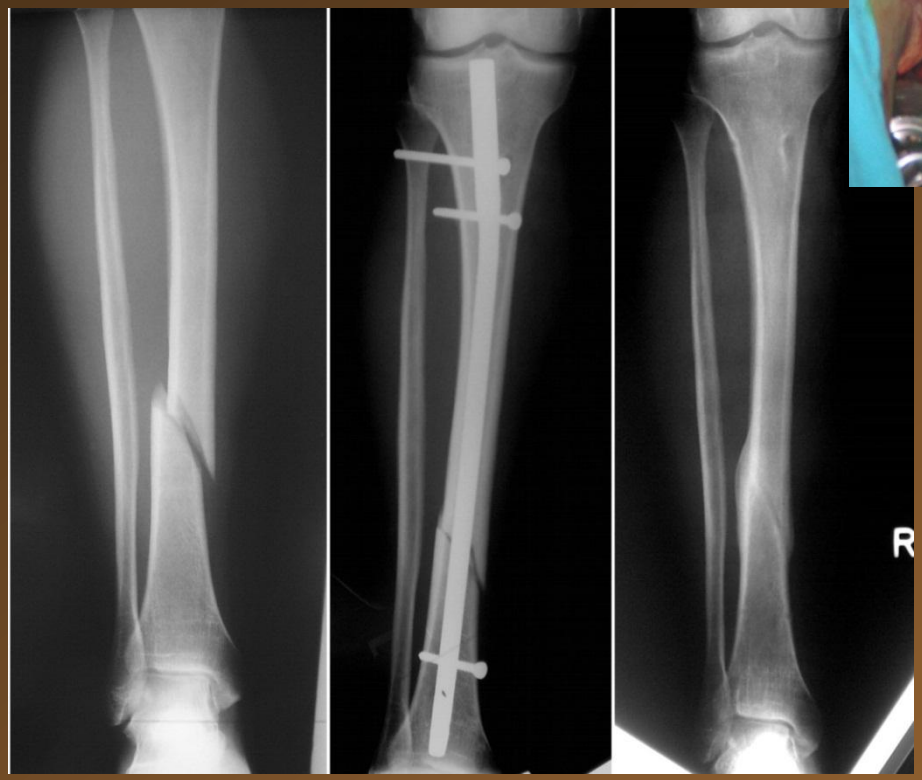
Negative self-bias of electrode [V]

TECHNOLOGY : RF CVD

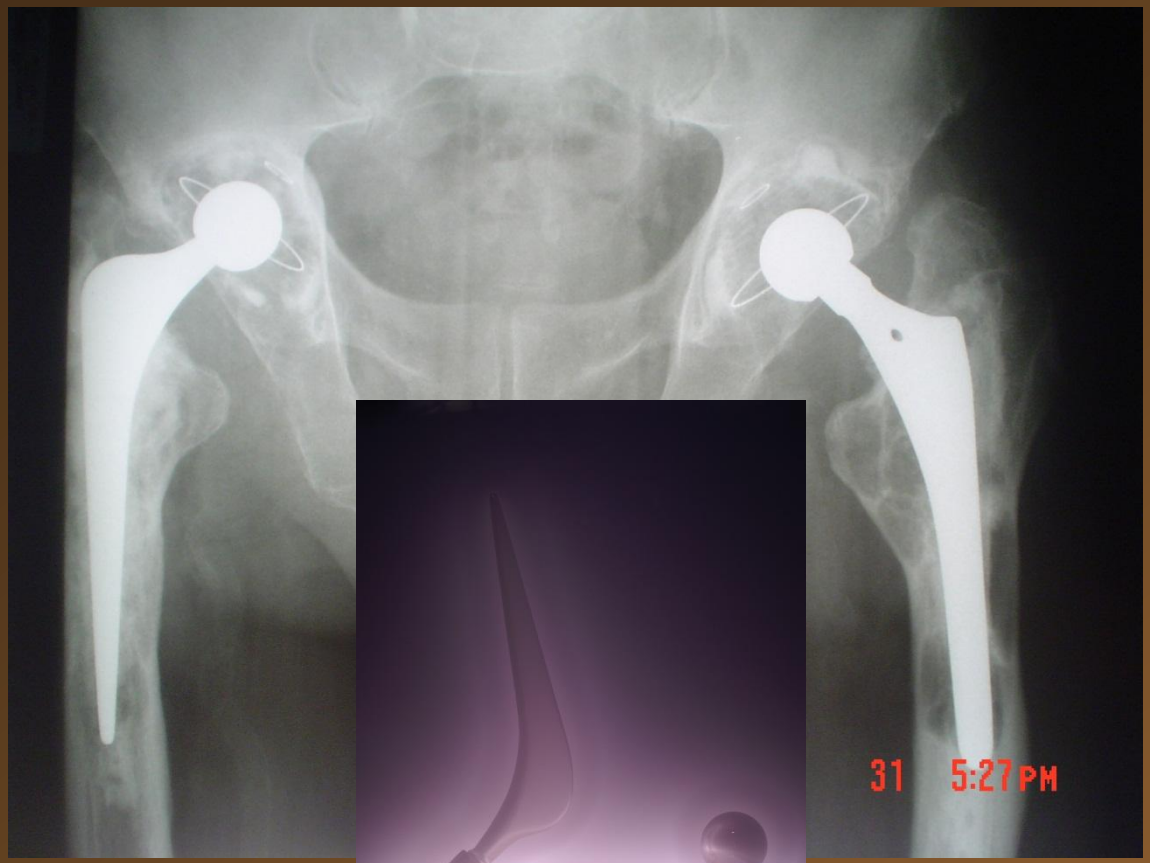


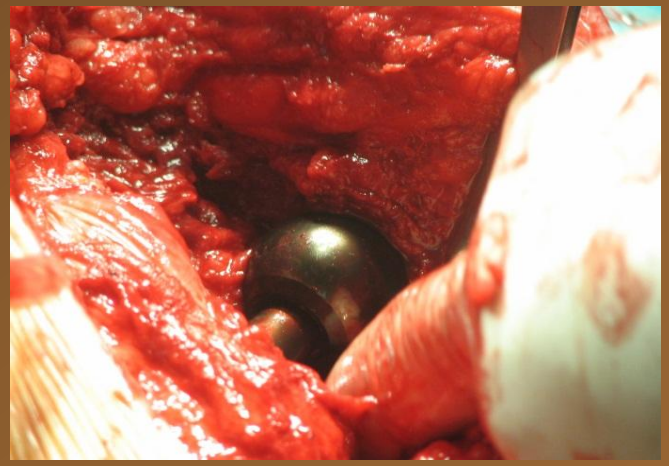
Clinical Results





J. Grabarczyk, I. Kotela ,Plasma modification of medical implants by carbon coatings depositions, Journal of Achievements in Materials and Manufacturing Engineering, vol. 37, 2009





- J. Grabarczyk, D. Batory, P. Louda, P. Couvrat, I. Kotela, K. Bakowicz-Mitura, Carbon coatings for medical implants, Journal of Achievements In Materiale and Manufacturing Engineering, volume 20 ISSUES 1-2, January-February 2007, str. 107-110
- K.Mitura, A.Karczemska, P.Niedzielski, J.Grabarczyk, W.Kaczorowski, P.Louda, and S.Mitura, ‘Nanocrystalline carbon coatings and powders for medicine’, Int. J. Nanomanufacturing, Vol. 2, Nos. 1/2, 2008, pp.29–39.

PPHU MEDGAL – Białystok, Poland

implementation

Antiallergic Implants – Implants with NCD Coatings

about 10000 implants used in surgery

Patent PL 199898 Sposób wytwarzania warstw nanokrystalicznego diamentu na powierzchni wyrobów metalowych, zwłaszcza na powierzchni gwoździ śródszpikowych

Tiara for Queen Elisabeth (2002)

Applications

Shuttle Missions:

STS 32 (Columbia),

STS 44 (Atlantis),

STS 46 (Atlantis),

STS 52 (Columbia),

MIR,

LDF

Jolanta Klemberg-Sapieha, *Polytechnique de Montreal, Canada*

Thank You Very Much

This work was supported by ERA-NET 357/2008 project

- Coordinator - Katarzyna Mitura – Technical University of Lodz, Poland
- Ewa Sawosz– SGGW, Warsaw University of Life Sciences , Poland
- Grzegorz Bartosz – University of Lodz, Poland
- Stefan Pierzynowski – Lund University, Sweden
- Andre Chwalibog – University of Copenhagen, Denmark