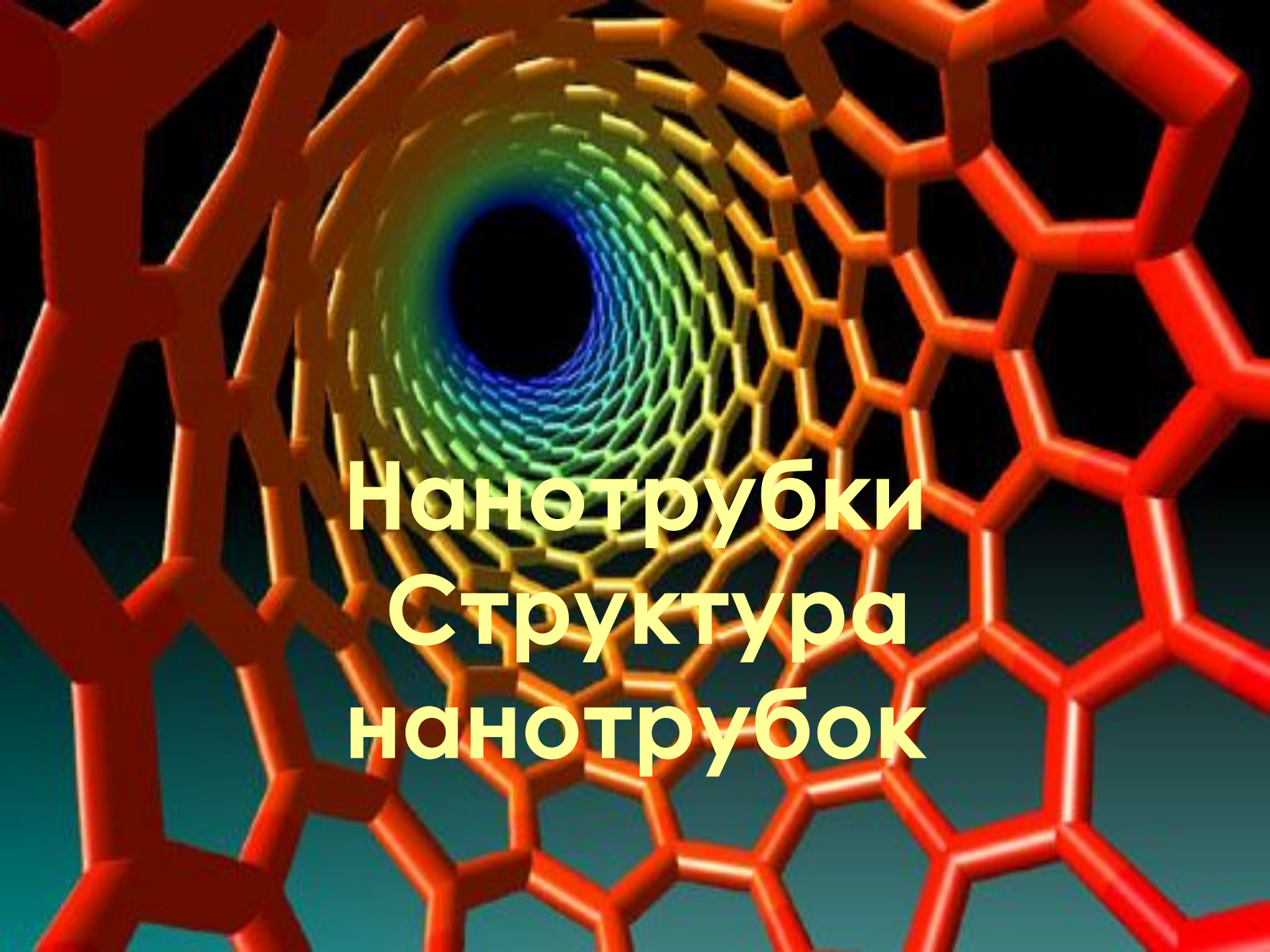
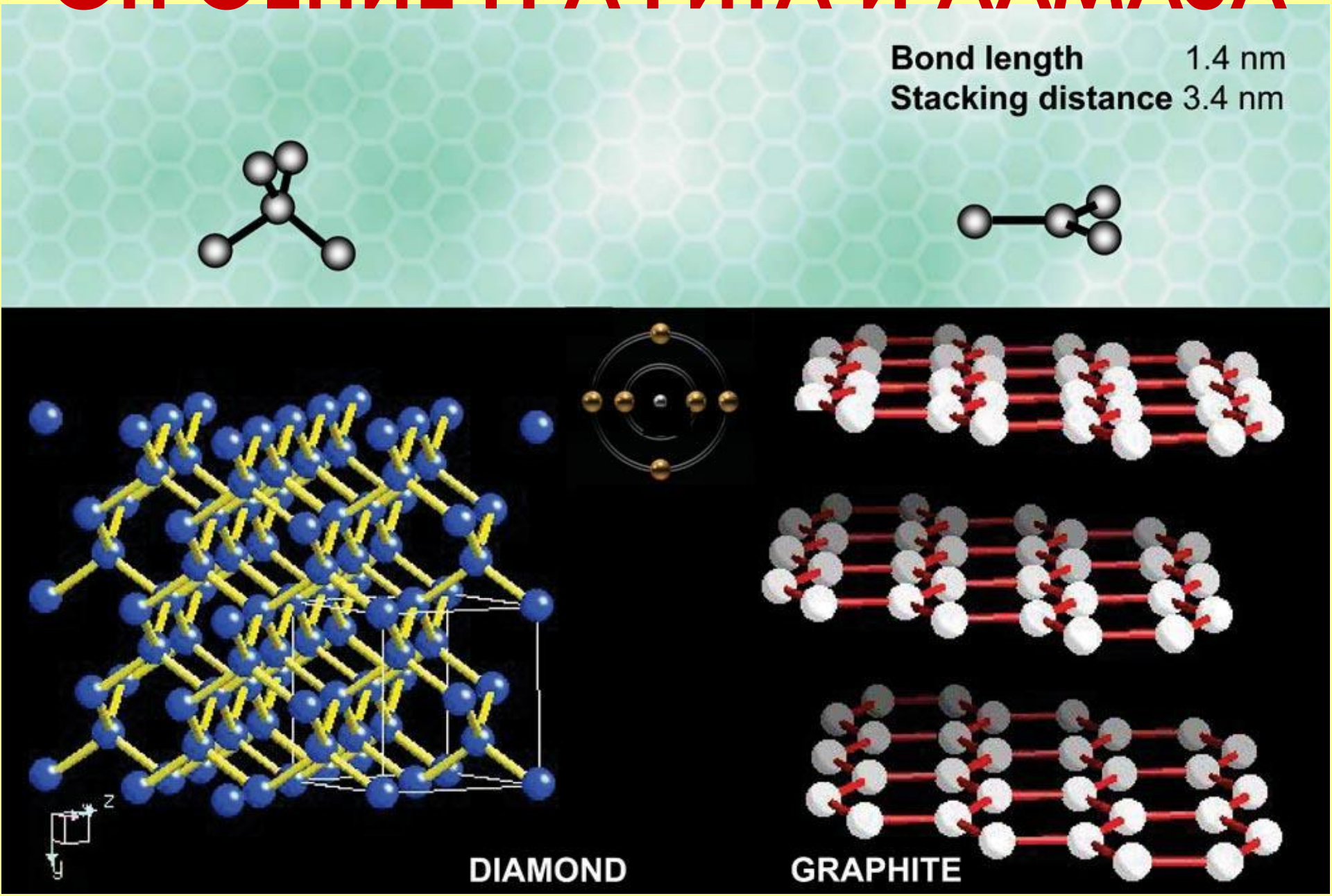
ОСНОВЫ НАНОИНЖЕНЕРИИ

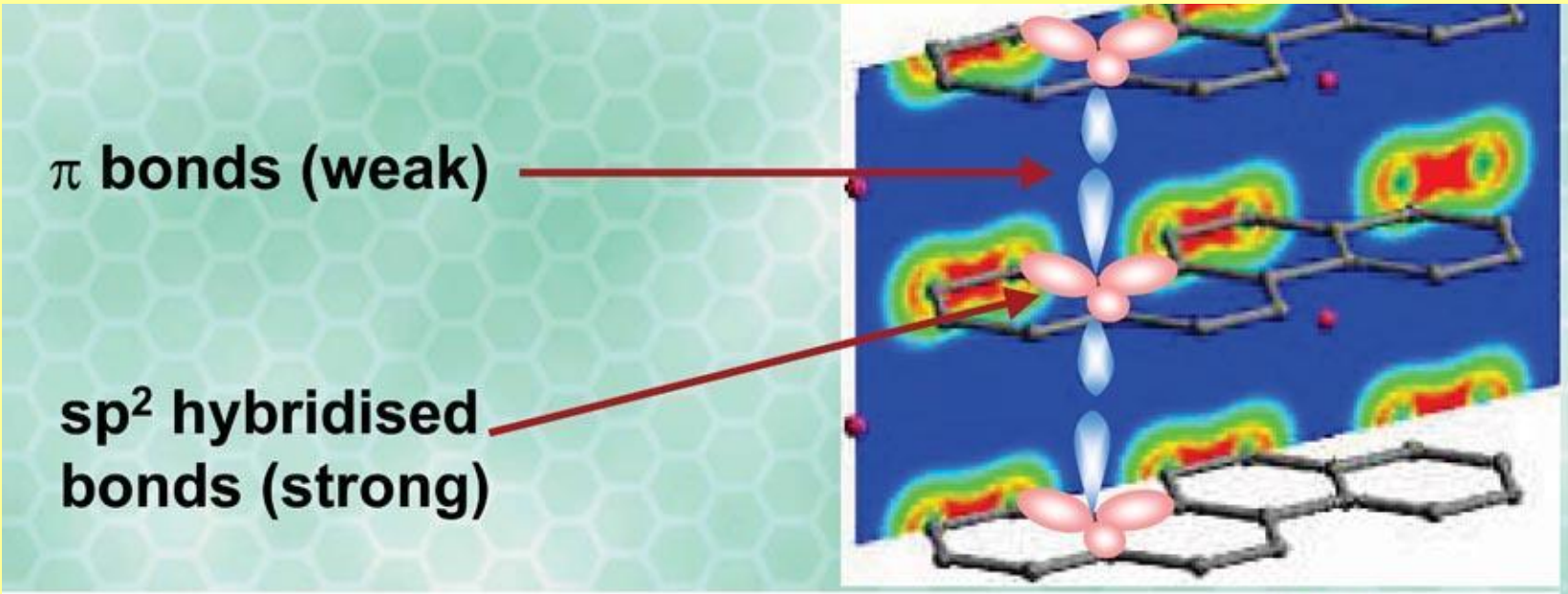
Классификация наночастиц

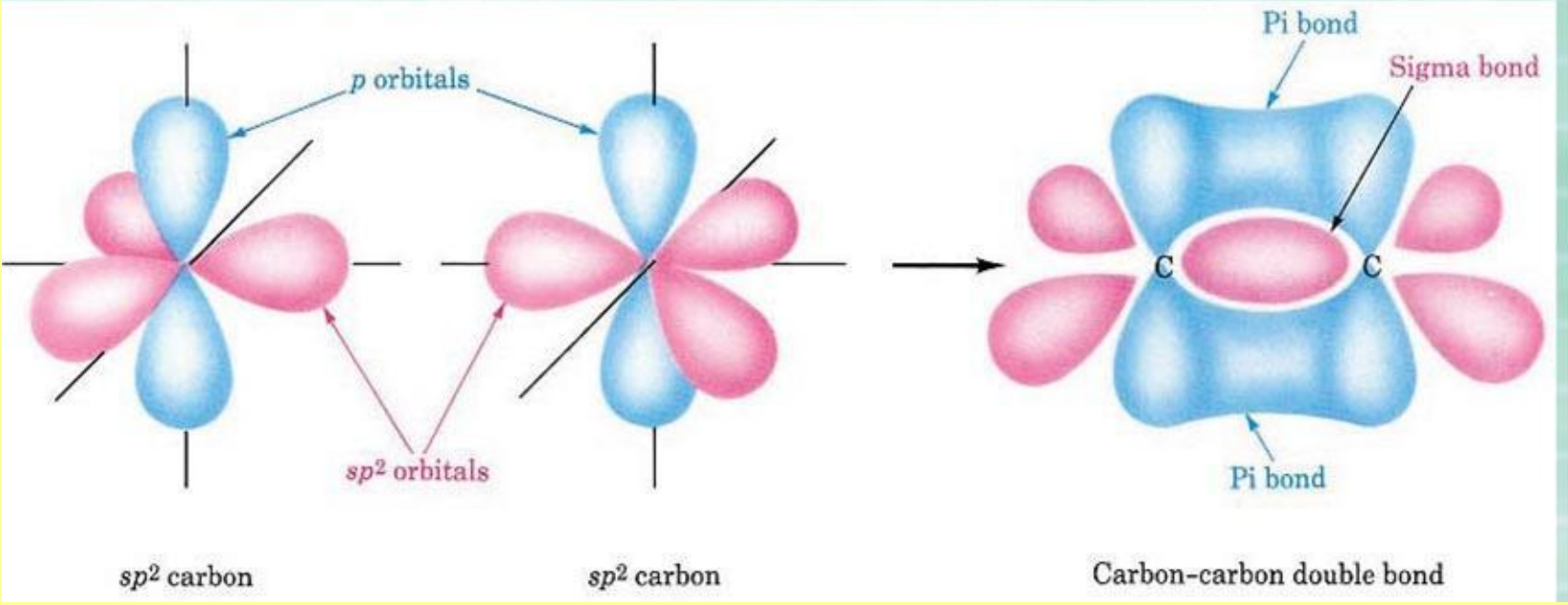

Нанотрубки
Структура
нанотрубок

СТРОЕНИЕ ГРАФИТА И АЛМАЗА



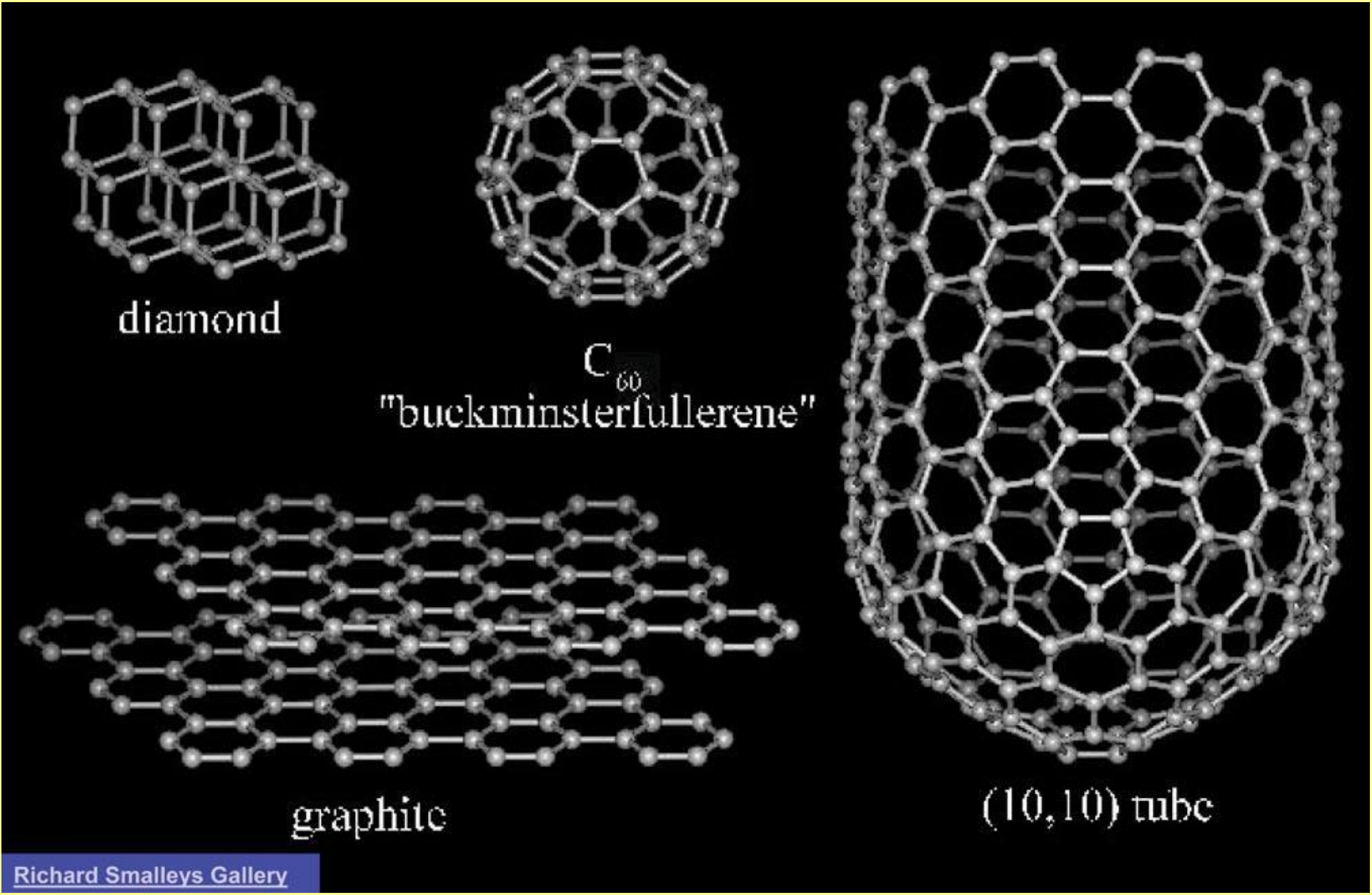
СВЯЗИ И ГИБРИДИЗАЦИЯ



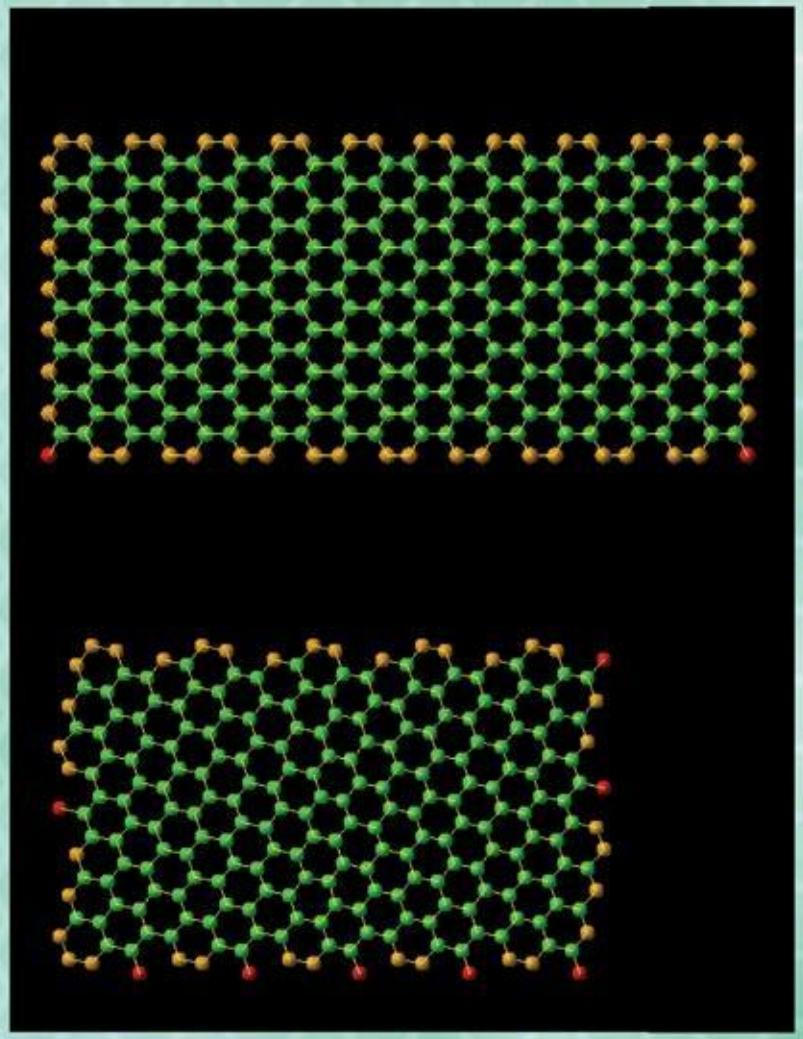


ПРАВДА УГЛЕРОД…?

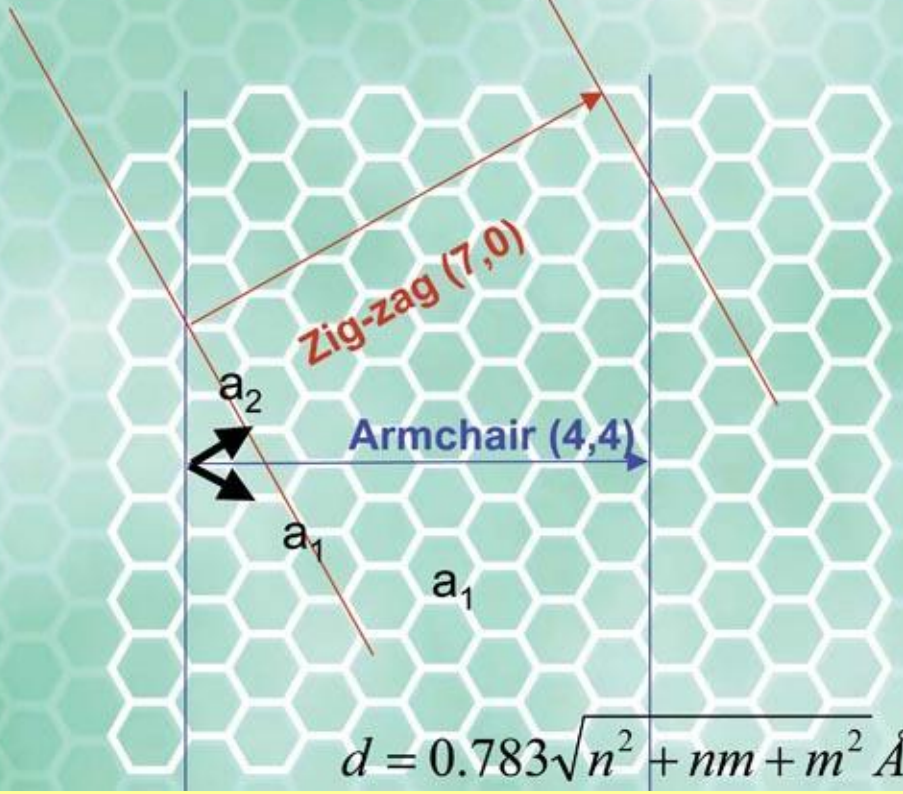
АЛЛОТРОПНЫЕ МОДИФИКАЦИИ УГЛЕРОДА



ВРАЩЕНИЕ СЛОЕВ ГРАФЕНОВ

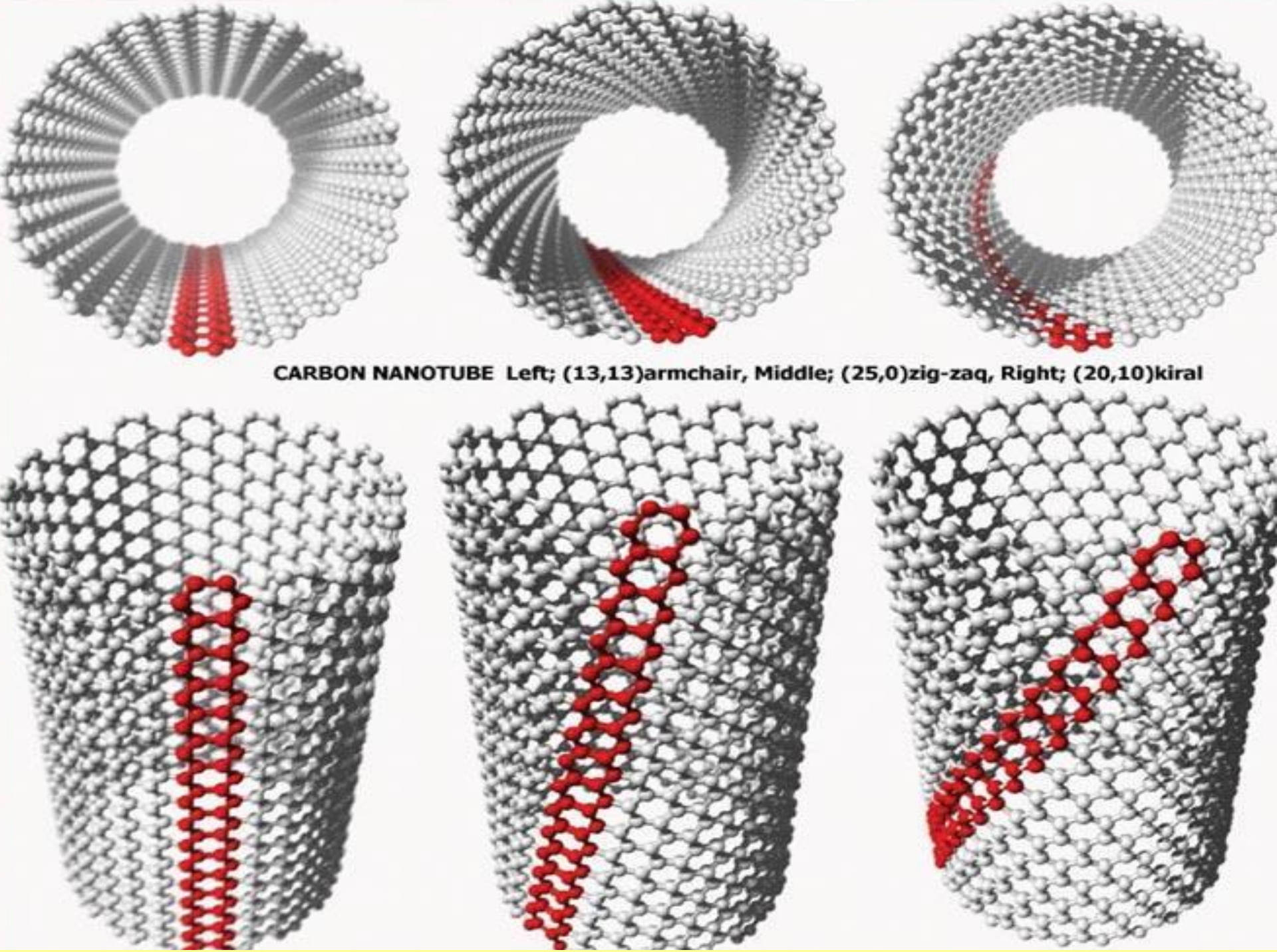


- Nanotubes can be rolled in different angles between 0 and 30 degrees.
- They are classified by the chirality vector given by the base lattice vectors a_1 and a_2: $C = n\,a_1 + m\,a_2$



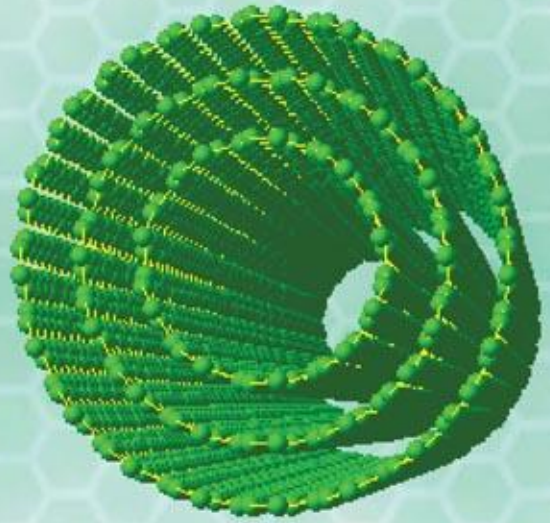
$$d = 0.783\sqrt{n^2 + nm + m^2}\ \text{Å}$$

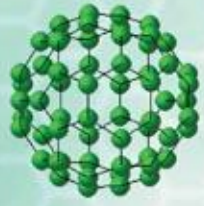
Simulation Gallery



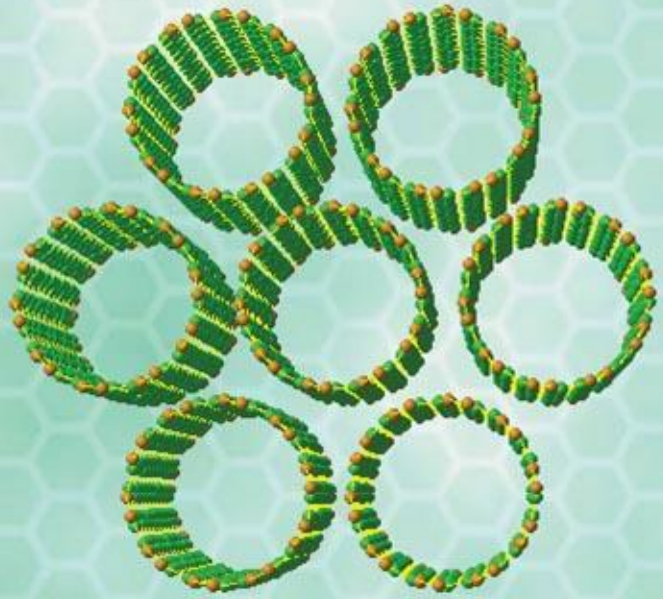
CARBON NANOTUBE Left; (13,13)armchair, Middle; (25,0)zig-zaq, Right; (20,10)kiral

ДРУГИЕ ВИДЫ НАНОТРУБОК





C60



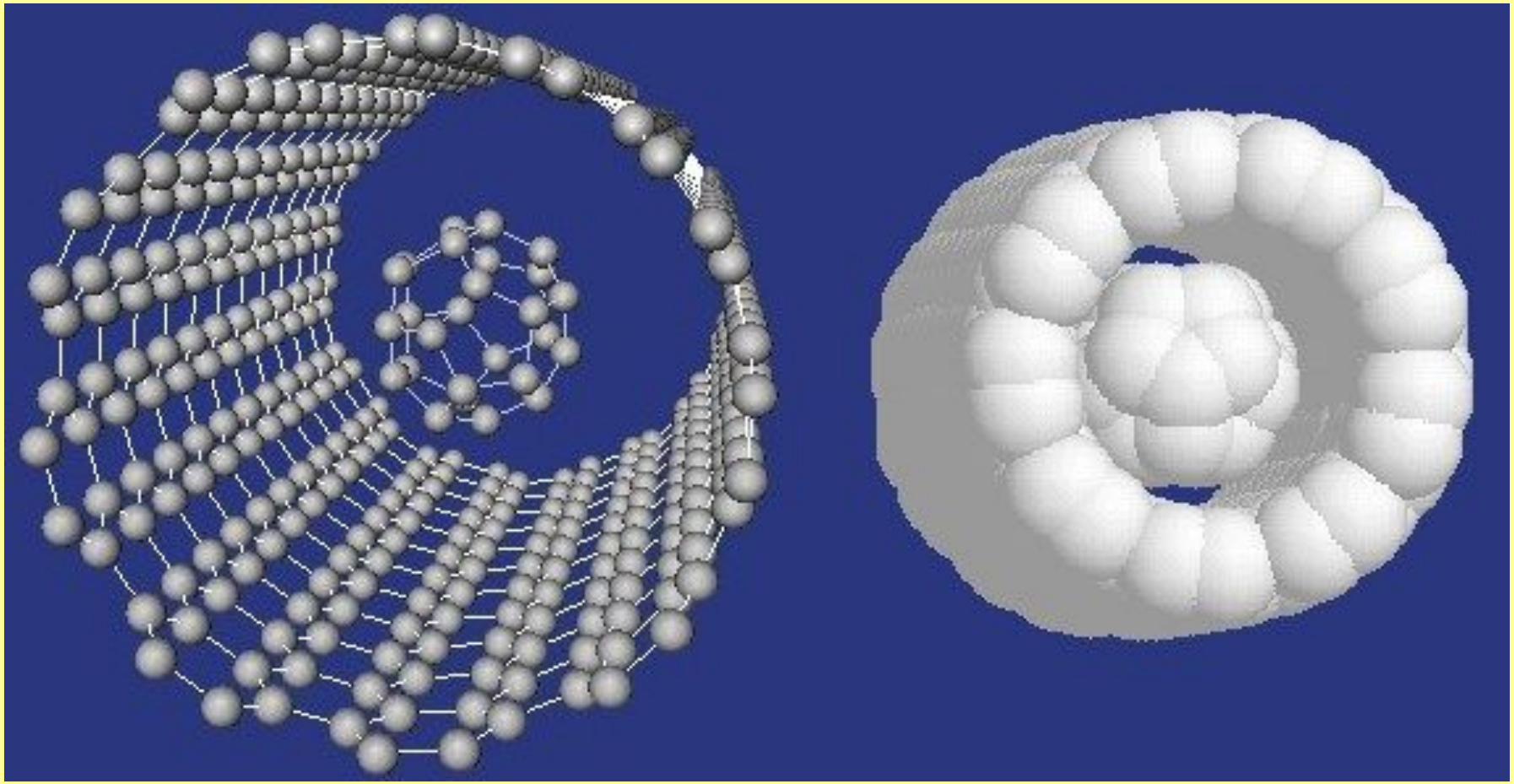
Multi-walled nanotube (MWNT)

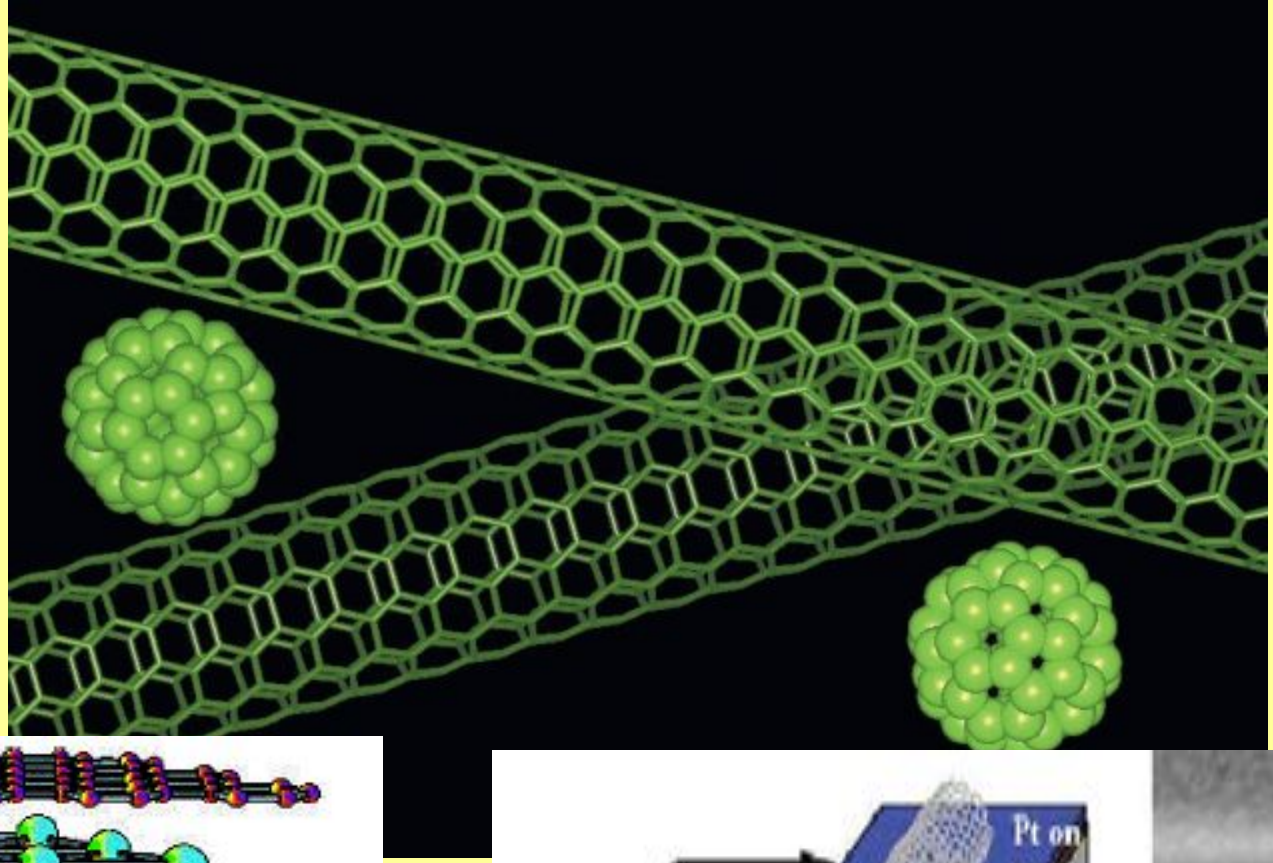
- 5-50 walls interspacing: 3.5 nm (like graphite)
- diameters normally around 10-50 nm (can be up to 200 nm)
- Can be very long, several 100 μm
- Walls slide easily inside each other (like graphite)
- The layers have independent chiralities (one may be armchair, the next zig-zag)

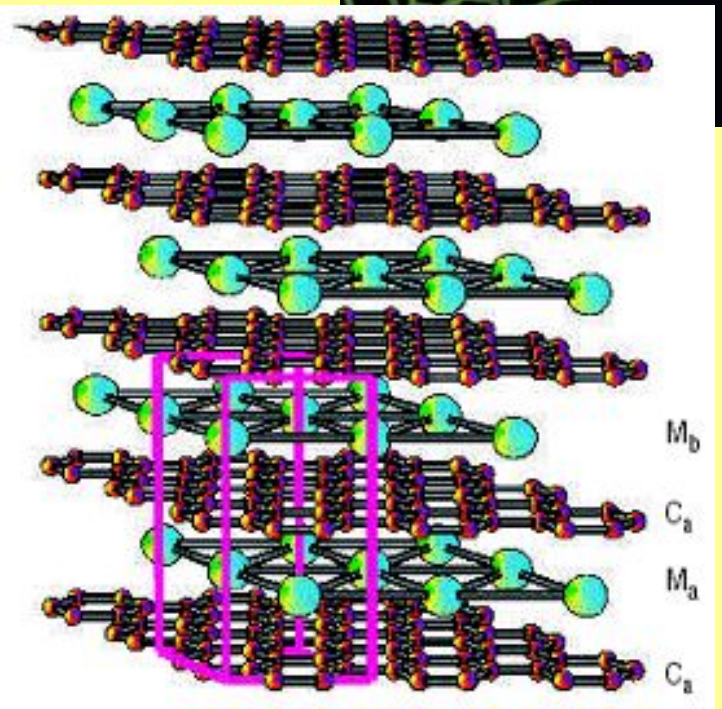
Nanotube rope

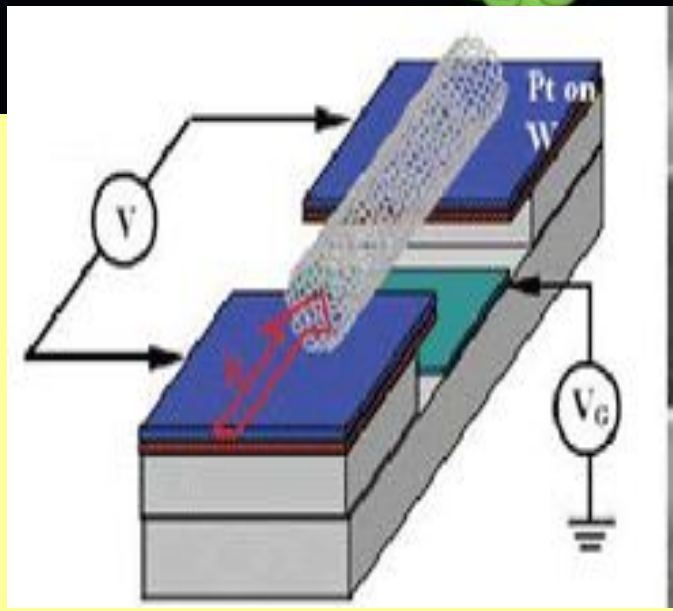
- Like graphite, the layers slide easily on each other
- Stick together by van der Waals forces

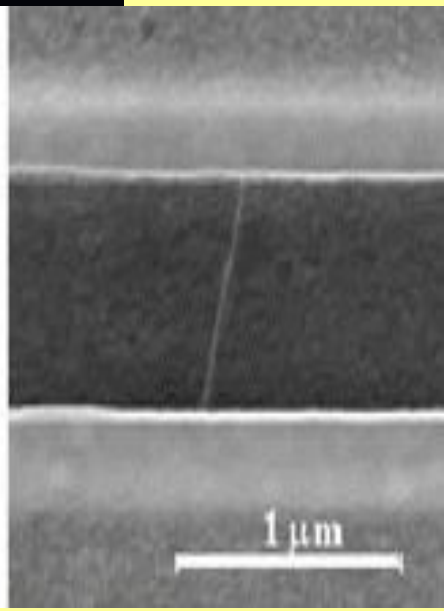
Нанопоршень из фуллерена и нанотрубки



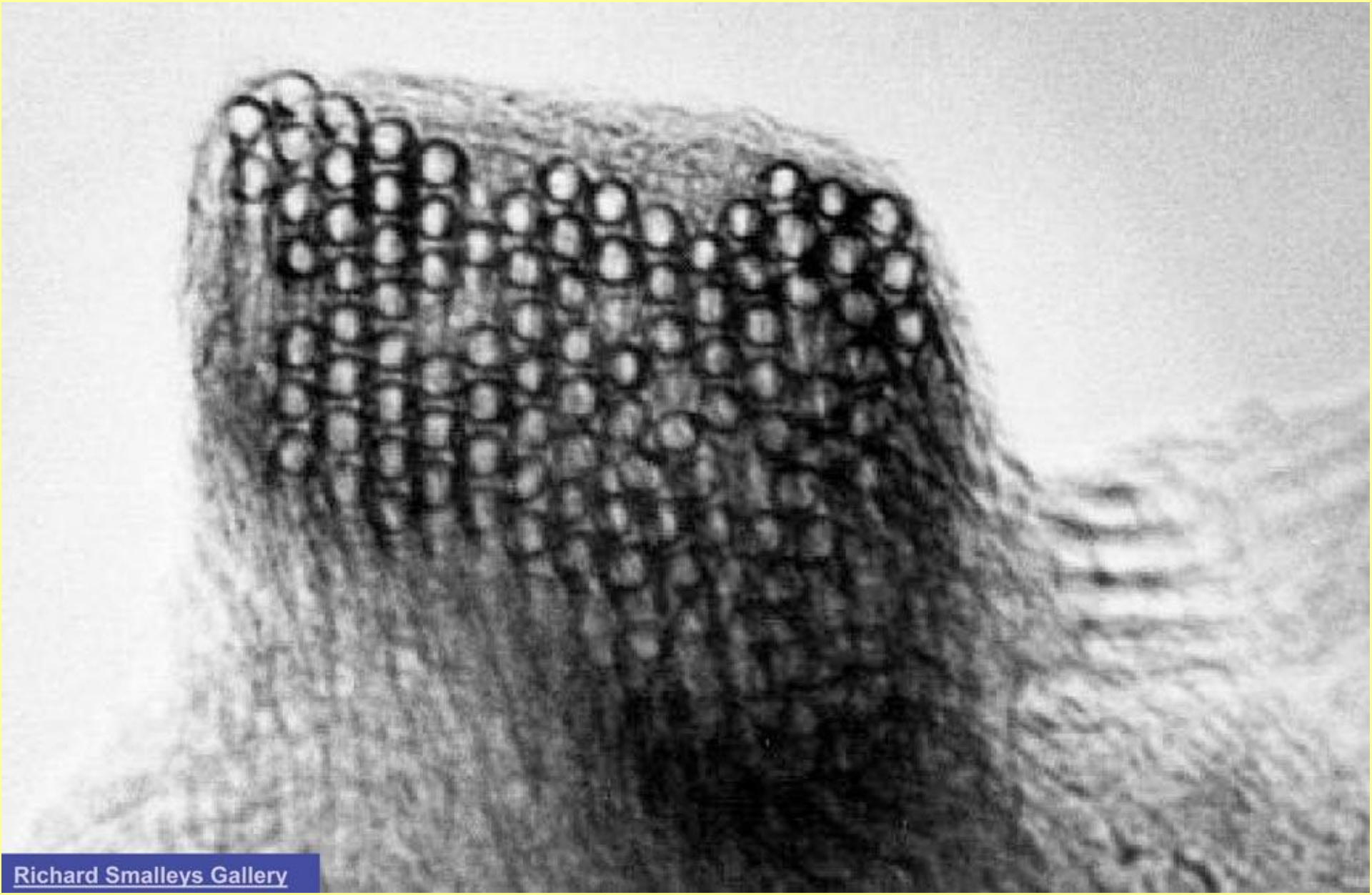



M_b
C_a
M_a
C_a


Pt on
W
V
V_G

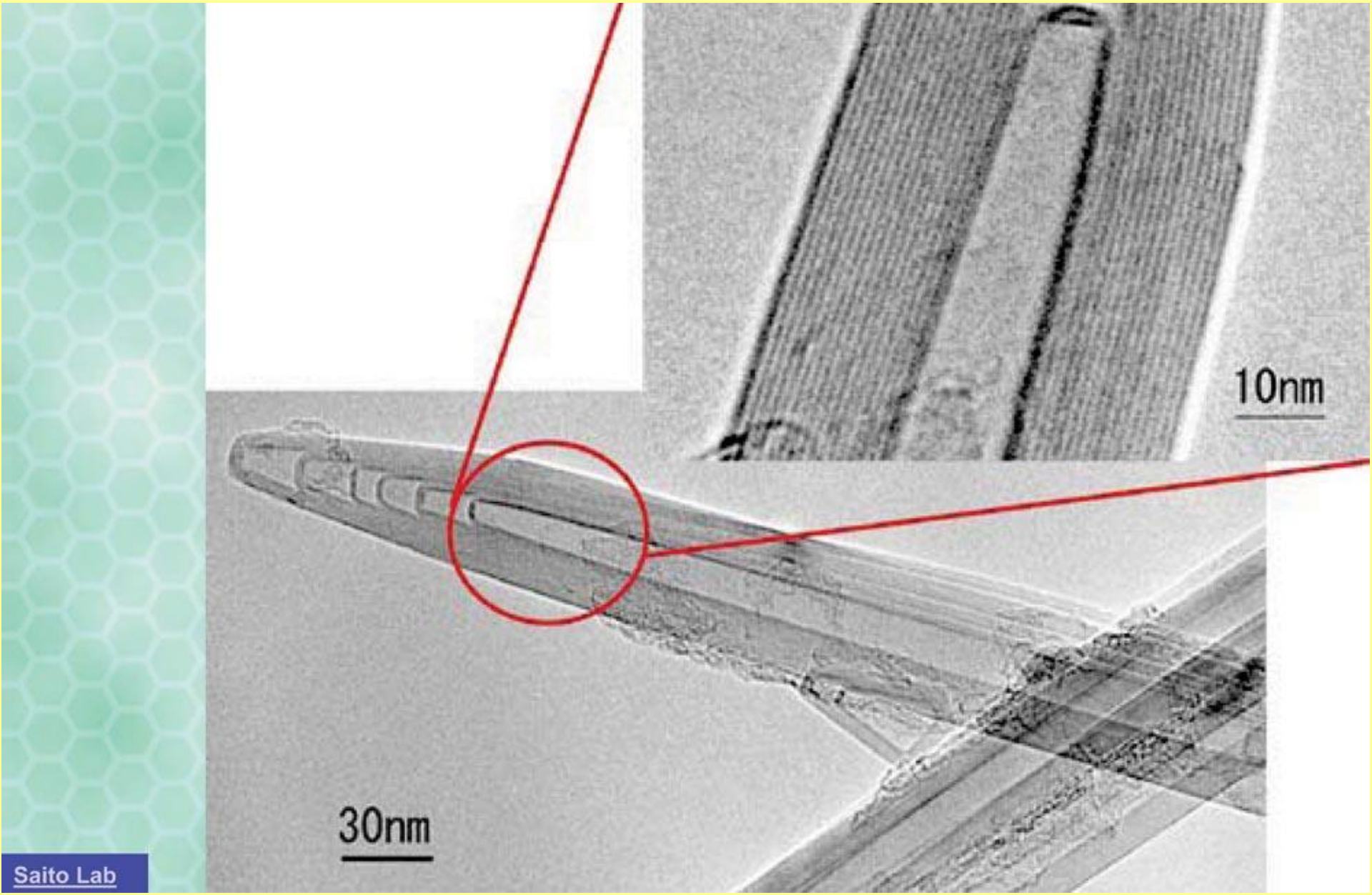

1 μm

ФОРМИРОВАНИЕ НАНОТРУБКИ



Richard Smalleys Gallery

МНОГОСЛОЙНЫЕ НАНОТРУБКИ



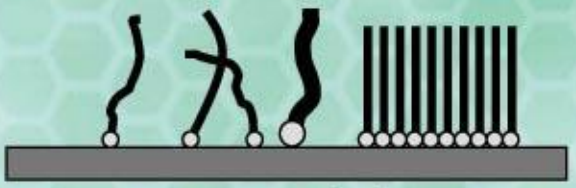
Методы формирования

МЕТОДЫ ПОЛУЧЕНИЯ НАНОТРУБОК

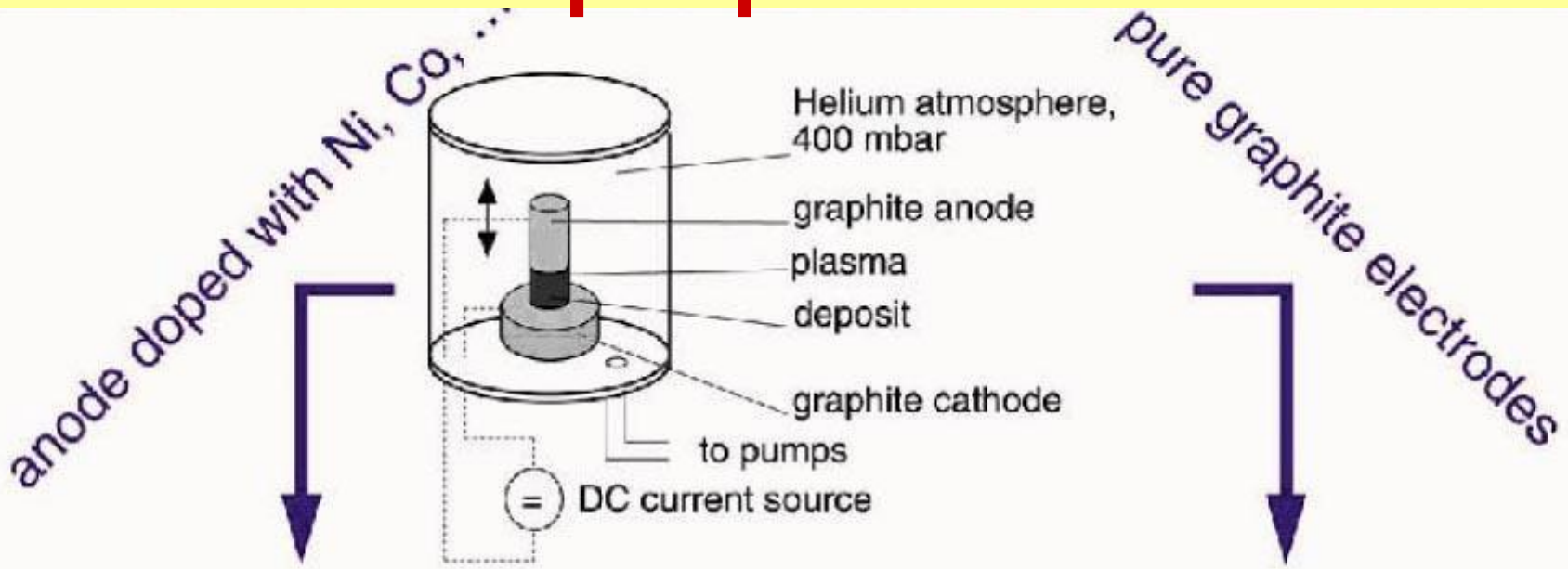
- **Arc discharge**
  - Carbon is evaporated by a plasma of Helium . This is ignited by a high current passing through a graphite anode and cathode

- **Laser evaporation**
  - Direct laser vaporization of transitional metal (e.g. Co-Ni,1%) graphite composite electrode targets is done in helium atmosphere at high temperatures (1200^{o}C).

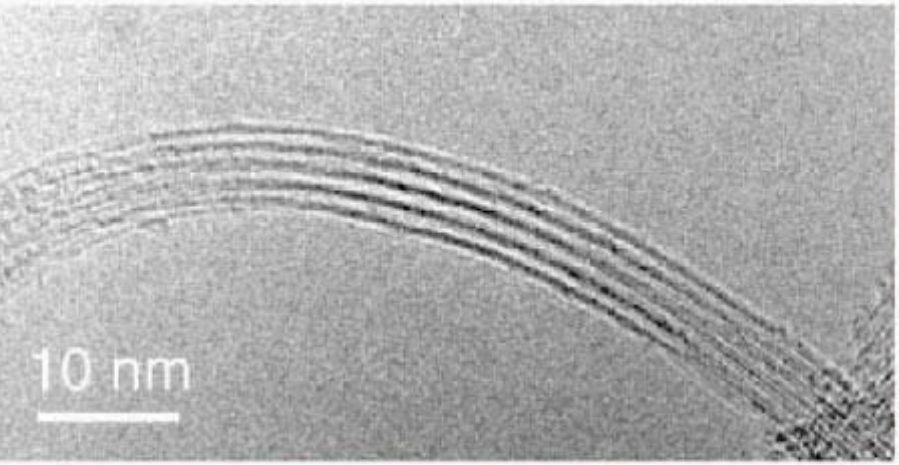
- **Chemical vapor deposition**
  - Organic gas is decomposed (e.g. Methane) in an oven containing catalyst particles, at 600-800C. The diameter and type of catalyst particles determine the nanotube diameter and properties.



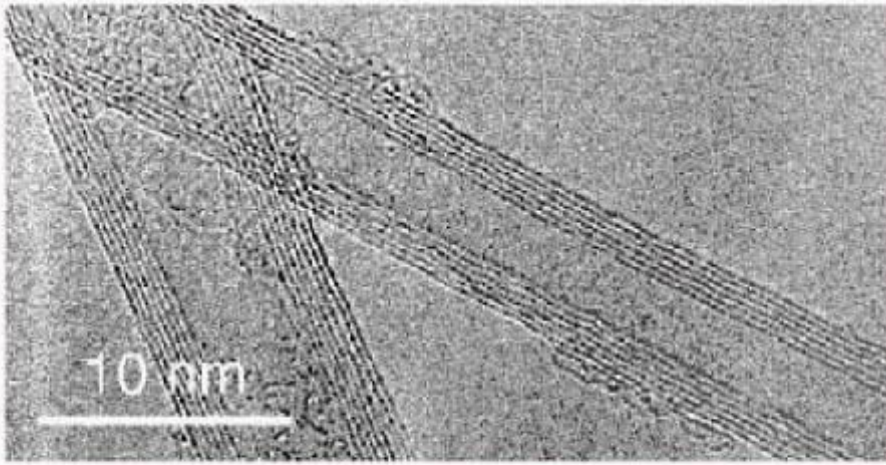
Электродуговое распыление графита



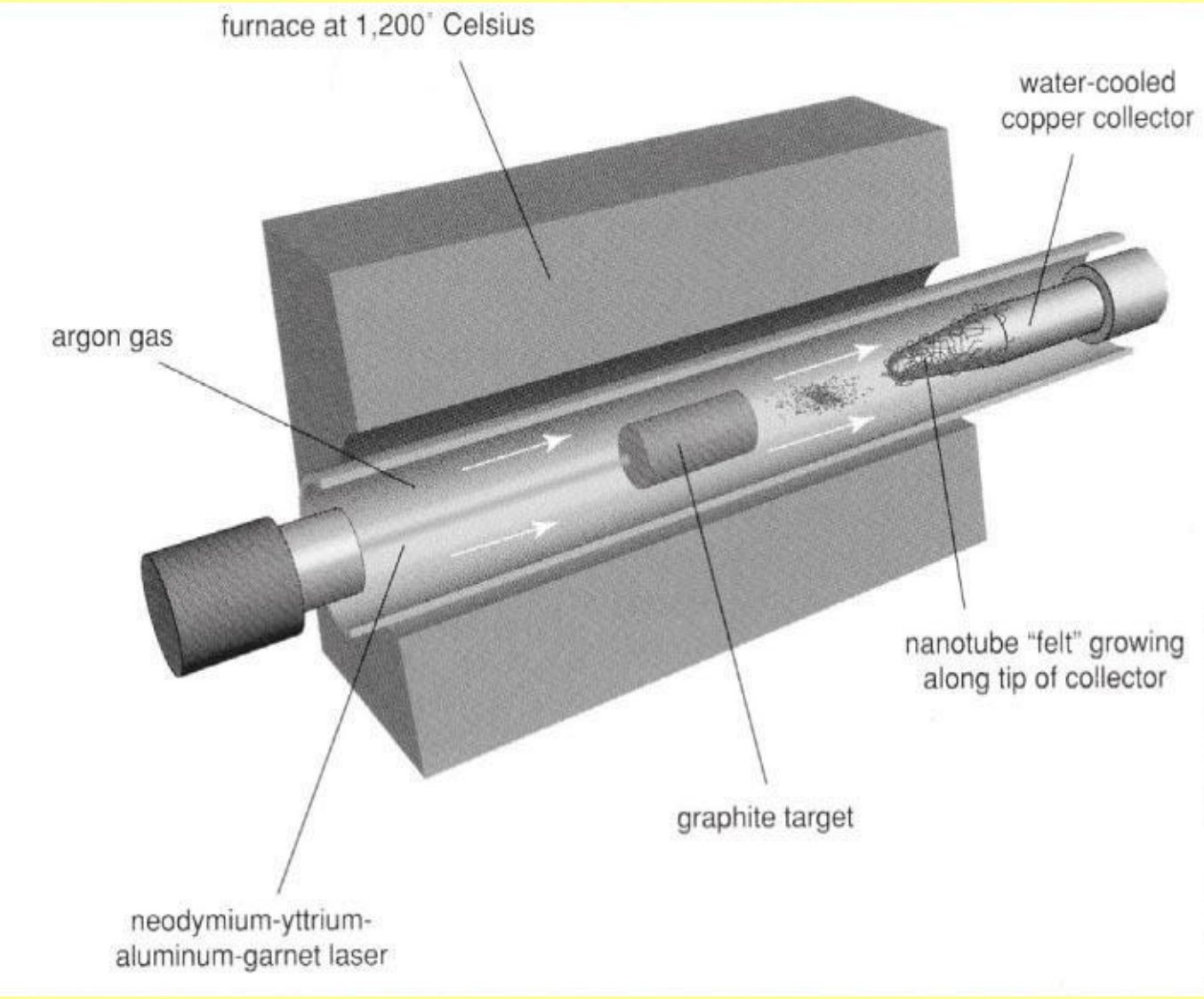
Single wall nanotubes

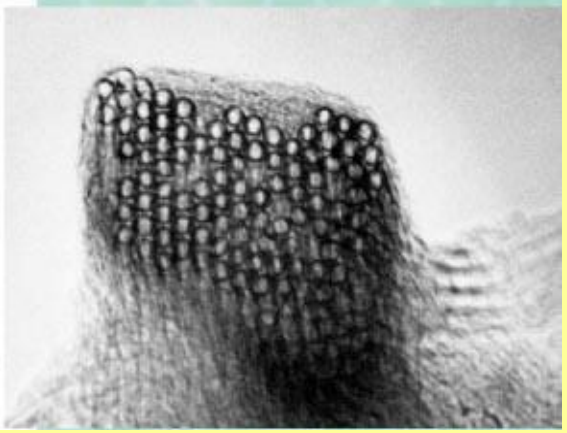


Multiwall nanotubes



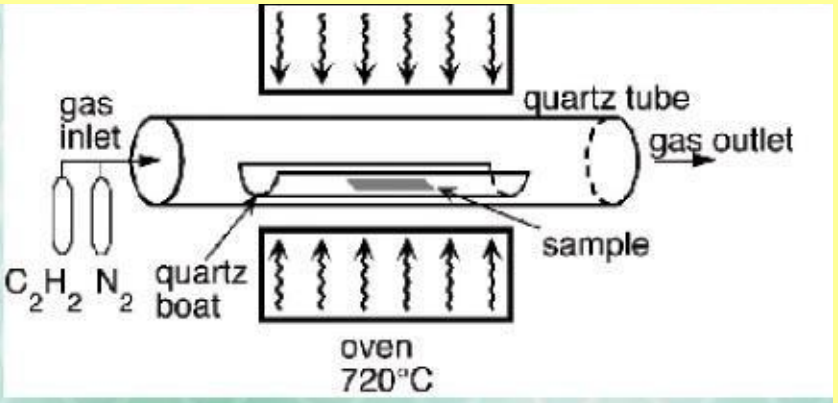
Лазерное испарение графита

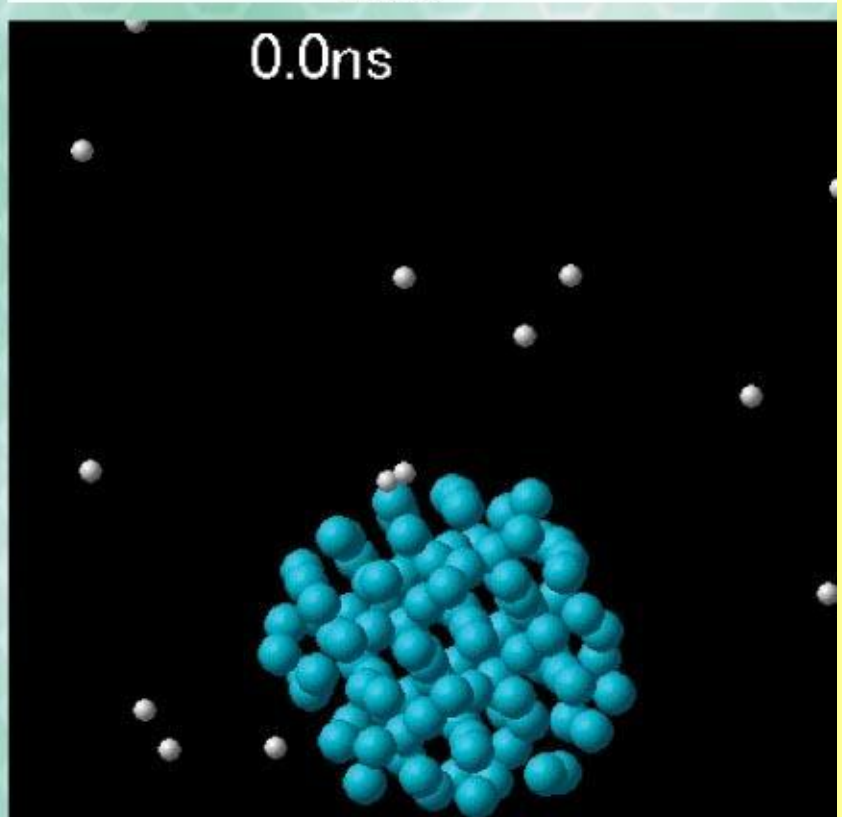




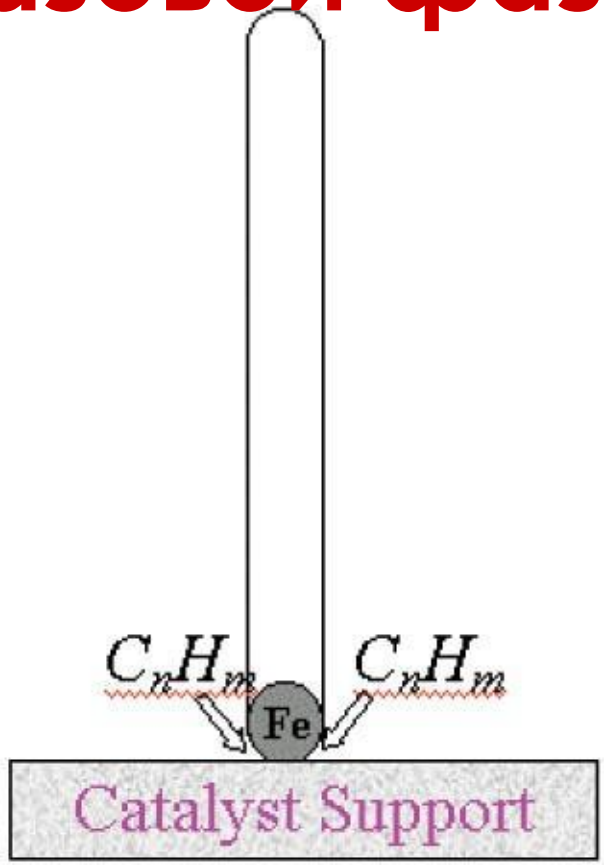
Метод химического осаждения из пара

- **CVD**
  - A hydrocarbon gas is decomposed at a high temperature
  - Carbon diffuses into catalyst particle Ni, Fe and is expelled in form of a nanotube
- **MWNT:**
  - Acetylene, 600 – 800°C.
- **SWNT**
  - Carbon monooxide, 900 – 1200°C (SWNT have higher formation energy)
- **Result:**
  - SWNT and MWNT of moderate quality
  - Many impurities and defects
  - large quantities, can be lithographically positioned

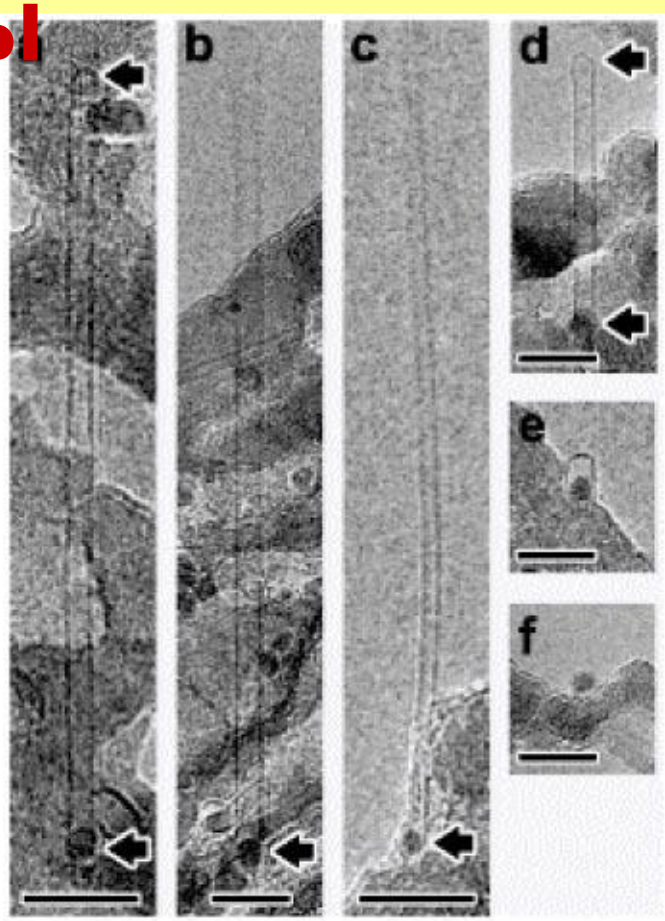




Химическое осаждение из газовой фазы



'Base' Growth Model

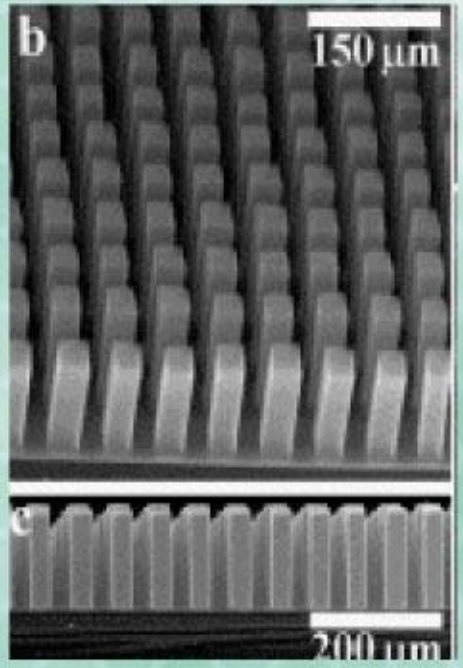


TEM data showing particle-tube relation

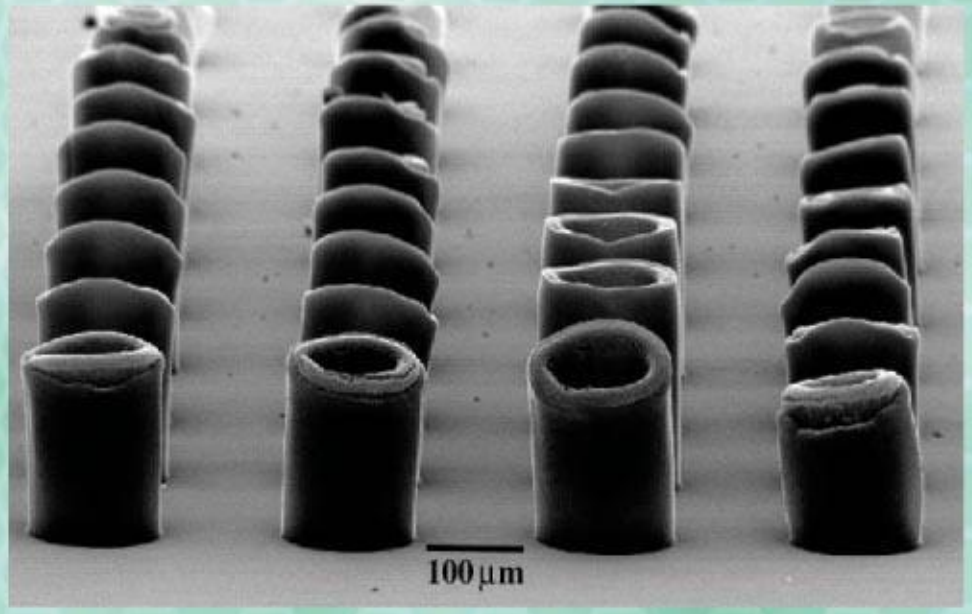
The catalyst particles grow from the base, and keep growing as long as the process continues and the catalyst is not encapsulated by carbon soot

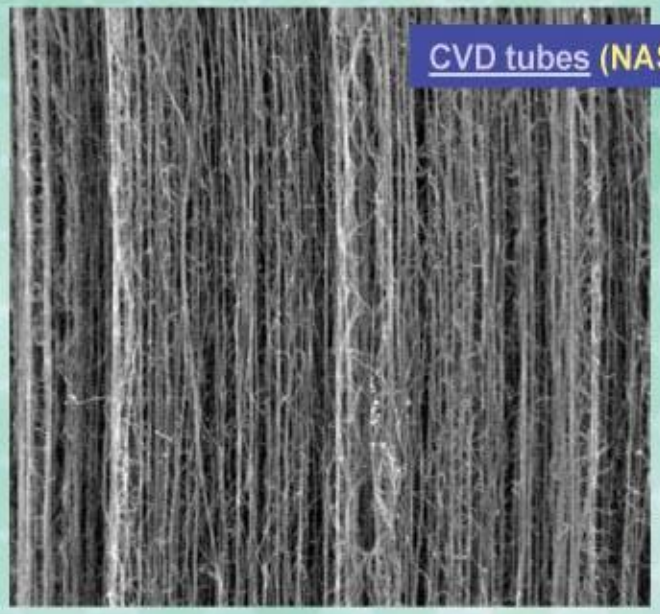
CVD tubes (Stanford)

- **Catalyst printing**
  - Catalyst material is lithographically deposited on a surface. The nanotubes grow straight up in thick ropes matching the footprint of the catalyst
  - Applications> field emission displays .



CVD tubes (Stanford)





CVD tubes (NASA)

ПОЛУЧЕНИЕ НАНОЧАСТИЦ СЕРЕБРА