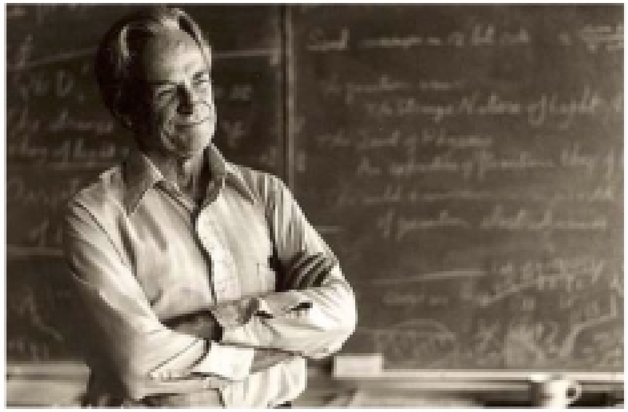
History

"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom."

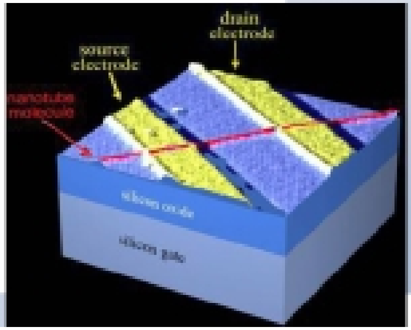
I am afraid to consider the final question as to whether, ultimately in the great future we can arrange the atoms the way we want; the very atoms, all the way down! ..."

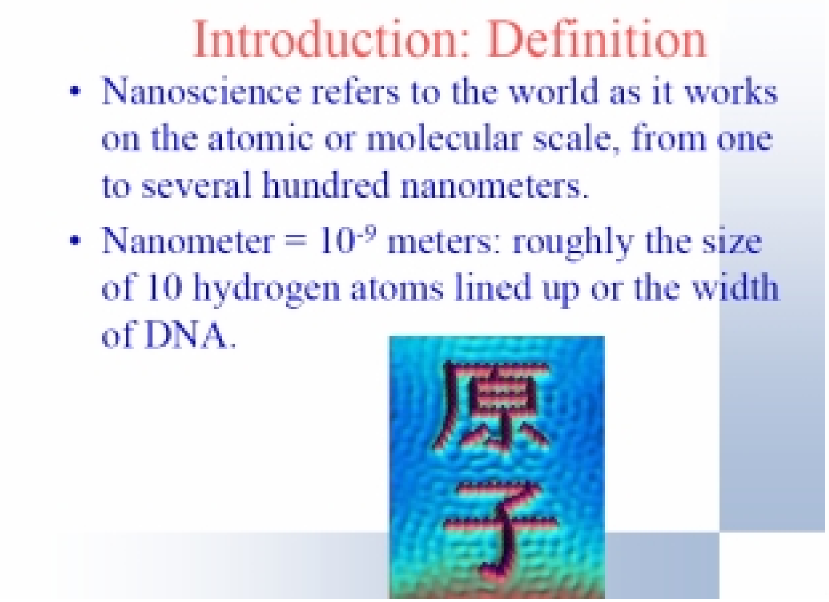


Richard Feynman (1959)

- *"...Why can't we make them very small, make them of little wires... the wires could be 10 or 100 atoms in diameter, and the circuits could be a few [hundred nanometers] across."*

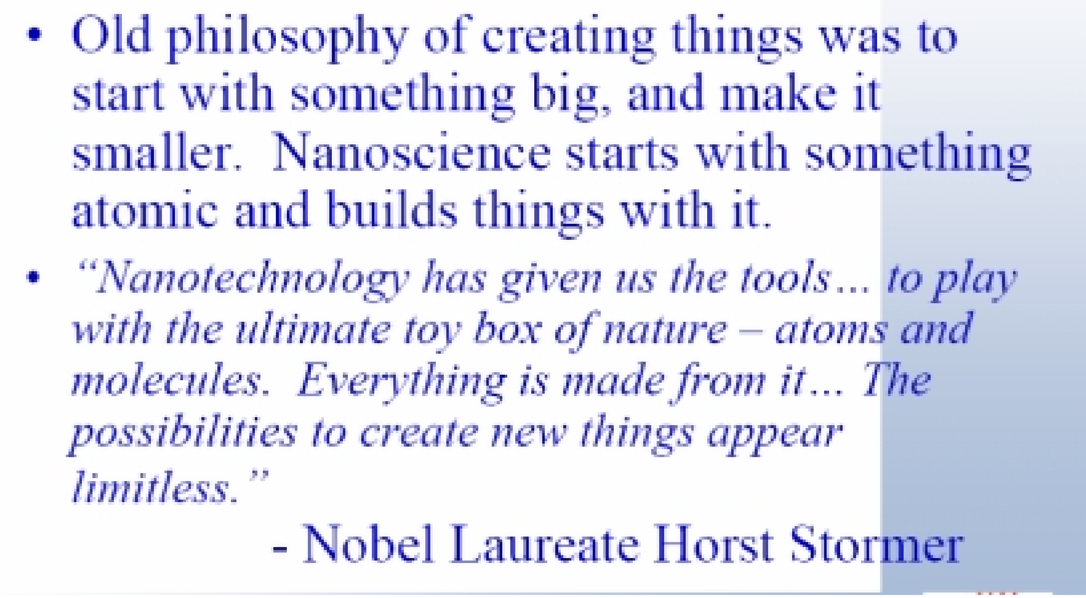
  – Richard Feynman on computers.





Introduction: Definition

- Nanoscience refers to the world as it works on the atomic or molecular scale, from one to several hundred nanometers.
- Nanometer = 10^{-9} meters: roughly the size of 10 hydrogen atoms lined up or the width of DNA.



- Old philosophy of creating things was to start with something big, and make it smaller. Nanoscience starts with something atomic and builds things with it.
- *"Nanotechnology has given us the tools… to play with the ultimate toy box of nature – atoms and molecules. Everything is made from it… The possibilities to create new things appear limitless."*

  \- Nobel Laureate Horst Stormer

Atoms and molecules are generally less than a nm and we study them in chemistry.

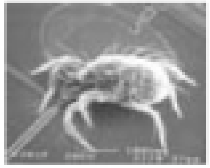
Quantum chemistry does not apply,
But the fundamental laws hold, and
And the system are not large enough
For classical laws of physics.

Nano – Tree

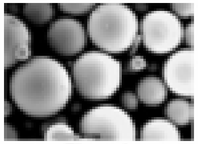
essential is invisible to the eye" A. de Saint-Exupery, "La Petit Prince"

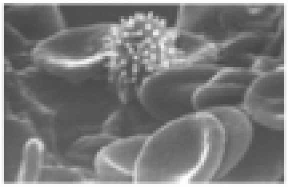
Realize Size

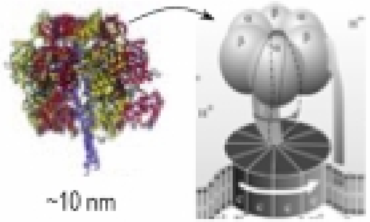
Things Natural


Dust mite
200 µm

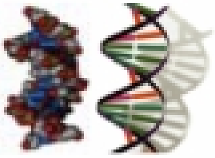

Ant
~ 5 mm

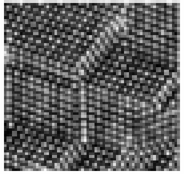

Fly ash
~ 10-20 µm

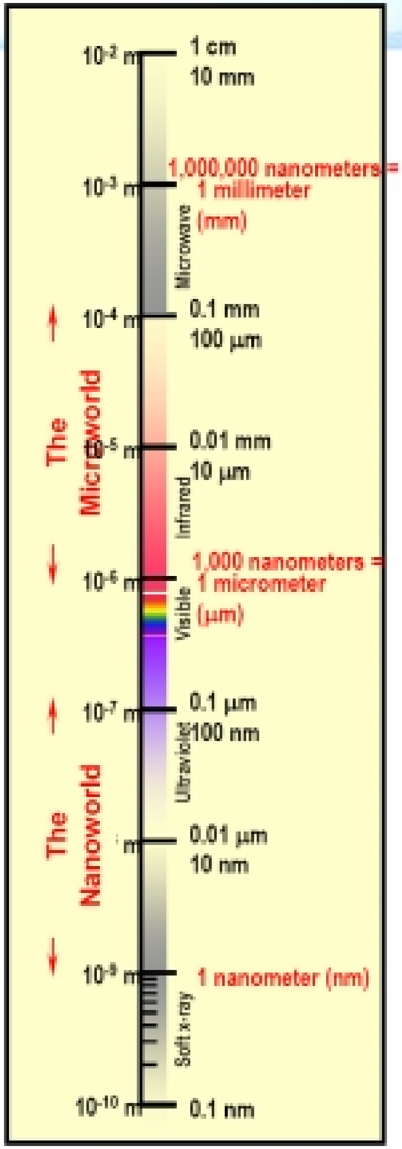

Red blood cells with white cell
~ 2-5 µm


~10 nm diameter

ATP synthase


DNA
~2-1/2 nm diameter

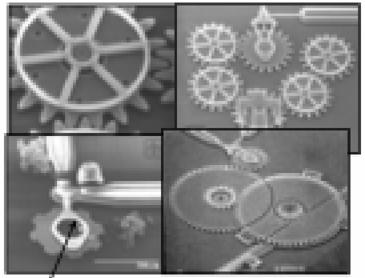

Atoms of silicon
spacing ~tenths of nm

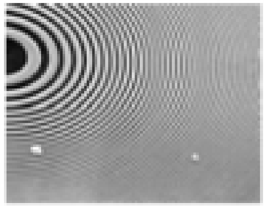


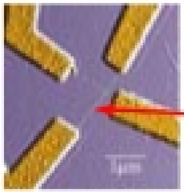
Things Manmade

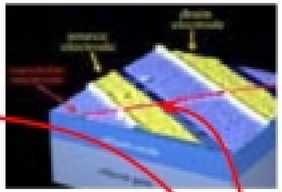

Head of a pin
1-2 mm

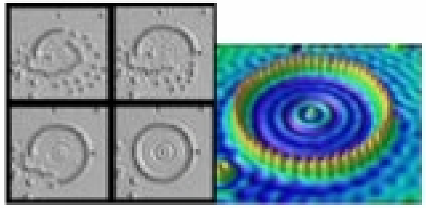
MicroElectroMechanical devices
10 -100 µm wide

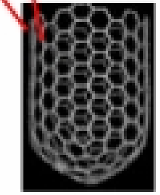

Red blood cells


Zone plate x-ray "lens"
Outermost ring spacing
~35 nm

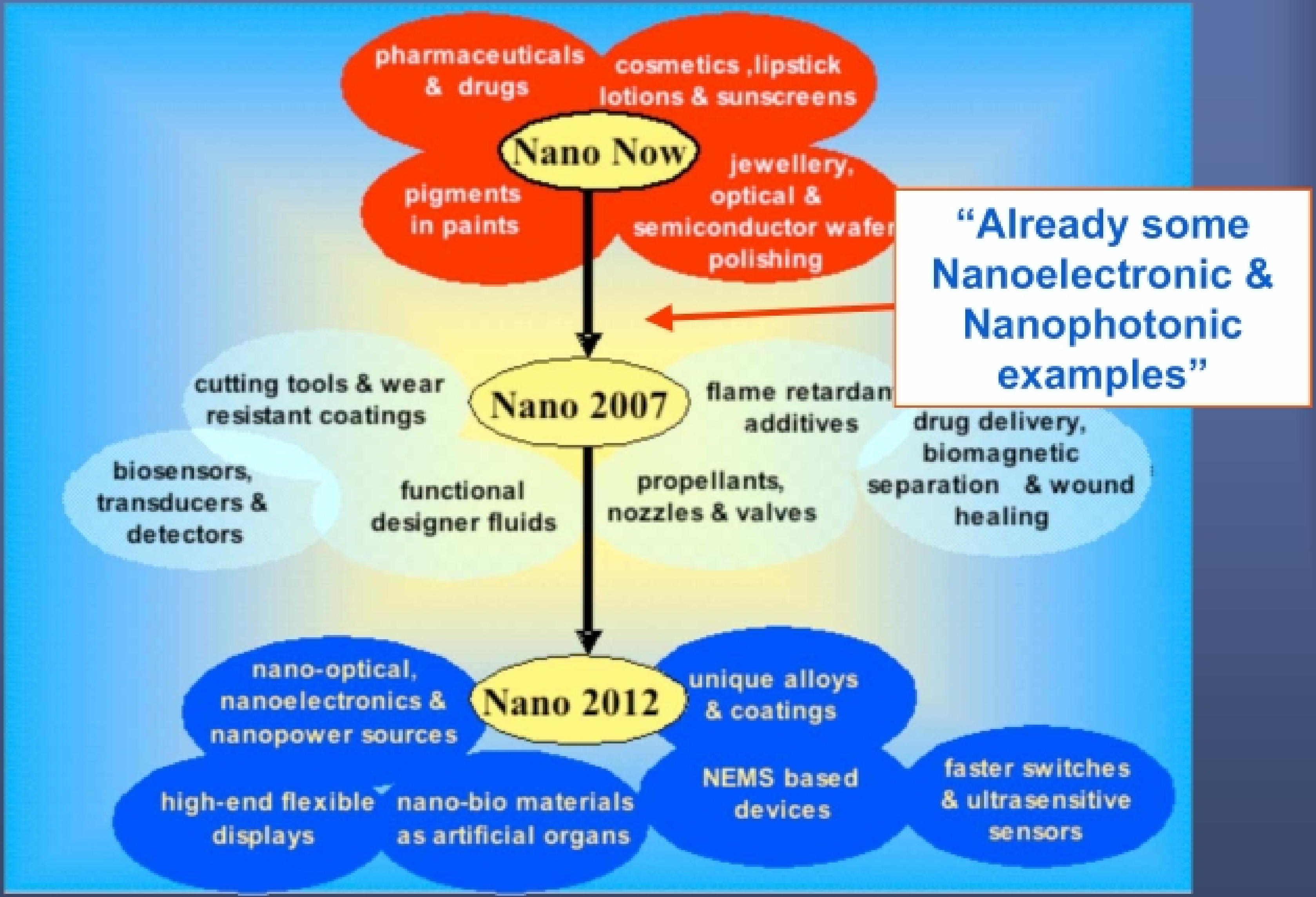

Nanotube electrode


Nanotube transistor


Quantum corral of 48 iron atoms on copper surface
positioned one at a time with an STM tip
Corral diameter 14 nm


Carbon nanotube
~2 nm diameter

Nanotechnology Timeline



Nano Now

pharmaceuticals & drugs

cosmetics ,lipstick lotions & sunscreens

pigments in paints

jewellery, optical & semiconductor wafer polishing

Nano 2007

cutting tools & wear resistant coatings

flame retardan additives

biosensors, transducers & detectors

functional designer fluids

propellants, nozzles & valves

drug delivery, biomagnetic separation & wound healing

Nano 2012

nano-optical, nanoelectronics & nanopower sources

unique alloys & coatings

high-end flexible displays

nano-bio materials as artificial organs

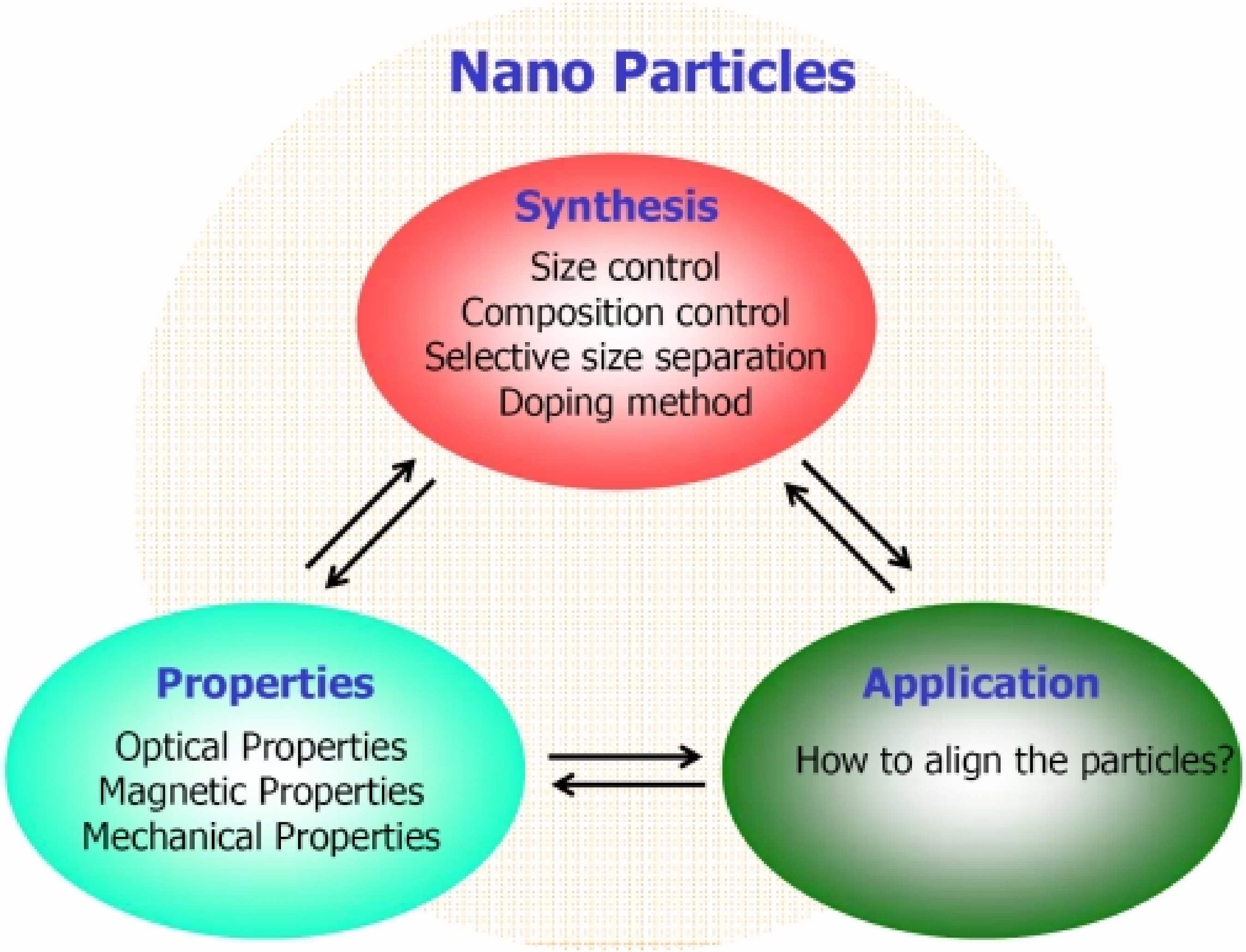
NEMS based devices

faster switches & ultrasensitive sensors

"Already some Nanoelectronic & Nanophotonic examples"

(Small Wonders, Endless Frontiers, Review NNI, NRC, 2002)

Research in Nanoparticles



Nano Particles

Synthesis

Size control
Composition control
Selective size separation
Doping method

Properties

Optical Properties
Magnetic Properties
Mechanical Properties

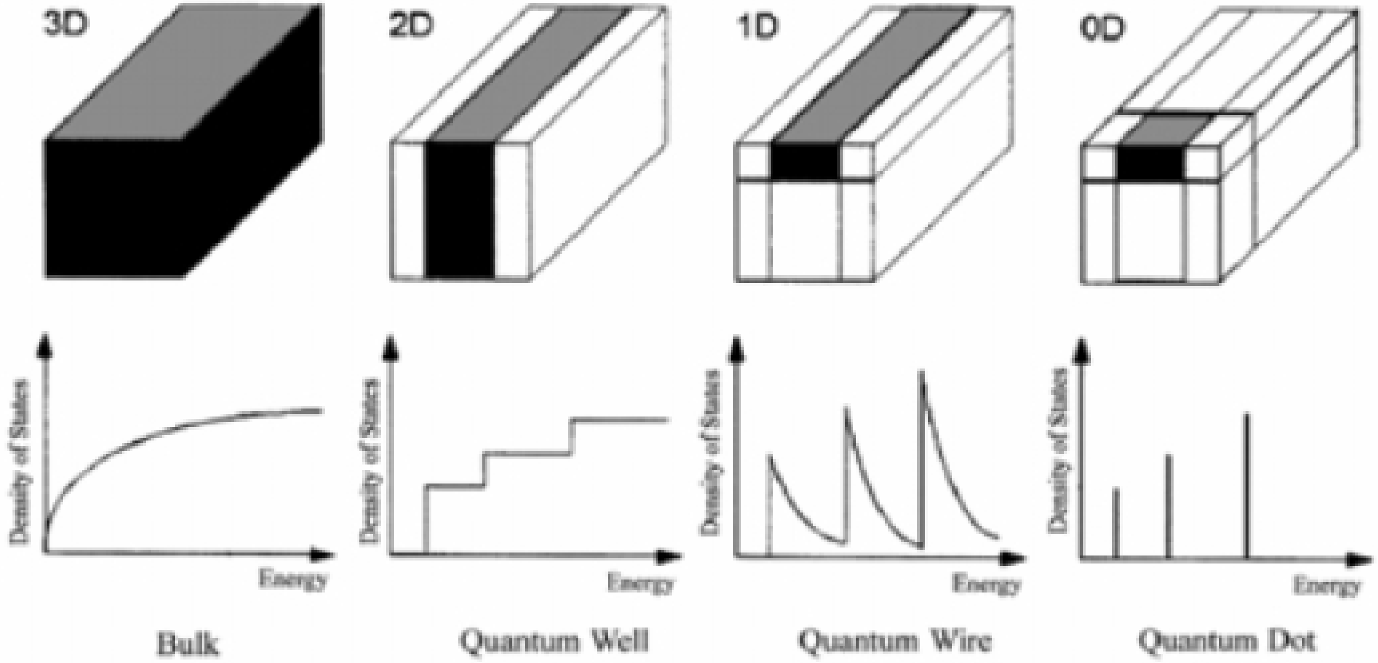
Application

How to align the particles?

Overview of Nanoparticle

- **Basic Concept**
  - Introduction of nanoparticles 125-70,000 atoms, < 100 nm
  - Size Dependent Properties
  - Colloidal Stability
- **Wet Chemistry**
  - Metal Nanoparticles
  - Semiconductor
  - Ceramics
  - Polymer nanoparticles
- **Other Methods**
  - Mechanochemical Process
  - VLC mechanism
  - Combustion method

Important Parameter



Bulk Quantum Well Quantum Wire Quantum Dot

FIGURE 2.5 Formation of a zero-dimensional (0D) quantum dot by the formal reduction of dimensions, correlating with the continuing discretization of the energy states.

1. Metal : Electron mean path

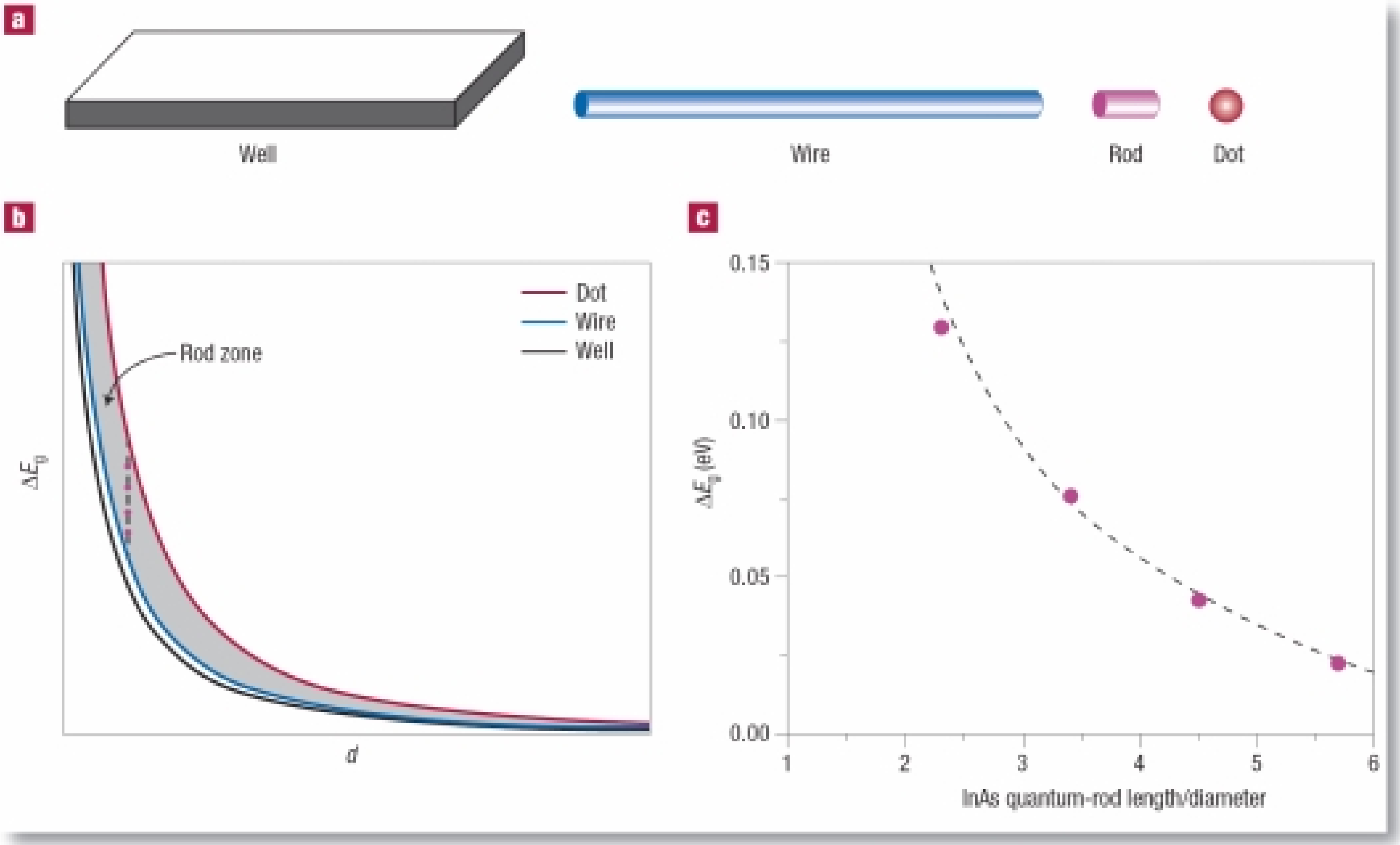
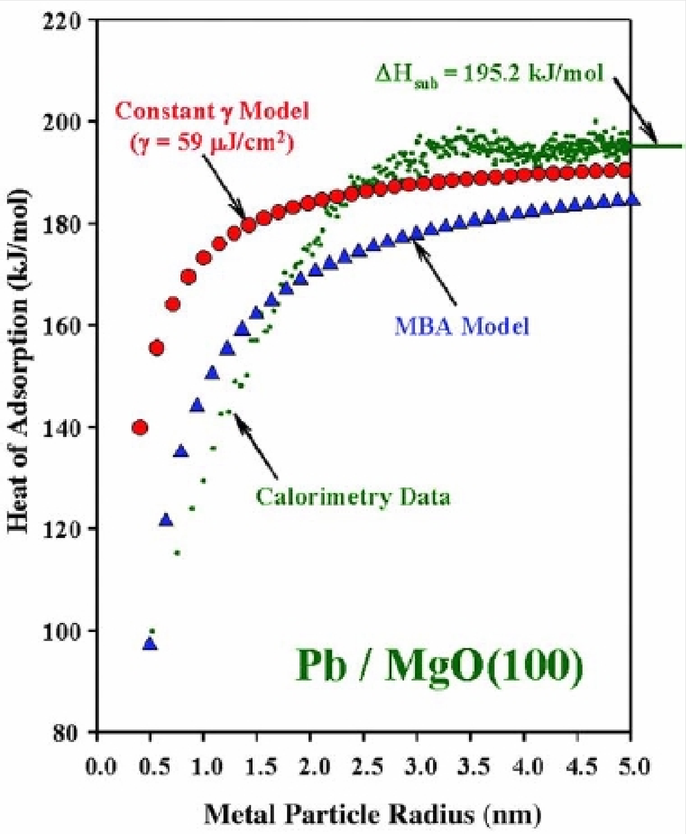


Figure 1 Comparisons of quantum wells, wires, rods and dots. **a,** Geometries of the different structures. **b,** Plots of ΔE_g (the increase in the bandgap over the bulk value) against *d* (the thickness or diameter) for rectangular quantum wells, cylindrical quantum wires and spherical quantum dots obtained from particle-in-a-box approximations. The grey area between the dot and wire curves is the intermediate zone corresponding to quantum rods. The vertical dotted line and points qualitatively represent the expected variation in the bandgap for InAs quantum rods of varying length/diameter ratio, as studied by Kan *et al.*[1]. **c,** A plot of ΔE_g against length/diameter ratio for the InAs quantum rods synthesized by Kan *et al.*, showing the dependence of the bandgap on the shape of the quantum rods. The dotted line represents the variation expected from a particle-in-a-box approximation[1].

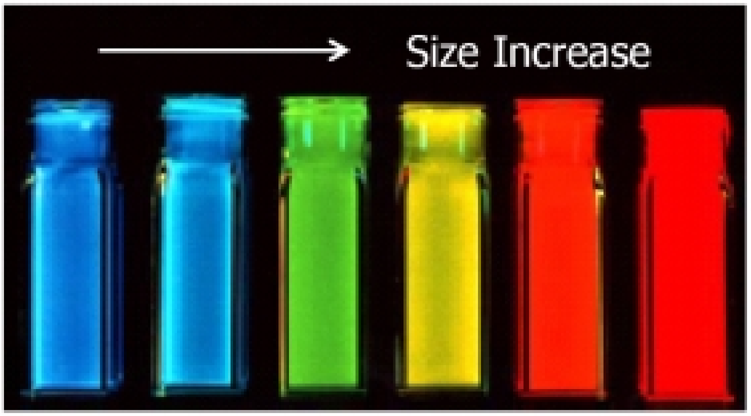
Calorimetric measurements show that the energy dependence of supported Pb particles vary much more quickly than predicted by the Gibbs-Thompson relationship.

“This shows that the surface energy increases substantially as the radius decreases below 3 nm.”

C.T Campbell et. al. Science 298 (2002) 811-814



Important Parameter-Semiconductor

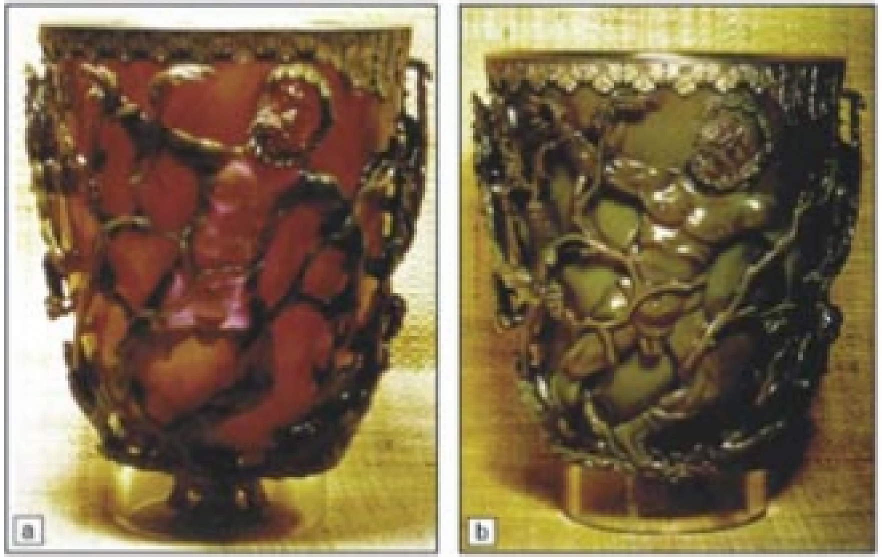


Ex) CdSe

2. Semiconductor : Exciton radius

Size Dependent Optical Properties

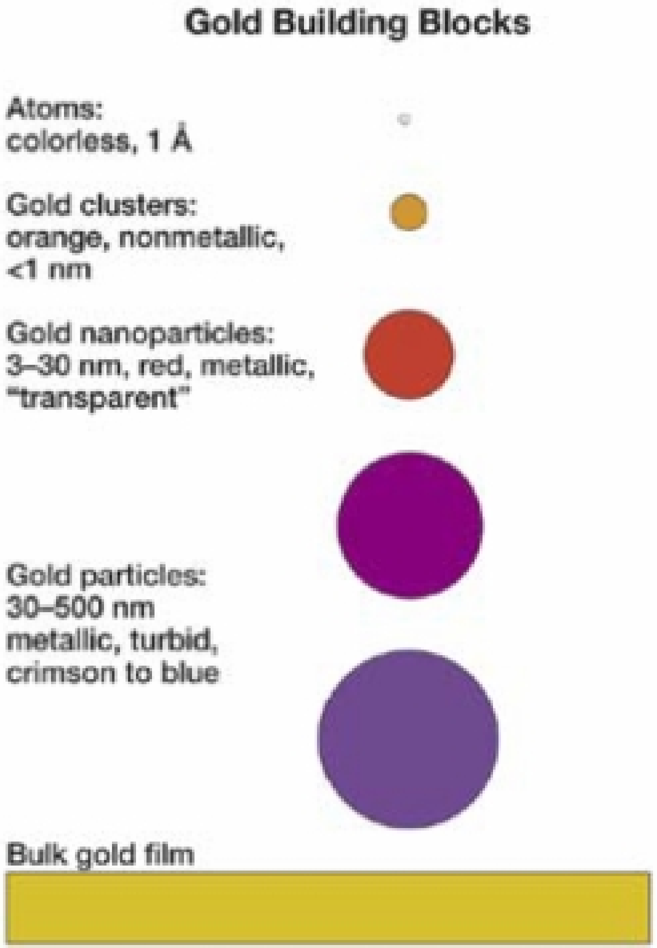
- Lycurgus cup (AD 4세기)



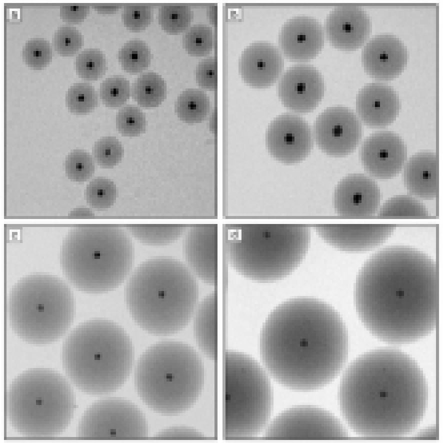
Transmitted light **Reflected light**

➔ 20nm 이하의 gold nano particle를 첨가

- Not all that's Gold does glitter



Size Dependent Optical Properties



- **Au@SiO$_2$ particles**
  - Core : 15nm Au
  - Shell : SiO$_2$
- **Coating Thickness**

→ **Control of Dipole coupling btw particles**

→ **Change of Assembly color**

Size Dependent Optical Properties

- **Au@SiO$_2$ particles**

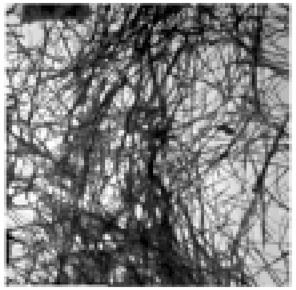

Decreasing gold particle spacing ⟶

The transmitted colors of a series of gold particle films with decreasing particle spacing. The gold core particles are 15nm in diameter; the shell thickness are from left to right, 17.5nm, 12.5nm, 4.6nm, 2.9nm, 1.5nm and 0nm. Films are each 1cm × 3cm. The spectra shift smoothly between the two curves shown in right figure as the spacing is varied.

Size Dependent Optical Properties

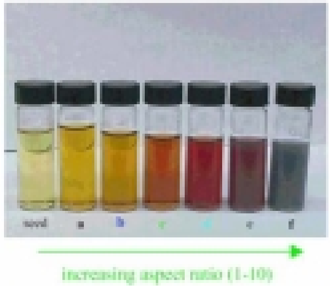
- **Nano Rod**

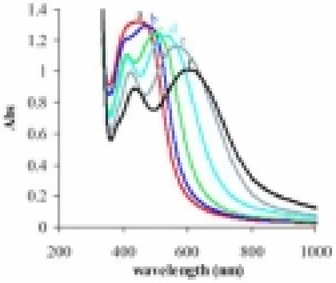
- **Nano Wire**



- **The Seed Mediated Method**

Size Dependent Optical Properties

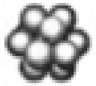
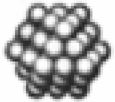
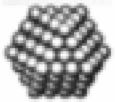
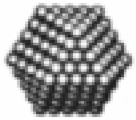
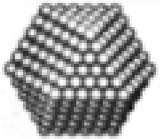
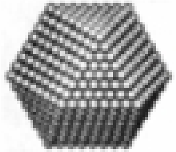




Aqueous solution of silver nanoparticles show a beautiful variation in visible color depending on the aspect ratio of the suspended nanoparticles: far left in the photograph, silver nanoparticles 4nm in diameter that are used as seeds in subsequent reactions: a-f) silver nanorods of aspect ratio 1~10.

Size Dependent Melting Point

TABLE 2.1 The relation between the total number of atoms in full shell clusters and the percentage of surface atoms

Full-shell Clusters			Total Number of Atoms	Surface Atoms (%)
1 Shell		6Å	13	92
2 Shells		10Å	55	76
3 Shells		14Å	147	63
4 Shells		18Å	309	52
5 Shells		22Å	561	45
7 Shells		26Å	1415	35

*Gold atomic size : 1.79Å (50nm : 6%)

- Melting Point of Gold (Tm=1064°C)

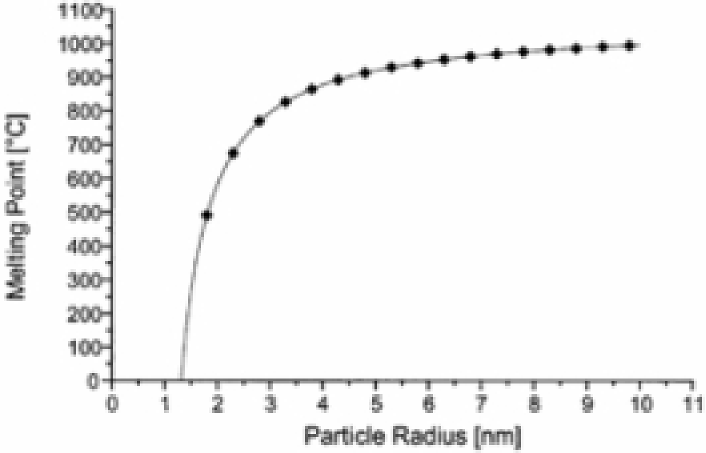
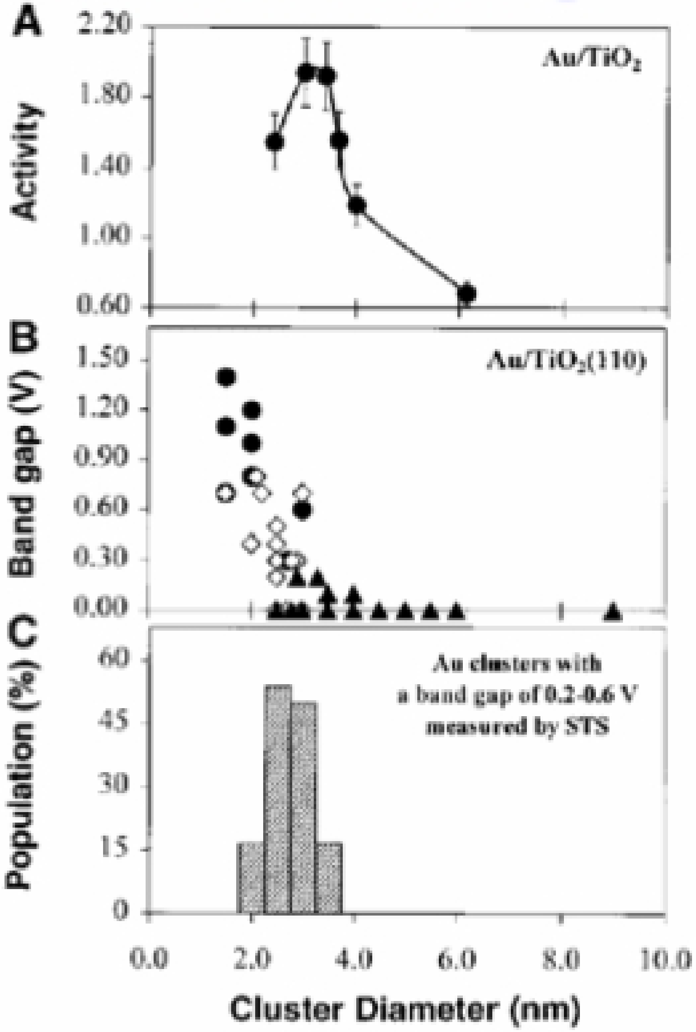


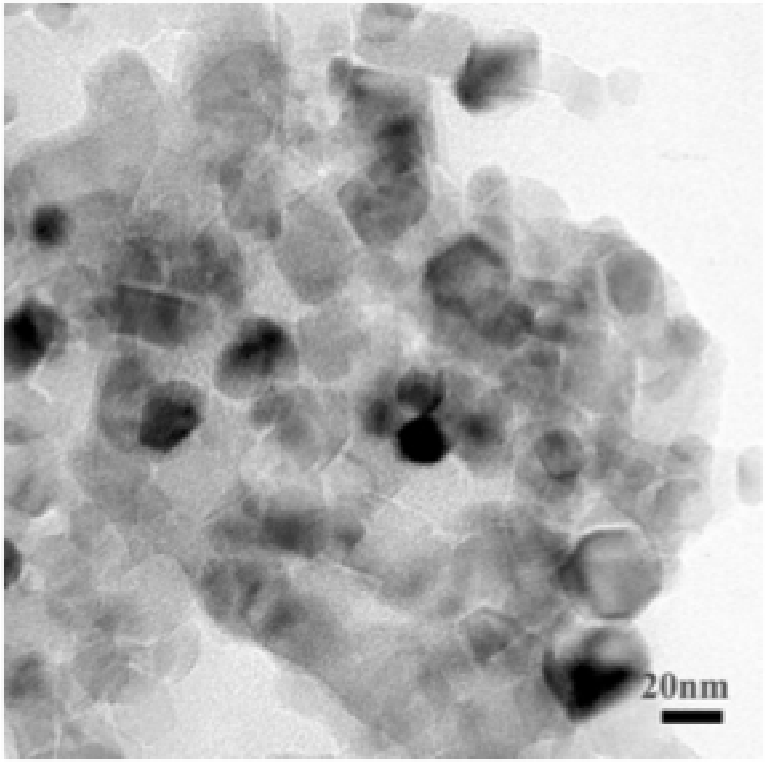
FIGURE 2.6 Relation between the size of gold particles and their melting point.

Size Dependent Chemical Reaction

- Catalytic Activity of Au Cluster on TiO_2



- Photocatalyst TiO_2 (Degussa P-25)



Colloids ?

- **Definition**

A suspension of finely divided particles in a continuous medium in which the particles are approximately 5 to 5,000 angstroms in size, do not settle out of the substance rapidly, and are not readily filtered

	Dispersed phase	Media	Example
Aerosol	Liquid	Gas	Fog, aerosol sprays
Colloids	Micelles	Liquid	Soap
Gels	Polymers	Liquid	Jellies, Glue
Emulsion	Liquid	Liquid	Milk, Butter

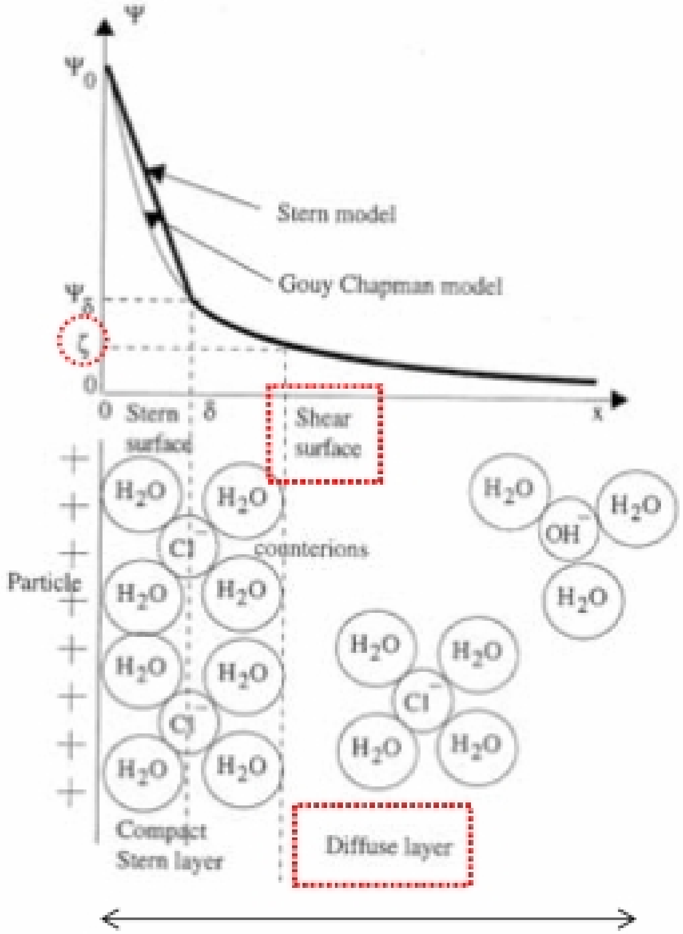
- **Thermodynamics → Agglomeration (Stable)**

➔ Need other forces for colloidal stability

Electrostatic force & Steric repulsive force

Force for Colloidal Stability

- **Electrostatic force**



Electric Double Layer

- **Electric double layer**

  ; Stern Layer + Diffuse Layer :

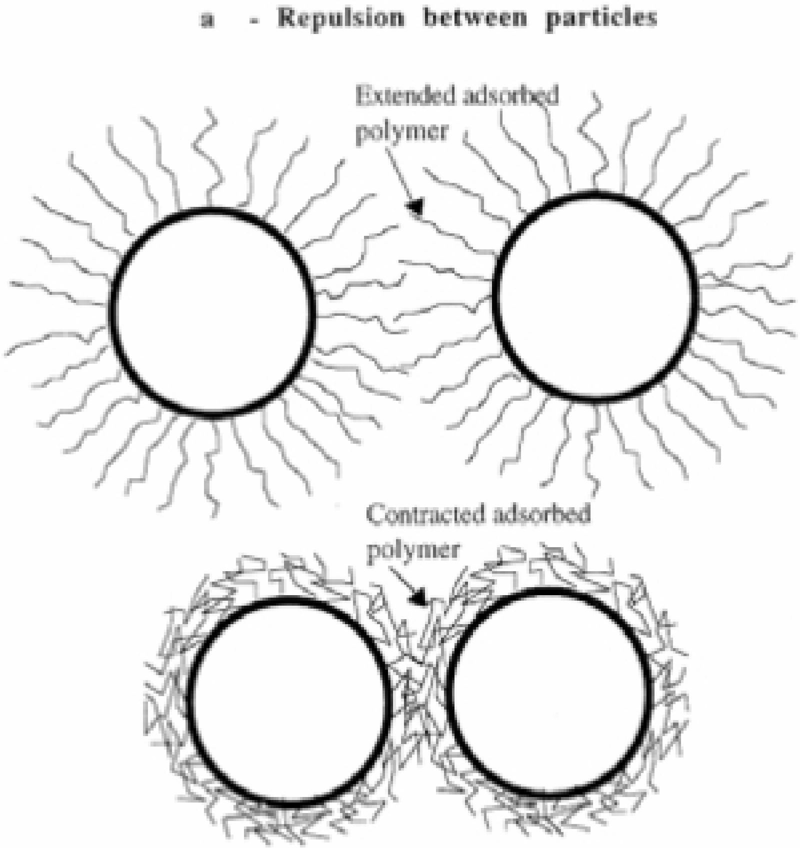
  - Stern layer : immobile adsorbed layer
  - Diffuse layer : mobile by thermal vibration

- **Zeta potential**

  ; the potential at the slippage plane.

Force for Colloidal Stability

- Steric repulsive force



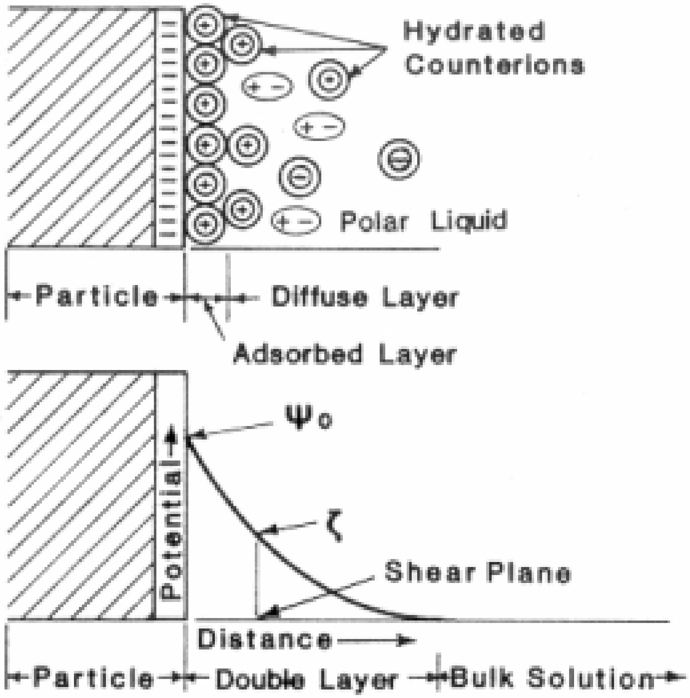
Enthalpy : Osmosis pressure ($\Delta H > 0$)

Entropy : Deg. of Freedom ($\Delta S < 0$)

$\Delta G > 0$

Prohibit coagulation btw. particles

Surface Potential



1. **Electrostatic interaction**

   favors a locally ordered ionic arrangement

2. **Entropic factor**

   randomized the uniform distribution (∵thermal E)

Poisson Equation!!

$$\frac{d^2\psi}{dx^2} = -\frac{\rho}{\varepsilon_r \varepsilon_0}$$

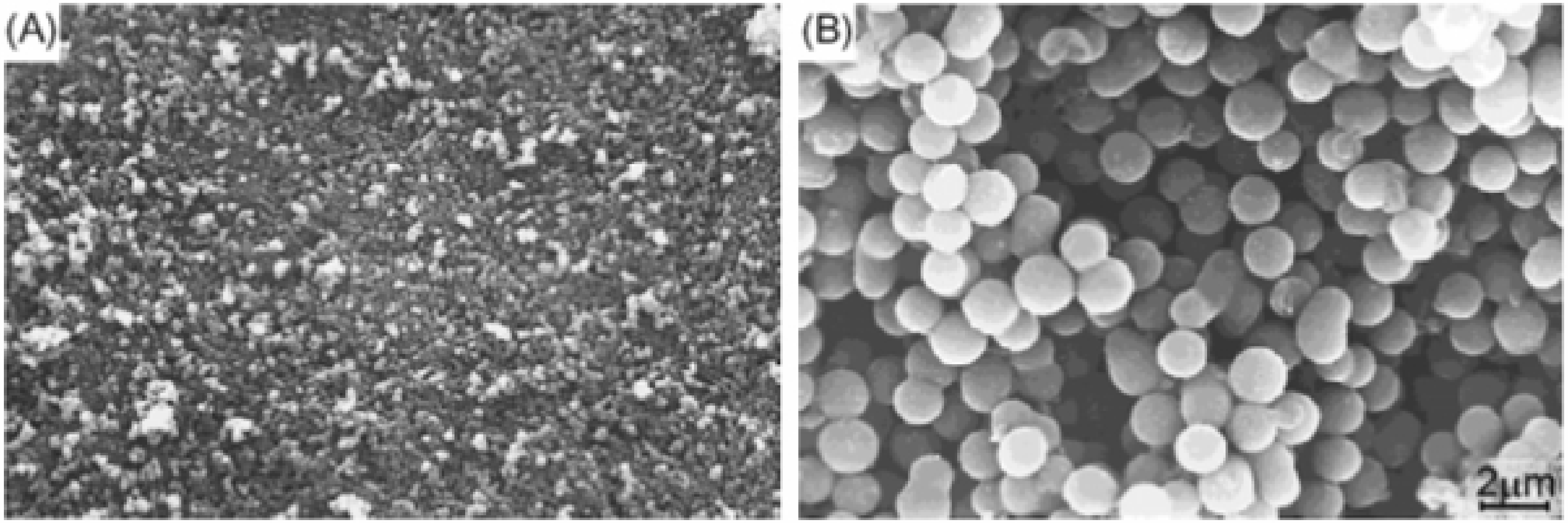
$$\rho = \sum n_i z_i e = \sum n_{i0} z_i e \exp\left(-\frac{z_i e \psi}{kT}\right)$$

Solution $\psi = \psi_o \exp(-\kappa x)$

Double Layer Thickness $\kappa^{-1} = \left(\frac{\varepsilon_r \varepsilon_0 N_A k_B T}{F^2 \sum N_i Z_i^2}\right)^{1/2}$

Control the Particle Size

- TiO2
- Different Solvent (Mixed solvent = n-PrOH + H_2O)



RH ratio	Dielectric Constant of solvent at 20 °C	Zeta Potential at 20 °C	Particle Morphology
0	80	18.3	Fine (aggregated)
1	48	11.4	Aggregated
2	36	6.7	Spherical, aggregated
3	32	4.5	Spherical, discrete

RH ratio = n-PrOH / H_2O

Control the Particle Size

- **Energy barrier** for colloidal stability

$$V_b = -\frac{Ad}{12h} + 2\pi d \varepsilon_r \varepsilon_0 \psi^2$$

Only dependent on Dielectric constant of solvent

Zeta potential of precipitate

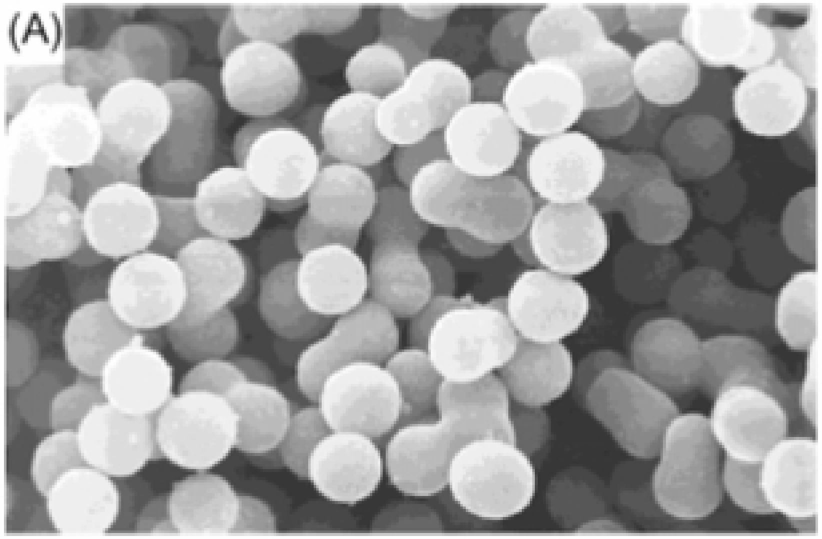
Lower Barrier ➔ Larger size

Higher Barrier ➔ Smaller size

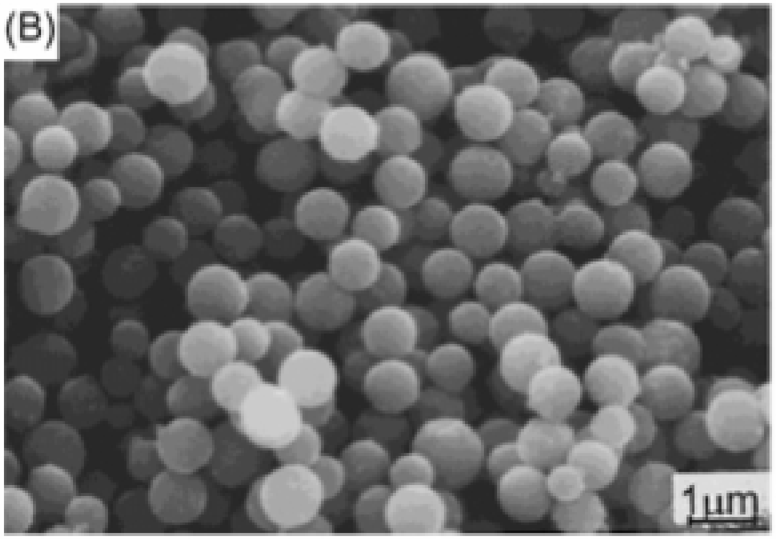
Hamaker constant (A) ≈ 10^{-20} J (water and aliphatic alcohol)

Dispersant Effect (Steric Force)

- **Without HPC**



- **With HPC**

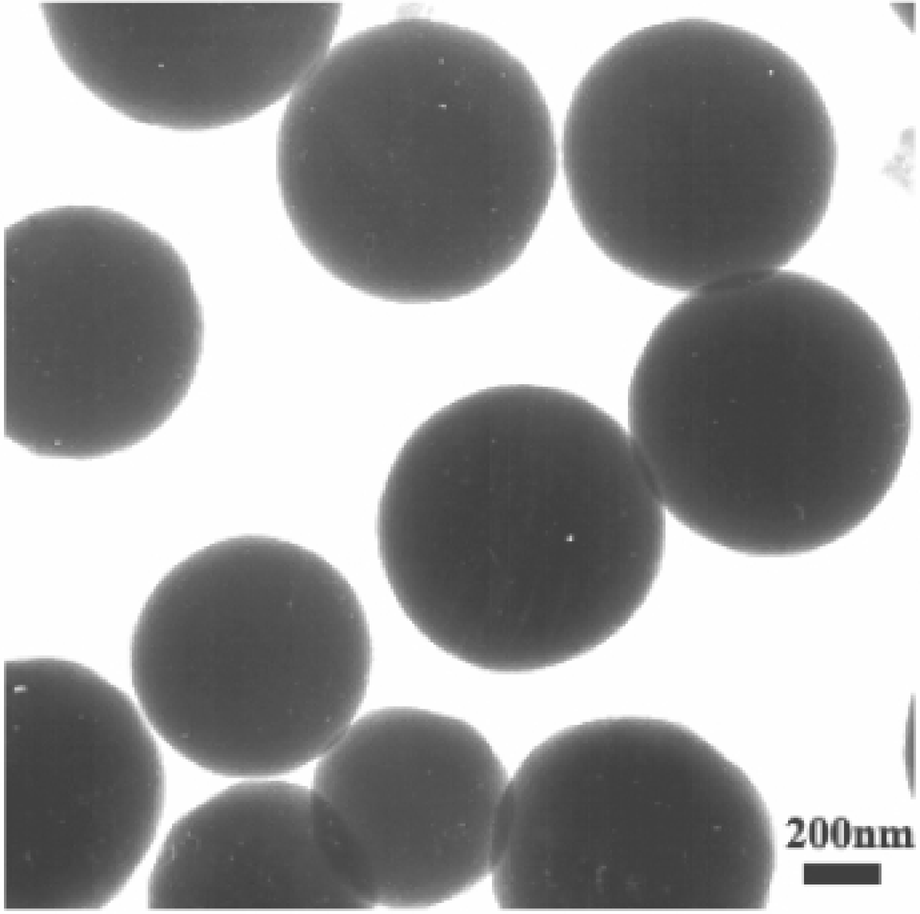


- **HPC: hydroxyprophyl cellulose (m.w. = 100,000)**

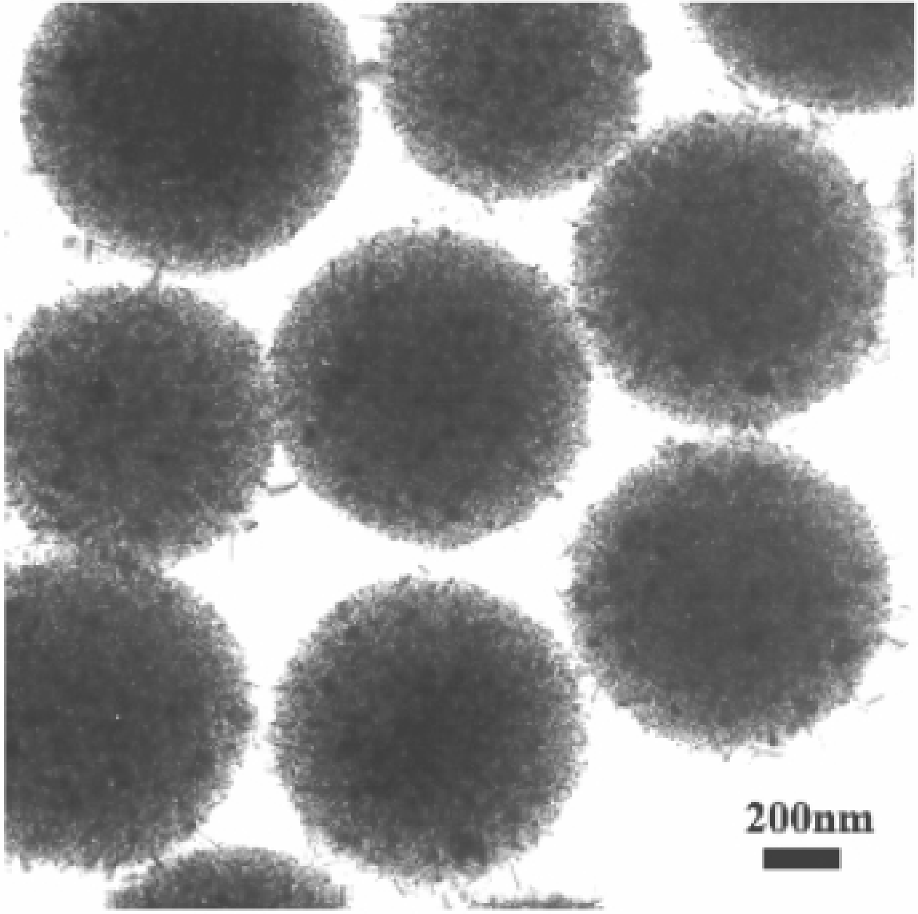
- **Reduce agglomeration**
- **Smaller particles size**
- **Spherical shape (No irregular shape)**
- **Well dispersed**

TEM Micrograph of TiO_2

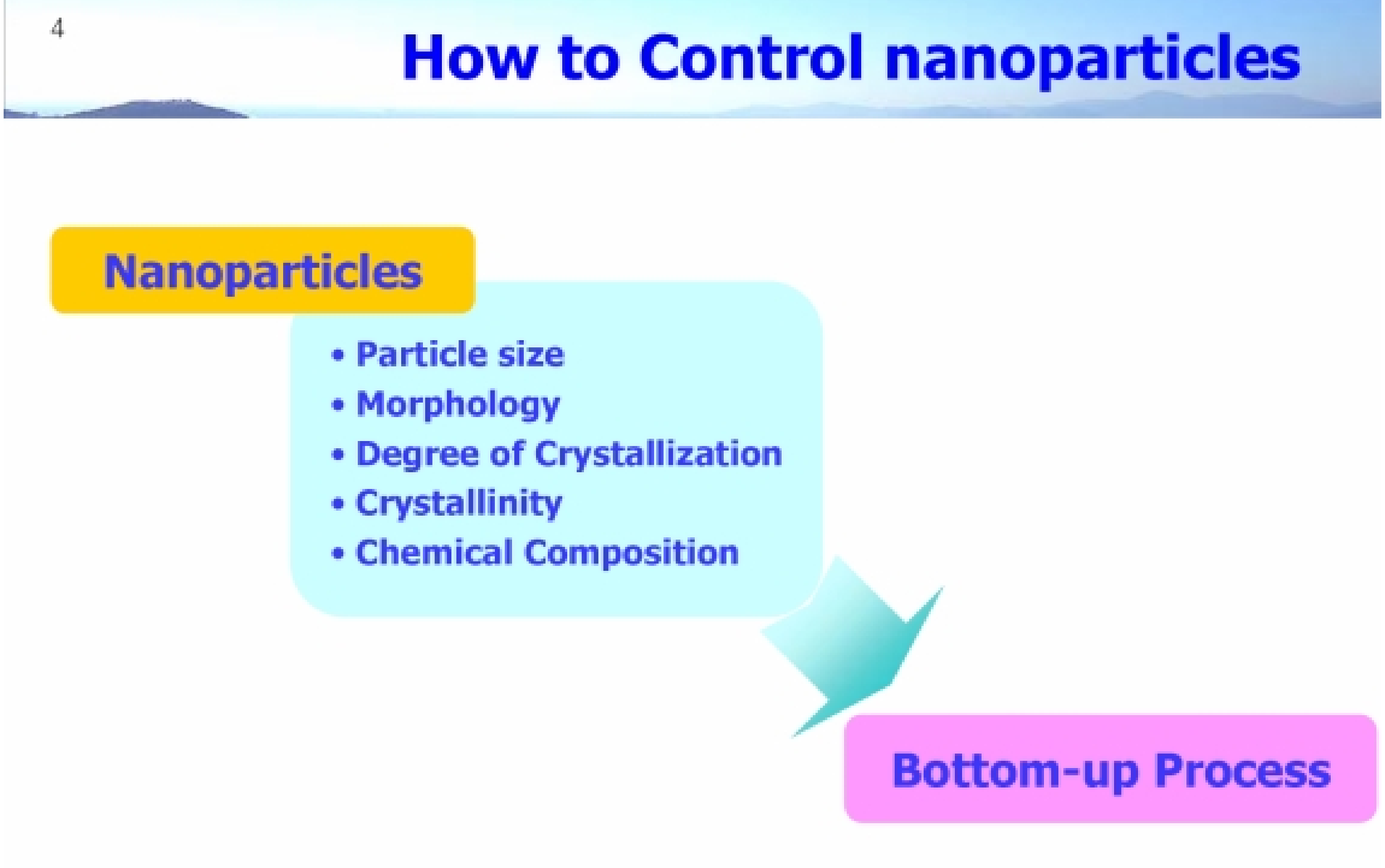
- **Amorphous Particles**



- **Crystallized Particles**



How to Synthesize Nanoparticles



How to Control nanoparticles

Nanoparticles

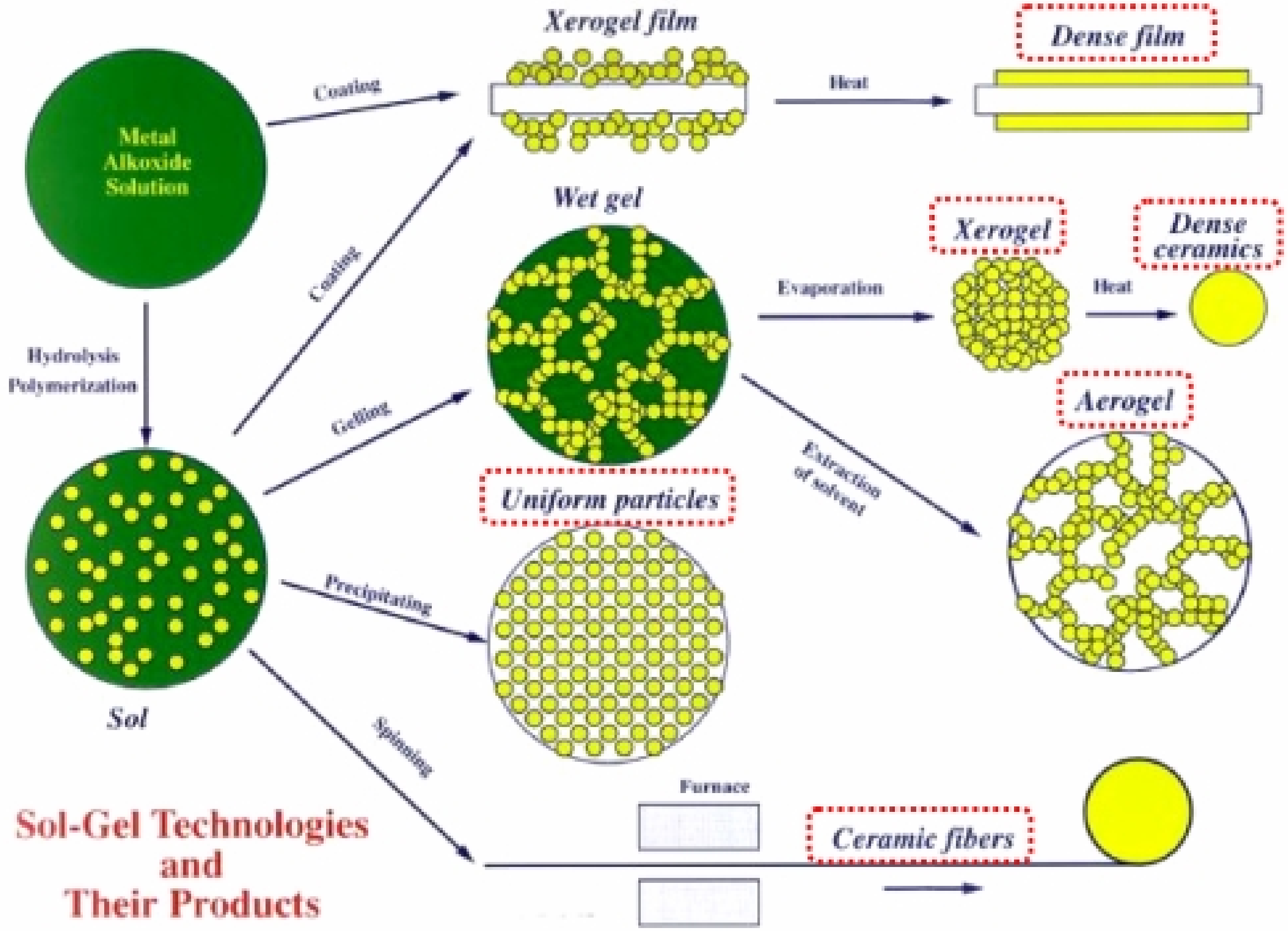
- Particle size
- Morphology
- Degree of Crystallization
- Crystallinity
- Chemical Composition

Bottom-up Process

Major efforts in nanoparticle synthesis can be grouped into two broad areas: gas phase synthesis and sol-gel processing.

Additional nanoparticle synthesis techniques include sonochemical processing, cavitation processing, microemulsion processing, and high-energy ball milling.

Sol-gel Process



Sol-gel processing is a wet chemical synthesis approach that can be used to generate nanoparticles by gelation, precipitation, and hydrothermal treatment

Advantage & Disadvantage

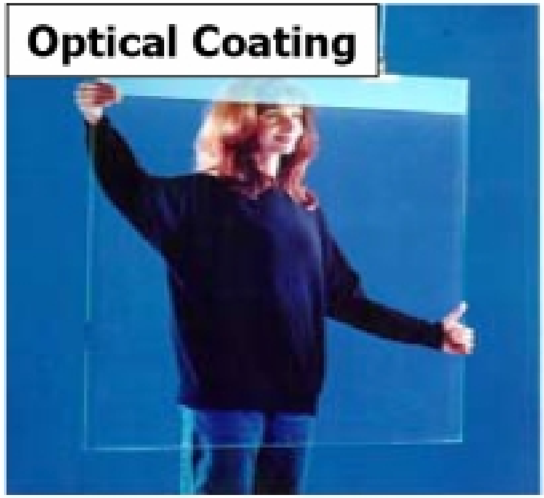
Advantage

- Large Area Scale
- Precise Composition Control
- Low-Temperature Synthesis
- High Homogeneity
- Easy Achieved

Disadvantage

- Sensitivity for Atmosphere Condition
- Expensive of Raw Materials
- Use of Toxic Solvent System

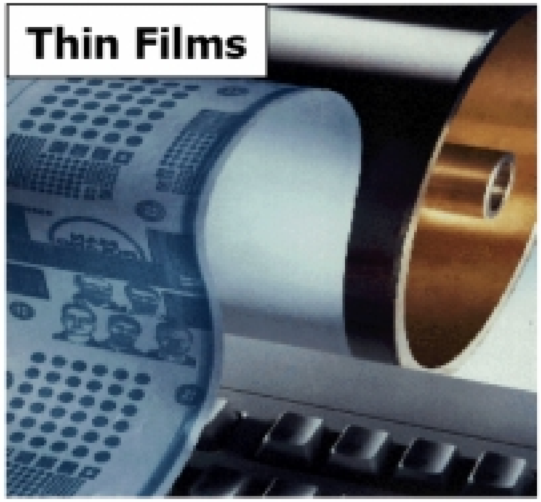
Application



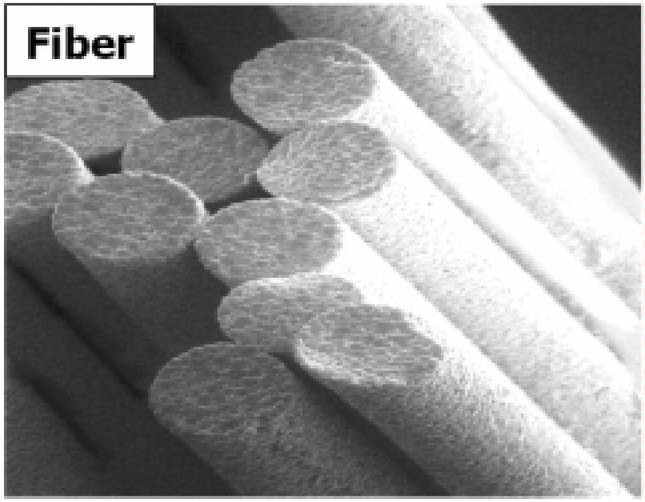
Optical Coating

Optical Coating

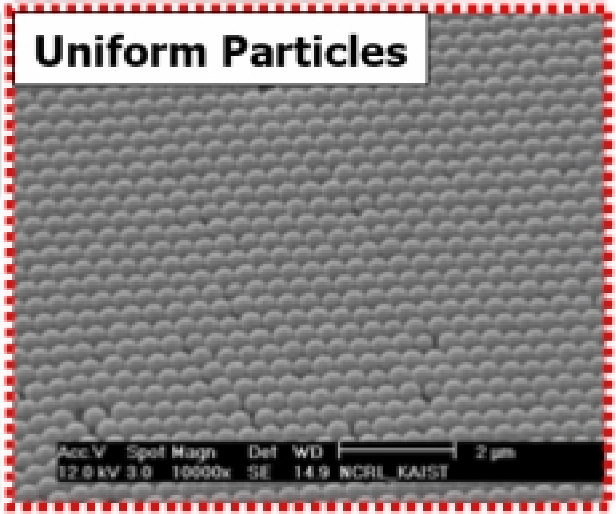
Dense Ceramics



Thin Films

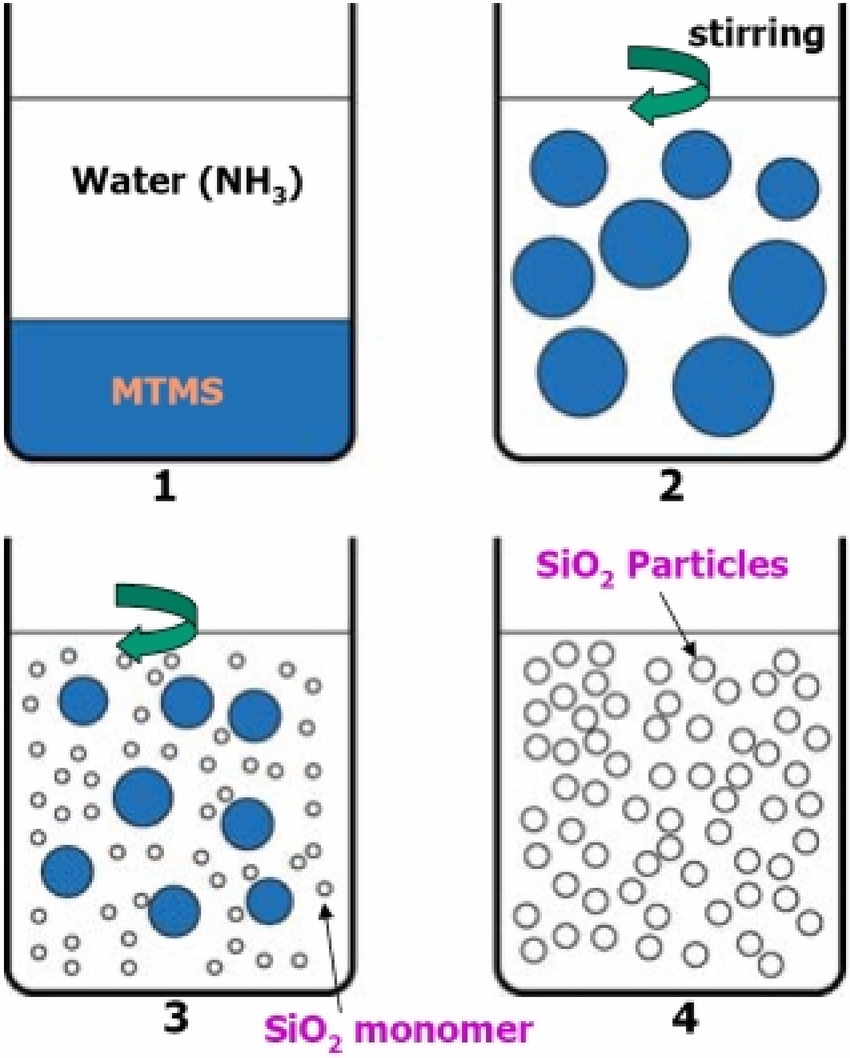


Fiber

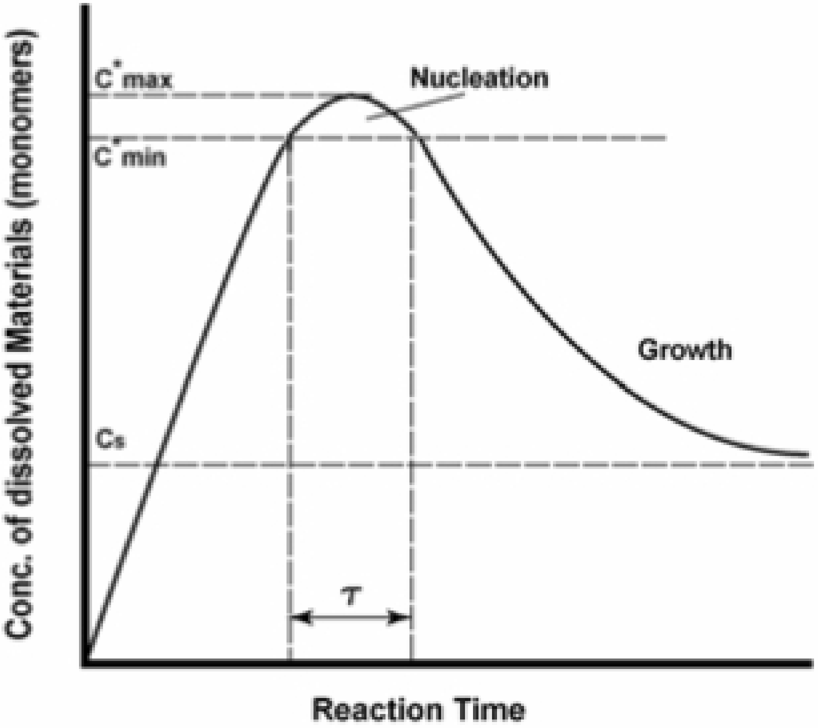


Uniform Particles

Formation of Monodisperse SiO_2 Particles

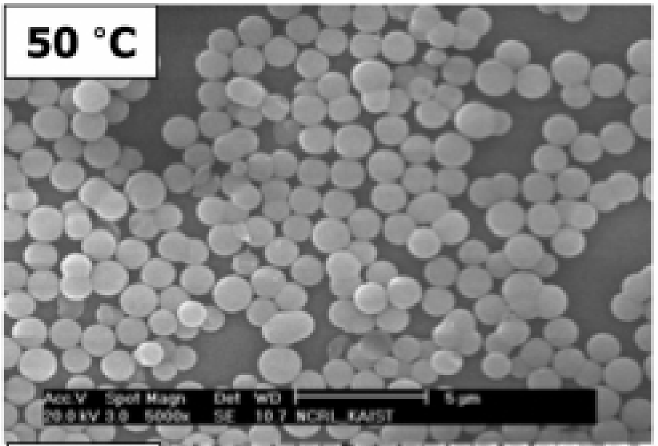


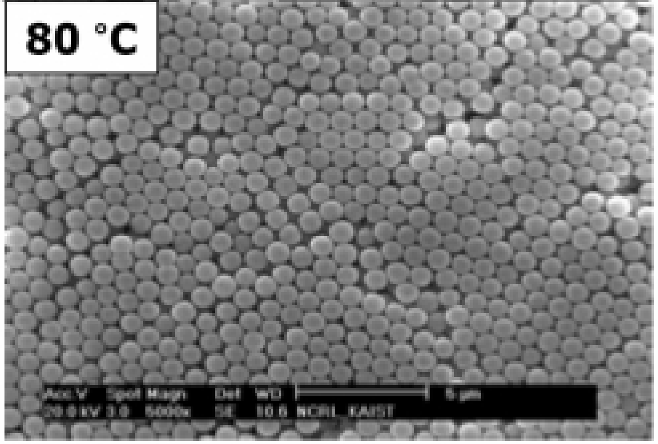
Lamer diagram



- To make monodispersed Particles, the time τ should be decreased.

Monodispersed SiO$_2$ From MTMS

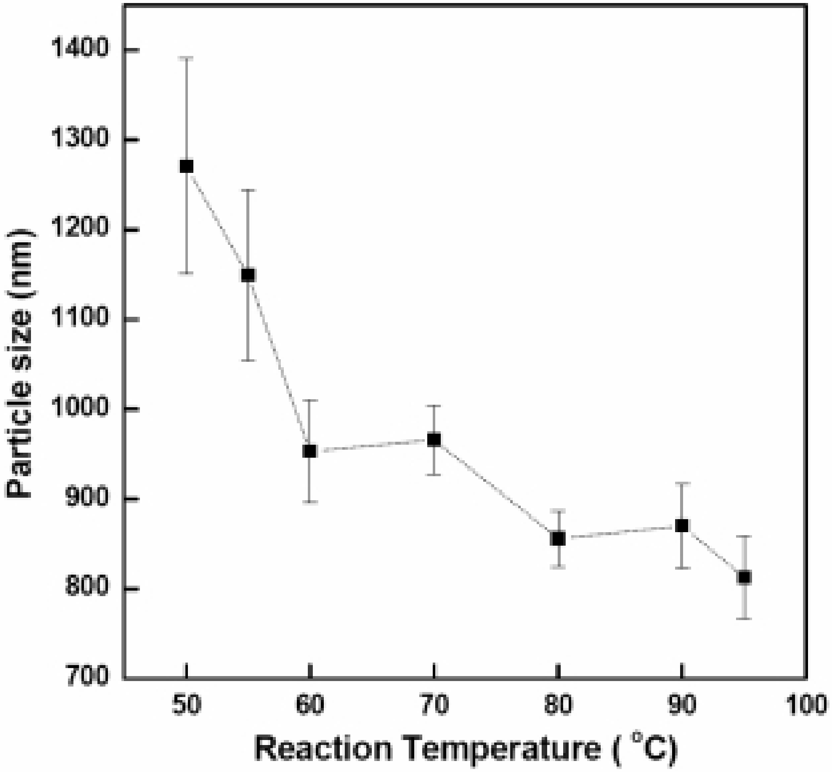




- **[MTMS]=0.6M, [NH$_3$]=1M**

MTMS; Methytrimethoxysilane

- **Particle size vs. Rx Temp.**

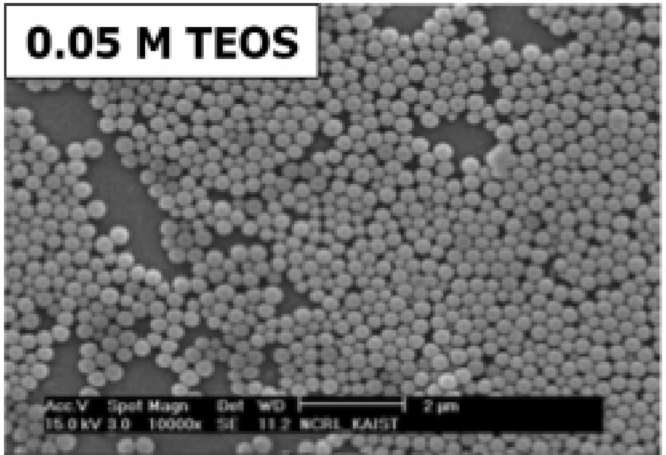


- **Temp. ↑ → Reaction rate ↑**
  ➔ Nucleation time ↓
  ➔ Size Distribution ↓

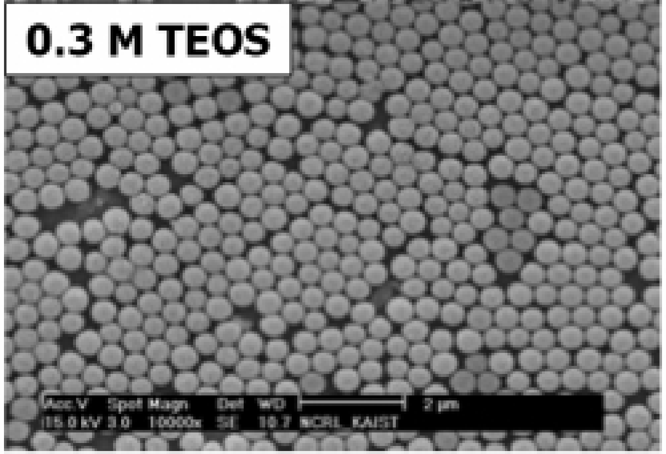
Monodispersed SiO_2 From TEOS

- **Stober Method**

0.05 M TEOS



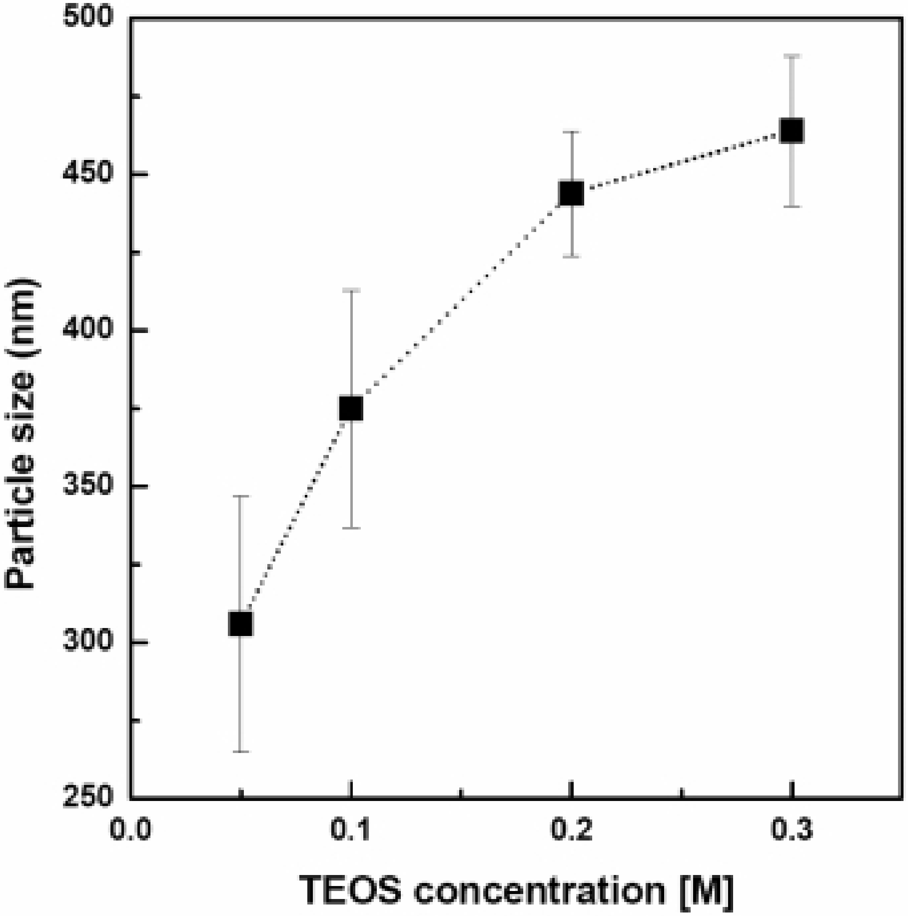
0.3 M TEOS



- **H_2O/EtOH=0.2, [NH_3]=0.7M, 22°C**

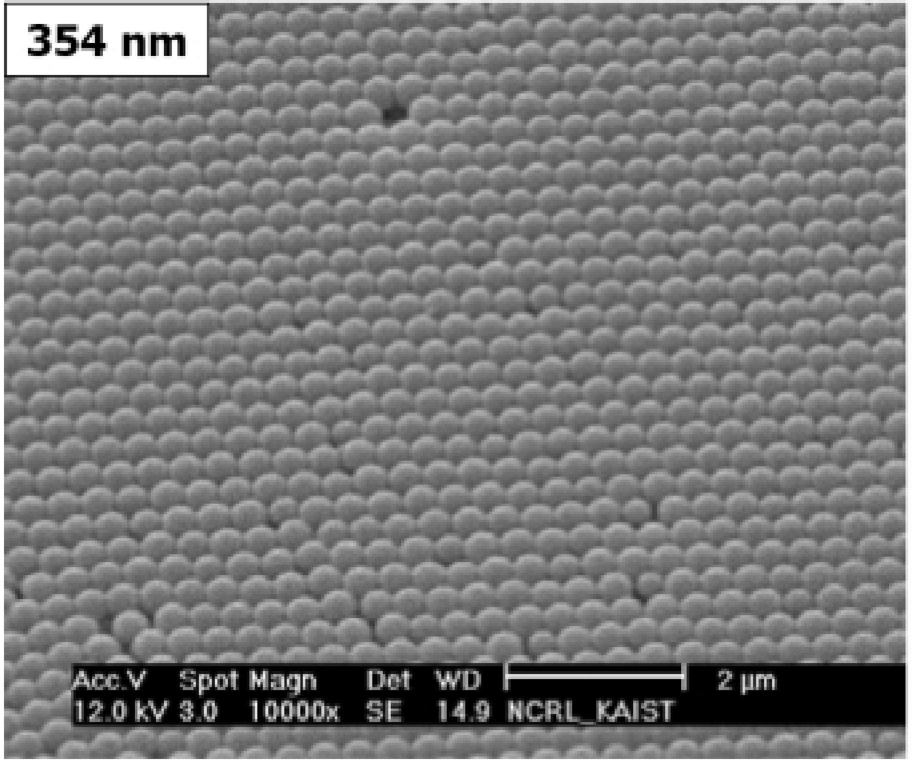
TEOS : Tetraethoxyorthosilicate

- **Particle size vs. TEOS Conc.**

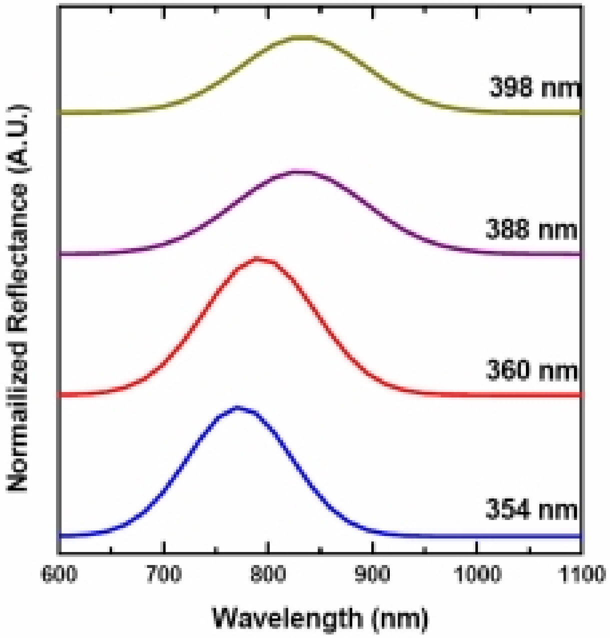


- **Conc. of TEOS ↑ → Particle size ↑**

Photonic Crystal



- **Reflectance vs. Particle size**



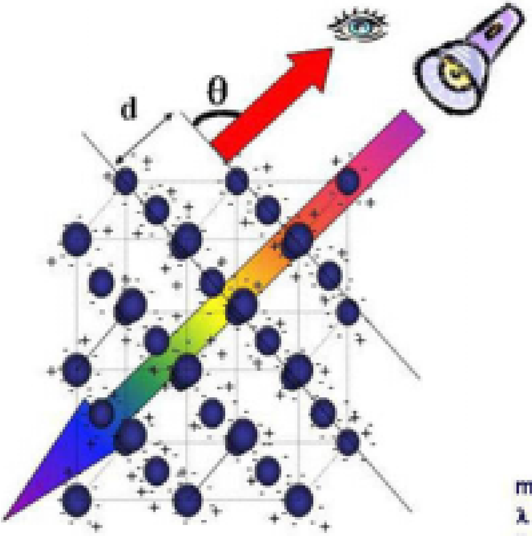
- **Bragg's Law**

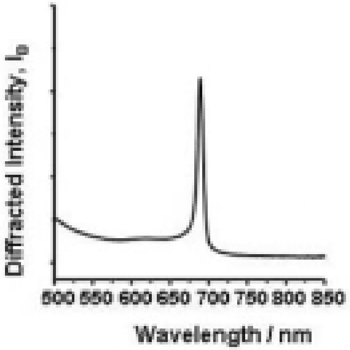
$$\lambda_{Bragg} = 2n_{eff} d_{111}$$

$$n_{eff} = \sqrt{{n_{SiO_2}}^2 \times f + {n_{air}}^2 \times (1 - f)}$$

$$d_{111(FCC)} = \sqrt{2/3}D \qquad f = \text{filling ratio}$$

Bragg Diffraction

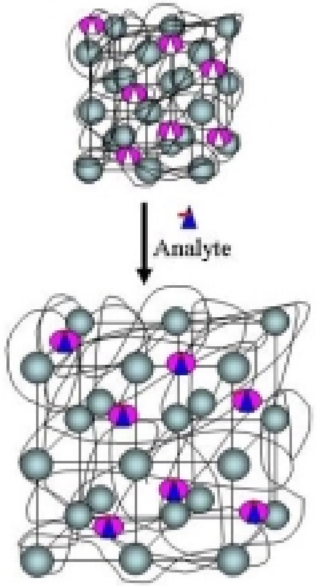


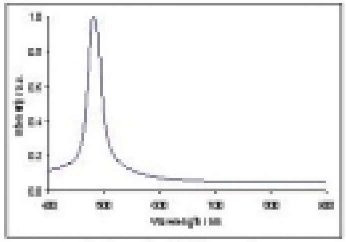


$$m\lambda = 2nd \sin \theta$$

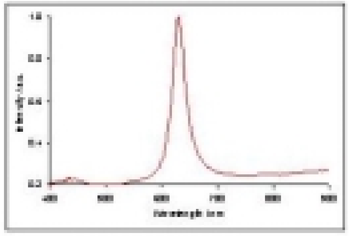
m = order of diffraction
λ = diffracted wavelength
n = refractive index of system
d = spacing between diffracting planes
θ = Bragg glancing angle

IPCCA: Chemical Sensing Material



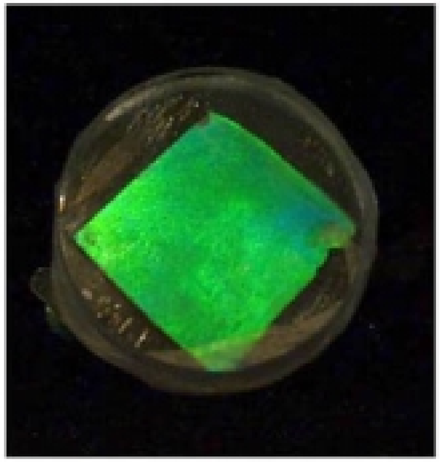


original diffraction

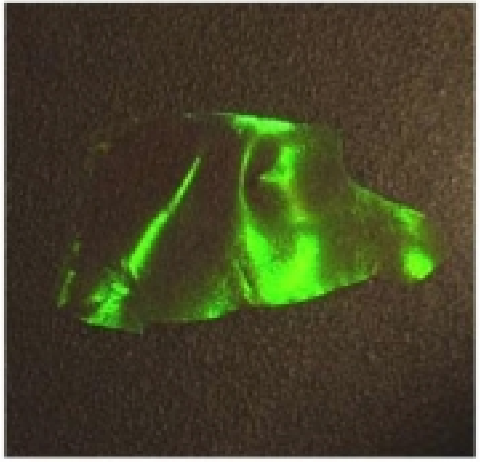


final diffraction

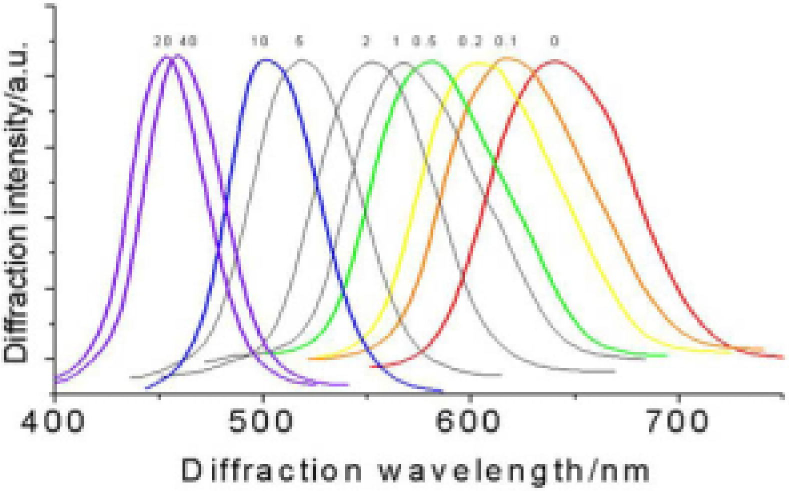
Diffraction from CCA and PCCA

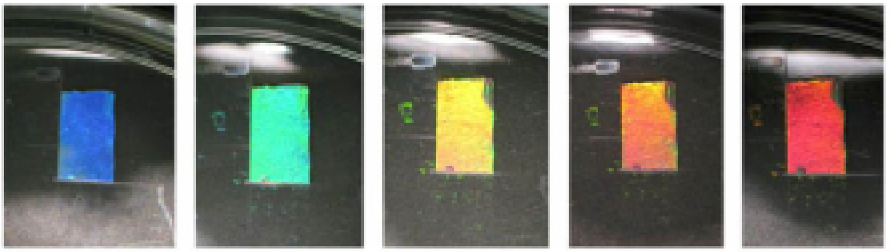


CCA



PCCA





Hydrothermal Synthesis

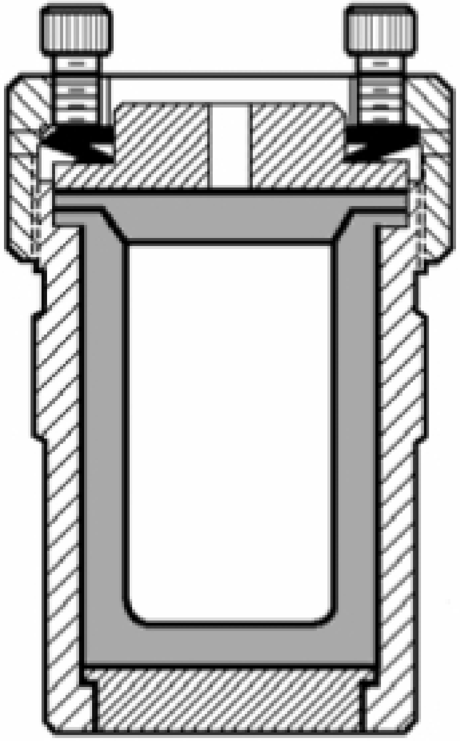
- **Development of Hydrothermal Processing**

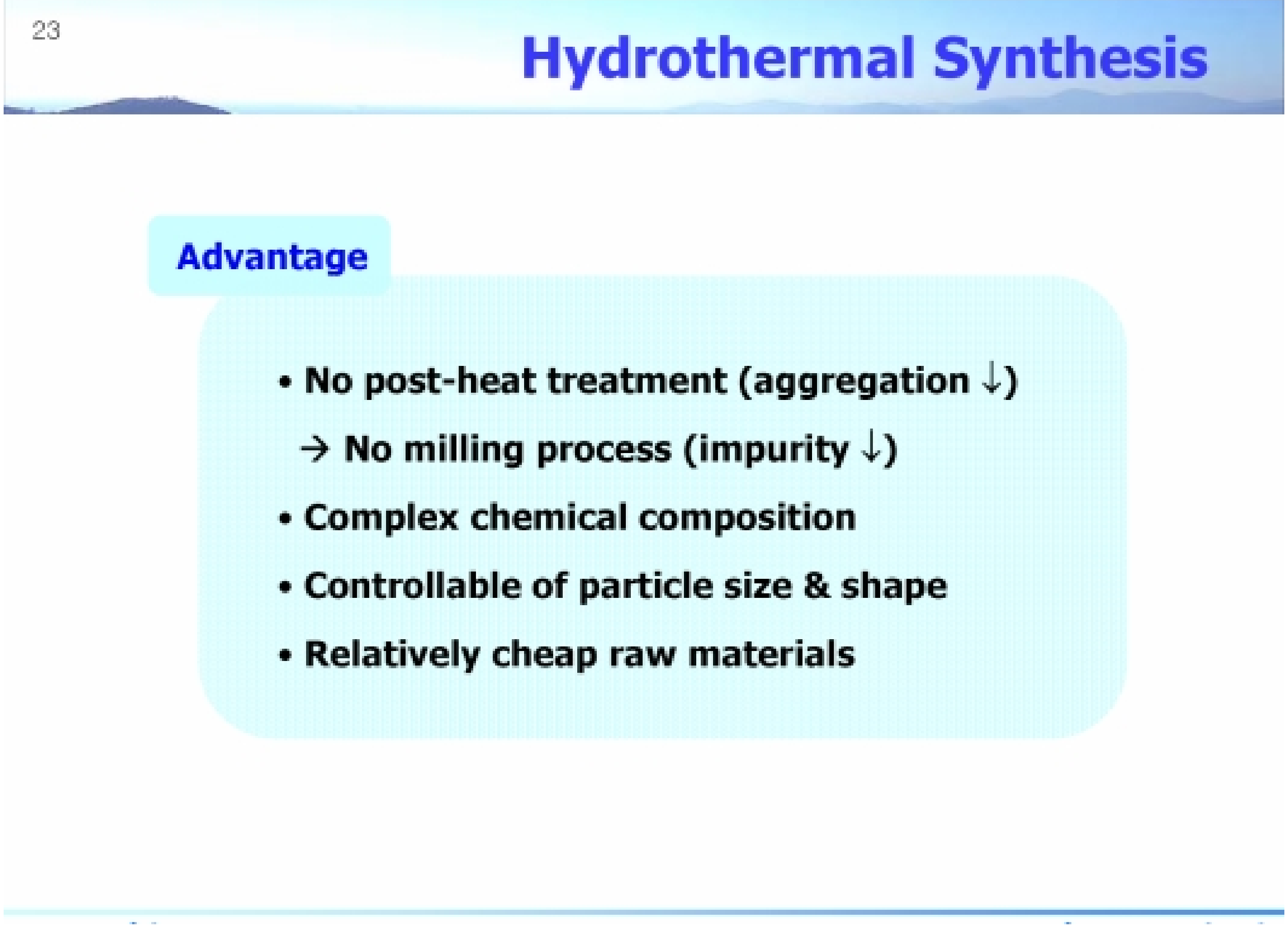
1. Crystal synthesis and Growth	Oxide, Sulfide, Fluoride… (1978 ~)
2. Controlled Fine Crystals, Size, Composition, Size, Shape	PZT, ZrO_2, $BaTiO_3$, HAp, ferrite (1978 ~)
3. Crystallized Thin/Thick Films	$BaTiO_3$, $SrTiO_3$, $LiNbO_3$ (1989 ~)
4. Etching, Corrosion, Polishing	Oxide, Nitride, Carbide
5. Combined with Electrical, Photo-, Radio-, Mechano-processing	Synthesis, Modification, Coating
6. Organic and Biomaterials Non-aqueous solution Continuous system	Hydrolysis, Extraction, Polymerization, Synthesis, Decomposition

Hydrothermal Reactor

- High Temperature & High Pressure

- Mediate Temperature





Hydrothermal Synthesis

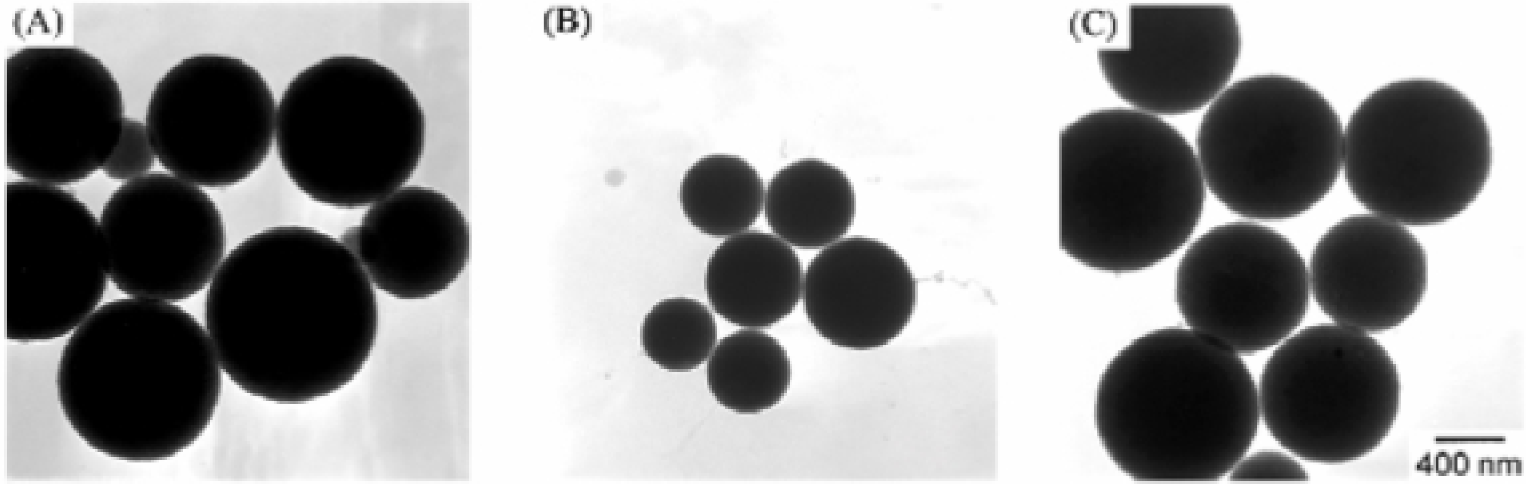
Advantage

- No post-heat treatment (aggregation ↓)
  → No milling process (impurity ↓)
- Complex chemical composition
- Controllable of particle size & shape
- Relatively cheap raw materials

The method, hydrothermal synthesis, is carried out using autoclaves. The autoclave must treated under 200 degree Celsius because the internal Teflon container is not durable over the temperature. A weighed amount of starting materials and water is mixed and sealed in the autoclave. The autoclave is kept in a temperature-controlled oven for planned time. Internal pressure depends on the temperature.

Perovskite Nanoparticles

- **Thermal Hydrolysis of Metal Salt (microwave heating)**

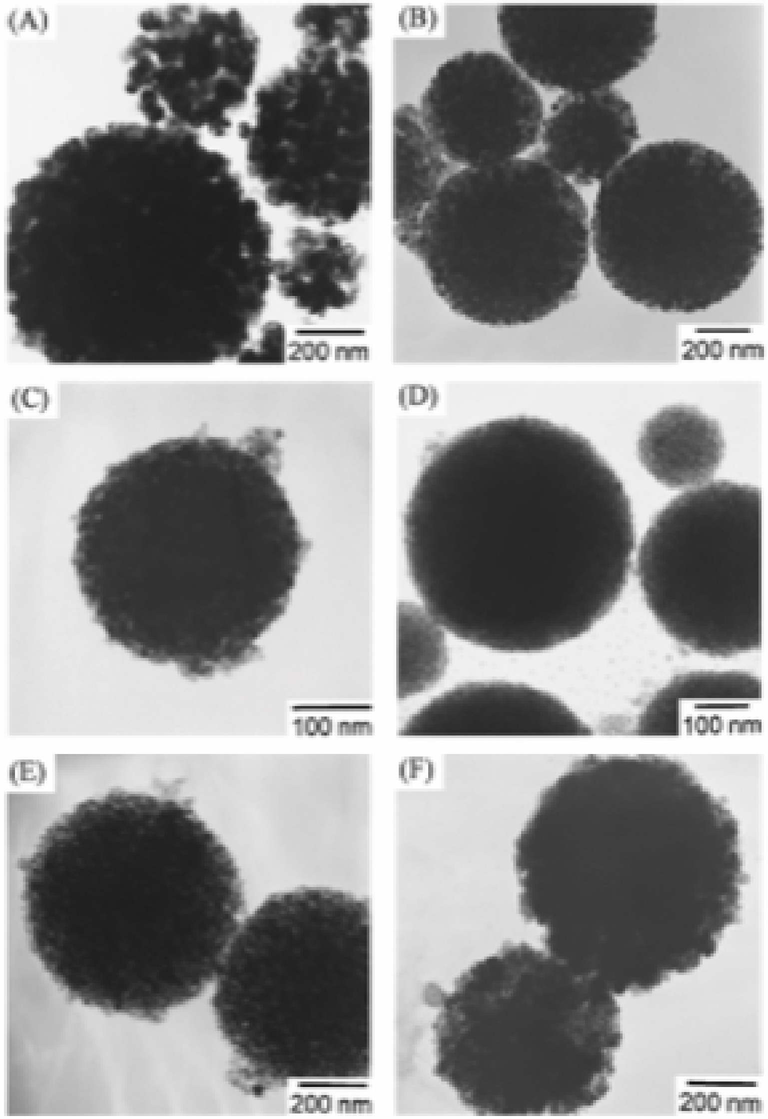


TiO_2 Gel **ZrO_2 Gel** **$ZrTiO_4$ Gel**

Hydrothermal Crystallization

- **Adding Pb, Ba, Sr source**
- **pH control**
- **Temperature & holding time**

Perovskite Nanoparticles



(A) $BaTiO_3$

(B) $SrTiO_3$

(C) $PbTiO_3$

(D) $PbZrO_3$

(E) $Pb(Ti_{0.5}, Zr_{0.5})O_3$

(F) $Ba(Ti_{0.5}, Zr_{0.5})O_3$

Solvothermal Synthesis

Solvothermal Synthesis

Solvothermal synthesis utilizes a solvent under pressures and temperatures above its critical point to increase the solubility of solid and to speed up reaction between solids

- Most materials can be made soluble in **proper solvent** by heating and pressuring the system close to its critical point
- Easily control a solubility of solute
  → Lower supersaturation state

1 Dimensional Nanostructure !

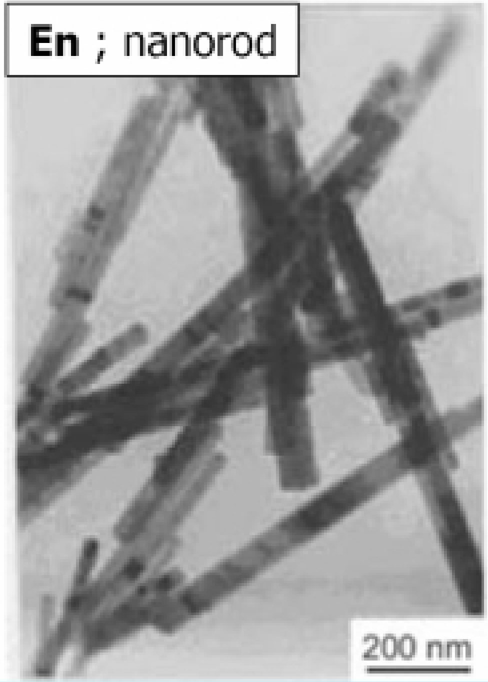
Solvothermal Synthesis

- **Semiconductor nanoparticles (CdE (E = S, Se, Te))**

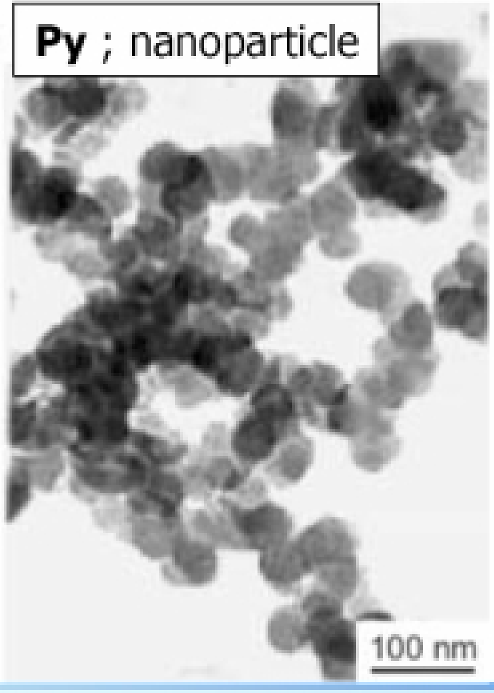
$$CdC_2O_4 + E \xrightarrow{\text{solvent}} CdE + 2CO_2 \uparrow$$

E ; Chalcogenide (S, Se, Te)

- Ethylenediamine
- Pyridine



En ; nanorod

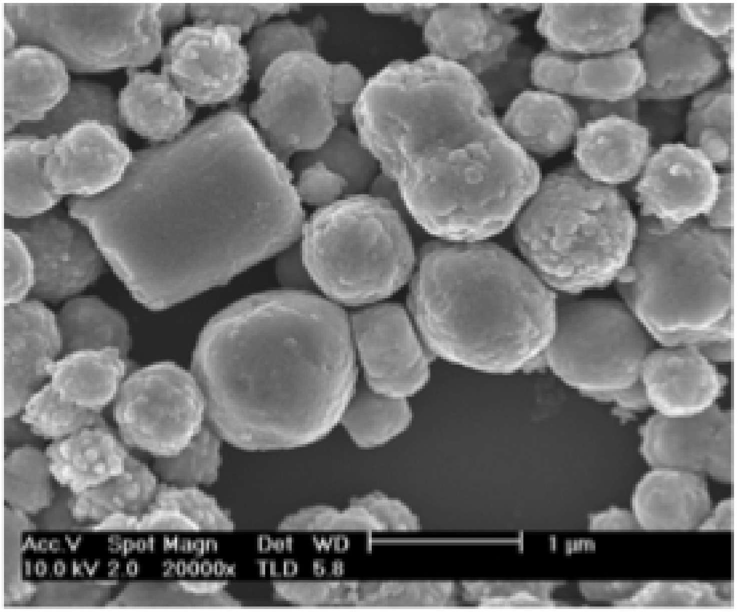


Py ; nanoparticle

Introduction – Reduction in Solution

<Reduction in Solution>

$$2Ni^{2+} + \underbrace{N_2H_4}_{\text{Reducing agent}} + 4OH^- \rightarrow 2Ni + 4H_2O + N_{2(g)}$$



- Random shape
- Random size
- Broad size distribution

- Heterogeneous Nucleation
- Additive (dispersant, complex agent)

Reducing agent

- **Guidelines for the choice of reducing agents**

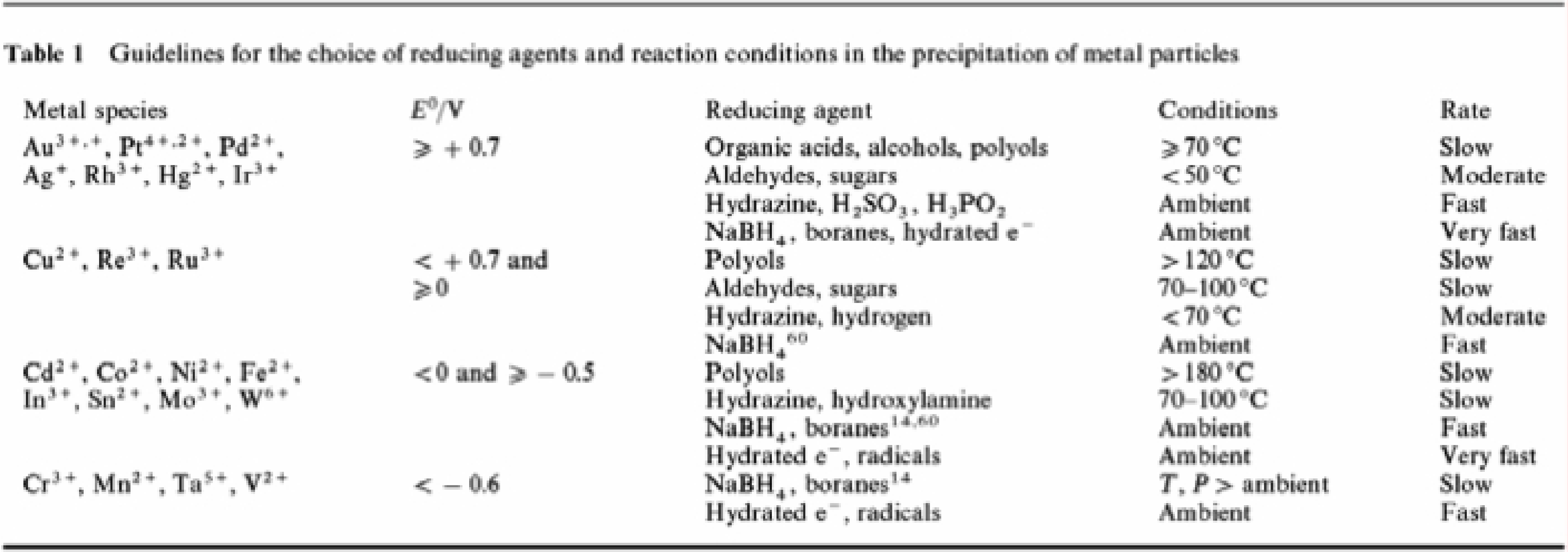


Table 1 Guidelines for the choice of reducing agents and reaction conditions in the precipitation of metal particles

Metal species	E^0/V	Reducing agent	Conditions	Rate
$Au^{3+,+}$, $Pt^{4+,2+}$, Pd^{2+}, Ag^{+}, Rh^{3+}, Hg^{2+}, Ir^{3+}	$\geqslant +0.7$	Organic acids, alcohols, polyols	$\geqslant 70$ °C	Slow
		Aldehydes, sugars	< 50 °C	Moderate
		Hydrazine, H_2SO_3, H_3PO_2	Ambient	Fast
		$NaBH_4$, boranes, hydrated e^-	Ambient	Very fast
Cu^{2+}, Re^{3+}, Ru^{3+}	$< +0.7$ and $\geqslant 0$	Polyols	> 120 °C	Slow
		Aldehydes, sugars	70–100 °C	Slow
		Hydrazine, hydrogen	< 70 °C	Moderate
		$NaBH_4$[60]	Ambient	Fast
Cd^{2+}, Co^{2+}, Ni^{2+}, Fe^{2+}, In^{3+}, Sn^{2+}, Mo^{3+}, W^{6+}	< 0 and $\geqslant -0.5$	Polyols	> 180 °C	Slow
		Hydrazine, hydroxylamine	70–100 °C	Slow
		$NaBH_4$, boranes[14,60]	Ambient	Fast
		Hydrated e^-, radicals	Ambient	Very fast
Cr^{3+}, Mn^{2+}, Ta^{5+}, V^{2+}	< -0.6	$NaBH_4$, boranes[14]	$T, P >$ ambient	Slow
		Hydrated e^-, radicals	Ambient	Fast

How to control the particles

- **Processing parameter**

  Temperature, Concentration , pH, Chemical composition … etc.

- **Seed (Heterogeneous Nucleation)**

- **Complex agent**

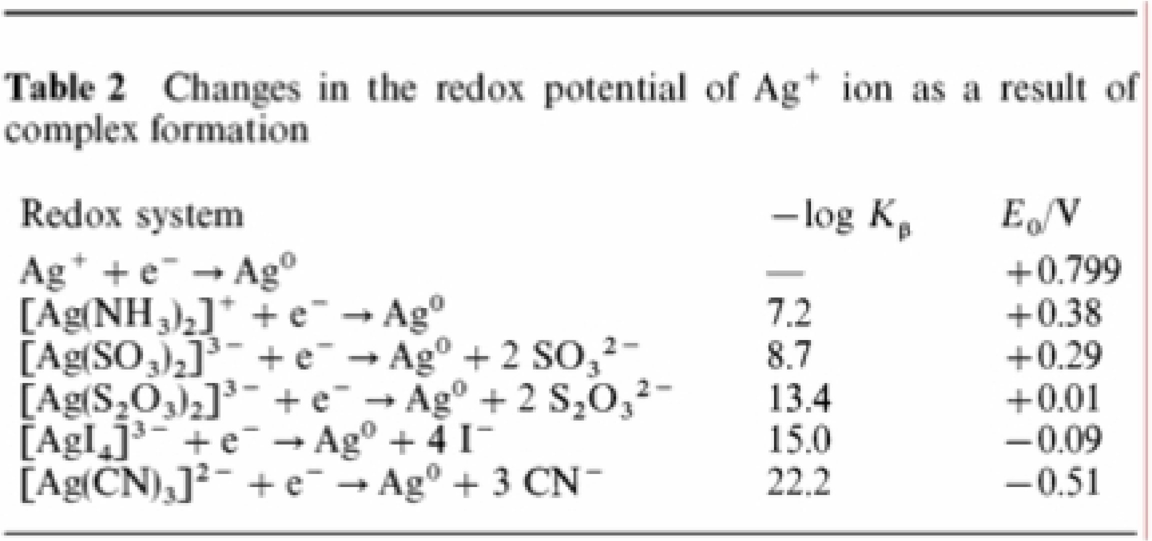
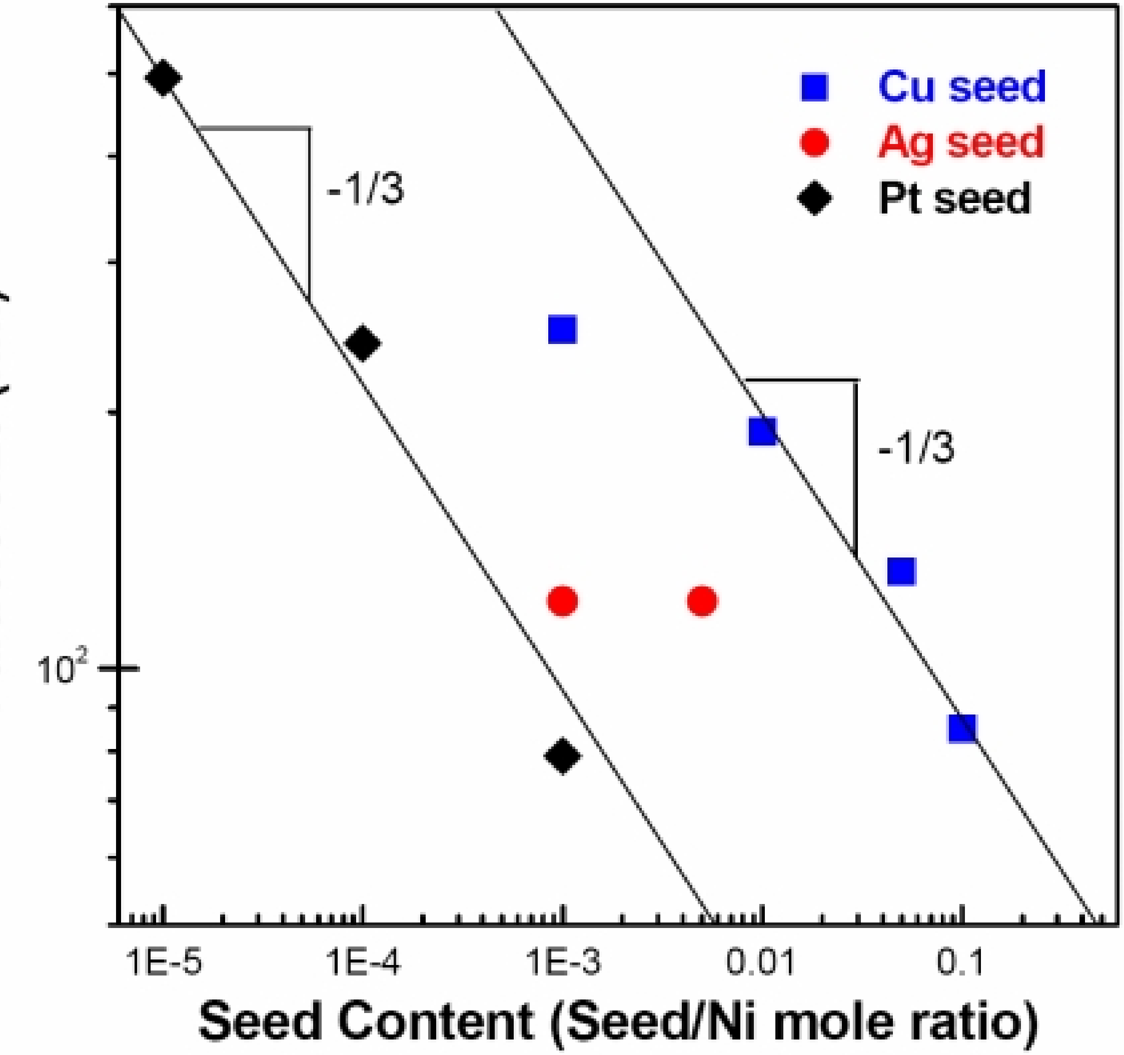


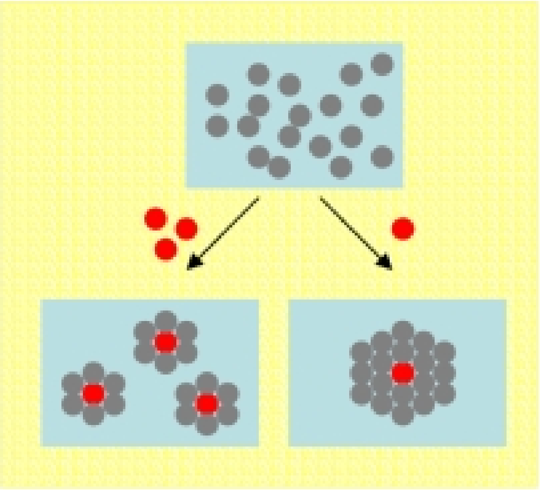
Table 2 Changes in the redox potential of Ag^+ ion as a result of complex formation

Redox system	$-\log K_\beta$	E_0/V
$Ag^+ + e^- \rightarrow Ag^0$	—	+0.799
$[Ag(NH_3)_2]^+ + e^- \rightarrow Ag^0$	7.2	+0.38
$[Ag(SO_3)_2]^{3-} + e^- \rightarrow Ag^0 + 2\ SO_3{}^{2-}$	8.7	+0.29
$[Ag(S_2O_3)_2]^{3-} + e^- \rightarrow Ag^0 + 2\ S_2O_3{}^{2-}$	13.4	+0.01
$[AgI_4]^{3-} + e^- \rightarrow Ag^0 + 4\ I^-$	15.0	−0.09
$[Ag(CN)_3]^{2-} + e^- \rightarrow Ag^0 + 3\ CN^-$	22.2	−0.51

Heterogeneous Nucleation (1)

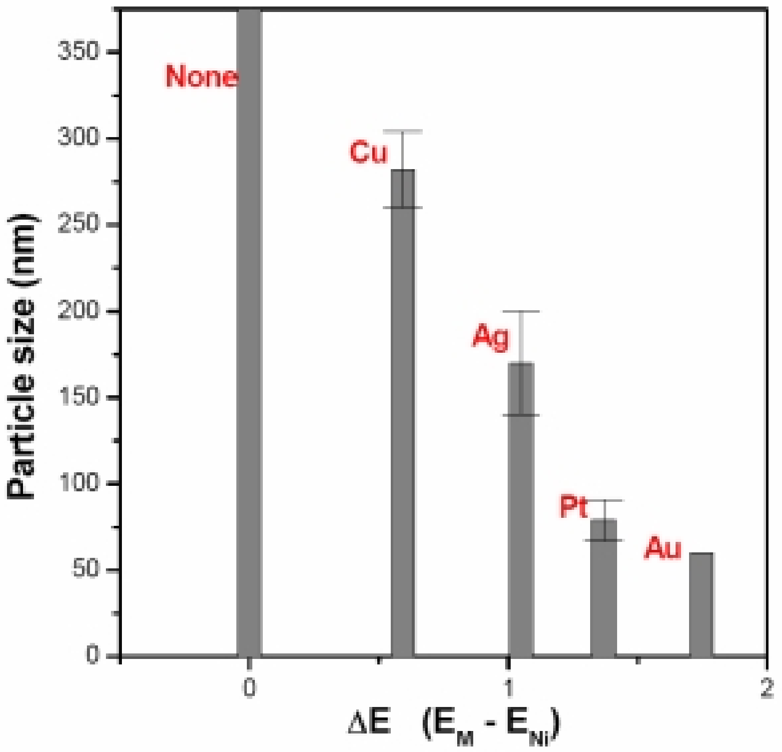
<Seed concentration Vs. particle size>

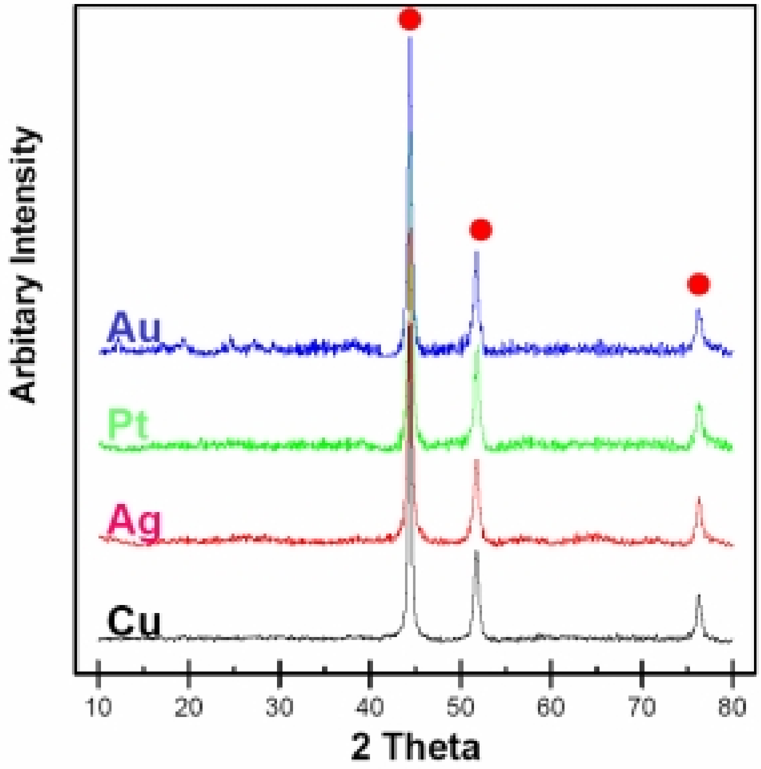




$$d_m = A\left[\mathrm{Seed}\right]^{-\frac{1}{3}}$$

Heterogeneous Nucleation (2)

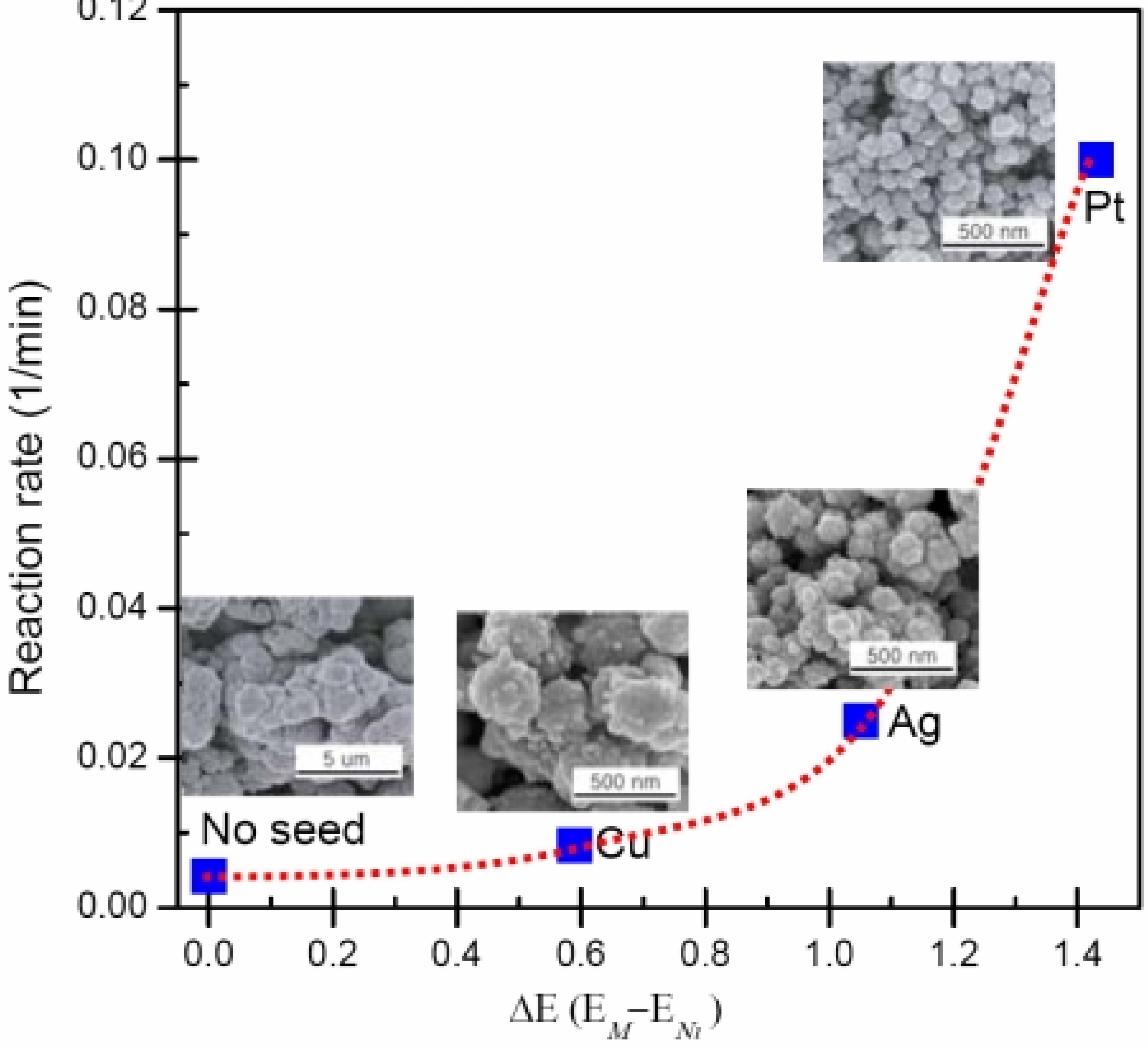




Seed	Vs SHE (eV)	Ni Particle Size(nm)
Cu	+0.34	282
Ag	+0.80	170
Pt	+1.18	90
Au	+1.50	≈ 60

Heterogeneous Nucleation (3)

< ΔE (Driving force) Vs. Reaction rate>

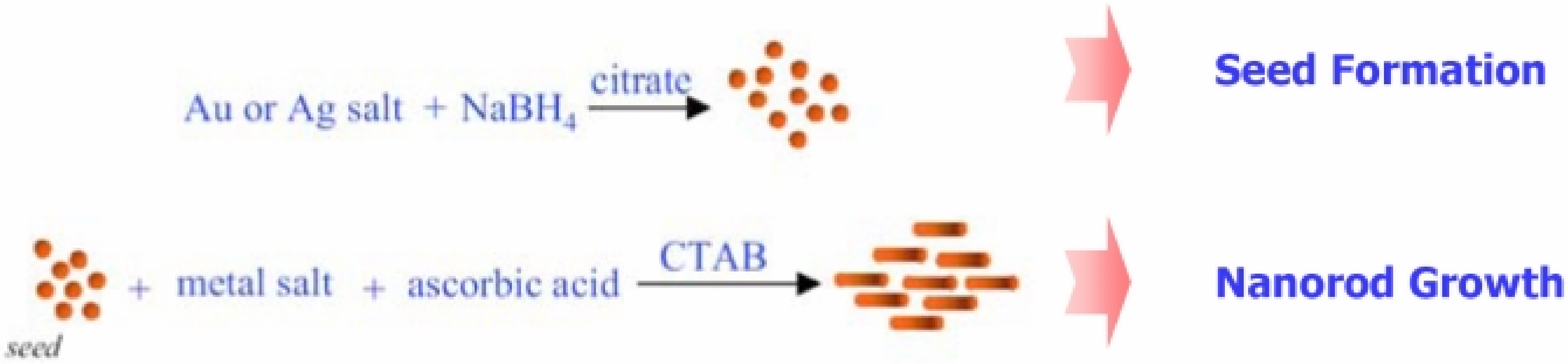


- **Driving Force : ΔE**
  → Redox potential
- **Reaction : ΔE > 0**
- **$\ln K_e = nF\Delta E/RT$**

Seed-Mediated Growth in Solution

- **Formation mechanism**

Seed-mediated growth for gold and silver

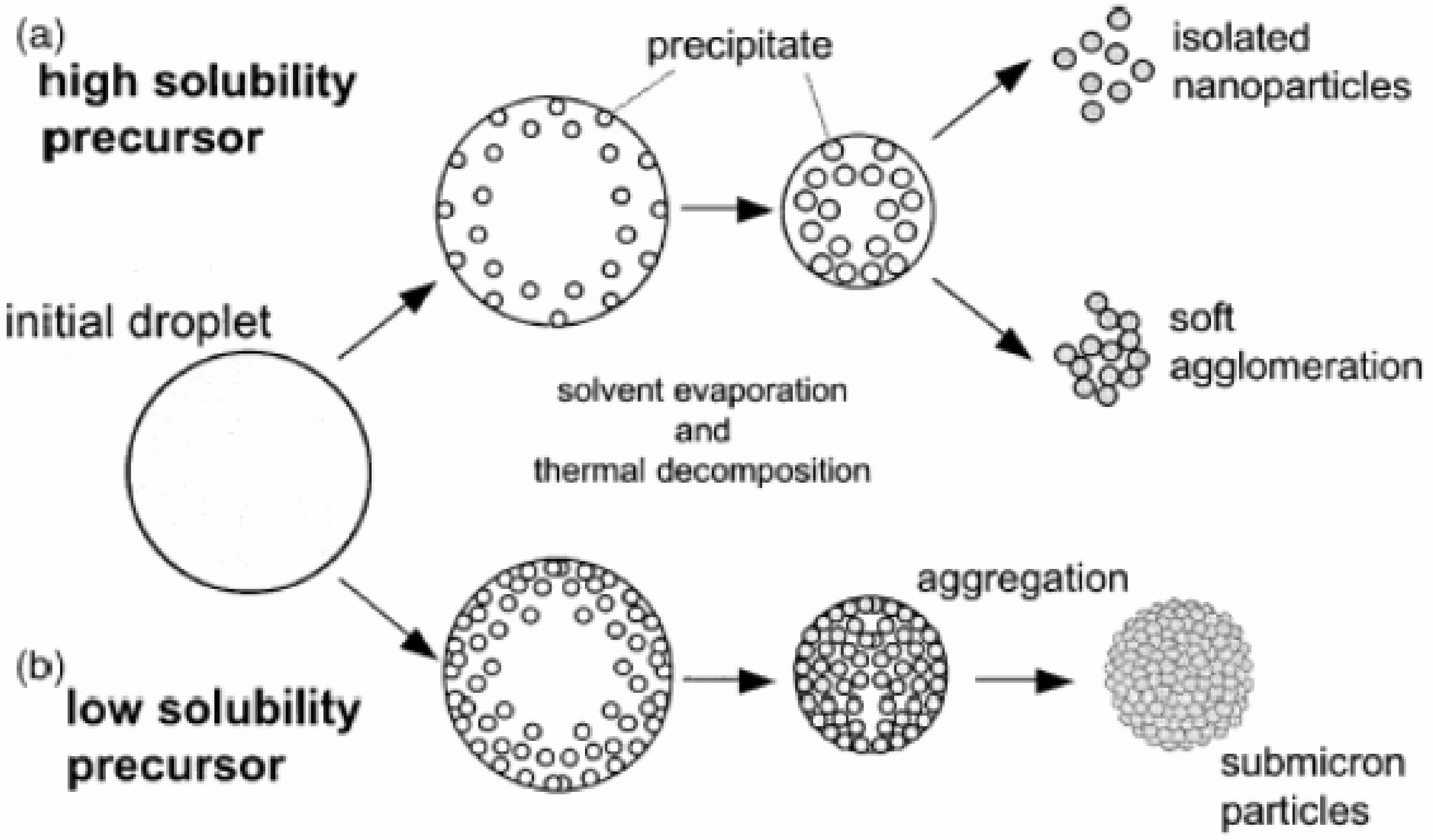


- **$NaBH_4$; Strong reducing agent**
- **Citrate ; capping agent (inhibit particle growth)**
- **Ascorbic acid ; Weak reducing agent**
- **CTAB ; Rod like template**

Synthesis Techniques

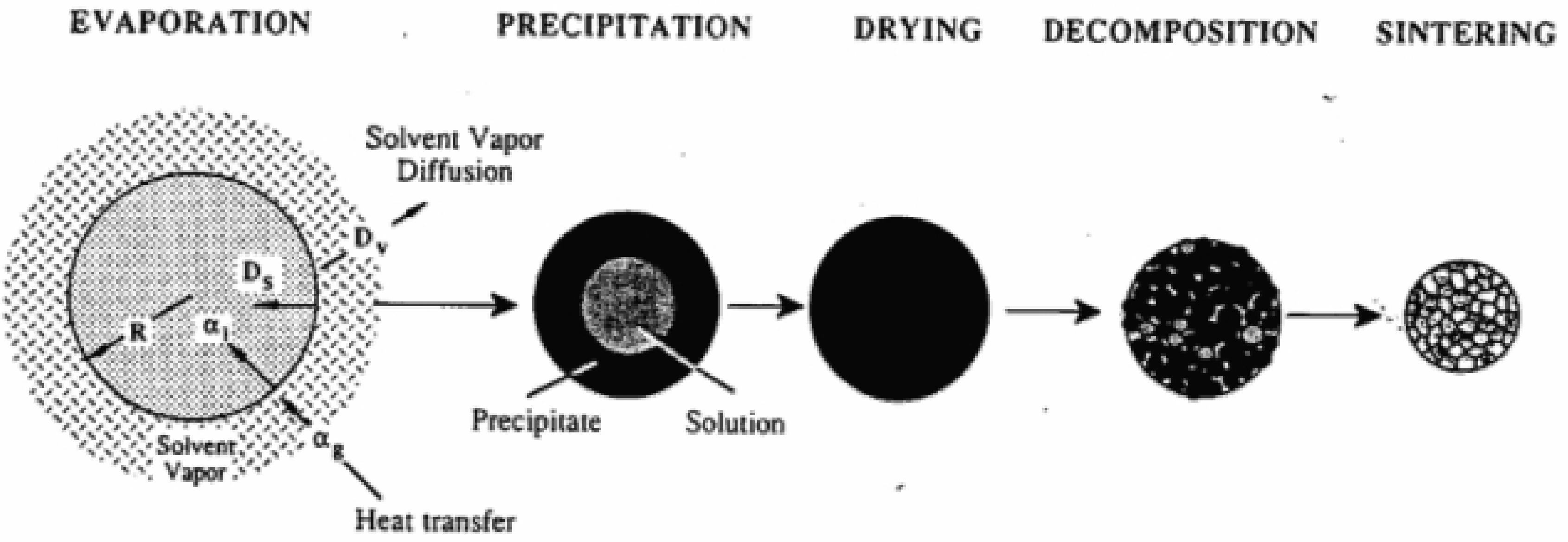
- **Mechanical:** Milling
- **Chemical:** Chemical vapor reaction
  Spray pyrolysis
  GNP (Glycine Nitrate Process)
- **Physical:** Evaporation-Condensation

Spray pyrolysis



Materials Research Bulletin 38 (2003) 1819–1827

Spray pyrolysis



Stages of Spray Pyrolysis Process

Considerations

- The precursor must be dissolved in the liquid, but must not reacted with it.
- The product must not dissolve in the liquid, and must not react with the liquid.
- There must be large volume change (decrease) for the reaction precursor production.
- Transport of the leaching agent in the liquid and the fugitive compound formed must be sufficiently rapid.

Experimental variables

- (substrate temperature)
- ambient temperature
- chemical composition of carrier gas and/or environment
- (nozzle to substrate distance)
- droplet radius
- solution concentration
- solution flow rate

NiO Nanoparticle

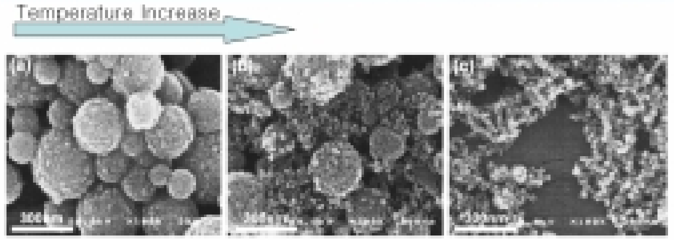
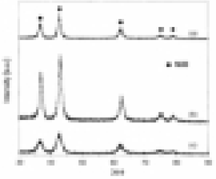


Fig. 3. NiO particles prepared from nitrate precursor at different temperatures: 400 °C (a), 700 °C (b), and 900 °C (c). Other conditions: operating pressure, 40 Torr; starting solution concentration, 0.15 mol/l; carrier gas flow rate, 2 l/min; glass filter size, 5.5 μm.



Filter expansion aerosol generator

Materials Research Bulletin 38 (2003) 1819–182

NiO Nanoparticle

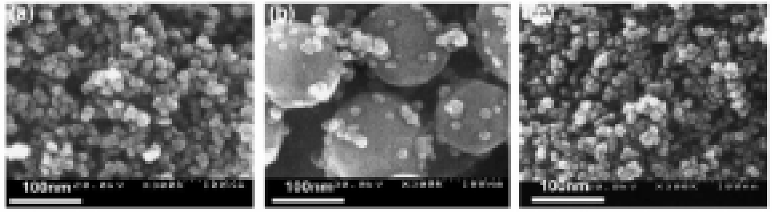
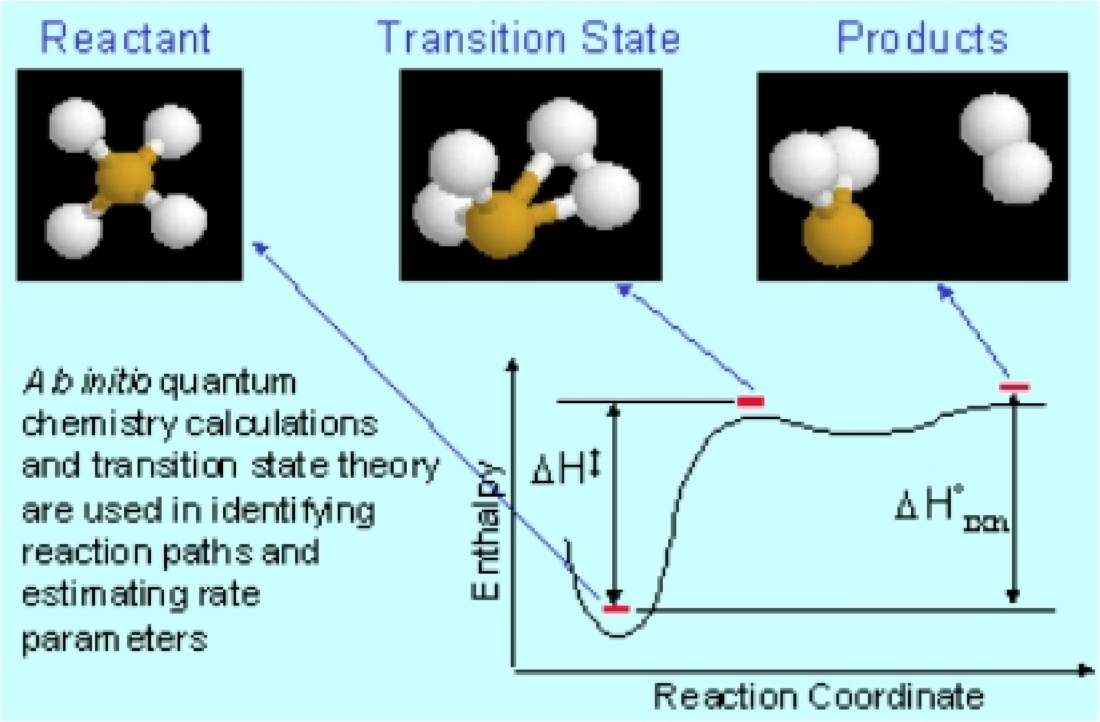


Fig. 5. NiO particles prepared at different residence time: 0.02 s (a) and 0.2 s (b) using 5.5 μm glass filter. (c) Particles prepared using 16 μm glass filter. Other conditions: nitrate precursor operating pressure, 40 Torr; starting solution concentration, 0.15 mol/l.

Aerosol Synthesis

- Particle nucleation:



Ab initio quantum chemistry calculations and transition state theory are used in identifying reaction paths and estimating rate parameters

- **Overall reaction:**

$$nSiH_4 \rightarrow Si_nH_{2m} + (2n-m)H_2$$

Advantage & Disadvantage

Advantage

- No Liquid Byproducts
- No Post Processing treatment
- Low-Temperature Synthesis
- High Homogeneity
- Easy Achieved

Disadvantage

- Sensitivity for Atmosphere Condition
- Expensive of Raw Materials
- Use of Toxic Systems

Experimental Setup

Starting Materials

Si precursor: Hexamethyldisiloxane
Oxidizer: Oxygen
Fuel Gas: Methane

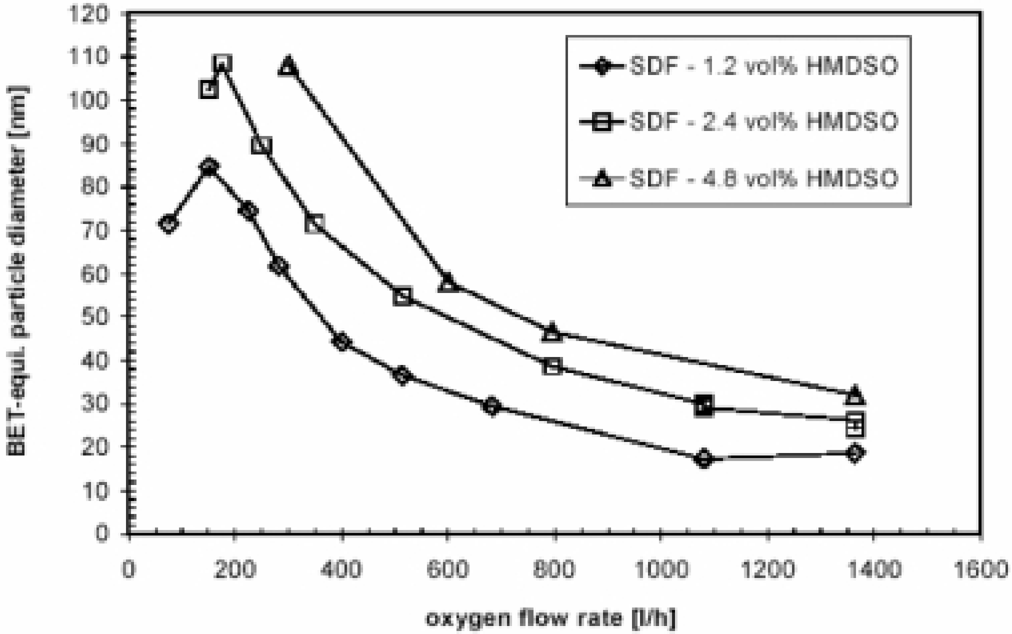
↓

Flame Hydrolysis

↓

SiO_2 nanoparticles

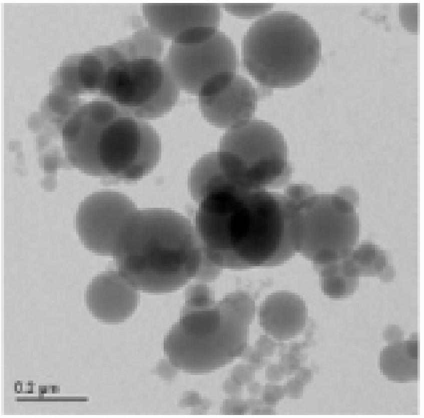
Size Control



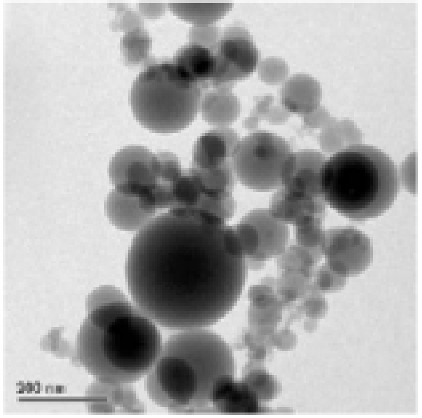
Higher precursor conc.

Bigger particles

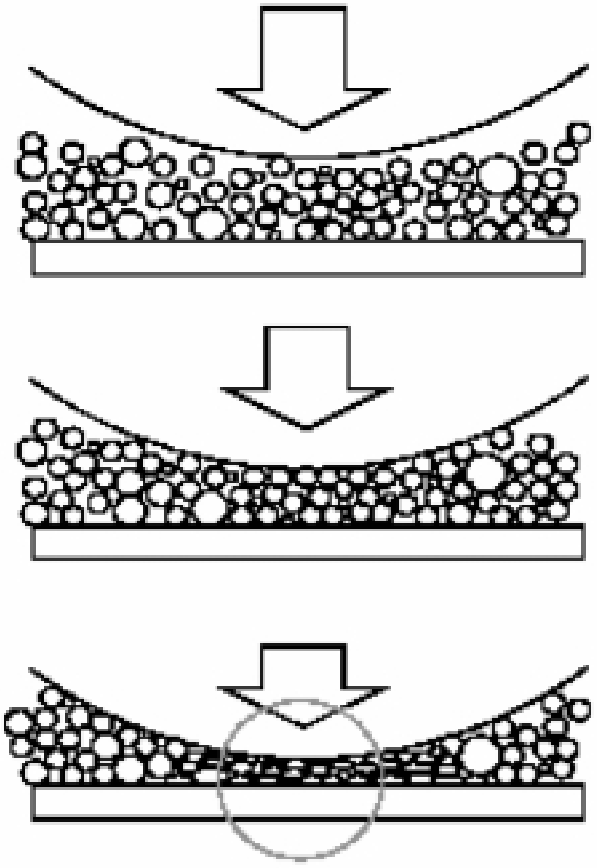
Precurser conc 2.4 vol%

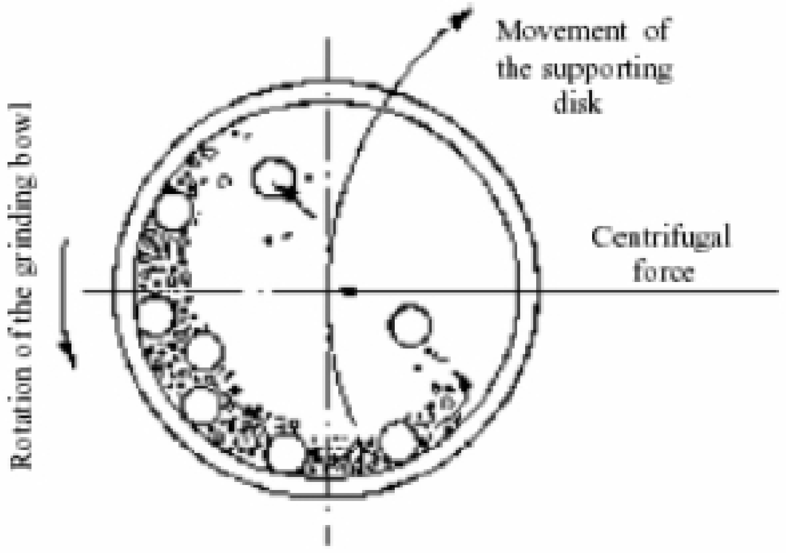


Precurser conc 4.8 vol%



Mechanochemical Process





From the viewpoint of changes of free energy Mechanical activation changes the amount of accumulated energy

Chemical Engineering Science 58 (2003) 815 . 821

Mechanical activation devices

Vibrating mill

Planetary mill

Reaction Kinetics

$BaCO_3 + TiO_2 \Rightarrow BaTiO_3 + CO_2$

$BaCO_3 + BaTiO_3 \Rightarrow Ba_2TiO_4 + CO_2$

$Ba_2TiO_4 + TiO_2 \Rightarrow 2BaTiO_3$

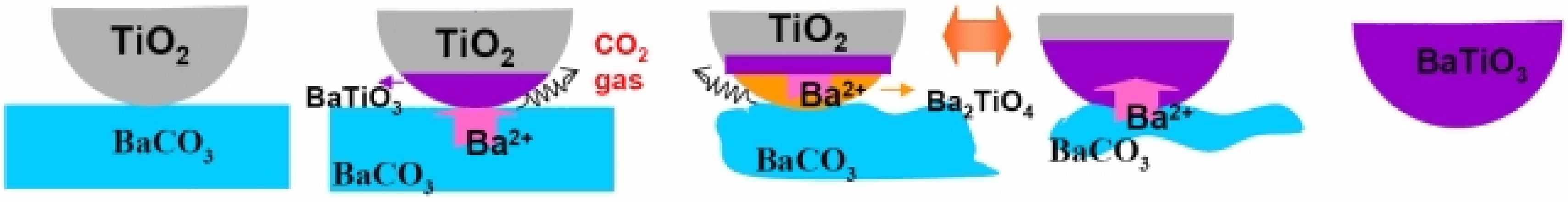
Smaller TiO_2 particle

- Increase Kinetics

Milling of $BaCO_3$

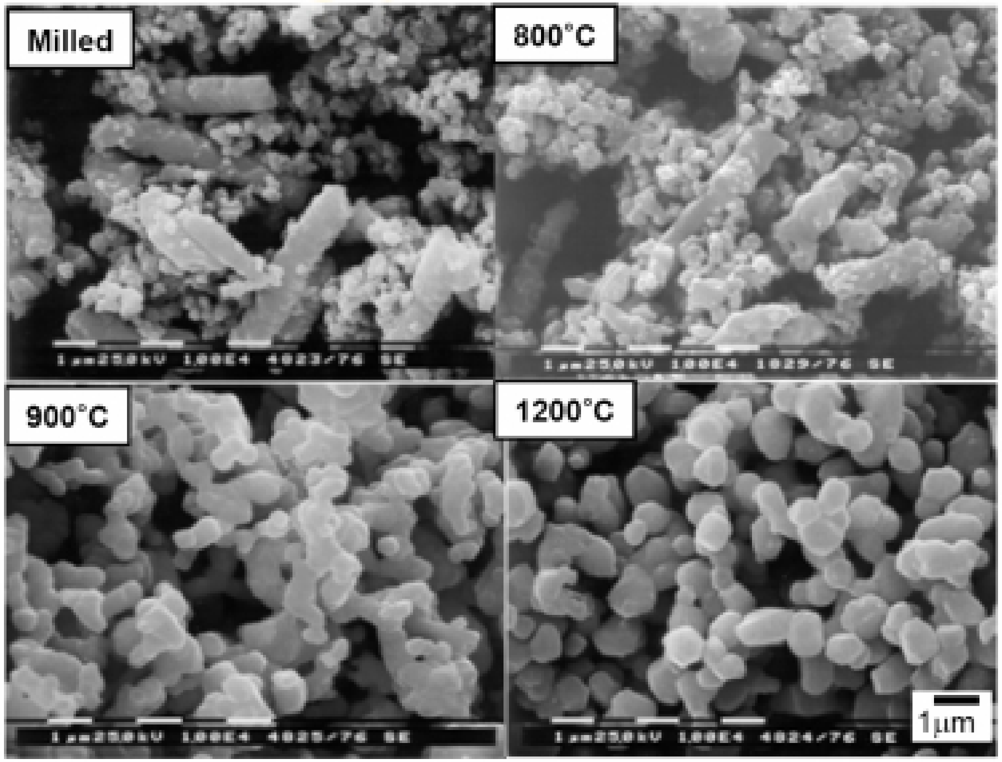
- Mechanical Activation

- **Schematic Diagram**



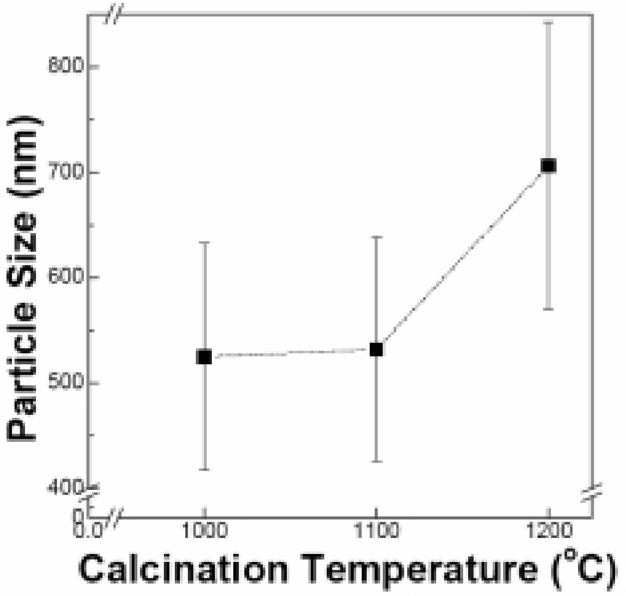
Particle Morphology

SEM Micrographs



- Just milled powder
  - TiO_2: Smaller spherical
  - $BaCO_3$: Large rod-like
- 800°C
  - Starting Ba Diffusion
  - No Ba_2TiO_4 phase
- 900°C
  - No elongated shape
  - Average particle size ⇑
- 1200°C
  - Single phase $BaTiO_3$
  - Shape similar to TiO_2

Particle Size



- Particle Size Increase with temperature
- Reaction completed at 1200°C

Polymeric Nanoparticles

- **Emulsion Polymerization**

  The "ingredients" for an emulsion polymerization include 1) a water soluble initiator, 2) a chemical emulsifier, and 3) a monomer that is only slightly soluble in water, or completely immiscible.

  The two differences between emulsion and suspension polymerization are: 1) that a suspension polymerization is a mechanical process, and must have a stabilizing agent until the droplets are far apart, and 2) the emulsion polymerization is a chemical process which requires a surfactant to make the monomer "emulsify."

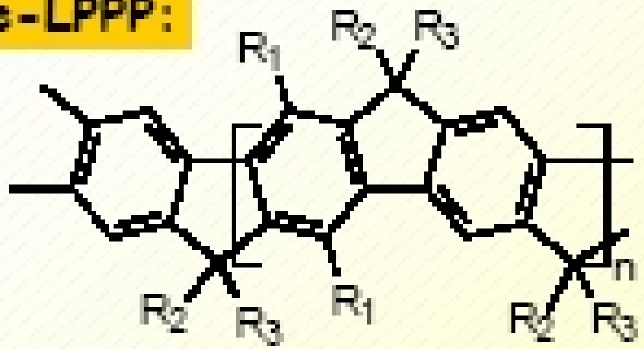
  Disadvantage- the surfactant is a soap and it contaminates the polymer.
  Advantage- better heat control; the size of the emulsion polymer is usually 0.05 to 5 microns, and the size of the droplets is usually in the 10- 1000 micron diameter range.

  Water-soluble initiators are used rather than monomer-soluble initiators. The end product is usually a stable latex--an emulsion of polymer in water rather than a filterable suspension.

Overview of Polymeric Nanoparticles (PNP) Applications

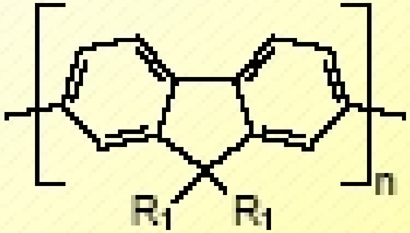
Application	Material	Purpose
Cancer Therapy	Polyalkylcyanoacrylate nanoparticles with anticancer agents, Oligonucleotides	Targeting, Reduce Toxicity, Increase uptake, Improve stability
Intracellular Targeting	Polyalkylcyanoacrylate/polyester nanoparticles with anti-parasitic, antibacterial or antiviral agents	Target reticuloendothelial systems for intracellular infection
Prolonged Systemic Circulation	Polyesters with adsorbed polyethylene glycols, pluronics or derivatized polyesters	Prolong systemic drug effect, Avoid uptake by the reticuloendothelial system
Vaccine Adjuvant	Polymethyl methylacrylate nanoparticles with vaccines, Oral and intra-muscular immunizations	Enhance immune response, Alternate acceptable adjuvant
Peroral Absorption	Polymethyl methylacrylate nanoparticles with proteins and therapeutic agents	Enhance bioavailability, Protect from gastrointestinal enzymes
Ocular Delivery	Polyalkylcyanoacrylate nanoparticles with steroids, Anti-inflammatory agents, Antibacterial agents for glaucoma	Improve retention of drug/reduce washout
Other Applications	Polyalkylcyanoacrylate nanoparticles with peptides, Nanoparticles with adsorbed enzymes, Polyalkylcyanoacrylate nanoparticles for transdermal applications, Nanoparticles with radioactive or contrasting agents	Cross blood-brain barrier, Enzyme immunoassays, Improve absorption, Imaging

Me-LPPP:

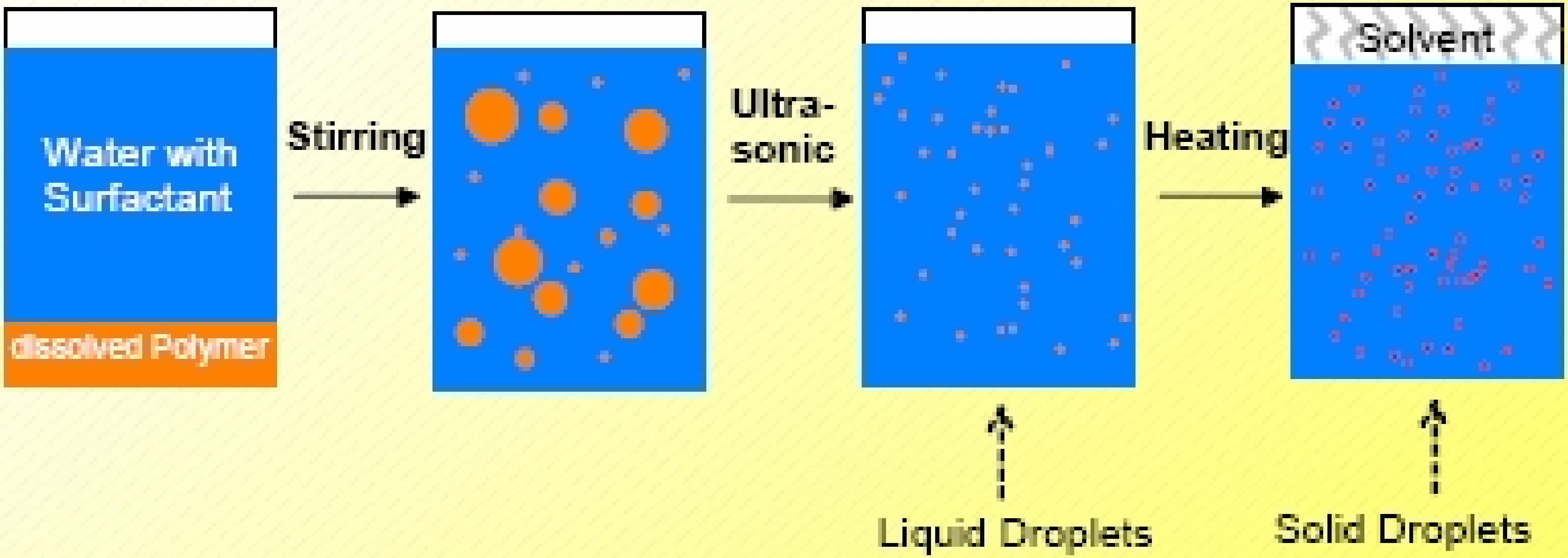


(-R1: hexyl, -R2: methyl, -R3: 4-decylphenyl)

PF:



PF 2/6: (-R1: alkyl: 2-ethylhexyl)
PF11112: (-R1: 3,7,11-trimethyldodecyl)



So far, the size of the particles could be controlled between 70-250nm. The solid contents of the miniemulsions used for the experiments are typically in the range of 4-10%.