

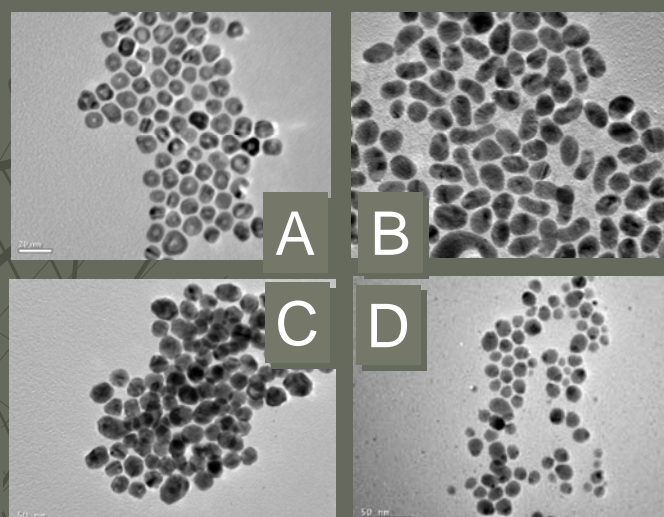
Phase Transfer Identification of Core-Shell Structure in Bimetallic Nanoparticles

- Core shell nanoparticles combine different properties of the core and shell components to satisfy the application requirements (e.g. optical properties of the core and the biocompatibility of the shell).
- Core-shell nanoparticles are often prepared by seed mediated reactions in which the core particles are used to seed the formation of the shell component.
- The formation of core-shell particles is commonly verified by TEM and XPS. The phase transfer method which utilizes the affinity of the shell component for a particular solvent, can be used to **visually** detect the formation of core-shell nanoparticles without elaborate instrumentation.
- With the phase transfer method we can show conclusively the formation of core-shell nanoparticles of Ag-Au, Ag-Pt, Ru-Ag, Pt-Au, Au-Ru and Pt-Ru when nanoparticles of the first metal are used as the seeds in seed mediated growth reactions.

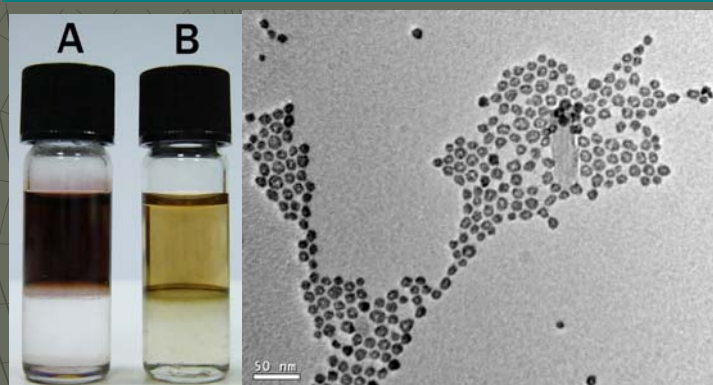
Average particle size and phase transfer properties of different seed nanoparticles

Metal nanoparticles	Mean particle size (nm)	EMA capable?	EMT capable?
Ag	9.6	Y	N
Ag	60.0	N	N
Au	5.0	Y	Y
Au	17.2	N	N
Pt	3.6, 16.6*	Y	Y
Ru	3.2, 21.2*	Y	N

*The size of the Pt and Ru nanoparticles were artificially increased through a core-shell construction using Ag and Au nanoparticle seeds respectively. This is because the prevailing methods of preparation are unable to produce large metal nanoparticles.



TEM images of core-shell Ag-Au (A), Au-Ru (B), Pt-Au (C), and Ru-Ag (D) nanoparticles produced by seed-mediated growth method.



(left) A: Bimetallic Ag-Pt nanoparticles obtained from Ag seeds are completely transferable from water to toluene; B: Bimetallic Ag-Pt nanoparticles obtained from Pt seeds could only be partially transferred. The transferred particles are identified to be Pt only; (right) TEM image of the core-shell Ag-Pt nanoparticles synthesized by seed-mediated growth method using 9.6 nm Ag nanoparticle seeds.

Bimetallic Ag-Au, Ag-Pt, Ru-Ag, Pt-Au, Au-Ru and Pt-Ru nanoparticles with the core-shell structure are obtainable only when the first metal nanoparticles are used as seeds. On the contrary, only a physical mixture of monometallic metal nanoparticles is produced when the synthesis order is reversed using nanoparticles of the second metal as the seeds.

Summary of bimetallic systems formed between different metals by seed mediated growth.

Ag-Au		Ag-Pt		Ru-Ag		Pt-Au		Au-Ru		Pt-Ru	
Seed ^(a)		Seed ^(b)		Seed ^(c)		Seed ^(d)		Seed ^(e)		Seed ^(f)	
Ag	Au	Ag	Pt	Ru	Ag	Pt	Au	Au	Ru	Pt	Ru
C-S	P-M	C-S	P-M	C-S	P-M	C-S	P-M	C-S	P-M	C-S	P-M
EMT		EMT		EMA		EMA or EMT		EMA or EMT		EMT	

C-S: core-shell; P-M: physical mixture. (a) 9.6 nm Ag and 5 nm Au NPs were used as seeds, respectively; (b) 9.6 nm Ag and 3.6 nm Pt NPs were used as seeds, respectively; (c) 3.2 nm Ru and 60 nm Ag NPs were used as seeds, respectively; (d) 3.6 nm Pt and 17.2 nm Au NPs were used as seeds, respectively; (e) 17.2 nm Au and 3.2 nm Ru NPs were used as seeds, respectively; (f) 3.6 nm Pt and 3.2 nm Ru NPs were used as seeds, respectively. EMA: ethanol mediated amine transfer; EMT: ethanol mediated thiol transfer. If the particles are transferable by both EMA and EMT, the EMA method is preferred because experimentally it facilitates the separation of the oil and water phases.

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