

## Characterization of Co<sub>core</sub>Au<sub>shell</sub> Nanoparticles with Transmission Electron Microscopy

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Recently core-shell nanoparticles have received considerable attention since by controlling their chemical composition and the relative sizes of the core and shell then their physical and chemical properties can be tuned. Gold coated magnetic nanoparticles have been produced by different research groups. However, such growth processes lack reproducibility and do not allow production of sufficient quantities of uniformly coated core-shell particles. This is due to the oxygen rich synthesis environment and the presence of water that accelerates the formation of cobalt hydroxide. Moreover, in this method the reduction reaction takes place too rapidly to form a uniform shell due to the use of a strong reducing agent (borohydride). It is also likely that instead of forming a shell, individual Au nanoparticles can be formed. It also becomes a critical issue to characterize the core-shell nanoparticles, especially the relative core-shell size, uniformity, and spatial distribution, since they directly affect the physical and chemical properties. In the present investigation, a reliable method has been developed for the reproducible synthesis of Co<sub>core</sub>Au<sub>shell</sub> nanoparticles by slowly reducing an organo-gold compound onto pre-made  $\epsilon$ -Co seeds with a weak reducer at mild condition (85-105°C). These core-shell nanoparticles are generated in a non-polar solvent in a controlled manner. A wide range of transmission electron microscopy analysis confirmed the successful preparation of core-shell nanoparticles.

Characterization of particles with an average size of 9 nm and 12 nm is reported here. The lighter core and the darker shell of the particles in routine transmission electron microscopy (TEM) images suggest the core-shell structure as shown in Figure 1a since the contribution of the atomic number to TEM contrast is also important, the heavier the element, the darker it appears in the TEM image. The corresponding high resolution image shows a single crystal Co core surrounded by multiple gold grains, suggesting that gold has multiple nucleation sites on the cobalt seeds during synthesis (Figure 1b). Fourier analysis on such an image shows clearly the different crystallites formed. The observation of a Co-L<sub>2,3</sub> edges in electron energy-loss spectroscopy using a 1 nm probe focused on the core, (and absence of the peak when focused on the shell) confirms the distinct chemical nature of the core (Co) and shell (Au) (Figure 2a). Z contrast in STEM mode shows also a lighter shell and darker center and confirms independently the spatial distribution of the two elements: a Co center with a homogeneous coating of Au (figure 2b). In the case of particles with a 12 nm mean size, Fig. 3 shows an example of the core shell structure in high resolution TEM. Several particles are shown in this case with identical core shell structure.

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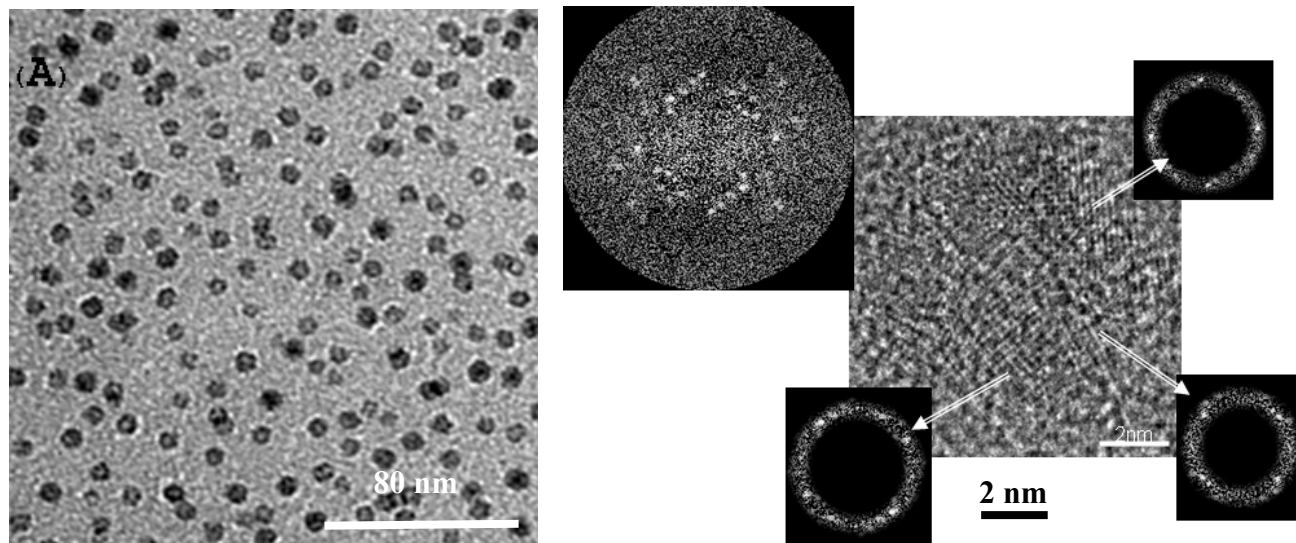


Fig. 1. Co-Au core shell particles. (a) Conventional TEM, (b) High resolution image with Fourier analysis, shell of homogeneous thickness is formed by crystallites.

Fig. 2. (a) EELS spectra from core shell nanoparticles. The beam position is indicated. (b) Z contrast image of nanoparticles

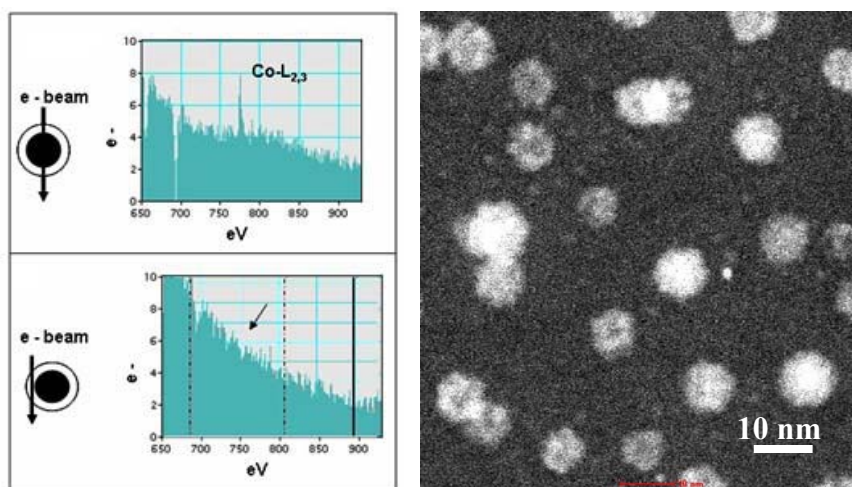


Fig. 3. High resolution image of core shell nanoparticles with an average size of 12 nm.

