



Supporting Information

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Multifunctional Nanoparticles with Magnetization and NIR Absorption

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Preparation of gold nanoparticles as seeds

The gold nanoparticles used as seeds were prepared by reducing chloroauric acid with sodium borohydride (NaBH₄). In brief, into 100 ml of deionized water, 2 ml of 1.0 wt % sodium citrate solution was added and stirred for 3 min. And then 1 ml of 1.0 wt % HAuCl₄·3H₂O was added and stirred for another 5 min. Thereafter, 1 ml of 0.1% NaBH₄ solution, prepared by dissolving NaBH₄ into 1.0 wt % sodium citrate solution, was quickly injected and the reaction was allowed for 10 min under rapid stirring. Then the sodium citrate stabilized gold nanoparticles were successfully prepared and stored at 4 °C for next application.

Characterization

The TEM images were taken with a JEM-1200EX (JEOL) transmission electron microscope. XRD measurement was performed on a Panalytical X'pert PRO X-ray powder diffractometer using Cu K α radiation ($\lambda = 0.15418 \text{ \AA}$). The operation voltage and current were kept at 45 kV and 40 mA, respectively. A MPMS XL superconducting quantum interference device (SQUID) magnetometer (Quantum Design) was used for the magnetic characterization. FTIR spectra were conducted with a FT/IR-420 (JASCO) Fourier-transform infrared spectrophotometer. The JSM-6700 (JEOL) scanning electron microscope was used to acquire the EDX analysis results. NIR absorption spectra were carried out on a DU800 spectrophotometer (Beckman Coulter). The external magnetic field used in this experiment is from an Alnico Horseshoe magnet (5.1 x 5.1 x 1.6cm) purchased from Fisher Scientific.

Additional TEM images of the nanoparticles

Figure S1 shows the TEM images and the UV-vis absorption spectra of the as-prepared Fe₃O₄@PAH@Au-shell nanoparticles. The gold nanoshell was formed on the surface of magnetite nanoparticles which were modified with PAH in the absence of the copolymer layer. Due to the absence of the copolymer layer between the magnetite core and the gold shell, no NIR plasmon absorption was observed although a thick and complete gold shell was formed on the magnetite surface (Figure S1c).

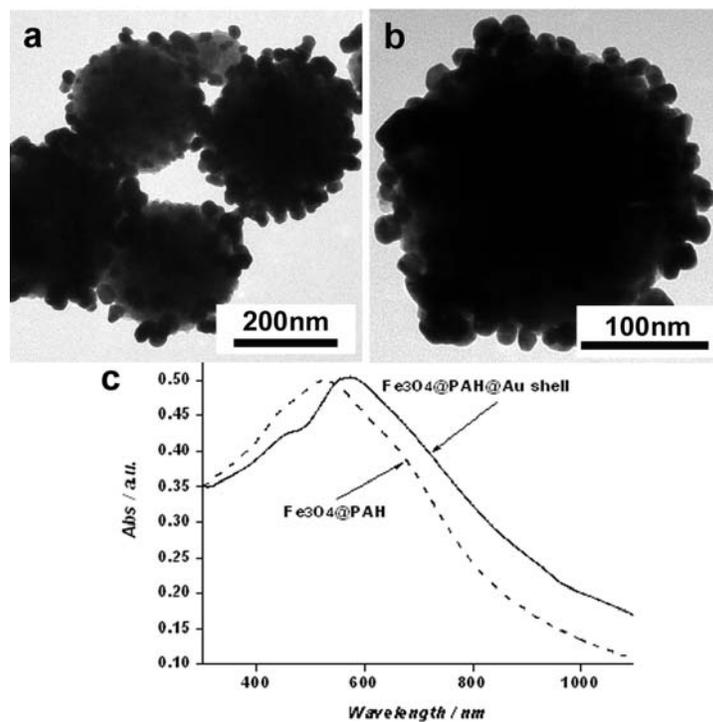


Figure S1. TEM images (a, b) and UV absorption spectra (c) of the Fe₃O₄@PAH and Fe₃O₄@PAH@Au-shell nanoparticles without copolymer layer.

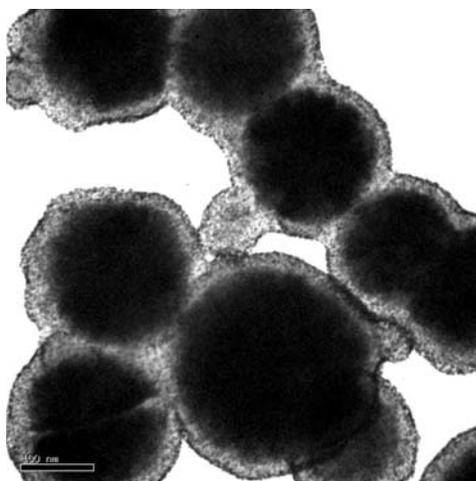


Figure S2. TEM image of the Fe₃O₄@polymer@Au-seeds nanoparticles with thick polymer layer. The scale bar is 100 nm. Gold nanoseeds appeared as black dots on the polymer surface.

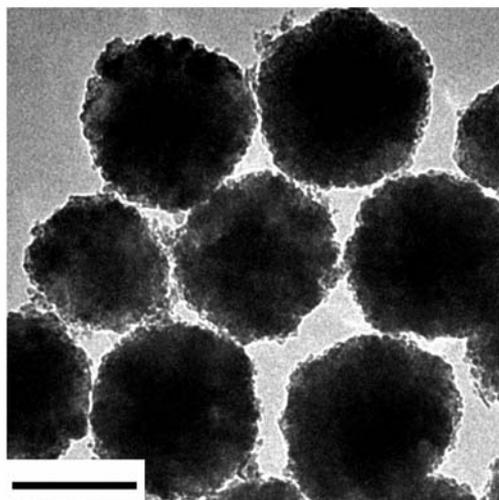


Figure S3. Large version TEM image of Fe_3O_4 @polymer@Au-shell nanoparticles as shown in Figure 1d. The scale bar is 200 nm.

FTIR analysis of the as-prepared nanoparticles

To prove the existence of the polymer, these nanospheres were also characterized by FTIR analysis. Figure S4 demonstrates the FTIR spectrum of the polymer-coated nanoparticles (red curve in Figure S4). As shown in Figure S4, the wide absorption around 3648 cm^{-1} can be attributed to $\nu_{as}(\text{O-H})$ in methacrylic acid and $\nu_{as}(\text{N-H})$ in acrylamide. The band of 2853 cm^{-1} are assigned to $\nu_s(\text{CH}_2)$ of the alkyl chain in the copolymer molecules. Also, the bands at 1640 cm^{-1} is assigned to C=O stretching vibration frequency of the carboxylic and amide groups in the coated polymer. The peaks around the range of 1162 to 1063 cm^{-1} are assigned to C-O and C-N vibration absorption. These results further prove the existence of the copolymer shell on the magnetite nanoparticles. After coating gold nanoseeds onto the polymer surface, all the absorption peaks were still visible although became weaker. However, once the gold nanoshell was formed, the intensity of the peak around 3648 cm^{-1} greatly decreased. At the meanwhile, the absorption around 1162 - 1063 cm^{-1} vanished. The results further support the formation of gold nanoshell was successful.

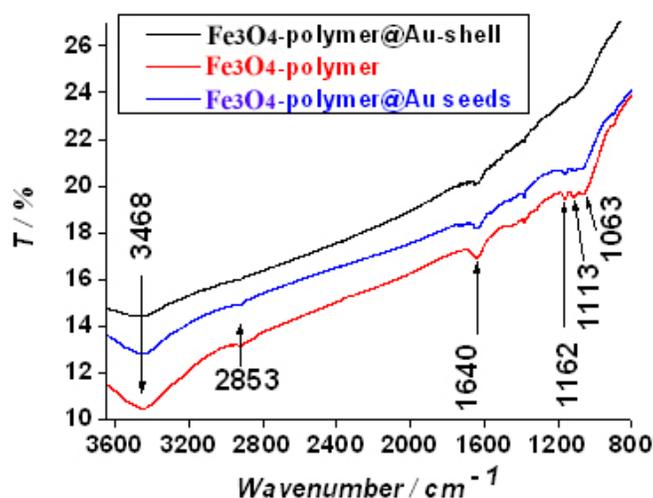


Figure S4. FTIR spectra of the nanoparticles.

XRD and EDX characterization of the nanoparticles

The XRD pattern of the magnetite cores were assigned to (220), (311), (400), (422), (333) and (440) reflections of the Fe_3O_4 (black spectrum, Figure S5). While the XRD pattern of Fe_3O_4 @polymer@Au-shell nanoparticles show the (111), (200) and (220) reflections of gold in addition to those of the Fe_3O_4 (blue spectrum Figure S5), suggesting the existence of gold nanoshell.

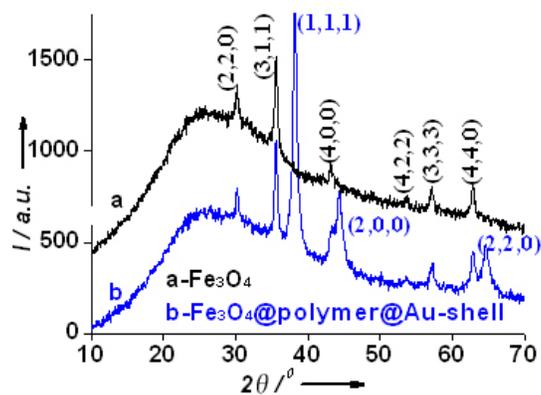


Figure S5. XRD patterns of the (a) Fe_3O_4 core and (b) Fe_3O_4 @polymer@Au-shell nanoparticles.

The composition of the as-synthesized Fe_3O_4 @polymer@Au-shell core-shell nanoparticles were also confirmed with energy dispersive X-ray (EDX) analysis. The EDX spectrum (Figure S6) shows the coexistence of iron and oxide peaks from magnetite nanoparticles, as well as strong peaks of gold from gold shells.

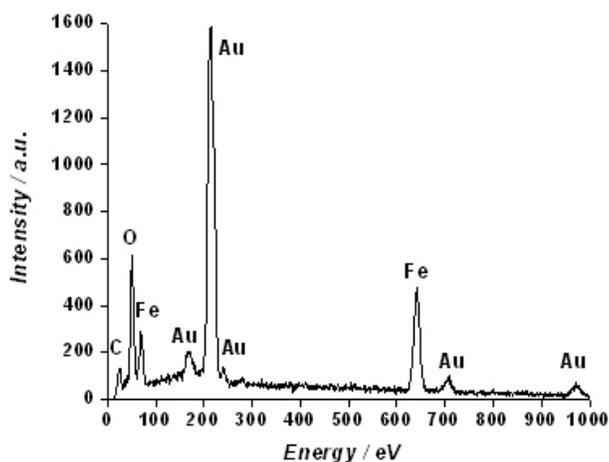


Figure S6. EDX analysis of the Fe_3O_4 @polymer@Au-shell nanoparticles.