Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C

Supplementary Information

Nanostructured Flexible Magneto-dielectrics for Radio Frequency Applications

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Elemental Analysis of Oxide Growth in Nanoparticles

Energy Dispersive X-ray Spectroscopy (EDS) of individual Fe/citrate and Fe/Ag core–shell nanoparticles was used to evaluate possible oxide layer growth. The oxidation characteristics of Fe nanoparticles with a citrate shell were investigated by exposing thermally annealed and non-annealed samples to ambient atmosphere at room temperature for 6 months. The EDS analysis shows that the non-annealed Fe nanoparticles are resistant to oxidation with their citrate shell remaining intact (Figure S1-A). However, the annealed Fe nanoparticles develop an oxide shell in the absence of the citrate shell over this time period. (Figure S1-B).

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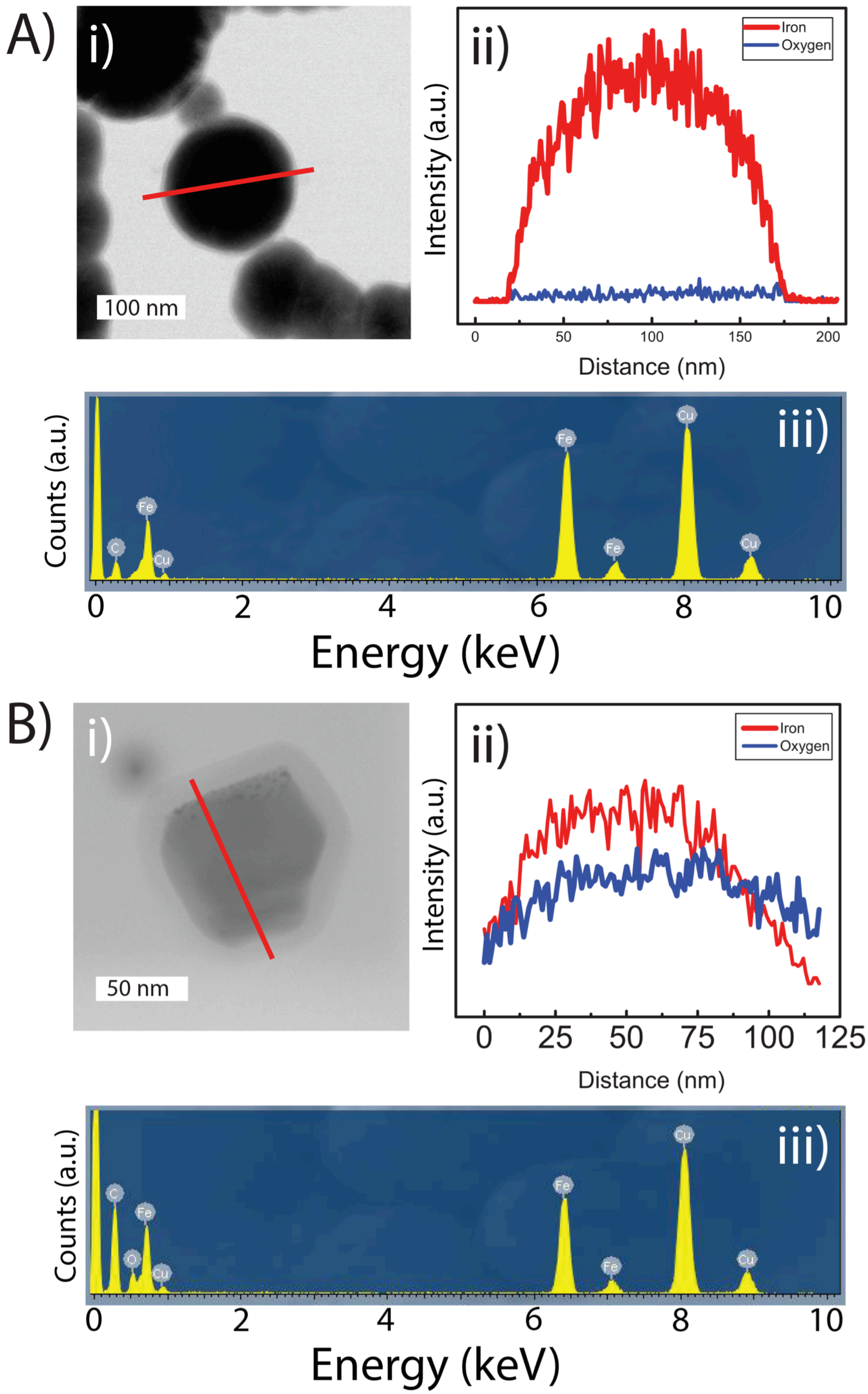

Figure S1. A) Scanning Transmission Electron Microscope (STEM) image (i), EDS elemental line scan (ii), EDS energy spectrum (iii) of non-annealed Fe/citrate nanoparticle. B) Scanning Transmission Electron Microscope (STEM) image (i), EDS elemental line scan (ii), EDS energy spectrum (iii) of annealed Fe/citrate nanoparticle.

EDS analysis also reveals that thermal annealing aids in preventing oxidation of Fe/Ag core-shell nanoparticles. The Fe/Ag core-shell nanoparticles remain unoxidized up to a week prior to thermal annealing (Figure S2-A). However, the discontinuous Ag shell layer of the Fe/Ag core-shell nanoparticles allows slow oxidation of the Fe core (Figure S2-B). As a result of slow oxidation, the oxide formation is detectable for core-shell nanoparticles that are not annealed and kept in ambient atmosphere for 6 months (Figure S2-B). Thermally annealed Fe/Ag core-shell nanoparticles that forms the Fe/Ag heterostructures show no further oxidation after 6 months (Figure S2-C). Thermal annealing leads to a thicker and continuous Ag shell that provides better protection against oxidation.

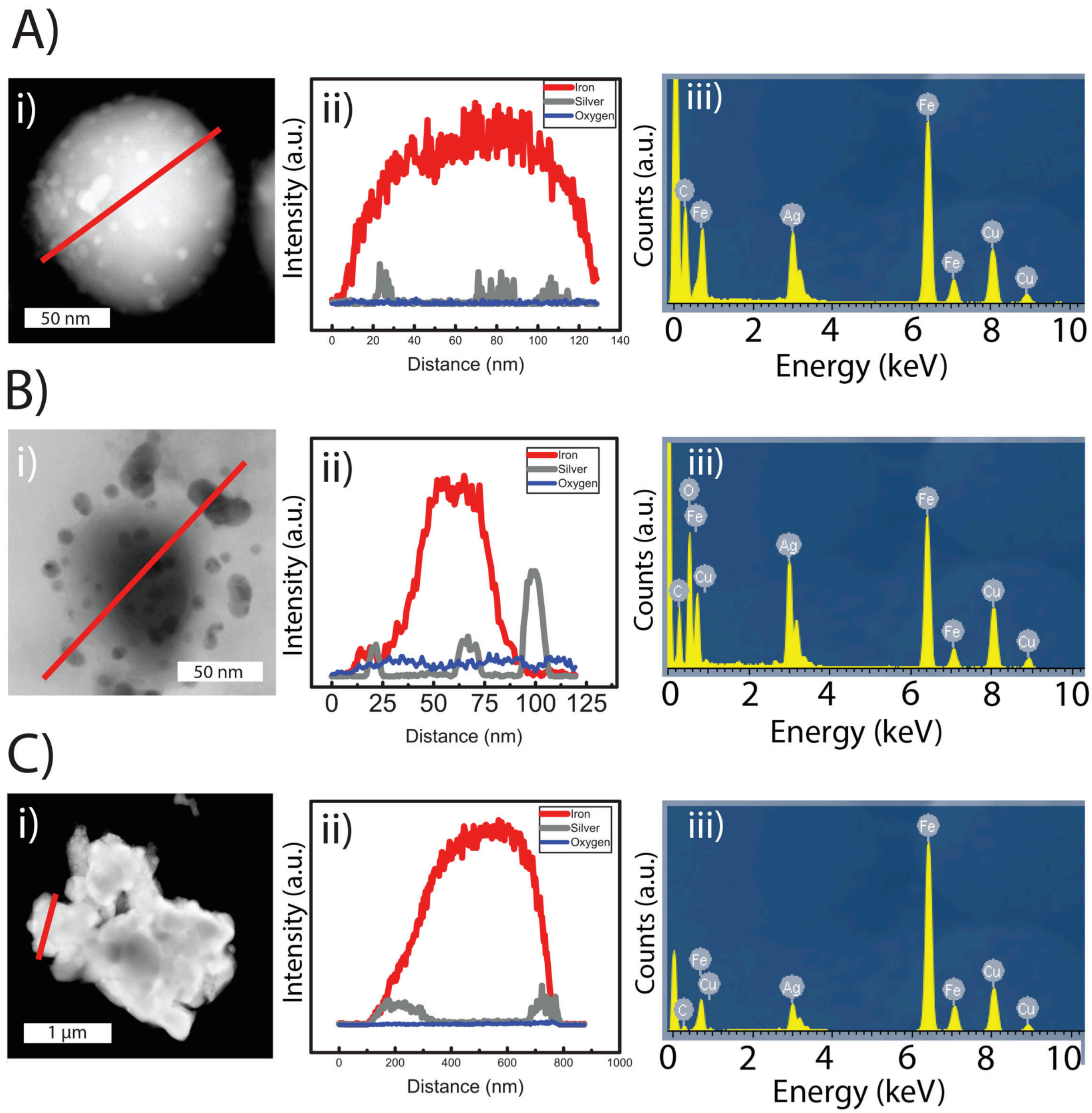

Figure S2. A) Scanning Transmission Electron Microscope (STEM) image (i), EDS elemental line scan (ii), EDS energy spectrum (iii) of Fe/Ag core shell nanoparticle (1 week after synthesis). B) Scanning Transmission Electron Microscope (STEM) image (i), EDS elemental line scan (ii), EDS energy spectrum (iii) of Fe/Ag core-shell nanoparticle (6 months after synthesis). C) Scanning Transmission Electron Microscope (STEM) image (i), EDS elemental line scan (ii), EDS energy spectrum (iii) of Fe/Ag heterostructures (6 months post synthesis).

Embedded-Trough Patch Radio Frequency Antennas

The device performance of flexible magneto-dielectric composites was tested by fabricating embedded-trough patch antennas with Fe/citrate nanoparticle and Fe/Ag heterostructure composites (75wt% nanoparticle loading). The flexible magneto-dielectric composites were placed in the trough of a patch antenna as illustrated in Figure S3-A and the reflected intensity spectrum was measured (Figure S3-C). The RF patch antenna with the Fe/citrate nanoparticle composite placed in the trough has a bandwidth of 12% at -10 dB. The bandwidth of the RF patch antenna with the Fe/Ag heterostructure composite was measured as 9.6% at -10 dB. The slightly higher bandwidth demonstrated by the Fe/citrate nanoparticle composite could be attributed to a higher μ/ε ratio. The RF antennas exhibit resonance at 1.7 GHz for the Fe/citrate nanoparticle composite trough and 1.9 GHz for the Fe/Ag heterostructure composite trough. The resultant size reduction percentages, as calculated from the resonance frequencies of equal length troughs, are 44% for the Fe/citrate nanoparticle composite and 38% for the Fe/Ag heterostructure composite.

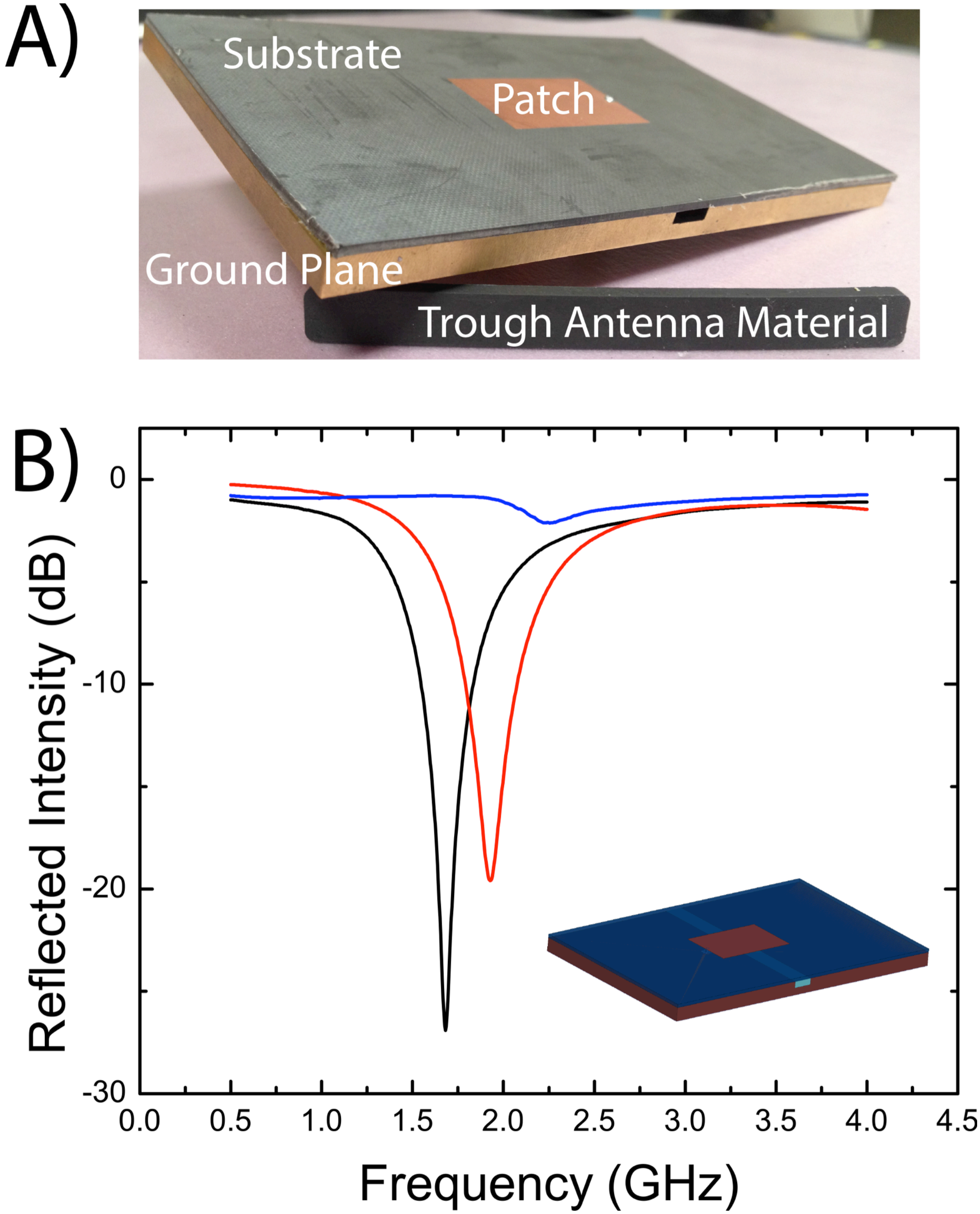

Figure S3. A) Image of embedded trough radio frequency antenna assembly. B) Reflected electromagnetic intensity spectrum for RF antennas with air filled trough (blue), Fe/citrate nanoparticle composite filled trough (black) and Fe/Ag heterostructure composite filled trough (red).