Synthesis and Characterization of Bi-magnetic FePt/Fe_3O_4 Nanoparticles

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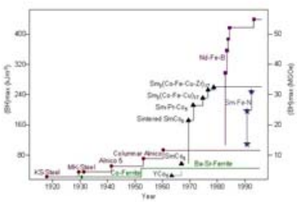
Abstract

Bimagnetic FePt/Fe_3O_4 nanoparticles are synthesized by means of high-temperature solution method by growing soft magnetic Fe_3O_4 phase on FePt nanoparticles. The soft phase can be coated or attached to the FePt particles in controlled manners. The size of the soft and hard phases can be tuned by changing reaction conditions. When the soft phase is coated on the hard phase particles, core/shell structured bimagnetic nanoparticles are formed; when the soft phase particle is attached to the hard phase, heterodimer bimagnetic nanoparticles are formed. Magnetic properties of these bimagnetic nanoparticles are affected by dimensions of the soft and hard components due to the exchange coupling between them. Upon a reductive annealing, an assembly of the nanoparticles is transformed into a hard magnetic nanocomposite with enhanced energy product $(BH)_{max}$ which is 36% higher than the FePt single phase.

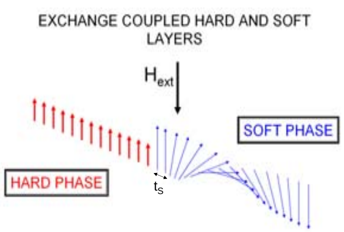
Motivation

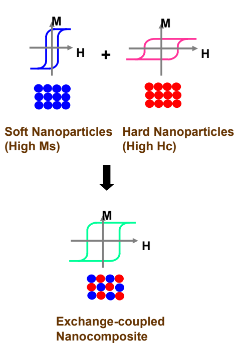
Stronger permanent magnets



Requirement for high BH_{max}
High magnetization (Ms) and high coercivity (Hc)
Limitations for BH_{max}
Materials with high Hc has low Ms and vice versa.
Solution
Exchange-coupled Hard/Soft Nanocomposite magnets

Figure 1. Development in maximum energy product (BH_{max}) of permanent magnet in last 100 years.





Requirement

Dimension of soft phase (t_s) < 2 (domain wall thickness in hard phase) ~ 10 nm

Proposed Research

1) Synthesize monodisperse hard nanomagnetic particles.
2) Coat soft magnetic shell on hard particles.
3) Control the exchange coupling by tuning dimension of hard and soft phases.

Experiments

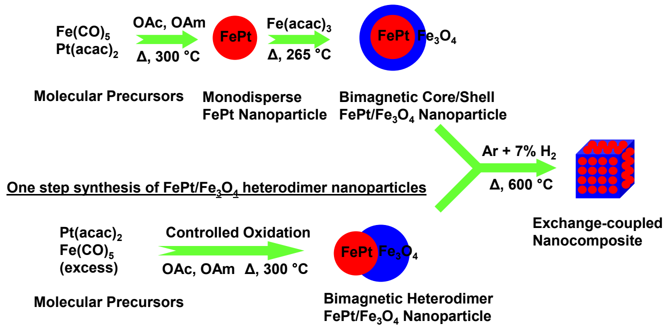


Figure 2. Schematic for synthesis of core/shell and heterodimer FePt/Fe_3O_4 nanoparticles and formation of exchange-coupled nanocomposite after reductive annealing at 600 ºC.

Structural Characterization

Bimagnetic FePt/Fe_3O_4 core/shell nanoparticles

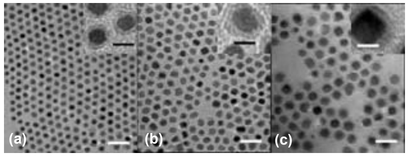


Figure 3. TEM images of as-synthesized FePt/Fe_3O_4 (a) 4 nm/2 nm (b) 6 nm/3 nm (c) 8 nm/3 nm, core-shell nanoparticles (Scale bar is 20 nm, inset scale bar is 5 nm)

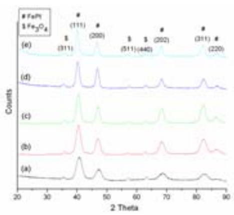


Figure 4. XRD of as-synthesized FePt/Fe_3O_4 core/shell nanoparticles with FePt core diameter (a) 4 nm (b) 5 nm (c) 6 nm (d) 7 nm and (e) 8 nm with 1 nm Fe_3O_4 shell thickness.

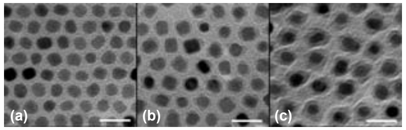


Figure 5. TEM images of as-synthesized (a) 7 nm FePt nanoparticles coated with (b) 1 nm and (c) 3 nm Fe_3O_4 shell. (Scale is bar 20 nm)

Bimagnetic FePt/Fe_3O_4 heterodimer nanoparticles

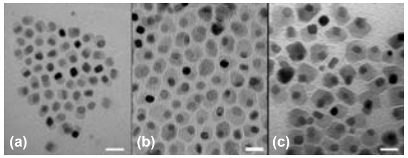


Figure 6. TEM images of as-synthesized FePt/Fe_3O_4 heterodimers with 8 nm FePt attached with (a) 3 nm (b) 6 nm and (c) 8 nm Fe_3O_4 phase. (Scale bar is 20 nm)

Magnetic Characterization

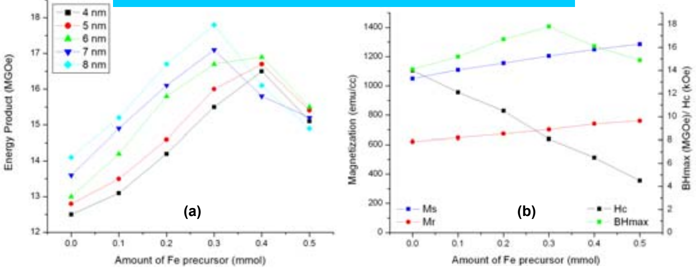


Figure 7. Dependence of amount of Fe precursor, $(Fe(acac)_3$ which was used to form Fe_3O_4 shell) on (a) energy product of FePt/Fe_3O_4 nanoparticles of different FePt core size (4-8 nm) (b) magnetization, coercivity and energy product in core-shell FePt/Fe_3O_4 nanoparticles with 8 nm FePt core.

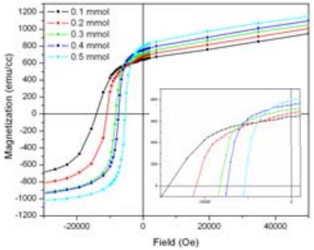


Figure 8. Room temperature hysteresis loops of FePt/Fe_3O_4 core/shell nanoparticles with 8 nm FePt core (after annealing at 600 ºC for 1h) with increasing amount of Fe precursor, $(Fe(acac)_3$ which was used to form Fe_3O_4 shell). Inset figure indicates how the squareness of the loop change with increasing amount of soft phase.

Conclusions

1. Bimagnetic hard/soft FePt/Fe_3O_4 nanoparticles were synthesized by chemical solution route. The morphology and size of the bimagnetic nanoparticles were controlled by changing various reaction conditions.
2. In the core/shell nanoparticles, the size of the core and shell was tuned from 4 to 8 nm and 1 to 3 nm, respectively. In heterodimers, the size of the FePt and Fe_3O_4 phase was tuned from 6 to 8 nm and 3 to 8 nm, respectively.
3. These bimagnetic nanoparticles were converted to hard/soft exchange-coupled nanocomposite after annealing at 600 °C in reducing atmosphere, with enhanced energy product higher than single phase FePt nanoparticles.
4. The energy product of core-shell nanoparticles was found to be dependent on dimensions of FePt and Fe_3O_4 phase. Core/shell FePt/Fe_3O_4 (8 nm/2 nm) nanoparticles produce the highest energy product of **17.8 MGOe** which is 36 % higher than that for FePt single phase.

References

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