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He Ion Irradiation Induced Phase Transformation of Icosahedral FePt Nanoparticles

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Motivation

$L1_0$ FePt nanoparticles are among the most promising materials when it comes to pushing the superparamagnetic limit to as small as possible sizes in order to increase the areal storage density of future magnetic data storage media (hard disks).

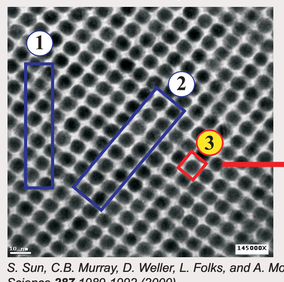
Such an ultra-high density medium is envisioned to be composed of individual hard-magnetic particles with sizes well below 10 nm, each of which is supposed to serve as a single bit. These bits are to be periodically arranged on appropriate substrates, and these particle films shall be magnetically textured such that the easy magnetization directions of all particles are parallel and roughly perpendicular to the film plane.

Today, these requirements are only partially fulfilled which is basically owed to the limitations of the preparation methods employed.

Storage Strategies

Comparison of storage strategies in self-organized magnetic arrays (SOMAs)
[D. Weller, JEMS 2004, Dresden]:

6nm FePt nanoparticles



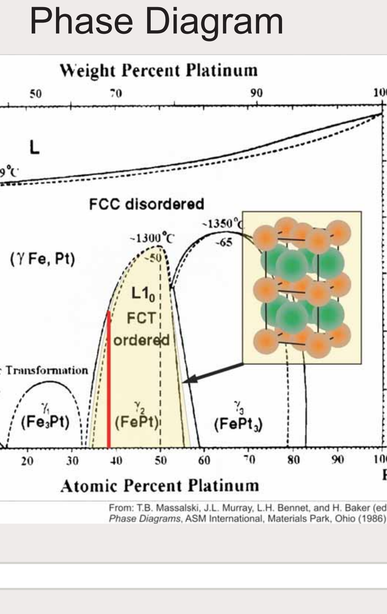
9 Tbit/in^2

*S. Sun, C.B. Murray, D. Weller, L. Folks, and A. Moser, Science **287** 1989-1992 (2000)*

① Conventional Granular Media
② Bit Patterned Media
③ Single-Grain-Per-Bit Patterned Media

Most promising approach in order to increase the areal storage densities.

The Superparamagnetic Limit



Individual, but ferromagnetically coupled magnetic moments.

Total particle moment („*super*“ moment).

Directional Stabilization: Anisoropy energy

$E_A = K_{eff} V$

K_{eff} = effective anisotropy constant
V = (particle) volume

Anisotropy energy is **size dependent**.

Thermal energy acts **destabilizing**.

$E_{Th} = \frac{f}{2} k_B T$

Since the number of magnetic degrees of freedom *f* is independent of the size (due to coupling):

Thermal energy is **size independent**.

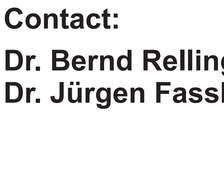
Superparamagnetic limit: $E_{Th} \sim E_A$

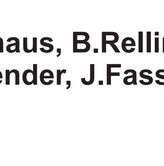
Material System

$L1_0$ – FePt

High magneto-crystalline anisotropy.

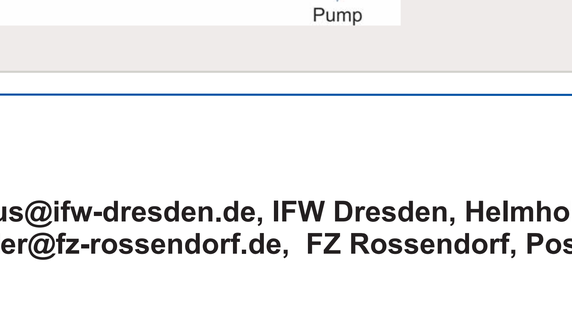
Promising material for media in future high density magnetic data storage





Tetragonal distortion

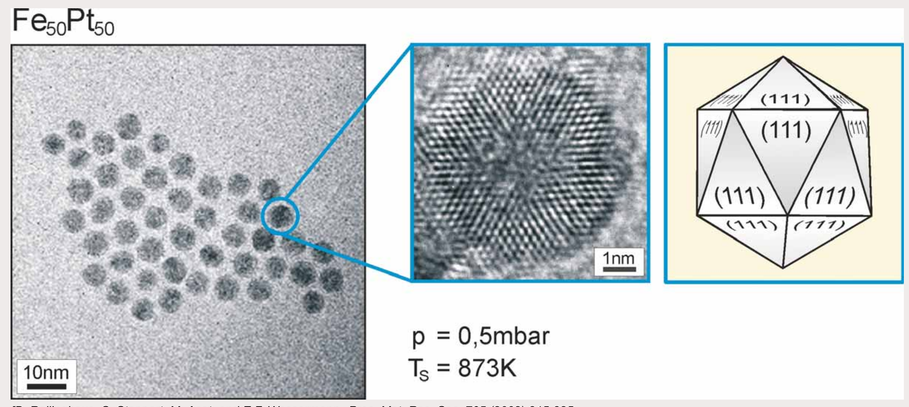
Phase Diagram



From: T.B. Massalski, J.L. Murray, L.H. Bennet, and H. Baker (eds.), *Binary Phase Diagrams*, ASM International, Materials Park, Ohio (1986) 1096.

Nanoparticle Gas Phase Synthesis

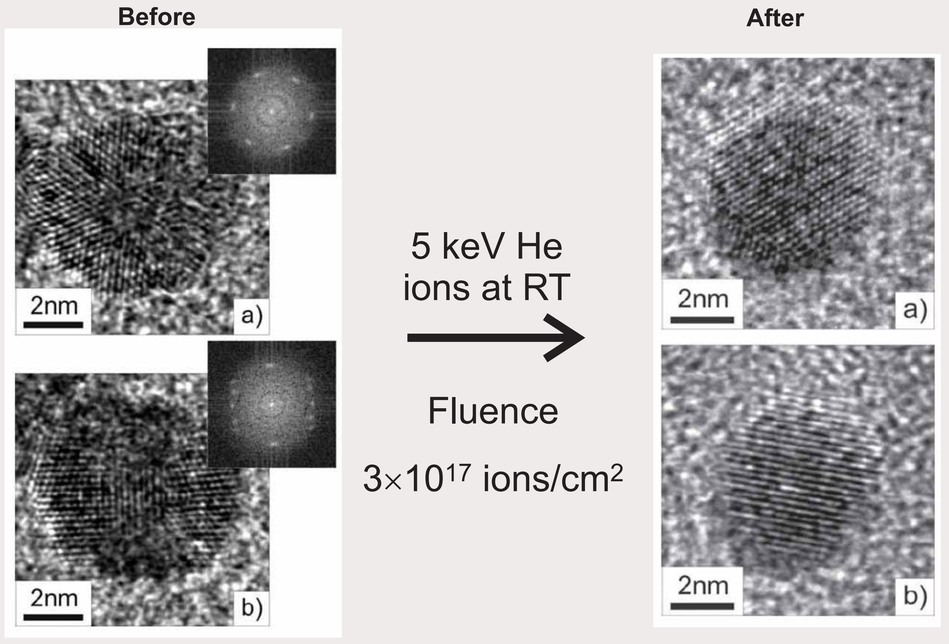
FePt - Icosahedra



*[B. Rellinghaus, S. Stappert, M. Acet, and E.F. Wassermann, Proc. Mat. Res. Soc. **705** (2002) 315-325.*
*S. Stappert, B. Rellinghaus, M. Acet, and E.F. Wassermann, Proc. Mat. Res. Soc. **704** (2002) 73-78.]*

- Monodisperse particles with d_P = 6 nm and σ_G = 1.1
- Icosahedral particles up to T_S = 1273 K
- No indication for the formation of $L1_0$ ordered particles
- “Poor” magnetic performance: superparamagnetic at RT

He ion irradiation



- Destabilization of icosahedral structures by means of He ion irradiation ($Fe_{42}Pt_{58}$)
- Size reduction due to sputtering (Exp.: 40 vol%, SRIM-Simulation: 70 vol%)
- Preferential sputtering: Shift of composition towards the Pt-rich side
- Sintering for neighboring particles (dimers) observed in some cases

Apparently: Lack of $L1_0$ order is due to kinetically induced changes in the thermodynamic equilibrium energetics.

Conclusion

- Gas phase preparation of icosahedral FePt particles
- Phase transformation to fcc upon He ion irradiation
- Chemically ordered $L1_0$ phase not observed
  - kinetic effects dominate over thermodynamic equilibrium energetics
  - $L1_0$ phase not equilibrium phase for FePt nanoparticles with sizes of roughly 5 nm

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