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Asymmetric hysteresis loops and horizontal loop shifts in purely ferromagnetic nanoparticles

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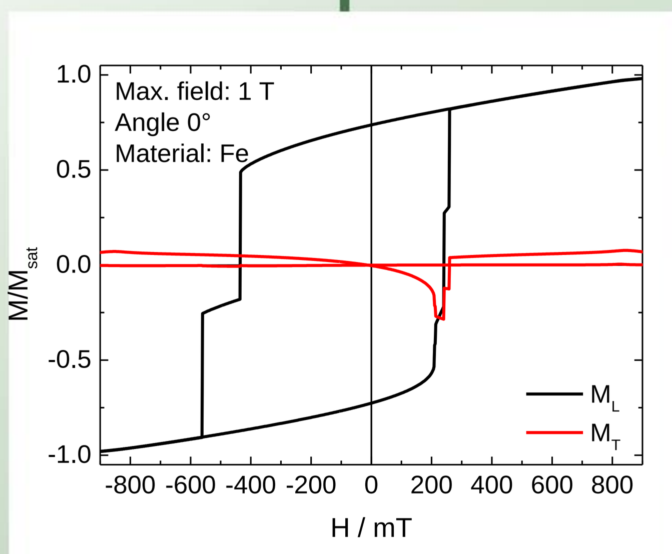
Exchange bias (EB)

Horizontally shifted hysteresis loops and asymmetric hysteresis loops are commonly related with exchange-biased samples, consisting of a ferromagnet exchange-coupled to an antiferromagnet or a ferrimagnet. In pure ferromagnetic samples, such effects may experimentally occur erroneously due to undetected minor loops or additional anisotropies [1,2], while in simulations they may occur due to thermal effects. However, performing simulations of ferromagnetic nanostructures at zero temperature with large enough saturation fields should not result in such asymmetries.



Apparent EB due to minor loop (cf. transverse magnetization MT)

Figure 1. Hysteresis loops

Experimental

- Micromagnetic simulator OOMMF (Object Oriented MicroMagnetic Framework) [3], based on finite differences and dynamically solving the Landau-Lifshitz-Gilbert (LLG) equation of motion
- Material: iron (Fe); corresponding material parameters in agreement with typical literature values: saturation magnetization Ms = 1700 · 10^3 A/m, exchange constant A = 21·10^{-12} J/m, anisotropy constant K_1 = 48·10^3 J/m^3, Gilbert damping constant α = 0.5 (quasistatic case), mesh size d = 5 nm
- Particle dimensions max. 100 nm x 100 nm x 10 nm, tests with different lateral shapes with cuts
- Random anisotropy axes were modeled, as typical for sputtered systems
- Simulations were performed for a temperature of 0 K to exclude thermal fluctuations

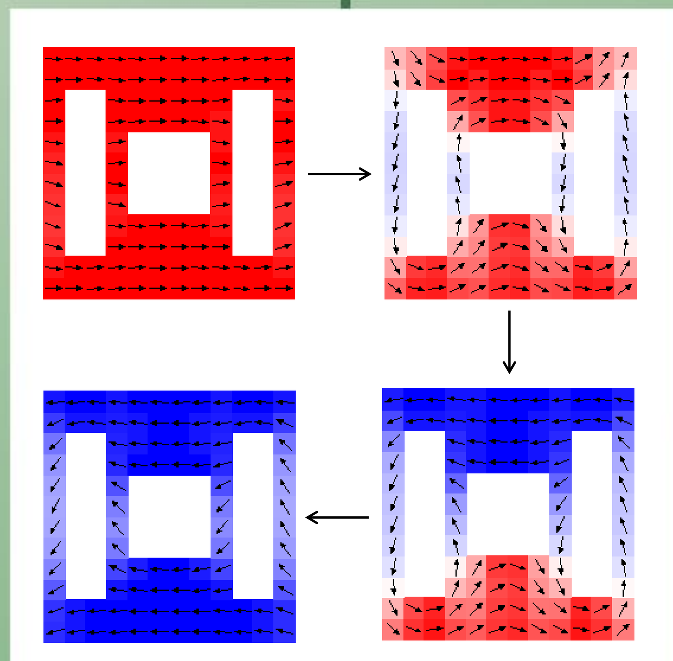


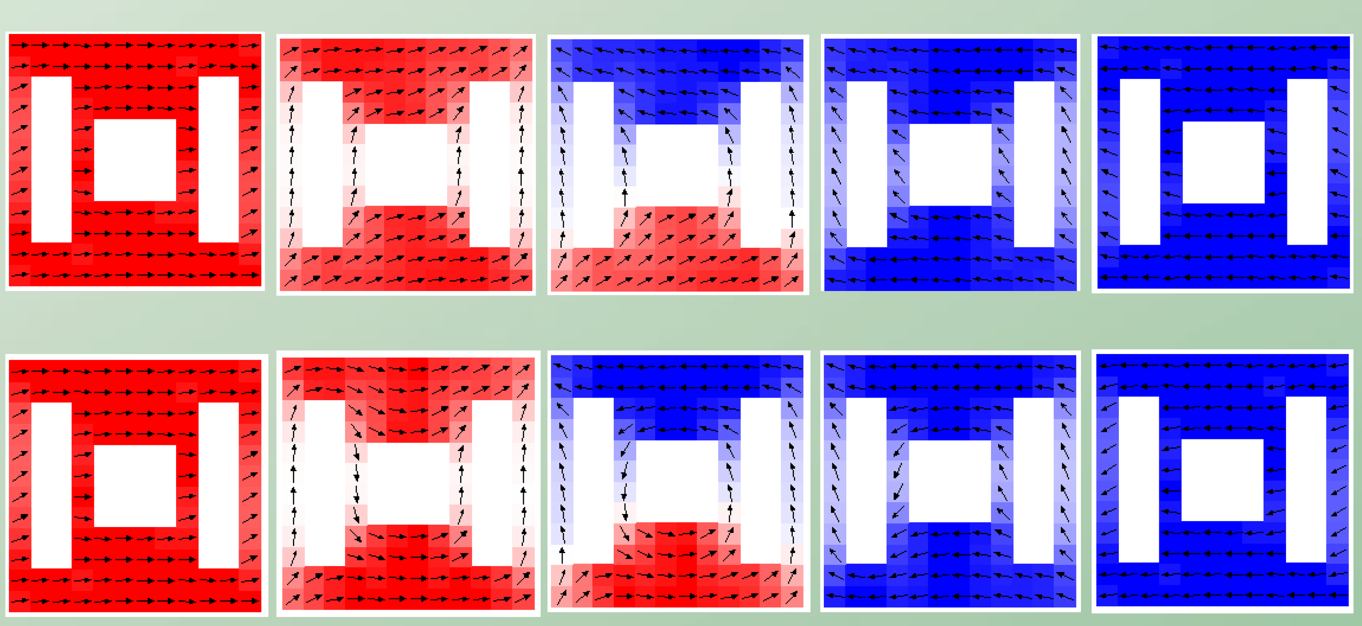
Figure 2. Pos. → neg. saturation

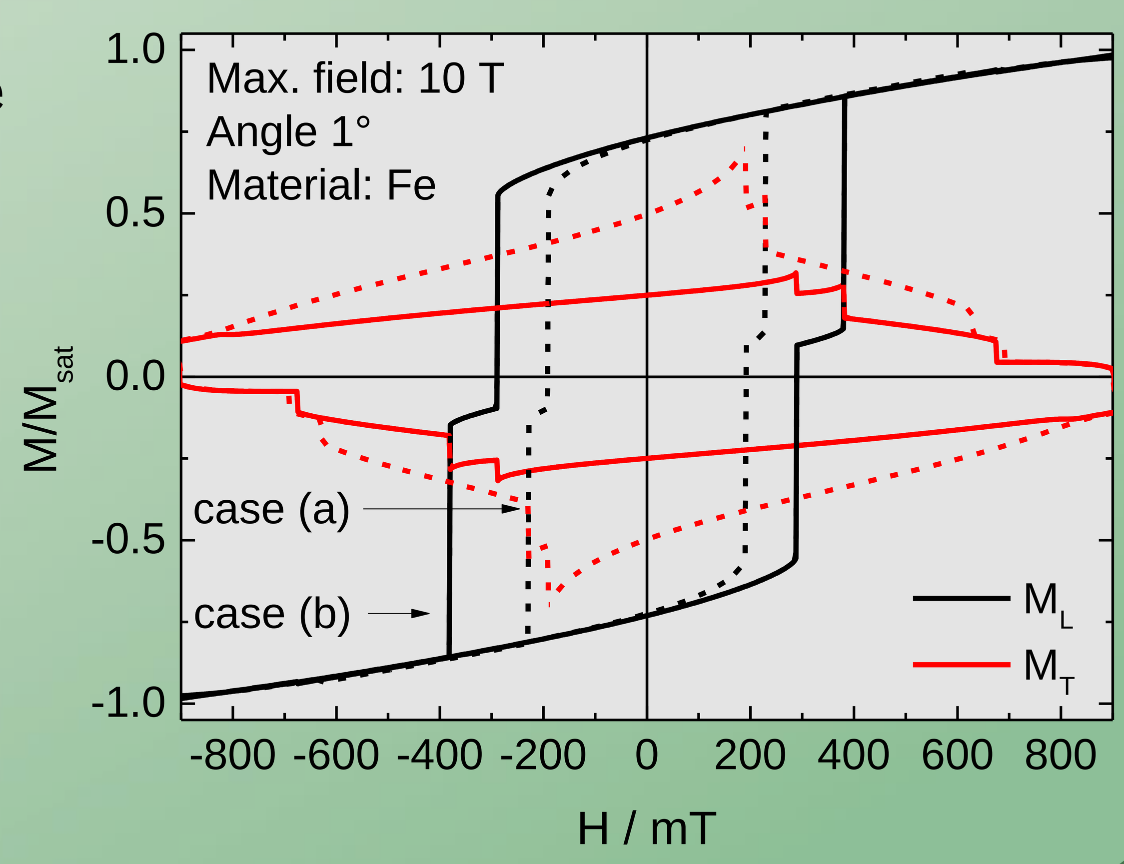
Exemplary results – reproducibility

In small nanoparticles, even large saturation fields (10 T) and canted field orientations (by 1°) are not sufficient to guarantee always identical magnetization reversal processes:

(a)

(b)





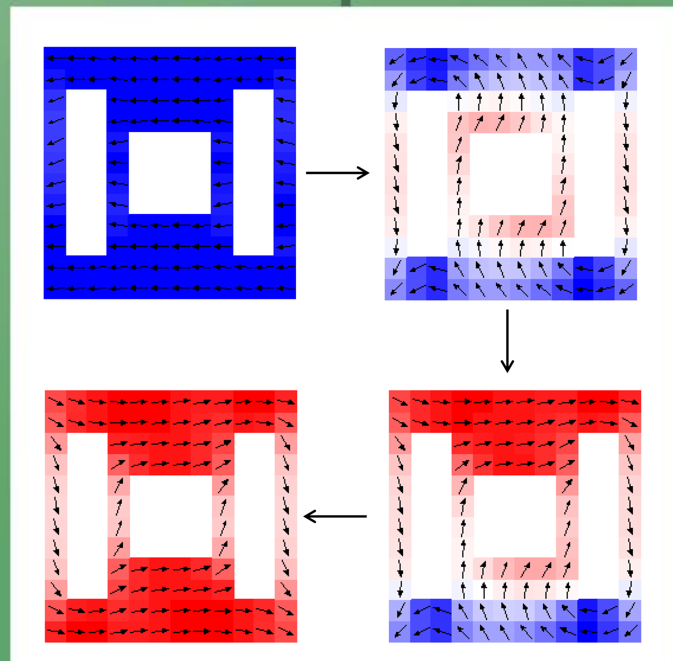


Figure 3. Neg. → pos. saturation

Conclusion

- Small deviations due to random anisotropy orientations in the different grains of nanoparticles may result in strong deviations of the magnetization reversal processes and hysteresis loops
- Asymmetric, horizontally shifted hysteresis loops can occur in ferromagnetic nanoparticles (cf. Figs. 1-3)

→ Possible technological application of such minor loops similar to exchange bias?

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