

Identification of the Curie Temperature Distribution from Temperature Dependent Magnetisation Data

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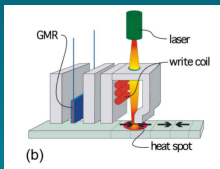
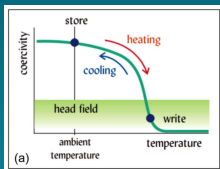
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In HAMR¹:

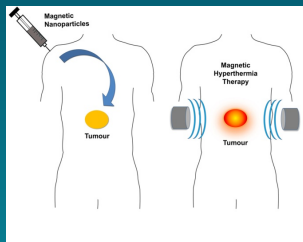
- T_C distribution affects the noise performance



E. Dobisz et al. Proc IEEE 96.11, 1836 (2008)

In Magnetic Hyperthermia²:

- Low T_C reduces tissue damage



Ângela Andrade et al. Coating Nanomagnetic Particles for Biomedical Applications (2011)

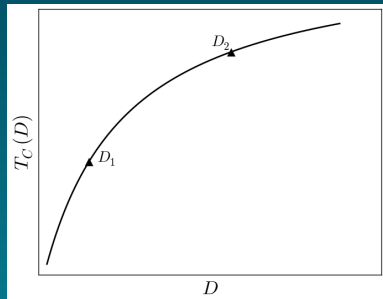
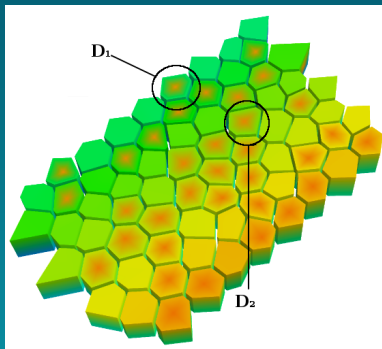
¹D. Weller et al. IEEE Transactions on Magnetics 50.1, 3100108 (2014)

²I Apostolova et al. Solid State Communications 149.25, 986 (2009)

Defining Finite Sized T_C

Correlation length $\propto |T - T_C^b|^{-\nu}$

Grain size, $D \propto |T_C(D) - T_C^b|^{-\nu}$



Distribution in D leads to
distribution in T_C

$$f_D(D) \implies f_{T_C}(T_C)$$

- ▶ Explicit measurement of individual grains.³
 - ▶ Switching temperature is measured by a laser system set up
 - ▶ This is related to T_C
- ▶ Identification from macroscale measurements⁴
 - ▶ Single measurement with magnetometer
 - ▶ Integral measure
 - ▶ But uses bulk relations

³S. Pisana et al. IEEE Transactions on Magnetics 51.4, 1 (2015)

⁴A. Berger et al. J. Appl. Phys. 91.10, 8393 (2002)

- ▶ Develop a universal method to identify the T_C distribution which incorporates the finite size effects of the individual grains
- ▶ Test the method against a well quantified benchmark (2D Ising system) in order to verify it's effectiveness for different distributions.

Magnetisation for Ensemble of Grains:

$$M(T) = M_o \int_0^{\infty} D^d m(D, T) f_D(D) dD$$

Single Grain Magnetisation:

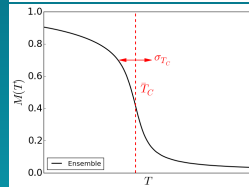
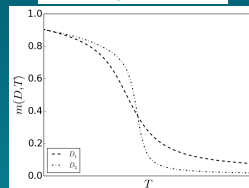
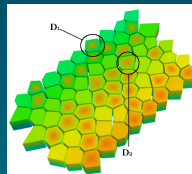
$$m(D, T) \propto D^{-\beta/\nu} \mu \left(D^{1/\nu} \frac{T - T_C^b}{T_C^b} \right)$$

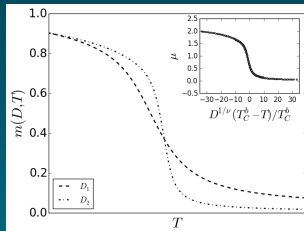
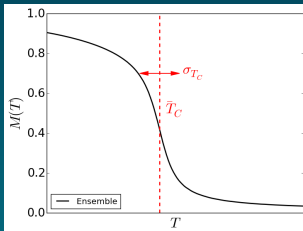
Change of Variables:

$$D = d_o \left(\frac{T_C^b - T_C(D)}{T_C^b} \right)^{-\nu}$$

Final Result:

$$M(T) = M_o^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(\frac{T - T_C^b}{t} \right) f_t(t) dt$$





$$M(T) = M_0^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(\frac{T - T_C^b}{t} \right) f_t(t) dt$$

- ▶ $M(T)$: To be fitted
- ▶ d, ν, β, μ : Known information about the material
- ▶ T_C^b : May be known, otherwise taken from fit
- ▶ $M_0^*, f_t [\bar{t}, \sigma_t]$: Taken from the fit

$$\bar{T}_C = T_C^b - \bar{t} \quad \sigma_{T_C} = \sigma_t$$

Test Case: 2D Ising Model

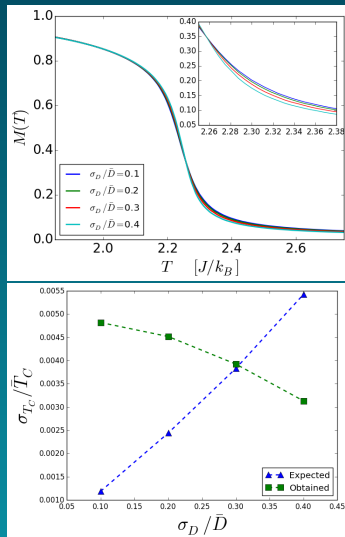
$$M(T) = M_o^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(\frac{T - T_C^b}{t} \right) f_t(t) dt$$

Used 2D Ising model as a benchmark:

- ▶ Simulated using Monte Carlo
- ▶ Analytical results for β, ν, T_C^b
 - ▶ $\beta = 1.25$
 - ▶ $\nu = 1$
 - ▶ $T_C^b \approx 2.269$

Tested against different f_D :

- ▶ All mean $\bar{D} = 100$
- ▶ Standard deviation $\sigma_D = 10, 20, 30, 40$



Test Case: 2D Ising Model

Introduce constraint⁵:

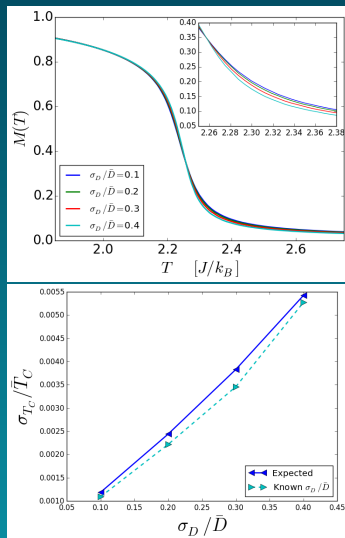
$$\Rightarrow \sigma_{T_C}^2 = (T_C^b - \bar{T}_C)^2 \left(\left(1 + \frac{\sigma_D^2}{\bar{D}^2} \right)^{1/\nu^2} - 1 \right)$$

In the Ising model:

$$\nu = 1$$

$$\Rightarrow \sigma_{T_C} = (T_C^b - \bar{T}_C) \frac{\sigma_D}{\bar{D}}$$

Fitted results far better!



⁵O. Hovorka et al. Appl. Phys. Letters 101.5, 052406 (2012)

- Universal method to find size dependent T_C distribution based upon fitting ensemble magnetisation:

$$M(T) = M_o^* \int_0^{T_C^b} t^{-d\nu+\beta} \mu \left(\frac{T - T_C^b}{t} \right) f_t(t) dt$$

- Successfully tested against 2D Ising model (without a loss in generality) and found a strong parameter correlation which can be solved by the constraint:

$$\sigma_{T_C}^2 = (T_C^b - \bar{T}_C)^2 \left(\left(1 + \frac{\sigma_D^2}{\bar{D}^2} \right)^{1/\nu^2} - 1 \right)$$

- Future work may find this insignificant in other systems. e.g. Heisenberg model, FePt Hamiltonian e.c.t.

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