January 1998

Kinetics of random-field induced domains in the two-dimensional Ising antiferromagnet Rb2Co0.85Mg0.15F4

Christian Binek
University of Nebraska-Lincoln, cbinek@unl.edu

Journal of Magnetism and Magnetic Materials 177–181 (1998) 209–210

Kinetics of random-field-induced domains in the two-dimensional Ising antiferromagnet $Rb_2Co_{0.85}Mg_{0.15}F_4$

W. Kleemann[a,*], Ch. Jakobs[a], Ch. Binek[a], D.P. Belanger[b]

[a] *Laboratorium für Angewandte Physik, Gerhard-Mercator-Universität, D-47048 Duisburg, Germany*
[b] *Department of Physics, University of California, Santa Cruz, CA 95064, USA*

Abstract

The kinetics of the two-dimensional diluted Ising antiferromagnet $Rb_2Co_{0.85}Mg_{0.15}F_4$ is studied via the temporal relaxation of the field-induced magnetization after field cooling (FC) and zero-field cooling (ZFC), respectively, to $T < T_N = 75.2$ K. After FC different non-exponential decay laws indicate a crossover from domain reorientation to wall rearrangement at decreasing T. After ZFC rapidly saturating magnetization of naturally grown domain walls precedes the slow random-field-controlled disordering process. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Antiferromagnets; Domain dynamics; Time-dependent magnetization; Random fields; Relaxation

The two-dimensional (2D) Ising model system does not exhibit long-range order (LRO) at any temperature T when exposed to arbitrarily weak quenched random-fields (RFs) [1, 2]. These are most efficiently controlled in diamagnetically diluted Ising antiferromagnets by an axial external magnetic field B (DAFF) [3, 4]. Disordering and ordering of a quasi-2D DAFF systems involving antiferromagnetic (AF) domain states [5] was investigated on $Rb_2Co_xMg_{1-x}F_4$ (RCM), $0.7 \leqslant x < 1$ after zero-field cooling (ZFC) and field cooling (FC), respectively, to below the Néel temperature, T_N [4]. The kinetics was investigated by Ikeda et al. [6, 7] by measuring the field-induced magnetization as a function of time, $M(t)$, on RCM with $x = 0.6$. Being close to the percolation limit, however, a large part of the observed slowing-down of this sample was certainly due to random-bond (RB) disorder. In order to increase the effects of RF-induced disorder we report here for the first time on $M(t)$ data of RCM with weak disorder, $x = 0.85$.

As a signature of the AF domain state, one observes excess magnetization, ΔM, which is due to field-aligned spins on both domain walls and the preferentially occupied sublattice within the domains [5]. After switching-off the field, however, ΔM destabilizes and partly survives as long-lived thermoremanent magnetization, $\delta M(t)$. Fig. 1 shows data obtained after FC from $T = 120$–20 K with SQUID magnetometry in axial magnetic fields, $2 \leqslant B \leqslant 5$ T, respectively. The decay curves are excellently described by the response function [8, 9]

$$\delta M(t) = \delta M_0 \int_0^{\infty} \mathrm{d}s\, n(s) s \exp[-(t/\tau_{\infty}) \mathrm{e}^{-C/s}]. \qquad (1)$$

It integrates over independent 'dynamically coupled domains' (DCD) [8, 9] obeying a size distribution function, $n(s)$, and relaxing exponentially with times $\tau(s) = \tau_{\infty} \exp(C/s)$, $\tau_{\infty} \approx 10^{-12}$ s. The solid lines in Fig. 1 refer to Eq. (1) with 3D percolation distribution functions. Increasing correlation factors C at decreasing B are probably due to domain growth on all length scales [5].

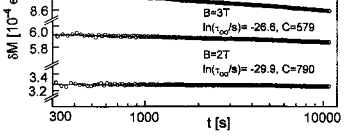

Fig. 1. Semilog plot of δM versus t after FC with $2 \leqslant B \leqslant 5$ T to $T = 20$ K and switching-off at $t = 0$. The solid lines are best fits to Eq. (1) with parameters as indicated.

* Corresponding author: Tel.: + 49 203 379 2809; fax: + 49 203 379 3163; e-mail: hm338kl@unidui.uni-duisburg.de.

PII S0304-8853(97)00671-9

Eq. (1) with $C > 0$ describes an activated low-T relaxation process, which is assumed to involve merely domain-wall rearrangements [10]. The domain walls relax under RB pinning due to the stochastic distribution of vacancies. Surface spin waves propagating on the highly disordered domain walls are, hence, involved as elementary excitations. Since the fractal domain surfaces are proportional to their volume s [11], energy steps $\delta W \propto 1/s$ describe the relaxing domain wall on its way from the excited to the ground state [8]. It should be noticed that fitting to a logarithmic power law [10]

$$\delta M(t) = a[T\ln(t/\tau)]^{-\psi} \tag{2}$$

with $\psi \approx 0.4$ and $\tau \approx 10^{-12}$ s, yields poorer results than Eq. (1). Hence, the traditional low-T wall migration model under RB pinning [10] seems to be less adequate than the DCD model.

An alternative description of the relaxation considers thermally activated reorientation of domains, which obey, again, a percolation-type distribution function $n(s)$ [11]. Activation energies $\Delta E = E_b s^y$ are overcome within individual relaxation times $\tau(s) = \tau_\infty \exp(E_b s^y / k_B T)$, where E_b and $y \geqslant 1$ are a microscopic energy barrier and a barrier exponent, respectively. In the 'late stage', i.e. for large enough values of $T\ln(t/\tau)$, a generalized power law,

$$\delta M(t) = \delta M_0 \exp[-\{(k_B T/E_b)\ln(t/\tau)\}^y], \tag{3}$$

has been proposed [12]. In fact, at $T > 30$ K this law describes our $M(t)$ data significantly better than Eq. (1). In this temperature range, volume relaxation starts to dominate and the model of size conserving heterogeneous domain relaxation, Eq. (1), does no longer hold.

Fig. 2 shows a universal plot of relaxation data measured after annealing for 2 h under $B = 5$ T at T_N and subsequent FC to $10 \leqslant T \leqslant 60$ K. According to Eq. (3) a plot of $-\ln(-\ln(\delta M/\delta M_0)$ versus $\ln(T\ln(t/\tau))$ with $\tau = 10^{-12}$ s and δM_0 obtained from individual fits, is expected to yield a straight line with slope $-y$ and ordinate segment $y\ln(E_b/k_B K)$. This is roughly confirmed by our data, although deviations from the expected universality (see also inset for individual fit parameters) are non-negligible. Whereas E_b decreases monotonically with increasing T, the exponent y increases from $y(10\text{ K}) \approx 1.5$ to $y(30\text{ K}) \approx 2.3$, and finally decreases again to come close to the simulated values [12], $y(60\text{ K}) \approx 1.3$.

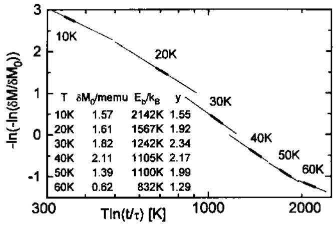

Fig. 2. Semilog plot of $-\ln(-\ln(\delta M/\delta M_0)$ versus $T\ln(t/\tau)$ (circles) measured after FC with $B = 5$ T to $10 \leqslant T \leqslant 60$ K and best-fitted to Eq. (3) (solid lines) with parameters as indicated.

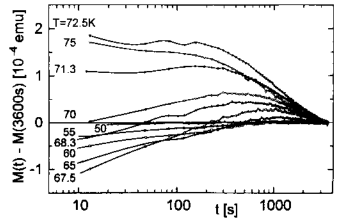

Fig. 3. Semilog plot of $M(t) - M(3600\text{ s})$ versus t measured in $B = 5$ T after ZFC to $50 \leqslant T \leqslant 75$ K (data points connected by eye-guiding lines).

Since the simulations [12] reveal universality over the whole range, $0 \leqslant T\ln(t/\tau) \leqslant 900$ K (setting $|J|/k_B \approx 80$ K for RCM [4]), the experimentally observed deviations are probably due to non-ideal 2D Ising-model properties of RCM. Tentatively, these are spin waves and interlayer coupling (explaining the observed 3D DCD relaxation at low T), and spin wave interactions (leading to renormalization of E_b at higher T).

After ZFC to below T_N the RF-induced growth of excess magnetization is partially obscured by a fast increase of magnetization. It 'decorates' spontaneous AF domain walls originating from critical fluctuations at $T \approx T_N$. In disordering experiments at $70 \leqslant T \leqslant 75$ K with $B = 5$ T this initial magnetization exceeds the final one (Fig. 3). After long times RF domains replace the relatively small natural ones. In contrast, a slow increase of $M(t)$ towards saturation is observed for $50 < T < 70$ K. Presumably in this annealed state RF domains are gradually forming within relatively large natural ones. Experiments are underway to better realize an initial single-domain state in order to study the RF disordering process in more detail.

We thank R.V. Chamberlin and U. Nowak for useful discussions, DFG and US DOE for financial support.

References

[1] J. Imry, S.-K. Ma, Phys. Rev. Lett. 35 (1975) 1399.
[2] J. Bricmont, A. Kupiainen, Phys. Rev. Lett. 59 (1987) 1829.
[3] S. Fishman, A. Aharony, J. Phys. C 12 (1979) L729.
[4] D.P. Belanger, A.P. Young, J. Magn. Magn. Mater. 100 (1991) 272.
[5] See review by W. Kleemann, Int. J. Phys. B 7 (1993) 2469.
[6] H. Ikeda, Y. Endoh, S. Itoh, Phys. Rev. Lett. 64 (1990) 1266.
[7] S. Itoh, H. Ikeda, T. Suzuki, Y. Endoh, J. Phys. Soc. Japan 60 (1991) 3238.
[8] R.V. Chamberlin, J. Appl. Phys. 76 (1994) 6401.
[9] R.V. Chamberlin, Europhys. Lett. 33 (1996) 545.
[10] T. Nattermann, I. Vilfan, Phys. Rev. Lett. 61 (1988) 223.
[11] U. Nowak, J. Esser, K.D. Usadel, Physica A 232 (1996) 40.
[12] M. Staats, U. Nowak, K.D. Usadel, Phase Trans., in press.