The effects of defects on mangetization reversal processes

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Defects and impurities strongly affect the timing and the character of the (re)ordering or disordering transitions of thermodynamic systems captured in metastable states. In magnetic systems, the transition driven by an external field usually occurs through the nucleation and the growth of magnetized clusters. Defects act as nucleation centres or pinning sites, respectively accelerating or hampering the passage to equilibrium. We focus on the acceleration effect by analysing the early stages of the magnetization reversal induced by sudden switching on of an external field. We consider the two-dimensional Ising model with quenched randomness, modelled in a new way as spins with a reversal lifetime considerably higher than the time of the experiment. As a result, defects are spins that remain fixed in position and with the same orientation throughout the simulation. We adapt the classical Johnson-Mehl-Avrami-Kolmogorov (JMAK) theory to account for the effects of defects on the free energy barriers, the critical droplet area, and the associated metastable time [1]. By increasing the impurity fraction in the system, both the critical area of the droplet and the free energy barrier decrease. Thus, the reversal process is favored and the metastable lifetime decreases exponentially with the defects fraction. The resulting predictions are successfully tested against Monte-Carlo simulations, performed by adopting the Glauber dynamics, to obtain reliable time-dependent results during the out-of-equilibrium transformations. Eventually, we study the pinning effect of defects during cluster growth by analysing hysteresis loops, focusing on a slow time-dependent magnetic field. We test the hypothesis that defects explain the nature of the Barkhausen noise by reproducing, with our simulations [2], the experimentally observed power law [3] in the probability distribution of the amplitude of the magnetization jumps. The effects of temperature and fraction of defects in the system are analyzed and quantified.

References

[1] F. Ettori, T.J. Sluckin, P. Biscari. The effect of defects on magnetic droplet nucleation. Physica A 611, 128426 (2023).
[2] F. Ettori, F. Perani, S. Turzi, P. Biscari, Finite-temperature avalanches in 2D disordered Ising models. arXiv preprint arXiv:2212.12707 (2022).
[3] E. Puppin, Statistical Properties of Barkhausen Noise in Thin Fe Films. Phys. Rev. Lett. 84, 5415-5418 (2000).